CLIMATE CHANGE IMPACTS ON RAINWATER HARVESTING POTENTIAL AND IRRIGATION WATER REQUIREMENT IN BANGLADESH

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CLIMATE CHANGE IMPACTS ON RAINWATER HARVESTING POTENTIAL AND IRRIGATION WATER REQUIREMENT IN BANGLADESH

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It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

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SAZIA AFREEN

Dedicated

To

My Parents

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ABSTRACT

In the present study a total of 58 years (1950 to 2007) of daily rainfall data from 34 stations of Bangladesh Meteorological Department has been analyzed for the entire country to identify the changes in rainfall distribution considering temporal as well as spatial distribution. From the rainfall analysis, it is observed that average annual rainfall of total 58 years is 2371 mm; while that of the recent 12 years (1996-2007) is 2505 mm.

From the decadal average rainfall analysis for each of the months considering 58 year rainfall data through GIS, it has been observed that for all of the decades during the months of January, February, November and December average rainfall is below 50 mm, while during June and July more than 400 mm of average rainfall is observed. From the comparison of decadal average monthly rainfall at different rinfall stations within eight hydrological regions, it has been observed that an increasing trend of regional average decadal rainfall is evident in NW region for the months of April and September; in NE region during April and in SW region during September. Regional average rainfall during the recent three decades (80s, 90s and 2000-2007) are higher than that of previous three decades as well as 58 year average in NW region during February and May, in NC region during September; in SW region during May, in SC region during July and in SE region during May.

Contribution of rainwater in meeting crop water requirement for three varieties of Rice and Wheat have been compared both temporally and spatially for the recent 12 years and total 58 years for eight hydrological regions of the country through normalization technique. It is noticed that for each month change of rainfall resembles to the change of rainwater contribution in meeting crop water requirement during different months of cropping period for each crop. It has been observed that during the cropping period of Boro (January to May), rainwater contribution in meeting crop water requirement has increased significantly in SC and RE regions during January, SW region during March, NW and NC regions during April, EH and RE regions during May. Again, for the same crop, rainwater contribution decreased significantly in NW and NE regions during January, NC and SE regions during February. For Aman (cropping period of July to November), rainwater contribution in meeting crop water requirement has increased significantly in SW region during September, NW, EH and RE regions during October. Again, for the same crop, rainwater contribution has decreased significantly in NW, SC

and EH regions during November. So, in general, for Boro, during the initial two months (January and February) rainwater contribution appears to be decreasing. For Aman, rainwater contribution is increasing during October but decreasing in November. This suggests that rainwater can be stored in October for irrigation in later months. From spatial variation of yield for three varieties of rice and wheat, it has been observed that percentage of area with yield at least 2000 kg/Ha for Boro is relatively high in all of the regions and large area of NW region show higher yield than the other regions.

From groundwater level assessment, it has been found that among three cropping periods, Kharif I (March to July) and Rabi (November to April) show worse condition specially in NW and NC regions. As significant increase of rainfall is observed during April in NW region, ground water recharge schemes can be implemented in this region. SE is the most vulnerable region due to arsenic and iron contamination with ground water. From rainfall analysis for SE region, it has been noticed that during May recent three decades show higher rainfall relative to that for previous three decades. Salinity problem is experienced in the coastal areas of SC and SW regions most. As there is significant increase of rainfall during January in SC region and during September in SW region, rainwater may be helpful to overcome the soil salinity problem in these regions.

To find out the potential of rainwater harvesting in an urban area, Dhaka city has been considered as a typical urban case. From long term rainfall analysis for Dhaka city, it has been found that average annual rainfall of 55 years (1953 to 2007) is 2073 mm and that for recent 12 years (1996 to 2007) is 2166 mm, and the annual rainfall follows an increasing trend. Variation of 5 year (moving) average annual rainfall as well as average monthly rainfall during March, May and September has been analyzed for Dhaka city considering 55 year duration. Comparatively higher rainfall has been observed during the recent three decades relative to that for previous decades. From the mass curve analysis of Dhaka city, it is found that the maximum excess water is available during October and maximum deficit occurs during April. Thus excess water obtained during rainy season can be stored in a proper way for the use in dry season. This analysis suggests that in Dhaka, RWH can be used in conjunction with conventional water supply system to improve the present water scarcity. An analysis of roof size distribution of different wards of Dhaka city has been made through GIS to find out suitable catchment area that can be used for RWH.

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LIST OF ABBREVIATIONS

ADB	Asian Development Bank
BARC	Bangladesh Agricultural Research Council
BCA	Bangladesh Country Almanac
BMD	Bangladesh Meteorological Department
BRRI	Bangladesh Rice Research Institute
BWDB	Bangladesh Water Development Board
DOE	Department of Environment
DWASA	Dhaka Water Supply and Sewerage Authority
GIS	Geographical Information System
GSRC	Geographical Solutions Research Center
IPCC	Intergovernmental Panel on Climate Change
NWMP	National Water Management Plan
OECD	Organization for Economic Co-operation and Development
PET	Potential evapotranspiration
RWH	Rainwater harvesting
SDNP	Sustainable Development Networking Programme
SRDI	Soil Resource Development Institute
UNEP	United Nations Environment Programme
WARPO	Water Resources Planning Organization

CHAPTER 1
INTRODUCTION

1.1 Background of the Study

Bangladesh has a humid, warm and tropical climate. Its climate is influenced primarily by monsoon and partly by pre-monsoon and post-monsoon circulations. The country is considered to be one of the most vulnerable countries to climate change. This is due to its unique geographic location, dominance of floodplains and low elevation from the sea. At the same time, the country has low adaptive capacity because of its poor economic condition with high population density and overwhelming dependence on nature.

According to the third assessment report of Intergovernmental Panel on Climate Change (IPCC, 2001), developing countries are expected to suffer the most from the negative impacts of climate change. It will have wide-ranging effects on the environment, and on socio economic and related sectors, including water resources, agriculture and food security, human health, terrestrial ecosystems, biodiversity and coastal zones. Changes in rainfall pattern are likely to lead to severe water shortages and flooding. The vulnerability due to climate change effects has been documented in many studies (ADB, 1994; Ali, 1996; Ali, 1999; IPCC, 2001; Kausher et. al., 1994; Rijsberman et. al., 1996; Warrick et. al., 1996, World Bank, 2000). The IPCC Special Report on the Regional Impacts of Climate Change (IPCC, 2007a) indicates that there would be drastic changes in rainfall patterns in the warmer climate and Bangladesh may experience 5-6% increase of rainfall by 2030, which may create frequent big and prolonged floods. In contrary, the country is facing drought in the northwestern region, which affects agriculture, food production, water resources and human health. The moderately drought affected areas will be turned into severely drought prone areas within next 20-30 years (IPCC, 2007a).

In recent times, the global community has brought into sharp focus of the need for effective management of water resources world-wide to ensure water for agriculture, health and nature. Sufficient food production is one of the main challenges for mankind which is directly related to water availability. Change of rainfall pattern due to climate change have the potential to modify existing cropping pattern by forcing farmers to rearrange transplanting and harvesting periods. To maintain the suitable conditions for

crop production, people have to take some measures such as storing rainwater to cope with the climate change effects. Rainwater harvesting (RWH) systems may function as a major alternative or supplementary source of water where the resource is limited, inaccessible or unusable like iron and arsenic contamination of ground water or salinity problem in coastal areas of Bangladesh. Adaptation through rainwater collection may be particularly effective in tropical monsoon countries like Bangladesh, where the seasonal cycle in rainfall is large, (Pandey et. al., 2003).

Global warming and climate change threatens settlements and the number of people displaced from their land due to riverbank erosion, permanent inundation and sea level rise is increasing rapidly every year. Due to migration from rural areas to urban areas the major cities of Bangladesh have become over populated during the recent decades. As an example of urban areas, Dhaka city will be considered in the present study to analyze the potential of roof top rainwater harvesting. Rain water harvesting along with other water supply options may be adopted in Dhaka city, where rain water may provide full coverage in the wet season and partial coverage during the dry season.

1.2 Objectives

The overall objective of the present study is to substantiate rainwater harvesting as an alternate source of water as an adaptation measure for climate change impacts.
Specific objectives of the study are as follows:

- To determine the change in spatial distribution of seasonal rainfall pattern in Bangladesh considering long term rainfall data.
- To analyze the change in spatial distribution of crop water requirement for rice and wheat in Bangladesh.
- To identify the areas where rainwater may also be used as an alternate source of water for drinking purposes taking into consideration of ground water depletion, arsenic, iron and salinity problems.
- To evaluate potential contribution of rainwater in meeting urban water demand. In the present study, Dhaka city has been considered for an example of urban area.

1.3 Scope of the work

For this study data from 34 BMD stations have been employed for rainfall analysis. Rainfall data for most of the stations is available from 1950. The present investigation covered rainfall data up to 2007. Out of these 34 BMD stations, some are relatively new and rainfall data is available from 1996.

Crop water related analyses have been done for three varieties of rice and wheat. For simplicity monthly crop water demand has been investigated instead of daily basis.

For analysis of urban water demand and evaluation of potential contribution of rainwater, Dhaka city has been considered. GIS maps of roof size distribution has been utilized for calculating rainwater catchment area. Maps of only 29 wards are available out of the 90 wards of the city.

1.4 Limitations of the work

- Changes of Rainfall over Bangladesh for a period of more than fifty years have been analyzed for the present study. Rainfall data for the recent two years (2008 and 2009) could not be considered in the present study as when the rainfall analysis has been stared, rainfall data of these two years was not available at BMD. Apparently some decrease of annual rainfall has been observed during the recent two years. So for the comparison of annual rainfall between 58 years and recent 12 years, inclusion of those two years rainfall data might impart different result.

- For rainfall analysis for BMD stations of Chuadanga, Madaripur, Mongla and Syedpur rainfall data is available for only recent 12 years (1996-2007). So, for these four rainfall stations long term rainfall analysis was not possible.

- It has been assumed in the present study that alteration of rainfall has been due to climate change effect. Also, due to local effects rainfall information at any station can not represent the rainfall for a large area as does temperature. So the

limited number of stations may not be adequate to represent the rainfall of a region.

- Again, for the analysis of rainfall contribution of crop water requirement for three varieties of rice and wheat, it has been assumed that crop water requirement has changed due to rainfall change. Here other climate related factors have not been considered.

1.5 Organization of the Thesis

This thesis contains eight chapters including introductory and concluding chapters. Chapter two contains literature review on climate change, potential impacts of climate change in Bangladesh and potential of rainwater harvesting as an adaptation to climate change. In chapter three methodology of the work has been discussed. Chapter four contains analysis of rainfall considering long term data for the whole country. Comparison between changes of recent rainfall pattern relative to long term rainfall has been presented in this chapter. In chapter five rainfall contribution in meeting crop water demand for three varieties of rice and for wheat have been analyzed considering long term average rainfall. Chapter six discusses the potential of rainwater harvesting in different areas of Bangladesh due to water scarcity for drinking purpose taking ground water depletion, arsenic, iron and salinity problems into consideration. In chapter seven potential of rainwater harvesting in Dhaka city has been analyzed. Chapter eight contains conclusions and recommendations of the study.

CHAPTER 2

LITERATURE REVIEW

2.1 General

Climate is statistical information, a synthesis of weather variation focusing on a specific area for a specified interval. It is usually based on the weather in one locality averaged for at least 30 years (Ramamasy et al., 2007). Variability of climate refers to the variations in the mean state and other climate statistics on all temporal and spatial scales beyond those of individual weather events.

The earth's climate has been alternating between the hot and cold periods for at least past million years. Records from polar ice cores show oscillating periods of glacial (ice ages) and interglacial (warm) periods. The earth is currently in an interglacial period. However, the observed warming since the 1970s cannot be explained by natural causes alone. During the past 200 years, human activities such as fossil fuel burning and land clearing have caused an increase in greenhouse gases in the atmosphere, which is called as the enhanced greenhouse effect that is trapping more heat and raising the earth's surface temperature (Ramamasy et. al., 2007).

The atmospheric concentrations of key greenhouse gases include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and ozone (O_3). Over the last century the level of carbon dioxide has increased by 25 percent, the level of nitrous oxide by 19 percent and the level of methane by 100 percent. They reached their highest recorded levels in the 1990s (Ramamasy et. al., 2007). Scientists say the world needs to cut emission of global warming gases by 50 to 70 percent just to stabilize the level of gases already in the atmosphere. From 1990 to 1998 global carbon dioxide emission was reduced only 1.7% (UN, 2005).

Over the past 100 years (1906 to 2005), the earth’s average surface temperature has risen by around 0.74°C, with the warming greater over land regions than over the oceans. The rate of warming averaged over the last 50 years is nearly twice the rate for the last 100 years. The increase in surface temperature in the northern hemisphere during the twentieth century is considered greater than for any century in the last 1000 years. Statistics show the global mean surface temperature has increased by 0.6±0.2°C for the past 140 years (1860 to 2000), the number of hot days in a year increased in

many places and the number of cold days decreased in nearly all land areas (IPCC, 2001). The late 1990s and the early 21st century have featured the warmest years since modern records began. Increased variability in the hydrologic cycle (i.e., more floods and droughts) is expected to accompany these global-warming trends.

The IPCC has confirmed in their report of the fourth assessment that global warming is accelerating rapidly (IPCC, 2007b). A further warming of about 0.2°C is projected for each of the next two decades. According to the IPCC, average global temperatures will increase between 1.8°C and 5.8°C over the next century, and the sea level will rise between 9 and 88 centimeters with midrange estimates of 3°C global mean warming and 45 cm sea-level rise, respectively (Kabir, N. , 2005).

The average global precipitation is projected to increase during the twenty-first century but at the regional levels, there will be both increases and decreases ranging from 5 percent to 20 percent (Ramamasy et al., 2007). Small changes in average conditions of rainfall can have big influence on extremes such as floods and droughts.

Though Climate change, the global environmental problem is the direct result of the burning of fossil fuel and wasteful consumption by the people in industrialized and rich countries, the people in developing and poor countries are the main victims of the impacts of climate change.

Bangladesh has little contribution to increase global warming, but the country has to face the adverse impacts of climate change. According to the recent World Development Indicators (2006) report of the World Bank, the per capita carbon emission from Bangladesh has been 0.3 Mt only, while these were 20.2 Mt and 9.2 Mt per capita for the USA and the UK (Mallick, 2007). The global per capita consumption has been 4.0. According to Warrick et al. (1993) the developing countries, representing nearly three-quarters of the world population, are responsible for less than one-quarter of the fossil-fuel carbon emissions whether the OECD countries, with about 15% of the world population, account for around 44% of the total emission. One country, the USA, is solely responsible for 23% of the total yearly fossil-fuel carbon emission to the atmosphere. In contras, Bangladesh contributes a minuscule 0.06%. Thus people of Bangladesh did not create the problem, but are the victims of the global climate problem.

2.2 Climate of Bangladesh

The country belongs to sub-tropical regions, where monsoon weather prevails throughout the year. The south-west monsoon originates over the Indian Ocean and carries warm, moist, and unstable air. The monsoon has its onset during the first week of June and ends in the first week of October, with some inter-annual variability in dates. Besides monsoon, the easterly trade winds are also active, providing warm and relatively drier circulation. In Bangladesh there are four prominent seasons based on rainfall, humidity, temperature and wind pressure, namely, winter (December to February), Pre-monsoon (March to May), Monsoon (June to early-October), Post-monsoon (late-October to November).

The normal maximum temperature of Bangladesh ranges from 25.2°C during January to 33.2°C during April and normal minimum temperature varies from 12.5° during January to 25.7°C during August. The average normal rainfall for the whole country varies from 9 mm during January to 523 mm during July (BMD, 2010). From this study it has been found that average annual rainfall over the country is about 2505 mm for recent twelve years (1996-2007), but there exists a wide spatial and temporal distribution. Annual rainfall ranges from 1532 mm in the extreme west to over 4345 mm in the east. The total precipitation in the dry regions is low but the rainfall often occurs in sudden heavy storms, which sometimes lead to flooding and soil erosion. More than 80% of the annual precipitation that falls on Bangladesh comes during the monsoon period (Smith et al., 1998).

Figure 2.1: Rainfall stations of Bangladesh Meteorological Department

Rainfall is observed at 337 stations in the country, 34 by Bangladesh Meteorological Department (BMD) and 303 by BWDB. Figure 2.1 shows locations of 34 stations of BMD over the country.

2.2.1 Observed changes in climate trends, variability and extreme in Bangladesh

Bangladesh is already facing many of the harmful impacts of climate change due to its geophysical location, hydrological influence by erratic monsoon rainfall and changes in regional water flow patterns. The country faces too much water in monsoon causing floods and too little water in dry season. This situation will be aggravated in the warmer climate resulting in severe droughts and increasing floods.

According to IPCC'S Fourth Assessment (2007b), the following changes have been observed in climate trends, variability and extreme events in Bangladesh:

i) In Bangladesh, average temperature has registered an increasing trend of about 1°C in May and 0.5°C in November during the 14 year period from 1985 to 1998.
ii) The annual mean rainfall exhibits increasing trends in Bangladesh. Decadal rain anomalies are above long term averages since 1960s,
iii) Serious and recurring floods have taken place during 2002, 2003, and 2004. Cyclones originating from the Bay of Bengal have been noted to decrease since 1970 but the intensity has increased.
iv) Frequency of monsoon depressions and cyclones formation in Bay of Bengal has increased.
v) Water shortages has been attributed due to rapid urbanization and industrialization, population growth and inefficient water use, which are aggravated by changing climate and its adverse impacts on demand, supply and water quality
vi) Salt water from the Bay of Bengal is reported to have penetrated 100 km or more inland along tributary channels during the dry season.
vii) The precipitation decline and droughts has resulted in the drying up of wetlands and severe degradation of ecosystems in some areas of the country.

2.2.2 History of extreme climatic events in Bangladesh

Bangladesh has a scarred history of extreme climatic events like floods, droughts, tropical cyclones, tornado, storm surge, tidal bore claiming millions of lives, losses of assets, belongings and destroying past development gains. Between 1991 and 2000, ninety three major disasters were recorded in Bangladesh, resulting in nearly 200,000 deaths and causing US $ 5.9 billion in damages with high losses in agriculture and infrastructure (DOE, 2007). The most devastating natural disasters affecting Bangladesh in recent history are the cyclones of 1970, 1991, 1997, 1998, 2007 and 2009 and the floods of 1998. Nicholls et al. (1995) estimated that 42 percent of the nearly 1.9 million cyclone-related deaths in the past two centuries have occurred in Bangladesh. The super cyclone SIDR hit the southwest coastal region of Bangladesh on 15 Nov. 2007 affecting 30 districts and killing 3,363 people (National Plan for Disaster Management, 2008).

Das and Radhakrishna (1991) documented a rise in mean sea level in the Bay of Bengal of 2.5 mm per year since the 1950s. Because of climate change, a sea level rise of 0.5 meter over the last 100 years has already eroded 65 percent landmass of 250 square kilometer of Kutubdia, 227 square kilometers of Bhola and 180 square kilometer of Sandwip islands. Over the past 100 years, the once 1,000 square kilometer island turned into a small 21 square kilometer landmass (DOE, 2007).

Bangladesh has been ravaged by floods of catastrophic proportion in recent years of 1998, 2004 and 2007. Heavy downpour over short spell has resulted in landslides. About 68 percent of the country's geographical area was flooded, affecting more than 30 million people and causing 918 fatalities at flood of 1998 (Choudhury, 1998). Economic losses were estimated at US$ 3.3 billion, equivalent to 8 percent of the country's GDP (Choudhury et. al., 1999). In 2007, the monsoon in the upstream basin was particularly heavy, leading to a series of floods.

Like floods, Bangladesh is also vulnerable to recurrent droughts. Between 1960 and 1991, droughts occurred in Bangladesh 19 times. Very severe droughts hit the country in 1951, 1961, 1975, 1979, 1981, 1982, 1984, 1989, 1994, 1995 and 2000. Past droughts have typically affected about 47 percent of the country and 53 percent of the population (Ramamasy et al., 2007). The associated decline in crop production, losses of assets and lower employment opportunities contributed to increased household food insecurity. Drought dried up most of the rivers in Northwest Bangladesh with dust

storms in several districts, including Naogaon, Nawabganj, Nilphamari and Thakurgaon.

2.2.3 Projected Climate change in Bangladesh

The climate models all estimate a steady increase in temperatures for Bangladesh, with little inter-model variance. The temperature projections over the next decades show significant temperature increase for both monsoon and winter period and in the report of OECD, Agrawala. et al. (2003) estimated that winter warming would be greater than for summer. According to the IPCC report, Bangladesh will experience 1.0-1.4°c rise in temperature in 2030-2050. By 2100, the average rise of temperature would be 2.4°c (Mallick, 2007). General Circulation Model (GCM) data also project an average temperature increase in Bangladesh of 1.0°C by 2030 and 1.4°C by 2050 (Ramamasy et. al., 2007). According to Ahmed et. al. (1999), little change in winter precipitation and an increase in precipitation during the monsoon will be experienced in the country.

Most of the climate models also estimate that precipitation will increase during the summer monsoon because they estimate that air over land will warm more than air over oceans in the summer. This will deepen the low pressure system over land that happens anyway in the summer and will enhance the monsoon. The estimated increase in summer precipitation appears to be larger than the standard deviation across models. The climate models also tend to show small decreases of rainfall in the winter months of December through February. However, with higher temperatures, increasing evapotranspiration combined with a small decrease in precipitation, dry conditions, even drought, are likely to be made worse condition during winter (Agrawala. et al., 2003).

The Bangladesh country study put the range at 30 to 100 cm of sea level rise by 2100, while the IPCC Third Assessment gives a global average range with slightly lower values of 9 to 88 cm. Kumar et al. (2002) estimated an increase of 15 to 38 cm sea level rise in the Bay of Bengal by 2050. It is predicted that for about 45 cm rise of sea level along Bangladesh coast may inundate 10-15% of the land by the year 2050 and may dislocate over 35 million people from the coastal districts. Sea level rise will also increase morphological activities in the river, inducing increased river flow. Accelerated river flow will increase river bank erosion too (Alam, 2003).

2.3 The potential impacts of climate change in Bangladesh

Very small changes in the temperature and rainfall can lead to severe consequences for a country like Bangladesh already stressed environmentally, socially and economically. Climate change induced impacts may also trigger a chain of consequences due to non-climatic activities and their outcomes.

The vulnerability of people living in the coastal zone has been demonstrated in numerous studies and is emphasized in the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2001). A subjective ranking of key climate change impacts and vulnerabilities for Bangladesh identifies water and coastal resources as being of the highest priority in terms of certainty, urgency, and severity of impact, as well as the importance of the resources being affected (Agrawala. et al., 2003).

The rising temperature and erratic rainfall (heavy and low and untimely rainfall) and their associated extreme events like drought, flood, water logging, landslides, cyclone, tidal surges, salinity intrusion in coastal regions, coastal erosion, riverbank erosion etc. are affecting ecosystems, productivity of land, agriculture, food security, water availability and quality, health and livelihood of the common people living in various climatic zones of Bangladesh.

2.3.1 Cyclone

Bangladesh currently has extreme vulnerability to cyclones, both on account of its somewhat unique location and topography (that creates an inverted funnel effect), and because of the low (though growing) capacity of its society and institutions to cope with such extreme events. Cyclones originate mainly in the deep Indian Ocean and track through the Bay of Bengal where the shallow waters contribute to huge tidal surges when cyclones make landfall. Existing literature records storm surges in the range of 1.5 to 9 meters, and some sources even cite particular cyclones as having resulted in surges almost 15 m in height. Storm surges contribute to flooding and loss of life and livelihoods far beyond the coast (Agrawala. et al., 2003).

2.3.2 Sea level rise

A total of 99 upazillas that are located behind the exposed coast are treated as interior coast. The exposed coast embraces the sea directly and is subject to be affected highly by the anticipated sea level rise (Agrawala. et al., 2003). The IPCC Special Report on

the Regional Impacts of Climate Change also indicates that Bangladesh is 'especially at risk' from sea-level rise and its implications: coastal erosion and land loss, inundation and sea flooding, and increasing salinity of rivers (IPCC, 2007a). According to NWMP (2001), projected sea-level rise of up to 44 cm by 2050, on top of an increasing tidal range of 1.2 m since 1960, will worsen flooding and drainage problems, as will the more intense rainfall expected with climate change. The main impacts of sea level rise on water resources are fresh water availability reduction by salinity intrusion.

In contrary according to Huq et al. (1996) there is no specific regional scenario for net sea level rise, in part because the Ganges-Brahmaputra delta is still active and the morphology is highly dynamic. Literature suggests that the coastal lands are receiving additional sediments due to tidal influence, while there are parts where land is subsiding due to tectonic activities. Since the landform is constituted by sediment decomposition, compaction of sediment may also play a role in defining net change in sea level along the coastal zone. A review of the literature and of expert opinion suggests that sediment loading may cancel out the effect of compaction and subsidence, so that net sea level rise may be assumed.

2.3.3 Salinity intrusion

Bangladesh is especially susceptible to increasing salinity of their groundwater as well as surface water resources, especially along the coast, due to increases in sea level as a direct impact of climate change. Reduced dry-season freshwater supplies from upstream sources resulting from climate change are expected to further exacerbate salinity conditions in the coastal area of Bangladesh (IPCC 1998). About 830,000 million hectares of arable land is affected by varying degrees of soil salinity. Approximately 1000 square kilometers of cultivated land and sea product culturing area is likely to become salt marsh (DOE, 2007).

Large-scale intrusion of salt water into surface and groundwater systems could have serious implications for drinking water supplies and food production due to unavailability of fresh water and soil degradation. The locality faces serious health risk due to increased salinity resulting in scarcity of drinking water. A World Bank (2000) study suggests that increased salinity alone from a 0.3 meter sea level rise will cause a net reduction of 0.5 million metric tons of rice production.

Salinity intrusion can also create drainage congestion, water logging and changes in morphodynamic processes resulting in increased riverbank erosion; therefore new approaches and technologies are needed to deal with existing and future salinity and cyclonic problems in the coastal area.

2.3.4 Flooding

Flooding in Bangladesh is a regular feature and has numerous adverse effects, including loss of life through drowning, increased prevalence of disease, and destruction of property. This is because, Bangladesh is located on a floodplain of three major rivers and their numerous tributaries. One-fifth of the country is flooded every year, and in extreme years, two-thirds of the country can be inundated (Mirza, 2002). During the monsoon season, 20% of the country is inundated each year, with over 60% in a peak flood (NWMP, 2001). Sudden, severe and catastrophic floods have intensified and taking place more frequently owing to increased rainfall in the monsoon. This vulnerability to flooding is exacerbated by the fact that Bangladesh is a low-lying deltaic nation exposed to storm surges from the Bay of Bengal. A projected increase in 20 to 30% in the associated precipitation could make the concerns even more serious.

The huge sediment loads brought by three Himalayan rivers, coupled with a negligible flow gradient add to drainage congestion problems and exacerbate the extent of flooding. As floods in Bangladesh are caused by intense monsoon precipitation over the basin areas of the Ganges, Brahmaputra and Meghna (GBM) rivers, future changes in precipitation regime have the following four distinct implications (Mirza, 2002).

1. The timing of occurrence of floods may change, with a possible change in the seasonality of the hydrological cycle
2. Increased precipitation in the GBM basins may increase the magnitude, depth, and spatial extent of floods
3. Timing of peaking in the major rivers may also change that may change the likelihood of synchronization of flood peaks of major rivers
4. Increased magnitude, depth, extent and duration of floods will bring a dramatic change in land-use patterns in Bangladesh.

2.3.5 Drought problem

Bangladesh is likely to face more hot days and heat waves, longer dry spells and higher drought risk due to the effect of climate change. The country has two distinct periods of

Dry season and the Monsoon having duration of seven months (November-May) and five months (June to October) respectively according to WARPO (SDNP, 2006). According to the definition of CCD, a reduction of water availability (falls below about 80% of the average availability of the preceding 30 or more years) and precipitation being significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resources production systems, might qualify as a drought (SDNP, 2006).

Existing drought in our country has already put various stresses on biophysical conditions degrading environment, productivity and socioeconomic situation that may increase poverty, food insecurity and social disruption. Projections suggest that the moderately drought affected areas of Bangladesh will be turned into severely drought prone areas within next 20-30 years (Mallick, 2007). There is enhanced possibility of winter (dry season) drought in certain areas. Impacts due to severe drought poses serious threats to the local community making them more vulnerable and it may cause population dislocation, cultural separation, habitation abandonment, and societal collapse.

The northwest region of Bangladesh has already been designated as drought prone mainly because of rainfall variability in the pre-monsoon and the post-monsoon periods. Rainfall mainly occurs during the monsoon. Its average temperature ranges from 35°C to 25°C in the hottest season and 9°C to 15°C in the coolest season (SDNP, 2006). The southern part of northwest Bangladesh (rajshahi and naogaon districts) is the driest part of the country, where rainfall is most unreliable in timing and amount. Agriculture, livelihood activities and human health are badly affected by the drought situation in the locality.

Based on annual rainfall, dry season net evapotranspiration and excess evapotranspiration (ETo-R), and dry season R/ ETo ratio value, a dry region is delineated. Considering the distribution of rainfall and evapotranspiration regimes, drought severity classes can be defined as non dry and dry regions. Dry regions may be divided again into two sub regions on the basis of severity of dryness as shown on Table 2.1 (SDNP, 2006).

Table 2.1: Severity of Dry Regions

Severity		Conditions/ Criteria Defined
Dry	Moderate	Annual Rainfall less than 1600 mm Excess Evapotranspiration more than 400 mm (ETo- R) R/ ETo ratio value less than 0.4
	Slight	Annual Rainfall 1600-2000 mm Excess Evapotranspiration 200-400 mm (ETo- R) R/ ETo ratio value 0.4 – 0.65
Non dry		Annual Rainfall more than 2000 mm Excess Evapotranspiration less than 200 mm (ETo- R) R/ ETo ratio value more than 0.65

Bangladesh experiences moderate to severe droughts over an area of 5.46 M ha (SDNP, 2006). With the assumption made and applied on the rainfall and evapotranspiration data available for the agro ecological zones of Bangladesh, the Northwest, Southwest and North central zones can be considered as dry region of the country.

Droughts in the period of June or July to October is created by sub-humid and dry conditions in the highland and medium highland areas of the country especially in the Barind of Bangladesh and it affect crops grown during Kharif II period (July to December). Droughts in the period January to May occur due to the cumulative effect of dry days, higher temperatures during Kharif I period (>40ºC in March-May) and low soil moisture. It affects crops grown in the period of Rabi season (November to April) and Kharif I period (March to July) (SDNP, 2006).

2.3.6 River erosion

A very high rate of sedimentation is predicted due to the increased flow in the rivers from increased rainfall in the upper catchment and from rapid melt of glaciers during summer in the next few decades (DOE, 2007). This will cause further erosion of the riverbanks, islands and coastal Bangladesh.

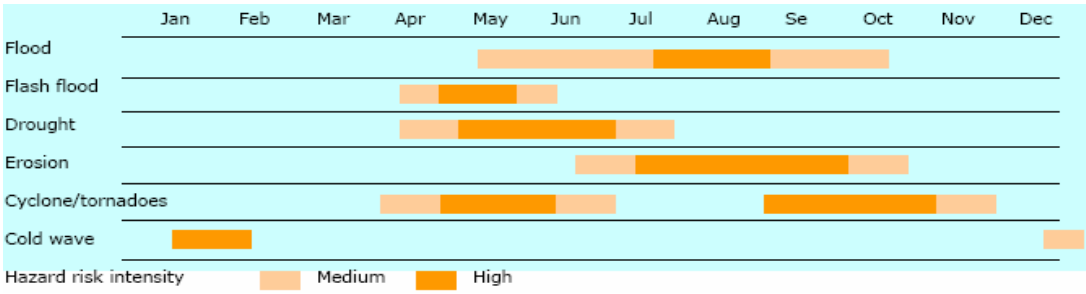


Figure 2.2: Climate Hazards Calendar of Bangladesh

A Climate Hazards Calendar developed by the DOE (2007) showing key climate related hazard risks for Bangladesh is summarized in Figure 2.2. The darker shade identify the period of a year when the risk is most critical.

2.4 Water Availability problems due to arsenic, iron and ground water depletion

Access to drinking water is insecure in some parts of the country all year round due to saline intrusion in the coastal area, while in a large part of the country groundwater is contaminated with iron and arsenic. Again scarcity of water during dry season is a major impediment which adversely affects drinking and domestic water supply, fisheries, forestry, navigation, irrigation, industries and above all the natural environment in large areas of Bangladesh. Dry season irrigation of Bangladesh is heavily dependent on groundwater. Future irrigation based mainly on groundwater would not be sustainable, as the amount of groundwater recharged each year is finite and the ground water layer is depleting to a unreachable layer.

In the northwest region of Bangladesh rainwater is the only major source of groundwater recharge. The withdrawal of more groundwater than its recharge causes the successive lowering of the groundwater table of this region. If the climatic change disfavours abundant precipitation in this locality, it will adversely affect the groundwater recharge system. Once there were many isolated small depressions in this region but those have since been converted into agricultural land. This landscape modification has affected the groundwater recharge and has increased dependence on rainwater.

2.5 Specific issues of different regions of Bangladesh

There are eight Hydrological regions in Bangladesh namely North-West region (NW), North-Central region (NC), North-East region (NE), South-West region (SW), South-Central region (SC), South-East region (SE), Eastern Hills region (EH) and Rivers and Estuary region (RE) (Figure 2.3).

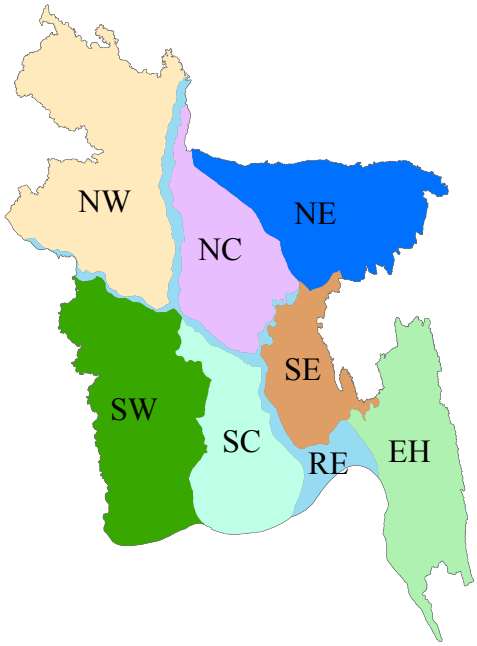


Figure 2.3: Eight Hydrological regions of Bangladesh

Vulnerable Areas and Most Impacted Sectors against Physical Impacts of different regions of Bangladesh are demonstrated in Table 2.2 according to Shaheduzzaman, M. (2006).

Table 2.2: Vulnerable Areas and Most Impacted Sectors against Physical Impacts

Physical Impacts	Critical Vulnerable Areas	Most Impacted Sectors
Temperature rise and drought	North-West	Agriculture (crop, livestock, fisheries), Water; Energy, Health
Sea Level Rise and Salinity Intrusion	Coastal Areas Islands	Agriculture (crop, fisheries, livestock), Water (water logging, drinking water), Human Settlement; Energy; Health
Floods	Central Region North East Region Char lands	Agriculture (crop, fisheries, livestock), Water (urban, industry), Infrastructure, Human settlement, Health, Disaster, Energy
Cyclone and Storm Surge	Coastal and Marine Zone	Marine Fishing, Infrastructure, Human settlement, Life and property
Drainage Congestion	Coastal Area Urban South –West	Water (Navigation), Agriculture (crop)

NWMP (2001) has detected some specific issues for eight hydrological regions of Bangladesh:

Northwest Region

The whole northwestern region of Bangladesh is facing low rainfall, ground water depletion, drought and deforestation for the last three to four decades. The region also suffers due to flooding in some parts. The channel migration, mainly the shifting of the Tista and the Atrai and their distributaries over the last couple of centuries, has greatly influenced the climatic conditions of the area. Geomorphic modifications gradually turned this area into a hot region (SDNP, 2006).

North Central Region

Major issues specific to the region are bulk water supplies and pollution clean-up for Dhaka City, flooding, drainage problems and water logging in parts of the region.

North East Region

Much of the NE region is taken up by the environmentally important haor basins, and efforts are needed to sensitively manage these in the context of the wider development requirements. Major issues specific to the region are crop damage due to flash flooding, erosion of old Brahmaputra left bank, drainage congestion in the Kalni–Kushiyara and other rivers.

South West Region

Major issues specific to the region are restoration of dry season freshwater inflows to the region, coastal drainage congestion, cyclone and flood. In the southwest brackish water coastal plains of Bangladesh, farmers use to have a paddy crop only during monsoon season when surface saline layer is depleted due to rainfall and for rest of the months the field is left for grazing.

South Central Region

Although the SC region has a marked excess of dry season water supplies, it experiences severe flooding from the Padma-Meghna rivers and a number of other problems in the coastal areas. Major issues specific to the region are siltation and drainage congestion, cyclone and flood.

South East Region

The SE region suffers similar problems to the SC region and is particularly affected by arsenic contamination. Major issues specific to the region are gaseous aquifers

improved cyclone protection, maintenance of the existing coastal embankment system and drainage congestion and protection of newly accreted lands against tidal flooding

Eastern Hills Region

This region, the most hilly in Bangladesh, is relatively short of water in the dry season but cannot be augmented feasibly from the main river systems. Its coastal fringe is particularly exposed to cyclones. Emphasis will be placed on making best use of dry season water resources, particularly the hilly charhas and the artesian wells, and programmes will be initiated to develop hill irrigation for high value crops.

Rivers and Estuary Region

Management of the main rivers is a particularly challenging task given the magnitude and ferocity of monsoon flows, and the strategic importance of the dry season waters they otherwise convey into the Bay of Bengal. Major issues specific to the region are cyclone, flood, river erosion mainly in Meghna river and coastal bank erosion.

2.6 Adaptive capacity of Bangladesh due to Climate change

According to the IPCC's Third Assessment Report (IPCC, 2001), developing countries are expected to suffer the most from the negative impacts of climate change because of climate-sensitive sectors such as agriculture and fisheries which are economically particularly important and because these countries have limited human, institutional, and financial capacity to anticipate and respond to the direct and indirect effects of climate change.

According to Sperling (2003) vulnerability to climate change is determined by geographic location; economic, social, and cultural characteristics; prioritization and concerns of individuals, households, and social groups; as well as institutional and political constraints. To understand how global warming and climate change will impact sustainable development, three considerations i.e. the geographic location, population and economic condition of the country are critical.

2.6.1 Geographic Location

The geographic location and geo-morphological conditions of Bangladesh have made the country one of the most vulnerable ones to climate change (DOE, 2007). The location of Bangladesh is in a deltaic plain of a major river basin, making it susceptible to floods and cyclones. Floodplains occupy 80% of the country (Rashid 1991).The

country has a very low and flat topography, except the northeast and southeast regions. Mean elevations of the country range from less than 1 meter on tidal floodplains, 1 to 3 meters on the main river and estuarine floodplains, and up to 6 meters in the Sylhet basin in the north-east (Rashid 1991). Over two-thirds of the country is less than 5 m above sea-level and densely populated (Agrawala. et al., 2003). Only in the extreme northwest elevations are greater than 30 meters above the mean sea level. The northeast and southeast portions of the country are hilly, with some tertiary hills over 1000 meters above mean sea level (Huq et. al., 1999). The country has 3 distinct coastal regions—namely, western, central, and eastern coastal zones.

2.6.2 Population of Bangladesh

The country is extremely populated in a small area, and one of the most densely populated in the world. So regardless of climate fluctuations, population growth will put extra stress on natural resources in Bangladesh and the country may become one of the worst affected by continued climate change.

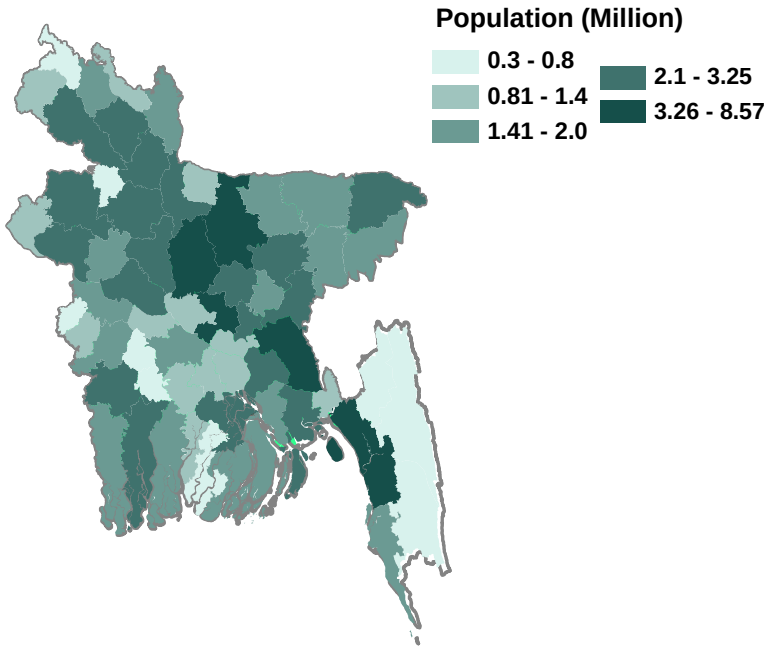


Figure 2.4: Population of Bangladesh, BBS 2001

Population density over Bangladesh has been mapped in Figure 2.4. This Figure clearly shows that Dhaka, Mymensingh, Tangail of NC region, Comilla in SE region and Chittagong in the EH region are most thickly populated. With a current population of 129 million expected to rise to 181 million by 2025 and to 224 million by 2050, the

country faces many challenges ahead in an era of increasing globalization. Rapid urbanization is expected with 40% of people (73 million) living in the towns and major cities by 2025, and 60% (136 million) by 2050 (NWMP, 2001).

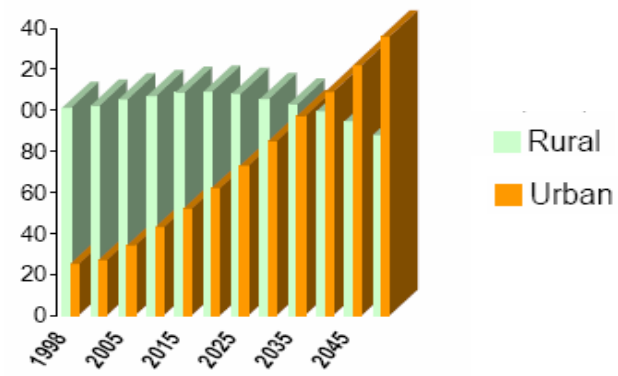


Figure 2.5: Population Projections (million) of Bangladesh, NWMP

NWMP (2001) has developed a chart showing the population projection of Bangladesh (Figure 2.5). From this Figure it can be observed that urban population is increasing day by day with an alarming rate.

2.6.3 Economic condition of Bangladesh

The per capita income in Bangladesh is US$370. This ranks below average per capita income for South Asian countries as well as the per capita income for low income countries (DOE, 2007). According to the UNDP Human Development Report 2006, population living on income of less than one US Dollar a day is 36 percent while 82.8 percent of the population is living on income below two US Dollars a day (DOE, 2007).

Access to income and employment is limited in this country. The majority of population is dependent for income and livelihood on agriculture. About one-quarter of the country's GDP comes from agriculture (DOE, 2007). Variability in rainfall pattern and temperature extremes are resulting in crop damage and failure, preventing farmers and those dependent from meaningful earning opportunities, which makes the country's economy relatively sensitive to climate variability and change. Climate change impacts would in fact pose a serious impediment to the economic development of Bangladesh.

2.7 Main sources of water in Bangladesh

About 15,000 Himalayan glaciers form a unique reservoir which supports perennial rivers such as the Indus, Ganges and Brahmaputra which, in turn, are the lifeline of

millions of people in Bangladesh (IPCC, 2007a). The two main sources of water are the transboundary inflows from the Brahmaputra, Ganges and Meghna rivers, and groundwater which is exploitable over 56% of the country, and is recharged annually by monsoon rainfall (NWMP, 2001).

The diversion of Ganges water by the Farakka barrage in India has contributed to the reduction of surface water availability and aggravated the desertification process in the western part of the country. The decreased stream flow also affects the river morphology as well as the ecosystem.

2.8 Water requirement in Agricultural sector

In Bangladesh agriculture is the largest sector of the economy, which is heavily dependent on rainfall. Rainfall over the country is highly variable both spatially and temporally. Precipitation provides part of the water crops need to satisfy their transpiration requirements. The soil, acting as a buffer, stores part of the precipitation water and returns it to the crops in times of deficit. In humid climates, this mechanism is sufficient to ensure satisfactory growth in rain fed agriculture. But when there isn't enough soil moisture to meet the needs of a particular crop at a particular time, agricultural drought occurs. In arid climates or during extended dry seasons, irrigation is necessary to compensate for the evaporation deficit due to insufficient or erratic precipitation.

Consumptive use of water in irrigated agriculture is defined as the water required in addition to water from precipitation (soil moisture) for optimal plant growth during the growing season. Optimal plant growth occurs when actual evapotranspiration of a crop is equal to its potential evapotranspiration and the net irrigation water requirement is the volume of water needed to compensate for the deficit between potential evapotranspiration and effective precipitation over the growing period of the crop. It varies considerably with climatic conditions, seasons, crops and soil types. Due to excessive rise in evaporation rates and reduction in dry season trans-boundary flows, irrigation water requirement has been increased. Erratic behaviour of temperature, rainfall and disruption of seasonal pattern will lead to reduction of crop yield, constraint growth of vegetation and increase of water demand and scarcity.

Rice and wheat are the two main cereal crops, which play central role in the human food chain in our country as well as in the region of South Asia. Demand for rice and wheat

in South Asia will grow at 2.5% per year over the next 20 years, but the per capita rice-wheat growing area has already shrunk from 1,200 m^2 in 1961 to less than 700 m^2 in 2001 (Ladha et al. 2000). Future growth in food production can only come from increased yield rather than area. In the specific case of paddy rice irrigation, additional water is needed for flooding to facilitate land preparation and for plant protection. In that case, irrigation water requirements are the sum of rainfall deficit and the water needed to flood paddy fields.

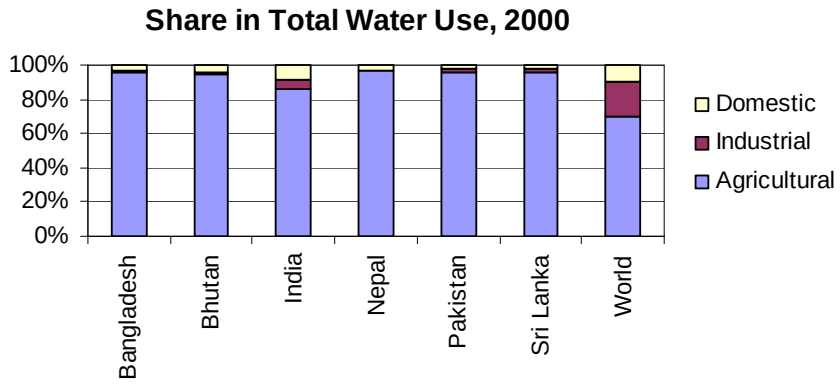


Figure 2.6: Share in Total water use, 2000

Figure 2.6 shows a bar chart which demonstrates the relative water use in different sectors for Bangladesh, the neighboring countries, as well as for the whole world. It can be found that water use in agricultural sector is very high in the South Asia region, which is 96% for Bangladesh and 70% for the whole world. So agricultural water use occupies the maximum value relative to water use in domestic and industrial sectors.

Shortage of rainfall affects the critical reproductive stages of crops during Kharif II period (July to December), e.g. transplanted Aman crops in December, reducing its yield, particularly in those areas with low soil moisture holding capacity. This drought also affects fisheries and other household-level activities. Drought during the period of January to May affects all the rabi crops, such as HYV Boro, Aus, wheat, pulses and potatoes, and kharif I crops such as t.aus, especially where irrigation possibilities are limited. It also affects sugarcane production. Dryland rabi crops may be grown in the dry season on poorly drained land which is flooded in the monsoon but dryland kharif crops must be grown on well-drained soils (SDNP, 2006).

Since scarcity of water being the main obstacle against intensive agriculture, during the dry season farmers use deep tubewells extensively for irrigation wherever surface water

is not readily available. As a result, seasonal water tables reach to lower levels, impacting on hand tubewells, which are commonly used in the rural areas for water supply for drinking. Climate change will exacerbate this problem.

2.8.1 Loss in Agriculture due to Drought, Flood, Salinity, Water logging

Crop damage due to flash floods, monsoon floods, crop failure due to drought, prolonged cold spell, salinity intrusion along the coast conduct to scarcity of potable water and redundancy of prevailing crop practices in different regions of Bangladesh. During the period of 1973–1987, about 2.18 million tons of rice was damaged due to drought and 2.38 million tons due to flood. Drought affects annually about 2.32 million hectares and 1.2 million hectares of cropped land during the Kharif (November to June) and Rabi (July to October) seasons respectively, while soil salinity, water logging and acidification affect 3.05 million hectares, 0.7 million hectares and 0.6 million hectare of crop land, respectively in the country (DOE, 2007). The IPCC Working Group II has reported in their fourth assessment that the production of rice and wheat might drop in Bangladesh by 8 percent and 32 percent respectively, by the year 2050 (DOE, 2007).

2.9 Human migration due to Climate change

There is higher rate of rural to urban migration in Bangladesh, because of endemic poverty and various social factors. The rate of urbanization has been rapid in Dhaka, the capital as well as in other metropolitan areas in the country over the past few decades. Thousands of people are becoming environmental and climate refugees in Bangladesh and living in city slums in inhuman condition without basic amenities. They are also putting enormous pressures on urban infrastructure, economy and service delivery systems. This process will be further aggravated in the warmer climate and associated sea level rise in Bangladesh (Mallick, 2007).

Human migration is a direct consequence of lack of income and other livelihood opportunities in the rural areas as well as loss of property, home and access to natural assets due to natural hazards and their impacts. In the decade of 1982 – 1992, over 106 thousand hectares of land has been eroded in the three major rivers of Bangladesh (the Ganges, the Brahmaputra and the Meghna) against an accretion of only 19 thousand hectares. Over 350 thousand people were displaced due to riverbank erosion in that decade alone, suffering severe economic and social consequences (DOE, 2007).

The worst case scenario is the permanent displacement of people from the coast. Substantial numbers of communities are being forced to displace from coastal islands, chars, and along the coastline as their settlements are destroyed due to frequent and intense storm surge and tidal bores. Assuming a population of the year of 1995 and no adaptation Nicholls et al. (1995) estimated that a one meter rise in sea level could displace as many as 15 million people. A more recent estimate by UNEP/GRIDArendal (2001) puts the number of displaced people at 17 million (15 percent of the population) for a rise in sea level of 1.5 m.

2.10 Adaptation and Mitigation measures to reduce vulnerability to climate change

Impacts of global warming and climate change have the potential to challenge our development efforts, human security in future. In a changing climate the pattern of impacts are eroding our assets and investment. Bangladesh must move on in its pursuit to develop and strive as a nation, taking into account its vulnerability, susceptibility and capacity to manage climate risks and adaptation. We must secure the well-being and development of Bangladesh by making the people and country resilient, through necessary resource and support, both internal and external.

Building adaptive capacity to cope with current climate is one way of preparing society to better cope with future climate. It should be addressed through the mainstreaming of climate risk into sustainable development strategies. The extent and nature of negative impacts imposed by climate change can be managed by effective adaptation. Collective efforts are now necessary to understand risks and take actions, thereby enhancing coping and adaptive capacity of the community to avoid worsening impacts over the coming decades.

Increased adaptive capacity through prioritized adaptation strategies should be incorporated into development plans in the water sector. For developing vulnerability and adaptation assessment, socioeconomic scenarios should also be taken into consideration. Efficiency of resource utilization can be improved in the water sector through conjunctive use of all forms of surface and groundwater for irrigation and urban water supply. Alternative storage options that need to be explored are ground water storage and rainwater harvesting.

2.10.1 Adaptation Strategy for Coastal Flooding

Mangrove plantation along the coastal river side and road side which can act as a natural barrier to rising tide levels and floods with involving target households and stakeholders can be promoted for preventing cyclone damages and also for protection against river bank erosion. Community link and network can be established. Infrastructures may be developed along the coast to reduce severity of impacts due to cyclone and tidal surge. In the coastal region rainwater harvesting can be adopted as an alternate source of drinking water as the other remaining sources are getting intruded with saline water.

2.10.2 Adaptation Strategy for Water sector

Addressing water problem holds the promise in future for a world compounded by climate change, growing population and decreasing water-impounding area of traditional tanks due to urbanization. Most of the adverse impacts of climate change in Bangladesh deal with water-related extreme events and related issues.

From the 1970s a movement toward demand-control policies has been challenging the expansion of water supply capacity in meeting growing needs (Hiessel, 2002). The simultaneous emergence of the goals and paradigms of sustainable water management facilitates, the development of constructive applications of new technologies should be initiated such as introducing safe water options such as rainwater harvesting systems for drinking and domestic use, excavation of ponds or re-excavation of the existing ponds, establishment of sweet water storage and conservation techniques and their proper management, water re-use and desalination of water in the salinity prone areas. Awareness should be built up among people for efficient use of sweet water.

In towns of economic importance, flood protection should be provided as a priority, and phased implementation of reasonable flood protection facilities will be introduced in Zila and Upazila towns. Several projects being implemented under the National Water Management Plan have the potential to address future adaptation to floods in Bangladesh. Through building of embankments, which can protect against enhanced flooding and also serve as highways and through building homes, more sustainable against frequent flooding can be taken as the adaptation measure against floods.

National water policies, integrated water resources management and water-related hazards management policy should have proper guideline for adaptation measures that will be taken to compensate climate change impacts.

2.10.3 Adaptation Strategy for Agriculture

One of the most fundamental aspects of adaptation to climate change is the capacity of the people who rely mainly on farming for their livelihoods to alter their activities. As the adaptation strategy for impacts of future climate change in agricultural sector, some measures can be taken by the farmers such as adjustment of planting dates and crop variety; crop relocation; diversification of agriculture such as promotion of salt tolerant rice varieties and other crops in salinity prone areas, efficient use of water for irrigation, improved land management through erosion control and soil protection by tree planting.

To overcome the adverse situation people of the drought prone areas may adopt some measure such as identification and demonstration of suitable varieties of crop and introduction of suitable drought tolerant crops, multiple cropping, crop rotation and diversification of crops. Capacity building; crop insurance; financial incentives can be taken into consideration while making policy framework.

According to IPCC (2001), Government of Bangladesh should develop and promote the use of hybrids and to develop infrastructure for post harvest management, marketing and agribusiness.

2.11 Rainwater harvesting as an adaptation to Climate change

The origin of the term “water harvesting” is not known, but it was probably first used by Geddes of the University of Sidney (Reddy, 2006). He defined water harvesting as “the collection and storage of any farm waters, either runoff or creek flow, for irrigation use.” Several modifications of the definition have broadened the term to mean “the process of collecting natural precipitation from prepared watersheds for beneficial use”.

Demand on water resources witness a substantial increase due to development, population increase, and global weather change. Adopting the concept of sustainability and conservation of water resources can help to cope with the global water shortage. So, efforts are needed to encourage innovative policy including managing the water demand and promoting rainwater harvesting system. The application of an appropriate rainwater

harvesting technology can make possible the utilization of rainwater as a valuable and necessary water resource and this technology can be promoted as a core adaptation strategy for achieving the global security and sustainability of water resources in an era of intensive climate change (Pandey et. al., 2003). In response to climate extremes this technology enhances the resilience of human society as it can help to reduce the demand on water resources for domestic, landscaping, and agriculture.

Jackson, R. B. (2001) gave many reasons for the relevancy of recent adoption of using rainwater harvesting to overcome the increasing demand of water beside the global weather changes. These reasons are

1. over half of the accessible freshwater runoff globally is already appropriated for human use;
2. more than 1 billion of people currently lack access to clean drinking water and almost 3 billion of people lack basic sanitation services;
3. because the human population will grow faster than increases in the amount of accessible freshwater, per capita availability of freshwater will decrease in the coming century;
4. climate change will cause a general intensification of the earth's hydrological cycle in the next 100 years, with generally increased precipitation, evapotranspiration, occurrence of storms and significant changes in biogeochemical processes influencing water quality.

People may resort to modify dwelling environments by adapting new strategies to optimize the utility of available water by harvesting rainwater rather than migrating to newer areas due to arsenic or iron problems (Pandey et. al., 2003). In the saline areas (the greater Khulna, Satkhira, Patuakhali, Barisal and Noakhali districts) the polders have the potential to revolutionize the drinking water supply systems through the construction of "sweet water ponds" which are replenished by rainwater in the monsoon (UNEP, 2007).

The volume of rainwater collected from rainwater harvesting system greatly vary from place to place and it depends extensively on weather. According to Pandey et. al. (2003) adaptation through rainwater collection may be particularly effective in tropical monsoon regions, where the seasonal cycle in rainfall is large.

According to Hussain (2006), rainwater harvesting is usually classified into two types according to the sector provided with rainwater.

- Harvesting rainwater for agriculture (irrigation) needs and
- Harvesting rainwater for domestic and other needs.

Considering the practice of collecting runoff from rainfall events rainwater harvesting can be classified into two broad categories: land-based and roof-based (Texas Water Development Board, 2006). Land-based rainwater harvesting occurs when runoff from land surfaces is collected in furrow dikes, ponds, tanks and reservoirs. Roof-based rainwater harvesting refers to collecting rainwater runoff from roof surfaces and it results in a much cleaner source of water. Rainwater harvesting can be used for both indoor and outdoor purposes in residential, commercial, and industrial applications. The health benefits of rainwater, and potential cost savings associated with rainwater collection systems have further spurred this interest. Climate policy and water policy would require to be streamlined to promote rainwater harvesting in the water-stressed areas of Bangladesh.

2.11.1 History of Rainwater Harvesting

Historical societal adaptations to climate fluctuations may provide insights on potential responses of modern societies to future climate change that has a bearing on water resources, food production and management of natural systems. Over thousands of years, people living in various geographical and climatic regions of the world have evolved diverse, indigenous rainwater harvesting and management regimes as an adaptation to climate change (Pandey et. al., 2003).

Rainwater harvesting has been the main source of water supply for potable and non-potable uses in the old days because the water conveyance systems were not used for water distribution during these days and the method used for rainwater harvesting was simple and primary, at the same time usage of the collected water volume from rainwater harvesting was direct and without any treatment (Mohammed et. al., 2008). Construction of early rainwater harvesting systems required simple scooping of the earth and putting up embankments or erecting elongated soil heaps along farm boundaries.

Many regions of the world have adopted strategies to conserve the available water resources including promoting the usage of rainwater harvesting technique for

landscaping and agriculture, thereby reducing the stress on water supply due to climate change impact. These regions are India, South America, Arabian Peninsular, North America, Europe, and Asia-Pacific (Mohammed et. al., 2008). Construction of rainwater harvesting structures is practices adopted to overcome drought periods in the above mentioned regions. According to Texas Water Development Board (2006), Germany has been a leader in promoting the widespread use of rainwater for domestic use, focusing mainly on non-potable uses.

Rainwater harvesting is used extensively in Latin America and the Caribbean, mainly for domestic water supply and, in some cases, for agriculture and livestock supplies on a small scale. In Brazil and Argentina, rainwater harvesting is used in semi-arid regions. In Central American countries like Honduras, Costa Rica, Guatemala, and El Salvador, rainwater harvesting using rooftop catchments is used extensively in rural areas (UNEP, 1997). The use of rainwater is very effective in lessening the demand on the public water supply system in the British Virgin Islands (UNEP, 1997). Also, because of the hilly or mountainous nature of the terrain in the majority of the British Virgin Islands, combined with dispersed housing patterns, rainfall harvesting appears to be the most practical way of providing a water supply to some residents.

France has recently enacted legislation to encourage the use of rainwater (Texas Water Development Board, 2006). In New South Wales, Australia, the government is requiring a 40 percent reduction in water use, and some studies have shown that rainwater harvesting systems can reduce municipal water demand there significantly (Coombes, 2004).

Rainwater harvesting in South Asia differs from that in many parts of the world. It has a history of continuous practice for at least the last 8000 years (Pandey et. al., 2003). The antiquity of rainwater harvesting as an adaptation to climate change in India is deep. Earliest examples of rainwater systems in India include the havelis of Jabalpur, bandh and bandhulia of Satna, virda of Gujarat, khadins of Rajasthan, ahar-pynes of Bihar, eri of Tamil Nadu, dhora of Aravalis and similar other earthworks throughout the country (Pandey et. al., 2003). Even after the disappearance of river Saraswati in India due to drainage disorganization and subsequent increase in aridity, people continued to occupy the region by adapting to climate change through rainwater harvesting. Indeed, the post-Saraswati society that developed in the Thar desert is essentially a rain-harvesting

society. Today, Thar is the most densely populated desert in the world and every settlement there has often more than one water collection pond and numerous earthworks to harvest rain developed over the last 5500 years of continuous and dynamic adaptation to climate change (Pandey et. al., 2003).

In Pakistan, in the mountainous and dry province of Balukhistan, bunds are constructed across the slopes to force the runoff to infiltrate. In China, with its vast population is actively promoting rain and stream water harvesting (Sivanappan, 2006).

Rainwater harvesting by the erection of bunds around farms is the most common and one of the earliest methods of rainwater harvesting in Bangladesh. Farmers have learned from experience to match their cropping cycle with rainfall pattern. In some areas of Bangladesh rainwater meets around 78% to 97% of land preparation water requirement for aman crops (UNEP, 2007). In some saline prone areas of Bangladesh, rainwater is used in the aman paddies to dilute saline river water until the river water becomes sweet. In the upland areas of Bangladesh (NC zone- Jhenaighati, Nokla thanas) rainwater is stored in low lying plots usually in between two hills to be used in times of necessary. Stored rainwater is also used for fish culture in this area. In the central zone (Jhenaidah thana), rainwater is collected from surrounding lands at higher elevations and carried to storage ponds through a culvert (UNEP, 2007).

In southern portion of Hatya and other remote islands in the Bay of Bengal, where there are very few tubewells, rainwater from these ponds is found to meet the drinking water requirement in the monsoon season. In the saline area of the SW zone, rainwater is also used for drinking purpose in monsoon and dry season. On the other hand, in the NC zone, rainwater is not used for drinking purposes but, instead, is used for cooking (6%) and bathing/washing (11%). In the NW zone, only 2% of the inhabitants reported using rainwater, for bathing only, as their entire requirement for drinking and cooking water is met from tubewells and, to some extent, from ponds/rivers and other surface waterbodies (UNEP, 2007).

2.11.2 Contemporary relevance and Advantages of Rainwater harvesting

A systematic support to local innovations on rainwater harvesting can provide substantial amounts of water and reduce demand on water supply systems. Rainwater harvesting systems have the potential to be used for emergency water supplies for either drinking purpose or for irrigation and serve as a move towards sustainable development

in both urban and rural settings. Harvested rainwater may be the only source of water supply for many rural and remote households where no other water supply is available. In urban and suburban environments, rainwater harvesting can help public water supply systems to reduce peak water demands and can minimize pressure on water treatment plants.

Rainwater collection and utilization schemes are optimal when implemented in conjunction with water demand management, as well as measures to enhance aquifer recharge. The technology is flexible, the construction, operation, and maintenance are not labor-intensive also the running cost is low. According to Krishna (2003), there are numerous potential benefits and advantages from rainwater harvesting.

- Wastage of heavy surplus water in to sea can be minimized.
- Rainwater collection and utilization are effective for flood control strategies.
- Reduce non-point source pollution;
- Reduce storm water run off and soil erosion
- Rehabilitate the existing traditional water harvesting structure like ponds, percolation tanks, baolis, tanks, etc
- Rainwater is pure and soft
- Reduce the demands on groundwater
- Rainwater harvesting provides a source of water at the point where it is needed.
- Because of construction of Rain Water Harvesting Tanks the loss due to flood damages can be minimized.

2.11.3 Effectiveness of the Technology

The feasibility of rainwater harvesting in a particular locality is highly dependent upon the amount and intensity of rainfall. As rainfall is usually unevenly distributed throughout the year, rainwater collection methods can serve as only supplementary sources of household water and for irrigation (UNEP, 2007). The viability of rainwater harvesting systems is also a function of the quantity and quality of water available from other sources; household size and per capita water requirements; and budget available. In case of roof water harvesting the potential for the water to be polluted by birds droppings, dust, etc., that accumulates on the rooftop requiring a regular programme of maintenance of the roof surface and filter.

Low storage capacities will limit rainwater harvesting so that the system may not be able to provide water in a low rainfall period. Increased storage capacities add to construction and operating costs and may make the technology economically unfeasible, Leakage from cisterns can cause the deterioration of load bearing slopes. Where treatment of the water prior to potable use is infrequent, due to a lack of adequate resources or knowledge, health risks may result; further, cisterns can be a breeding ground for mosquitoes.

2.11.4 Potential of Rainwater harvesting to be adopted as an alternate source of water for drinking purposes

Groundwater being the main current source of water for domestic use, the depletion of ground water level during dry period, the contamination of arsenic, iron and other materials pose a major threat to provision of safe water supplies. In salinity prone areas people face scarcity of sweet water. Rainwater harvesting has the potential to be used as an alternate source of water in the affected areas having the above mentioned problems. Rainwater harvesting may provide the following benefits to the people living in areas having problems due to shortage of drinking water.

- Rain water harvesting replenishes the ground water table depleted due to over exploitation and enables the dug wells and bore wells to yield in a sustained manner.
- Provide good-quality of water if groundwater quality is unacceptable i.e. contaminated with arsenic, iron and other materials.
- Mitigating the effect of droughts and achieving drought proofing
- Prevent salinity ingress in coastal areas.

Arsenic contamination of shallow aquifers has been identified as a major problem in many locations of Bangladesh with about 25% of the population exposed to levels exceeding Bangladesh standards (0.05 mg/litre). A further 21% live in areas where evidence suggests that arsenic concentration exceeds current WHO standards (0.01 mg/litre) (NWMP, 2001). According to Ahmad et al. (1998), about 40 million people of Bangladesh are at risk of arsenic poisoning. Intake of arsenic contaminated water adversely affects the health of millions of people by causing arsenicosis and increase the risk of cancer. The presence of iron, boron and other contaminants in groundwater are also important concerns for drinking purpose. Iron has no direct health relevance but its

presence in groundwater can impart colour, turbidity and taste to drinking water and consequently consumers can reject groundwater.

In case of widespread arsenic poisoning rainwater harvesting has great potential as a possible solution. Deep wells are being advocated as a remedy, that may provide a source of clean water; but the solution is only a provisional one. Rainwater harvesting is a better option to provide arsenic-free, safe water in a cost-effective and accessible manner, particularly for drinking and food preparation.

2.11.5 Rainwater Harvesting for Irrigation in Rural area

In a fluctuating Holocene climate, rainwater harvesting by early farmers may have been pivotal for emergence and diversification of food production. Rainwater can be captured, diverted, and stored for the purpose of using it for plant irrigation. Degree of saturation for catchment ground surface and its nature should also be considered for adopting rainwater harvesting for irrigation. Using rainwater for irrigation can reduce the water consumption. A rainwater harvesting system for irrigation has three components (Mohammed et. al., 2008), namely

- The supply source (the catchment),
- The demand (landscape water requirement), and
- The conveyance system (system that moves the water to the plants).

Rainwater is a clean source of water for plants (free from salt). The system can reduce salt accumulation and contribute in a good soil environment for root growth. The salt concentration in root zone of plants is reduced when collected rainwater percolates deep into the soil and diluting available salt in this zone. This will result in greater root growth and water uptake, which increases the drought tolerance of plants (Mohammed et. al., 2008).

The selected type of plant, age, size, and spacing between successive plants are factors which contribute in the success of using rainwater for irrigating landscape areas (Mohammed et. al., 2008). The rainwater harvesting tanks should be located in the initial reaches of streams, so that the stored water can be utilized for filling the minor irrigation tanks when there is scanty rainfall and hence crops can be grown successfully. The tanks should essentially have a sluice and a surplus weir to dispose off flood water. The sluice can let down water to the down stream existing minor irrigation tanks

(Sivanappan, 2006). There is a need to formulate a coherent policy or strategy towards strengthening extension and technical support regarding Rainwater harvesting tanks for crop production.

To determine the amount of irrigation water available from storage of rainwater harvesting system and also the supplement volume of irrigation water needed, computation of monthly supply or rainfall harvest potential and the monthly demand or plant water requirement for a period of one year can be done by applying the Rational method (Mohammed et. al., 2008):

$$S = A \times R \times C \tag{2.1}$$

Where S is monthly yield of rainwater harvest, A is catchment area, C is runoff coefficient, and R is the monthly rainwater depth. Although in reality the amount of water available fluctuates on a daily basis but for simplicity the computation can be done on a monthly basis. The volume of water required by the plants (demand) is computed based on monthly evapotranspiration data using the following equation (Mohammed et. al., 2008):

$$D = ETo \times \beta \times A \tag{2.2}$$

Where D is monthly water demand or volume of irrigation water, (ETo) is monthly evapotranspiration, β is the plant factor, and A is the irrigated area. Equations (2.1) and (2.2) are usually used to compute yield and demand for both new and established landscapes. The plant factor represents the percent of ETo that is needed by the plant and it mainly depends on the type of the irrigated plant (high, medium, or low water use).

Yield fluctuates from year to year depending on the weather and also for which month the rainfall occurs. Demand of water for crop may increase when the weather is hotter than normal and will increase as the plants of the landscape ages and its sizes increase. Demand is also high during the plant establishment period which requires more frequent irrigation for new landscapes.

Types of Rainwater Harvesting Systems for Irrigation

In rainwater harvesting system rainwater can be stored in natural depression, excavated pit, or a tank and a pump may be used to supply the rainwater for irrigation. A self-sufficient rainwater harvesting system should provide enough irrigation water in an

average year where the surplus volumes of rainwater can be stored in a tank and then be used for irrigation between rainfall events or at dry period. Before the rainwater is stored it should be filtered to remove large particles and debris. The degree of filtration is dependent on the size of the distribution pipes and the size of emitters. According to Asati, et al. (2006) following are the structures generally used for the rainwater harvesting.

Recharge Pits: Recharge pits are constructed for recharging the shallow aquifers. These are constructed 1 to 2 m. wide and 2 to 3 m. deep which are backfilled with boulders, gravels and coarse sand.

Recharge Trench: These are constructed when the permeable strata are available at shallow depths. Trench may be 0.5 to 1 m. wide, 1 to 1.5 m. deep and 10 to 20 m long depending upon the availability of water. These are backfilled with filter materials.

Open wells: Existing open wells may be utilized as recharge structures and water should pass through filter media before putting it into open well.

Hand Pumps: The existing hand pumps may be used for recharging the shallow or deep aquifers, if the availability of water is limited. Water should pass through filter before diverting it into hand pumps.

Recharge Wells: Recharge wells of 100 to 300 mm diameter are generally constructed for recharging the deeper aquifers and water is passed through filter media to avoid choking of recharge wells.

Recharge Shafts: For recharging the shallow aquifers, which are located below clayey surface, recharge shafts of 0.5 to 3 m diameter and 10 to 15 m depth are constructed and back filled with boulders, gravels and coarse sand.

Lateral shafts with bore wells: For recharging the upper as well as deeper aquifers lateral shafts of 1.5 to 2 m wide and 10 to 30 m length depending upon availability of water with one or two bore wells are constructed. The lateral shaft is back filled with boulders, gravels and coarse sand.

Deserted wells: Recharge water is guided through a canvas pipe of 100 mm diameter to the bottom of well or below the water level to avoid scouring.

2.11.6 Urban water supply option through Rainwater Harvesting

The rate of the growth in the urban area is about four times that of the rural areas (Mohammed et. al., 2008). In urban areas water resources are fast depleting due to rapid increase in population and unrestricted use of water. Optimization of water usage and the conservation of water as a natural resource can help to overcome water shortage. Based on this fact, the concept of sustainability must be considered in planning and management of the available water resources. Rainwater harvesting can be considered as an option for water source. With the development and growth of urban populations, the paved and roof area increase and this situation is ideal for implementing rainwater harvesting techniques.

Urban catchment integration is an important aspect of rainwater collection and utilization. The construction of a rooftop rainwater catchment system is very simple. Rainwater harvesting simply collects the rain which fall onto roofs, then stores it in a tank, the water is then pumped to the point of use, thus displacing what would otherwise be a demand for mains-water. In the process, a volume of water is kept out of the storm-water management system, thereby helping to reduce flooding risks. In urban areas the following benefits can be achieved through adopting rainwater harvesting system.

- The rainwater harvesting system provides an essential reserve in times of emergency or in case of breakdown of public water supply systems, particularly during natural disasters.
- Help utilities in reducing peak demands in the summer
- The rainwater harvesting system is cost effective thus overall water supply cost can be reduced.
- Reduction in the use of energy for pumping water and consequently the costs.
- Provide water for non-potable indoor uses;
- The system can provide water for fire protection

It is preferable to integrate the rainwater harvesting systems with the existing conventional water supply systems. This will help to meet the increasing demand of water supply and contribute in the sustainability of the water supply.

Potential of Rainwater Harvesting System in Dhaka city

There were once lakes and canals within and running through many of the city zones of Dhaka. Rapid urbanization in Dhaka city has led to the loss of wetlands. About 250 sq. km (Khan, 2005) of watersheds around the Dhaka city surrounded by the rivers Buriganga and Shitalakhya have either been encroached upon or dried up due to inadequate flow from the main water bodies. Ground water is not an unlimited resource, and continuous lowering of groundwater table day by day can cause geological imbalance and meteorological change in the country. For water availability borewells in the city have to go deeper and deeper. Current annual withdrawal of groundwater in the city is in excess of annual recharge of the aquifers. Withdrawal rate in the city should be, in fact, reduced to prevent further lowering of the water table. So, new sources for extra water need to be identified for exploitation and there is an urgent need to find ways of saving, reusing and recycling water.

Rain water harvesting may be adopted in Dhaka city, where rain water may provide full coverage in the wet season and partial coverage during the dry season. Stored water may also ensure short-term security against the failure of other sources. In the process, a volume of water is kept out of the storm-water management system, thereby it may help to reduce water logging in the city. Rain water may also contribute in ground water recharge process. Dual plumbing systems, to use rainwater harvesting systems in conjunction with existing municipal water systems may be effective in Dhaka city. With the application of appropriate water quality standards, treatment methods, and cross-connection safeguards, rainwater harvesting can be effectively used in conjunction with public water systems.

Rainwater can be used for potable and non-potable uses. The potable uses include drinking, bathing, and cooking and washing. Usually, the rainwater used for this purpose must be treated to remove the contaminants. Non-potable uses include flushing toilets, watering garden and washing floor and treatment of rainwater is not required for these purposes.

Components of Domestic Rainwater Harvesting System

Most of the domestic rainwater harvesting system around the world is composed of the roof, gutter, down pipes, primary screening, first flush diverters, storage tanks, the pipes

and water treatment unit. Figure 2.7 shows the schematic of typical rainwater catchment system (UNEP, 1997).

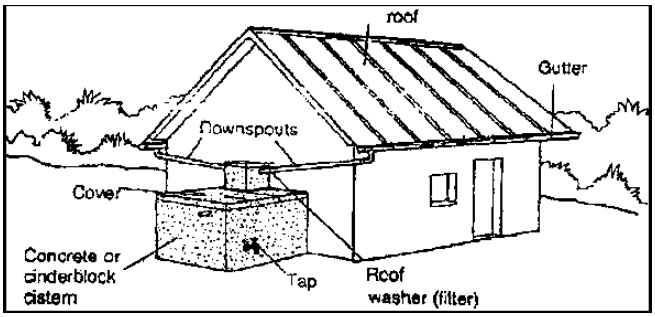


Figure 2.7: Schematic of a Typical Rainwater Catchment System *(Source: UNEP, 1997)*

According to UNEP (2007) household rooftop rainwater collection systems consist of the following elements:

Catchment: Rainwater may be collected from any kind of roof. Tiled or metal roofs are easiest to use, Concrete roof may also be used for rain water harvesting. Rooftops in buildings can be designed to collect rainwater.

Guttering: Guttering collects the rainwater runoff from the roof and conveys the water to the downpipe. Gutters may be constructed of plain galvanized iron sheets or of local materials such as wood, bamboo, etc. All gutters should have a mild slope to avoid the formation of stagnant pools of water.

Down pipe: A vertical down pipe is required to convey the harvested rainwater to the storage tank. An inlet screen (#20 wire mesh) to prevent entry of dry leaves and other debris into the down pipe should be fitted.

Foul Flush Diversion: The first flush of water from the roof is likely to contain dust, bird dropping and debris which are collected on the roof. This contaminated water should be diverted from the storage tank to avoid polluting the stored rainwater. Such a diversion can be achieved manually by including a ninety degree elbow on the down pipe so that the pipe can be turned away from the storage tank to divert the flow for the first 5 to 10 minutes of a storm.

Filter: A filtering system may be placed between the down pipe and the storage tank, after the foul flush system. Filters can be constructed using locally available materials such as sand, gravel, or charcoal, etc. placed within a container to a depth of 1.2 m.

Storage Tank: The size of the storage tank in a particular area should be matched to the volume of water expected to be harvested based upon the area of the roof. The volume of the tank should also be related to the quantity of water required by its users, and be appropriate in terms of cost, resources required and construction methods.

For determining storage tank size Mass Curve Analysis can be followed. This analysis appears to be a common method used in determining the necessary capacity of the tank (Ahmed et. al., 1999, Handia, 2003 and Smet, 2003). It involves identification of critical periods in data where the difference between cumulative runoff volume and cumulative demand of water are at a maximum. This difference represents the maximum volume of water available for future use.

For adopting domestic rainwater harvesting system at first the volume of rainwater should be estimated. It is also important to know the water demand of the people for whom rainwater would be harvested. The determining factors for obtaining information about water demand may include the number of inhabitants to be supplied with water and their demographics, the consumption habits of the population, the type of development, property size and the property landscape.

2.11.7 Qualitative Assessment of Rainwater

The physical and chemical properties of rainwater may be superior to those of surface waters that may have been subjected to pollution (UNEP, 1997). The rainwater harvesting system provides pH neutral or slightly acidic water which is naturally soft (UNEP, 2007). There is no need for water softeners for treatment and rainwater requires less soap and detergent than most public water supplies because of its natural softness. This system provides good quality water also for landscape irrigation.

Depending on where the system is located, the quality of rainwater itself can vary, reflecting exposure to air pollution caused by industries such as cement kilns, gravel quarries, crop dusting, and a high concentration of automobile emissions (Mohammed et. al., 2008). Heavy metals such as lead are potential hazards especially in areas of high traffic density or in the vicinity of heavy industries. Organic chemicals such as organochlorines and organophosphates used in biocides can also contaminate rainwater. Serious atmospheric contamination of rainwater is normally limited to urban and industrial locations (Mohammed et. al., 2008). Despite the numerous sources of atmospheric pollution, in most parts of the world, especially in rural and island

locations, levels of contamination of rainfall are low. Most contamination of rainwater occurs after contact with the catchment surface (roof or ground), it can wash many types of bacteria, moulds, algae, protozoa and other contaminants into the cistern or storage tank. Matt et. al. (2001) recommended six common water quality tests to be performed on water samples to obtain the background on water quality relevant for rainwater harvesting. The proposed tests for rainwater samples are pH, turbidity, conductivity, hardness, total suspended solids, and coliform colony count.

From properly maintained rooftop catchment systems, equipped with storage tanks having good covers and taps, is generally suitable for drinking, and frequently meets WHO drinking water standards (UNEP, 2007). There are several simple methods of treatment for water before drinking, such as;

- Boiling water will kill any harmful bacteria which may be present
- Adding chlorine in the right quantity (35ml of sodium hypochlorite per 1000 litres of water) will disinfect the water
- Slow sand filtration will remove any harmful organisms when carried out properly

Texas Water Development Board (2006) established minimum water quality guidelines for indoor use of rainwater, which are demonstrated in Table 2.3.

Table 2.3: Minimum Water Quality Guidelines for Indoor Use of Rainwater according to Texas Water Development Board (2006)

Category of Use	Rainwater Quality for Non-Potable Indoor Use	Rainwater Quality for Potable Uses
Single Family Households	Total Coliforms <500 cfu / 100 ml Fecal Coliforms <100 cfu / 100 ml Water testing recommended annually	Total Coliform – 0 Fecal Coliform - 0 Protozoan Cysts – 0 Viruses – 0 Turbidity < 1 NTU Water testing recommended every 3 months
Community or Public Water System	Total Coliforms <500 cfu/100 ml Fecal Coliforms <100 cfu/100 ml Water testing recommended annually	Total Coliform – 0 Fecal Coliform - 0 Protozoan Cysts - 0 Viruses - 0 Turbidity < 0.3 NTU Water testing required Monthly

2.11.8 Operation, Maintenance and Installment cost of RWH

Inspection and maintenance of a rainwater harvesting system before each rainy season and ideally after every rain event can keep the system operating at optimum performance. Maintenance of rainwater harvesting system consists of:

- Regular cleaning of the catchment surface (i.e., the rooftop) and storage tank to avoid physical and bacteriological contamination of the rain water;
- Periodic inspection of the catchment surface for leaks;
- Regular cleaning of the filters to maintain good water quality and acceptable rate of filtration.

The rainwater harvesting technology is highly cost-effective since it uses locally available materials for constructing the system (UNEP, 2007). Capital costs are limited to the cost of gutters, down pipes, filters and storage tanks. However, all these can be constructed using low cost materials thereby reducing the overall cost. The recurring costs for maintenance of the system include regular cleaning and leak prevention (UNEP, 2007). For a community, a common large water reservoir may be constructed and people living in that community can share the total cost for the installation of the rain water harvesting system. Compared to deep and shallow tubewells, rainwater collection systems may be more cost effective, especially if the initial investment does not include the cost of roofing materials.

CHAPTER 3

METHODOLOGY

Rainfall data from 34 Meteorological Stations (BMD) allover Bangladesh was collected up to 58 years (1950-2007). From the daily rainfall data of 58 years, average monthly rainfall is calculated for total 58 years and recent 12 years (1996-2007) for all the stations. Also, average annual rainfall and decadal average rainfall (50s, 60s, 70s, 80s, 90s and for the period of 2000 to 2007) have been calculated for each station. Rainfall pattern change due to probable climate change effects at Bangladesh has been analyzed over space and time.

Rainfall data for all stations is not available for 58 years. For stations at Chuadanga, Madaripur, Mongla and Syedpur only recent 12 years (1996-2007) data is available.

3.1 Impact of Climate Change in Rainfall Pattern considering Temporal and Spatial Variation

A point shape file of rain gauge stations is created from the latitude and longitude using GIS. Then point shape file is converted into polygon shape file following Thiessen polygon method. Contour of average annual rainfall over Bangladesh has been developed using GIS for recent 12 years (1996 to 2007) and total 58 years (1950 to 2007) for comparing recent average annual rainfall with long term average annual rainfall. For developing the contour maps the point shape file of average annual rainfall is interpolated to Raster file considering Spline method of the Spatial analyst tool. After surface analysis of the raster file, contour maps of the average annual rainfall both for the recent 12 years and the total 58 years have been prepared.

Maps showing spatial distribution of average annual rainfall for recent 12 years and total 58 years have also been developed using GIS. For every month, GIS maps of decadal average rainfall (50s, 60s, 70s, 80s, 90s and for the period of 2000 to 2007) have also been developed.

Bar chart of the average monthly rainfall has been prepared for 5 decades (1950 to 1959, 1960 to 1969, 1970 to 1979, 1980 to 1989, 1990 to 1999); for recent 8 years (2000 to 2007) and for total 58 years (1950 to 2007) at different stations in the eight hydrological

regions of Bangladesh (Figure 2.3) to observe monthly change of rainfall distribution pattern due to possible climate change effect.

GIS maps have been developed showing the normalized change of average rainfall in eight hydrological regions for recent 12 years (1996 to 2007) relative to long term rainfall of 58 years (1950 to 2007) for each month of a year. The normalized change of average rainfall (A) has been calculated by subtracting the 58 year monthly average rainfall (C) from the 12 year monthly average rainfall (B) and then normalizing the subtracted value (B-C) with respect to the 58 year monthly average rainfall (C) for each station of a region, shown in Equation (3.1).

$$A = [B - C] / C \tag{3.1}$$

The normalized change of rainfall has been generalized for the region describing by five criteria, which are shown in Table 3.1.

Table 3.1: Criteria of normalized change of rainfall for each region

Names of normalized change of rainfall	**Criteria**
Significant increase of rainfall	Overall increase and at least 40% increase in one station of a particular region
Increase of rainfall	Overall increase in maximum stations (more than 50% stations) of a particular region
Mixture of increase and decrease of rainfall	Simultaneously significant increase and decrease of rainfall in the stations of a particular region
Decrease of rainfall	Overall decrease in maximum stations (more than 50% stations) of the region
Significant decrease of rainfall	Overall decrease and at least 40% decrease in one station of a particular region

3.2 Impact of Climate Change on Rainfall Contribution in meeting Crop Water Requirement

The monthly potential evapotranspiration (PET) value for 34 meteorological stations (BMD stations) have been obtained from a shape file containing grid data of PET received from Bangladesh Country Almanac (BCA, 2002). From the latitude and longitude of each BMD station PET value for every month for all stations have been detected. Cropping period of various kinds of rice and wheat grown in Bangladesh as well as their crop coefficients are described in Table 3.2. Values of crop coefficients for initial phase (just after sowing), middle phase (development stage) and late phase (when the crop is ripening to be harvested) of crop period for rice are 1.1 (Kci), 1.25 (Kcm) and 1 (Kce) respectively. For wheat calculated values of crop coefficient are 0.45 (Nov), 0.85 (Dec), 1.05 (Jan), 0.82 (Feb) and 0.39 (Mar) respectively following Mondal (2004).

Table 3.2: Crop coefficients regarding different phases of cropping period for various kinds of Rice and Wheat

Crops	**Rice**						**Wheat**	
	Boro		**Aus**		**Aman**			
Phases of Crop Period	Crop period	Crop coeff.	Crop Period	Crop coeff.	Crop Period	Crop coeff.	Crop period	Crop coeff.
Initial phase	January	1.1	March	1.1	July	1.1	November	0.45
	February	1.1	April	1.1	August	1.1	December	0.85
Middle phase	March	1.25	May	1.25	September	1.25	January	1.05
	April	1.25	June	1.25	October	1.25	February	0.82
Late phase	May	1	July	1	November	1	March	0.39

The crop water requirement (evapotranspiration, ETc in mm) in different months of the cropping period for three rice varieties and wheat have been calculated from PET of each station by multiplying the potential evapotranspiration (PET) with a crop-specific coefficient (Kc), shown in Equation (3.2).

$$Etc = Kc \times PET \tag{3.2}$$

To assess the present conditions of yield, which may have been influenced by altered rainfall due to climate change impacts, graphical variation of yield as well as area occupied by three varieties of rice have been developed. A graphical comparative

analysis of rainfall contribution (in percentage) in meeting crop water requirement over recent 12 years (1996-2007) and total 58 years (1950-2007) for 34 BMD stations located in eight hydrological regions of Bangladesh for every month of the cropping period of Aus, Boro, Aman and Wheat has been made. It can be illustrated through Equation (3.3), where, Rainfall contribution in meeting crop water requirement has been termed as C, monthly rainfall in mm is noted as R and the crop water requirement (evapotranspiration, mm) has been termed as ETc.

$$C = R / Etc \times 100 \tag{3.3}$$

GIS maps have been prepared to show comparative differences of contribution of rainwater to meet crop water requirement from recent 12 years to total 58 years for Aus, Boro, Aman and Wheat.

3.3 Identify Ground water depletion, Arsenic, Iron and Salinity prone areas of Bangladesh

Monthly ground water level data of five consecutive years (1998 to 2002) has been obtained from Bangladesh Country Almanac (BCA, 2002). GIS maps showing groundwater level have been developed to assess the availability of ground water during different cropping periods namely, Kharif I (March to July), Kharif II (July to December) and Rabi (November to April) considering the average ground water level value for each cropping period. Percentage of area exceeding 7 m of ground water level of eight hydrological regions and also for the whole country have been calculated using ‘Calculate area’ tool of Arc GIS 9.2. Variation of ground water level has been investigated through GIS using monthly ground water level data of consecutive 5 years (1998 to 2002) for three distinct cropping periods.

GIS maps showing Arsenic and Iron prone areas according to their concentrations over Bangladesh have been developed using point data of tubewells having arsenic and iron concentration, obtained from Bangladesh Country Almanac (BCA, 2002). Percentage of areas having water contaminated with significant concentration of Arsenic (>= 0.05 mg/l) and Iron (>= 1 mg/l) in eight hydrological regions as well as for the whole country have been calculated using ‘calculate area’ tool of Arc GIS 9.2.

A GIS map has been developed showing salinity prone areas of Bangladesh using salinity information from Bangladesh Country Almanac (BCA, 2002). Percentage of areas having saline water in affected hydrological regions as well as for the whole country have been calculated using 'calculate area' tool of Arc GIS 9.2.

A GIS map has been developed showing Arsenic, Iron and salinity prone areas simultaneously exceeding their tolerable limits in Bangladesh. From the GIS map showing surface water bodies over Bangladesh, percentage of surface water bodies of the total area of the country has also been calculated. These maps show whether people of affected areas due to Arsenic, Iron and salinity can use rainwater as an alternative source considering the surface water bodies that can be utilized to identify the perennial and intermittent ponds and lakes all over Bangladesh and also can be used as potential reservoirs for RWH.

3.4 Evaluating potential contribution of rainwater in meeting Urban water demand

A bar chart has been developed showing relative variation of urban population density of Bangladesh for two different years of 1991 and 2004. Population density for the whole country, for Dhaka mega city and for Dhaka City Corporation has been considered for comparison.

Using population data and water supply information, water demand of Dhaka city and percentage of water deficit have been calculated. Using rainfall data of 55 year duration (1953-2007) of Dhaka city, variation of annual rainfall has been developed. The average annual rainfall of Dhaka city for 55 years (1953 to 2007) is also calculated.

From annual rainfall of Dhaka city, cumulative of annual rainfall for the city has been made considering 55 year duration (1953-2007), by summation of the annual rainfall for consecutive years from 1953 to 2007. For the same duration cumulative of average annual rainfall (2073 mm) has also been developed and it is compared with the cumulative of annual rainfall for Dhaka city to observe the distribution of annual rainfall during this period. Again variation of 5 year (moving) average annual rainfall, as well as variation of 5 year (moving) average monthly rainfall during March, May and September has been prepared considering 55 year duration (1953-2007) for Dhaka city. Here 55 year average monthly rainfall as well as the variation of monthly rainfall over

this period has also been shown. For plotting the moving 5 year average rainfall curve, average annual rainfall for consecutive 5 years has been calculated first, i. e., from 1953 to 1962, then from 1954 to 1963, etc. Then the average 5 year rainfall values have been plotted against the years from 1955 to 2005.

Bar chart of decadal average rainfall of Dhaka city has been developed considering rainfall data of 55 years (1953 to 2007) for 5 consecutive decades (50s, 60s, 70, 80s and 90s) and for the period of 2000 to 2007. Average annual rainfall data for 55 years has been used for this purpose.

Percentage of normalized change of average rainfall in a decade relative to the average rainfall of 55 years of Dhaka city has been calculated and is shown through a bar chart to find the trend of rainfall in 5 consecutive decades (50s, 60s, 70, 80s and 90s) and for the period of 2000 to 2007. For this purpose, average rainfall of each decade has been calculated at first. Then this decadal average rainfall has been normalized relative to the average rainfall of 55 years. It can be illustrated in Equation (3.4), where, Percentage of normalized change of average rainfall in a particular decade has been termed as P, then Average rainfall of the corresponding decade is termed as R and Average rainfall of total 55 years for Dhaka city is termed as A.

$$P = [R - A] \times 100 / A \tag{3.4}$$

Average annual rainfall of Dhaka city for recent consecutive12 years (1996 to 2007) is calculated, to assess the quantity of rain water for harvesting in the city. Monthly Distribution of average rainfall of recent 12 year (1996-2007) duration of Dhaka city has been developed for twelve months of a year from monthly average rainfall data of 12 years.

3.4.1 Contribution of rainwater in meeting water demand of Dhaka city

A mass curve has been developed to find out the maximum water deficit and maximum excess water in a year. Time period of such occurrence has also been calculated. For developing the mass curve, available rainwater can be estimated from Equation (3.5).

$$Q = C \times I \times A \tag{3.5}$$

Where Q is the total quantity of rainwater available in m^3/year, C is coefficient of available runoff, I is the rainfall intensity in m/year and A is the catchment area in m^2. Assuming 25 per cent of the rainwater to be lost by evaporation and for washing the catchment area using first rain that produces inferior quality rainwater in the present study, value of C is taken as 0.75. From monthly average rainfall of 12 years (1996 to 2007) for Dhaka city, rain water availability per square meter (Q/A) has been calculated by summation of consecutive average effective rainfall for consecutive months and thus mass curve (can be also termed as 'rainwater availability curve') has been developed. The minimum catchment area A, required for the collection of rainwater for N number of people supplied with q litres per capita per year of water can be derived from Equation (3.6).

$$A = [q \times N] / [C \times I] \tag{3.6}$$

For developing water demand per capita curve, from average annual rainfall (2166 mm) and coefficient of available runoff (0.75), value of CI in m^3 per square meter of catchment area per year become: (2.166 × 0.75 =) 1.62. From this data, average monthly available rainfall is obtained as (1.62/12 =) 0.135. Then water demand per capita curve is developed by summation of consecutive monthly available rainfall in consecutive months. Finally, from the difference of rainwater availability curve (mass curve) and water demand per capita curve, maximum excess water and maximum water deficit has been obtained.

A simple analysis was done to evaluate the water demand against the water availability of the city. Water requirement has been calculated from the gross water demand and from the average annual rainfall of Dhaka and employing a moderate runoff coefficient of 25%, effective rainfall (2166 × 0.75) is obtained. Then the catchment area that would be needed to capture the required water is calculated.

Again, quantity of water has been calculated for a building with a terrace of 100 sq meter area for harvesting rainwater with 60 % efficiency. Thus water availability per day has been obtained. From water demand of a family of 6 members per day, percentage of water demand that can be met by RWH with individual harvesting system has been calculated.

For a multistoried building with a terrace area of 500 sq meters and assuming that the building has 16 flats, availability of water per flat has been calculated. Percentage of water demand met by RWH with community based rainwater harvesting system has been calculated.

The Roof size distribution from building area of different wards of Dhaka city have been mapped using GIS. The GIS data has been obtained from GSRC (Geographical Solutions Research Center), where data from only 29 wards are available out of 90 wards. Percent of buildings with roof size greater than 100 m^2 for each ward has been calculated.

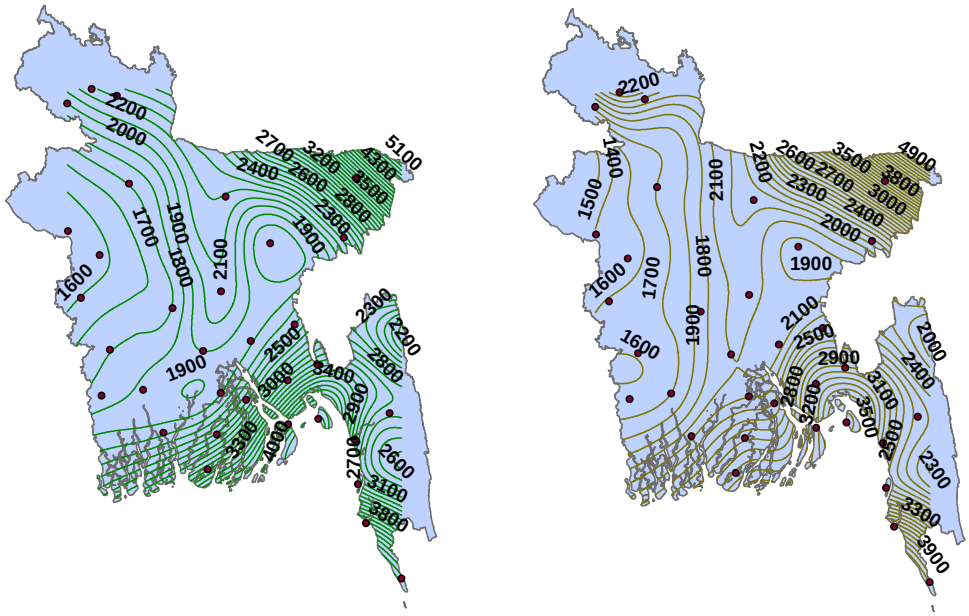
CHAPTER 4

LONG TERM RAINFALL ANALYSIS OVER BANGLADESH

4.1 General

In this Chapter average annual rainfall of Bangladesh has been analyzed. Considering long term data of rainfall of 58 years (1950 to 2007) decadal rainfall for each month of a year has been analyzed for 34 BMD stations. Decadal monthly rainfall in eight hydrological regions of Bangladesh has been analyzed. Average monthly rainfall for recent years relative to long term average has been compared for eight hydrological regions of Bangladesh.

4.2 Analysis of Average Annual Rainfall in Bangladesh



12 year average (1996 to 2007) 58 year average (1950 to 2007)

Figure 4.1: Contour of average annual rainfall (mm) over Bangladesh

Contour of average annual rainfall over Bangladesh has been developed using GIS for recent 12 years (1996 to 2007) and total 58 years (1950 to 2007), which show relatively higher rainfall in the Eastern part of the country than the Western part (Figure 4.1). The spatial distribution of this analysis is also shown in Figure 4.2 for 34 BMD stations over Bangladesh. The lowest average annual rainfall is observed in Rajshahi (1505 mm for

58 year average and 1532 mm for 12 year average) and highest average annual rainfall is observed in Sylhet (4006 mm) for 58 year average and in Teknaf (4345 mm) for 12 year average.

From the normalized change of average rainfall for recent 12 years (1996 to 2007) relative to that for total 58 years (1950 to 2007), it has been observed that increase of rainfall occurs during the recent 12 years in NW region (up to 13%), in NC region (up to 7%), in NE region (up to 9%), in SW region (up to 14%), in SC region (up to 10%), in SE region (up to 4%), in EH region (up to 11%) and in the RE regions (up to 21%). Again it has been found that average annual rainfall of total 58 years (1950-2007) is 2371 mm; while that of the recent 12 years (1996-2007) is 2505 mm.

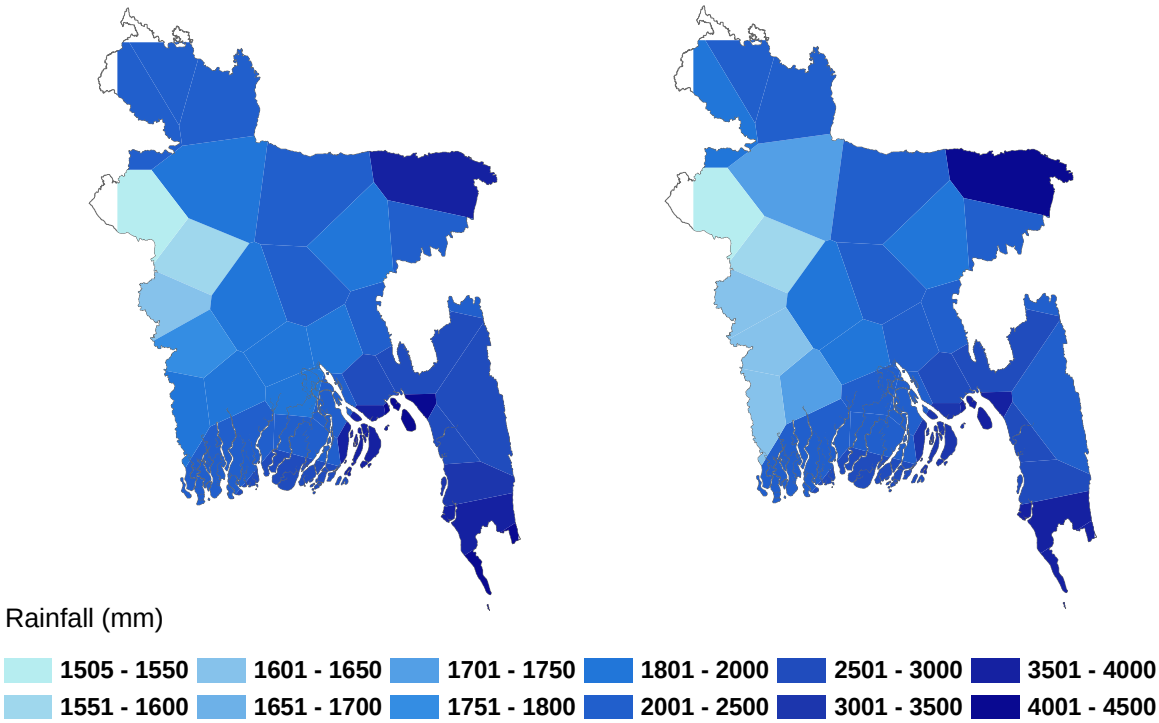


Figure 4.2: 12 year (1996-2007) average annual rainfall (Left) and 58 year (1950-2007) average annual rainfall (Right).

NB: For stations Chuadanga, Madaripur, Mongla and Syedpur only recent 12 years (1996-2007) data is available.

4.3 Analysis of Average Decadal Rainfall for each month of a year over 58 years

The average decadal rainfall for every month of a year has been calculaed for 5 decades (1950 to 1959, 1960 to 1969, 1970 to 1979, 1980 to 1989, 1990 to 1999); for recent 8 years (2000 to 2007) and for total 58 years (1950 to 2007). For the month of January, in

50s rainfall varies from zero to 22 mm and average rainfall is 13.1 mm; in 60s rainfall varies from 0.8 mm to 17 mm and average rainfall is 6 mm; in 70s rainfall varies from zero to 17 mm and average rainfall is 5 mm; in 80s rainfall varies from 0.7 mm to 17 mm and average rainfall is 7.2 mm; in 90s rainfall varies from 0.3 mm to 17 mm and average rainfall is 9.1 mm; in years 2000 to 2007 rainfall varies from 0.5 mm to 18.4 mm and average rainfall is 6.6 mm. The average rainfall for 58 years for this month varies from 1.6 mm to 11.4 mm and average rainfall is 7.5 mm. The variation of average decadal rainfall for this month is shown in Appendix A.1 and the variation of average decadal rainfall for all of the months of a year is shown in Table 4.1.

Table 4.1: Variation of average decadal rainfall for all of the months of a year

Months	Decade / Rainfall (mm)	50s	60s	70s	80s	90s	2000-2007	1950-2007
January	Minimum	0	0.8	0	0.7	0.3	0.5	2
	Maximum	22	17	17	17	17	18	11
	Average	13	6	5	7	9	7	8
February	Minimum	0.3	0	0	5	5	2	6
	Maximum	48	81	30	45	62	39	43
	Average	16	12	14	20	34	16	20
March	Minimum	5	10	0	7	6	9	14
	Maximum	88	115	105	132	176	112	115
	Average	42	46	25	43	70	47	47
April	Minimum	3	38	25	62	40	39	53
	Maximum	214	260	304	444	298	398	329
	Average	80	96	97	151	108	111	109
May	Minimum	106	65	14	142	127	148	128
	Maximum	817	411	477	616	562	612	549
	Average	245	183	222	285	263	294	252
June	Minimum	188	241	141	207	213	246	235
	Maximum	881	954	805	964	992	1035	953
	Average	485	451	422	446	431	513	457
July	Minimum	173	249	281	274	294	287	320
	Maximum	971	1048	917	928	1128	1142	1013
	Average	443	493	482	538	527	521	511
August	Minimum	216	213	119	209	230	184	218
	Maximum	648	876	795	843	1015	890	904
	Average	399	421	385	438	425	349	400
September	Minimum	108	149	147	231	218	269	234
	Maximum	452	517	451	633	556	666	507
	Average	281	292	270	323	330	372	322
October	Minimum	101	104	14	97	99	141	118
	Maximum	290	288	318	245	290	448	256
	Average	206	165	151	158	174	233	183
November	Minimum	0	3	0	6	3	3	7
	Maximum	62	48	208	109	106	73	77
	Average	29	16	47	43	44	33	37
December	Minimum	0	0.4	0	3	3	0.9	3
	Maximum	16	32	27	27	27	13	14
	Average	3	7	10	11	11	5	8

From Table 4.1 it can be observed that in the months of January, February, November and December average rainfall for all of the decades is below 50 mm. More than 400 mm of average rainfall is observed during the months of June and July for all the

decades. Average rainfall for 58 years during June is 457 mm and that during July is 511 mm.

For the month of February, in 50s rainfall varies from 0.3 to 48 mm and average rainfall is 15.6 mm; in 60s rainfall varies from zero to 81 mm and average rainfall is 12 mm; in 70s rainfall varies from zero to 30.4 mm and average rainfall is 13.7 mm; in 80s rainfall varies from 5.3 mm to 45 mm and average rainfall is 20.3 mm; in 90s rainfall varies from 5 mm to 62 mm and average rainfall is 34 mm; in years 2000 to 2007 rainfall varies from 2.3 mm to 39 mm and average rainfall is 16 mm. The average rainfall for 58 years for this month varies from 5.7 mm to 43.3 mm and average rainfall is 20 mm. The variation of average decadal rainfall for this month is shown in Appendix A.2.

For the month of March, in 50s rainfall varies from 5.3 to 88.2 mm and average rainfall is 41.6 mm; in 60s rainfall varies from 9.8 to 114.8 mm and average rainfall is 45.6 mm; in 70s rainfall varies from zero to 104.6 mm and average rainfall is 25 mm; in 80s rainfall varies from 6.7 mm to 132.1 mm and average rainfall is 42.7 mm; in 90s rainfall varies from 5.8 mm to 176.3 mm and average rainfall is 69.7 mm; in years 2000 to 2007 rainfall varies from 9.1 mm to 111.8 mm and average rainfall is 47 mm. The average rainfall for 58 years for this month varies from 14.2 mm to 114.5 mm and average rainfall is 47 mm. The variation of average decadal rainfall for this month is shown in Appendix A.3.

For the month of April, in 50s rainfall varies from 3.3 mm to 213.8 mm and average rainfall is 80.3 mm; in 60s rainfall varies from 37.7 mm to 260.3 mm and average rainfall is 95.6 mm; in 70s rainfall varies from 25.3 mm to 304 mm and average rainfall is 96.6 mm; in 80s rainfall varies from 62.1 mm to 443.5 mm and average rainfall is 151 mm; in 90s rainfall varies from 40 mm to 298.4 mm and average rainfall is 108 mm; in years 2000 to 2007 rainfall varies from 39.2 mm to 398 mm and average rainfall is 111 mm. The average rainfall for 58 years for this month varies from 52.5 mm to 329.3 mm and average rainfall is 109 mm. The variation of average decadal rainfall for this month is shown in Appendix A.4.

For the month of May, in 50s rainfall varies from 106.2 mm to 816.8 mm and average rainfall is 245.4 mm; in 60s rainfall varies from 65.3 mm to 411 mm and average rainfall is 182.6 mm; in 70s rainfall varies from 74 mm to 476.6 mm and average

rainfall is 221.5 mm; in 80s rainfall varies from 141.8 mm to 616 mm and average rainfall is 284.6 mm; in 90s rainfall varies from 127 mm to 562 mm and average rainfall is 263 mm; in years 2000 to 2007 rainfall varies from 148 mm to 612 mm and average rainfall is 294 mm. The average rainfall for 58 years for this month varies from 128.2 mm to 549.3 mm and average rainfall is 252.3 mm. The variation of average decadal rainfall for this month is shown in Appendix A.5.

For the month of June, in 50s rainfall varies from 188.3 mm to 880.8 mm and average rainfall is 485 mm; in 60s rainfall varies from 241.3 mm to 954.4 mm and average rainfall is 450.5 mm; in 70s rainfall varies from 141.3 mm to 805.4 mm and average rainfall is 421.5 mm; in 80s rainfall varies from 206.7 mm to 963.7 mm and average rainfall is 446 mm; in 90s rainfall varies from 212.8 mm to 991.5 mm and average rainfall is 431 mm; in years 2000 to 2007 rainfall varies from 246.4 mm to 1034.8 mm and average rainfall is 513 mm. The average rainfall for 58 years for this month varies from 235.2 mm to 952.5 mm and average rainfall is 457.2 mm. The variation of average decadal rainfall for this month is shown in Appendix A.6.

In Figure 4.3, the average decadal rainfall for the month of July has been shown. From this figure it can be observed that, in 50s rainfall varies from 172.7 to 971.3 mm and average rainfall is 439.4 mm; in 60s rainfall varies from 248.8 mm to 1048.3 mm and average rainfall is 492.5 mm; in 70s rainfall varies from 281 mm to 917.4 mm and average rainfall is 482 mm; in 80s rainfall varies from 274 mm to 928.3 mm and average rainfall is 537.8 mm; in 90s rainfall varies from 294 mm to 1128.3 mm and average rainfall is 526.5 mm; in years 2000 to 2007 rainfall varies from 286.5 mm to 1142 mm and average rainfall is 521 mm. So, it is evident that in the recent decades of 80s, 90s and 2000 to 2007, average rainfall is more than 500 mm which is higher than that during the previous decades. The average rainfall for 58 years for this month varies from 319.7 mm to 1012.6 mm and average rainfall is 511 mm.

For the month of August, in 50s rainfall varies from 216 to 648 mm and average rainfall is 399 mm; in 60s rainfall varies from 213 to 876 mm and average rainfall is 421 mm; in 70s rainfall varies from 119.3 mm to 795 mm and average rainfall is 385 mm; in 80s rainfall varies from 208.7 mm to 843 mm and average rainfall is 438 mm; in 90s rainfall varies from 230 mm to 1015 mm and average rainfall is 425 mm; in years 2000 to 2007 rainfall varies from 183.8 mm to 890.3 mm and average rainfall is 349 mm. The average

rainfall for 58 years for this month varies from 218 mm to 904 mm and average rainfall is 400 mm. The variation of average decadal rainfall for this month is shown in Appendix A.7.

In Figure 4.4, the average decadal rainfall for the month of September has been shown. From this figure it can be observed that in 50s rainfall varies from 108 mm to 451.6 mm and average rainfall is 281 mm; in 60s rainfall varies from 149 mm to 517 mm and average rainfall is 292 mm; in 70s rainfall varies from 147 mm to 451 mm and average rainfall is 270 mm; in 80s rainfall varies from 231 mm to 633 mm and average rainfall is 323 mm; in 90s rainfall varies from 218 mm to 556 mm and average rainfall is 330 mm; in years 2000 to 2007 rainfall varies from 269 mm to 666 mm and average rainfall is 372 mm. The average rainfall for 58 years for this month varies from 234 mm to 507 mm and average rainfall is 322 mm.

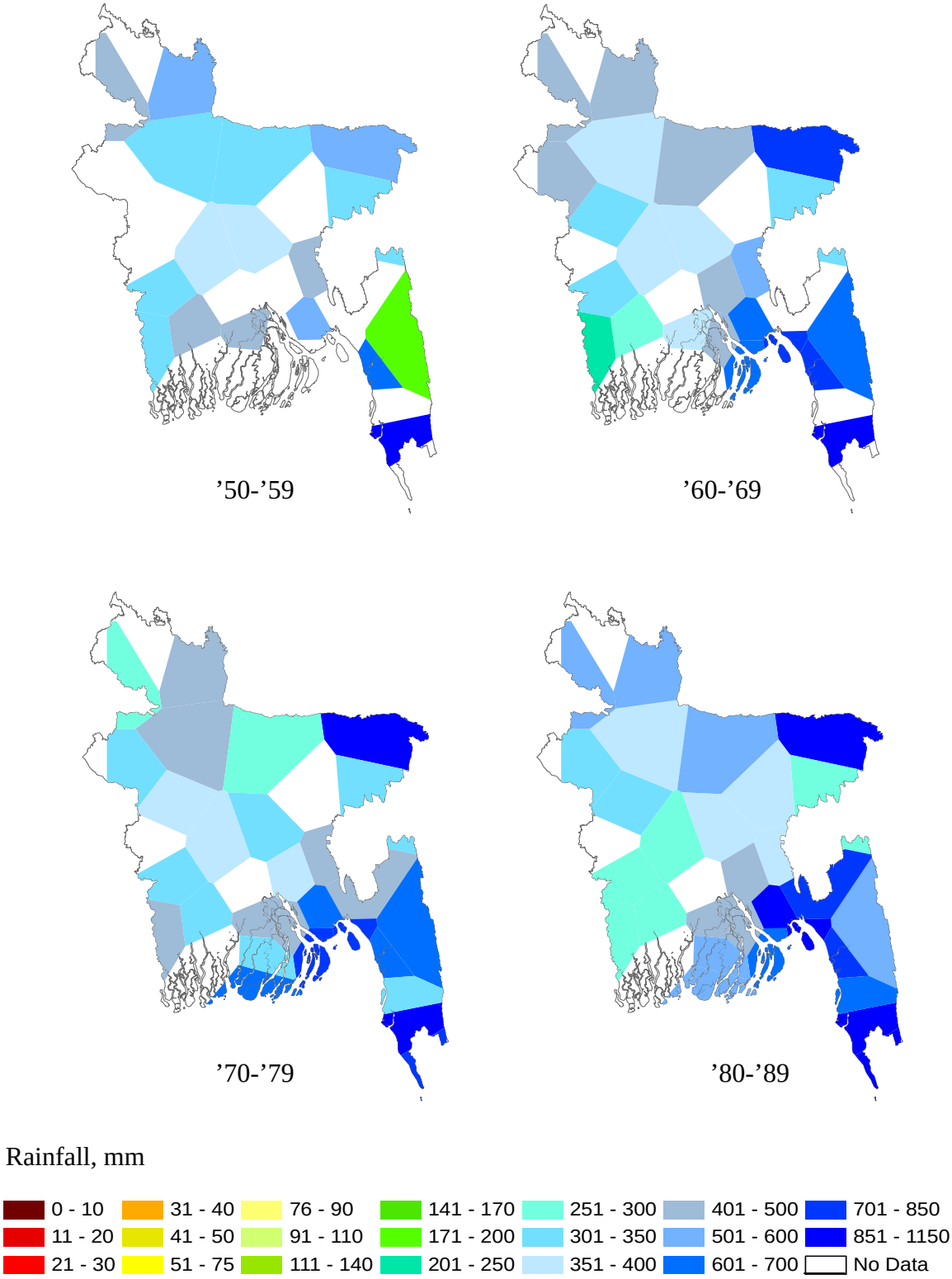


Figure 4.3: Decadal average rainfall of July for 58 years (1950-2007)

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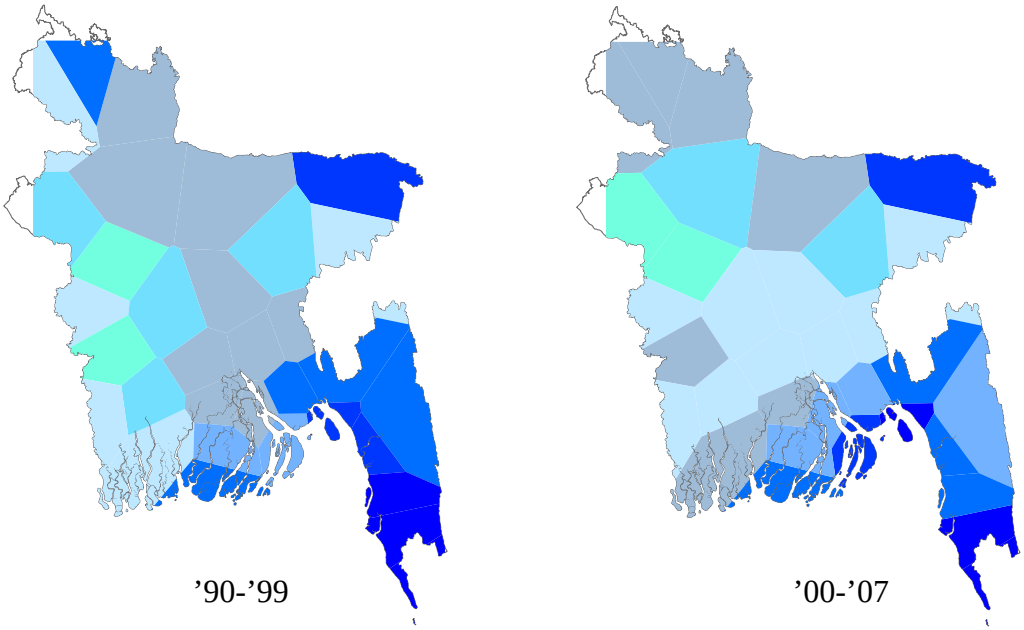

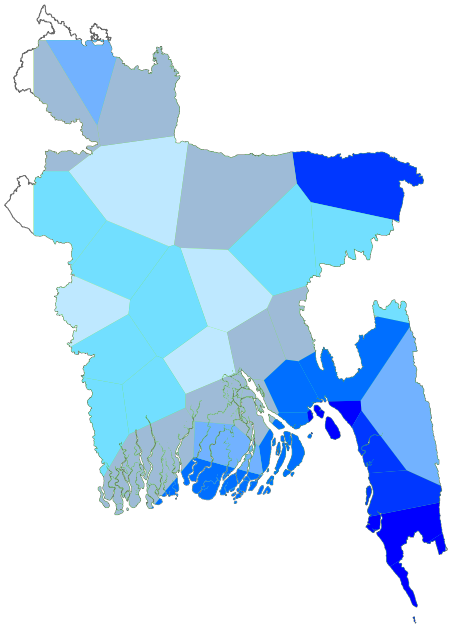

Average rainfall of 58 years (’50-’07)

Rainfall, mm

0 - 10	31 - 40	76 - 90	141 - 170	251 - 300	401 - 500	701 - 850
11 - 20	41 - 50	91 - 110	171 - 200	301 - 350	501 - 600	851 - 1150
21 - 30	51 - 75	111 - 140	201 - 250	351 - 400	601 - 700	No Data

Figure 4.3: Decadal average rainfall of July for 58 years (1950-2007)

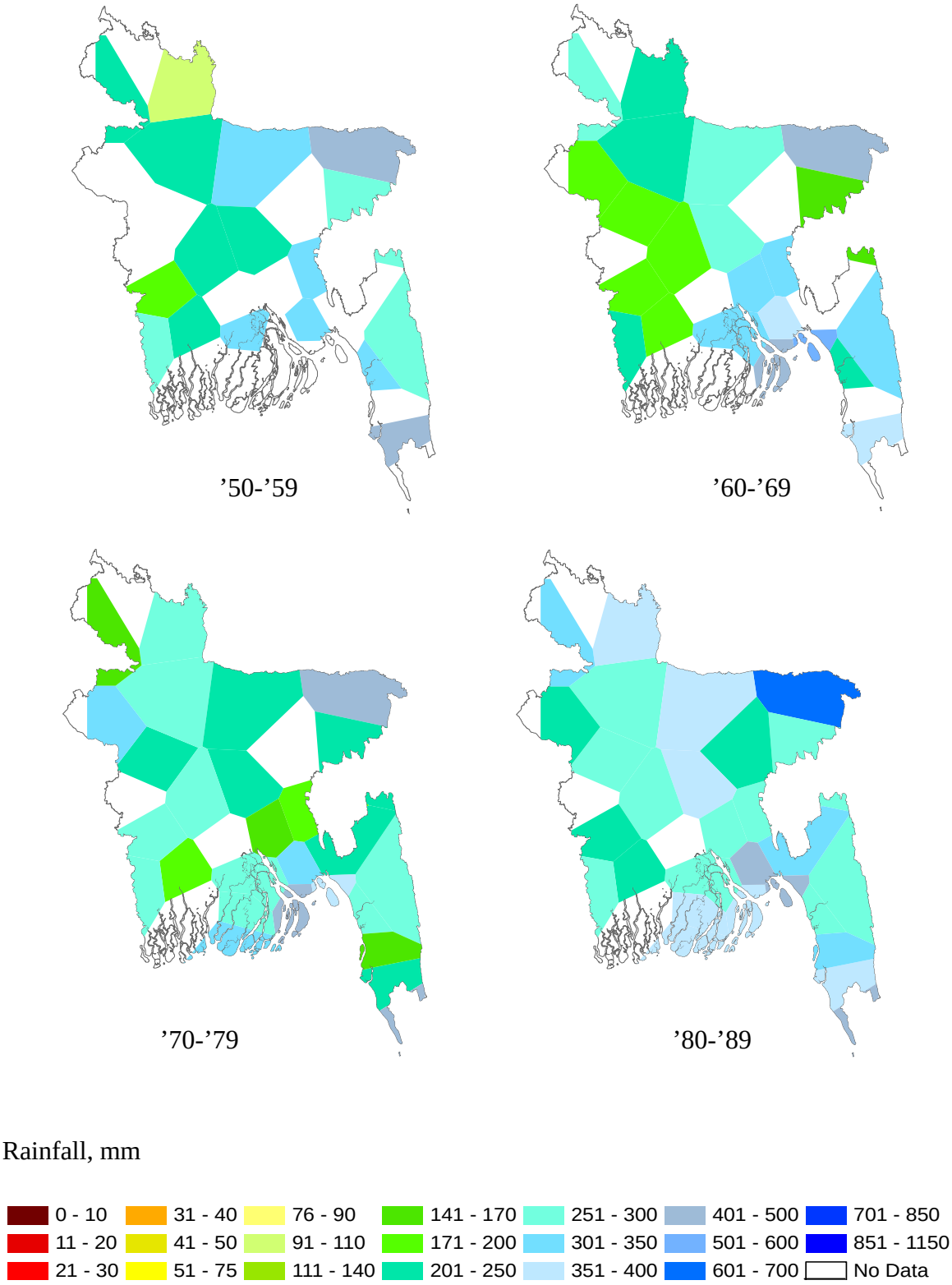

Figure 4.4: Decadal average rainfall of September for 58 years (1950-2007)

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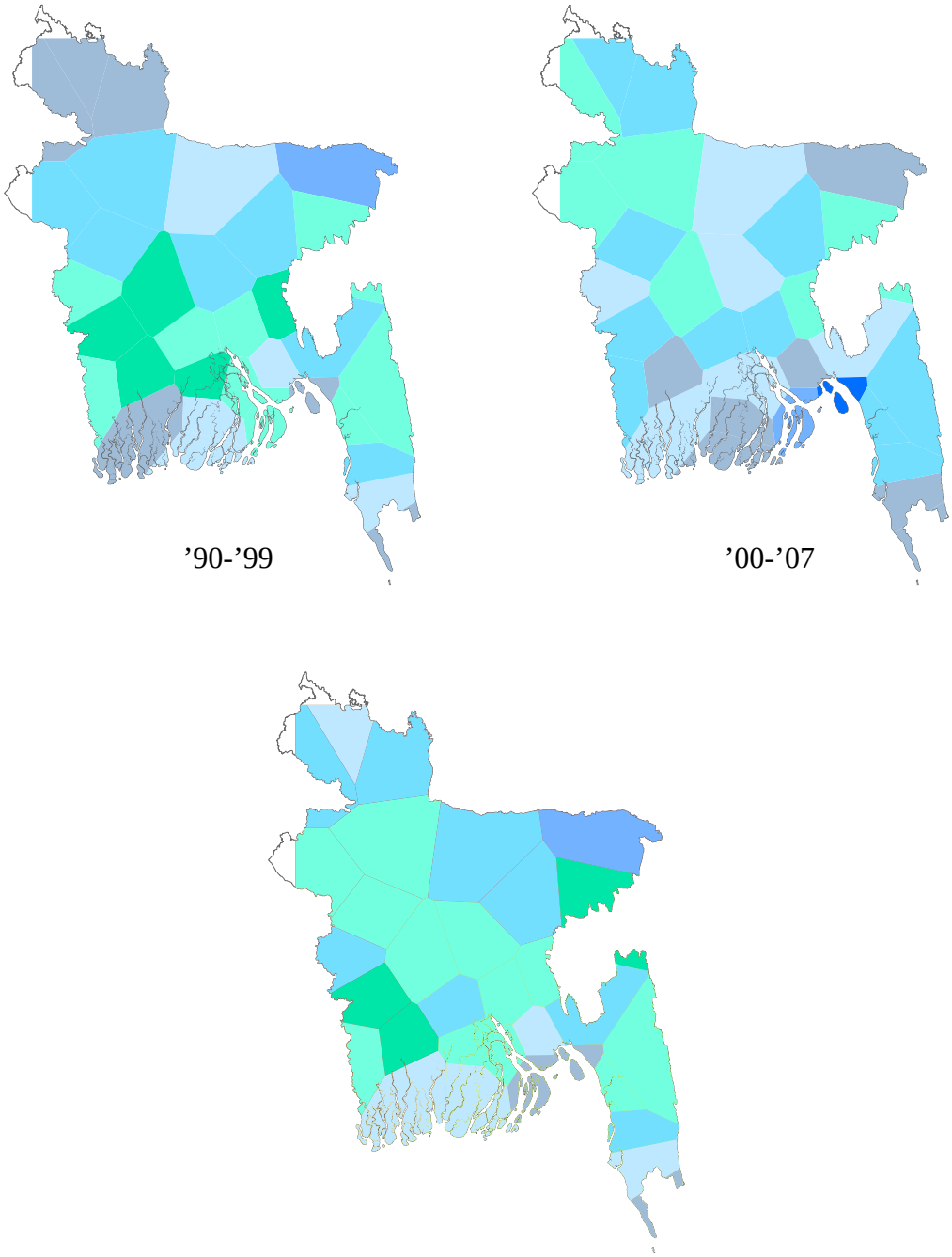


Average rainfall of 58 years (’50-’07)

Rainfall, mm

0 - 10	31 - 40	76 - 90	141 - 170	251 - 300	401 - 500	701 - 850
11 - 20	41 - 50	91 - 110	171 - 200	301 - 350	501 - 600	851 - 1150
21 - 30	51 - 75	111 - 140	201 - 250	351 - 400	601 - 700	No Data

Figure 4.4: Decadal average rainfall of September for 58 years (1950-2007)

For the month of October, in 50s rainfall varies from 101 to 290 mm and average rainfall is 206 mm; in 60s rainfall varies from 104 to 288 mm and average rainfall is 165 mm; in 70s rainfall varies from 34 mm to 318 mm and average rainfall is 151 mm; in 80s rainfall varies from 97 mm to 245 mm and average rainfall is 158 mm; in 90s rainfall varies from 99 mm to 290 mm and average rainfall is 174 mm; in years 2000 to 2007 rainfall varies from 141 mm to 448 mm and average rainfall is 233 mm. The average rainfall for 58 years for this month varies from 118 mm to 256 mm and average rainfall is 182.5 mm. The variation of average decadal rainfall for this month is shown in Appendix A.8.

For the month of November, in 50s rainfall varies from zero to 62 mm and average rainfall is 29 mm; in 60s rainfall varies from 2.6 to 48 mm and average rainfall is 16 mm; in 70s rainfall varies from zero to 208 mm and average rainfall is 47 mm; in 80s rainfall varies from 6 mm to 109 mm and average rainfall is 43 mm; in 90s rainfall varies from 2.8 mm to 106 mm and average rainfall is 43.5 mm; in years 2000 to 2007 rainfall varies from 3 mm to 73 mm and average rainfall is 33 mm. The average rainfall for 58 years for this month varies from 7.4 mm to 77 mm and average rainfall is 37 mm. The variation of average decadal rainfall for this month is shown in Appendix A.9.

For the month of December, in 50s rainfall varies from zero to 16.3 mm and average rainfall is 3 mm; in 60s rainfall varies from 0.4 to 31.5 mm and average rainfall is 7.2 mm; in 70s rainfall varies from zero to 27 mm and average rainfall is 9.6 mm; in 80s rainfall varies from 3.3 mm to 27.3 mm and average rainfall is 11 mm; in 90s rainfall varies from 3 mm to 27 mm and average rainfall is 11 mm; in years 2000 to 2007 rainfall varies from 0.9 mm to 13 mm and average rainfall is 5 mm. The average rainfall for 58 years for this month varies from 3 mm to 14.4 mm and average rainfall is 8 mm. The variation of average decadal rainfall for this month is shown in Appendix A.10.

4.4 Analysis of Decadal Average Monthly rainfall in eight Hydrological regions of Bangladesh

Bar chart of the average monthly rainfall has been developed for eight hydrological regions of Bangladesh considering rainfall data for 5 decades (1950 to 1959, 1960 to 1969, 1970 to 1979, 1980 to 1989, 1990 to 1999); for recent 8 years (2000 to 2007) and for total 58 years (1950 to 2007).

Northwest Region

Figure 4.5 shows the average monthly rainfall at different stations in the North-West region of Bangladesh. In this figure average rainfall (of all stations) of the region has also been shown with the right most bar of each time period.

From this figure it can be observed that average rainfall (of all stations) are 14, 6, 10, 9, 11, 5 and 8 mm in January during the time periods 50s, 60s, 70s, 80s, 90s, 2000 to 2007 and for 58 years respectively. Comparatively less rainfall has been found in the recent eight years for this month.

In February during 50s average rainfall (of all stations) is found to be 5 mm, from 60s to 90s the average rainfall of all stations show an increasing trend (4, 10, 14, 15 mm). during the period of 2000 to 2007 there is some decrease of average rainfall (13 mm) and the average rainfall (of all stations) during 58 years for this month is 11 mm.

In March there is a decreasing trend of averge rainfall (of all stations) from 50s to 70s (32, 28 and 14 mm), during 80s and 90s average rainfall are 23 mm and 17 mm respectively; but during 2000 to 2007 the highest rainfall (35 mm) for this month is observed and for 58 years average rainfall is found to be 27 mm.

In April there is an increasing trend of averge rainfall from 50s to 80s (41, 57, 61 and 80 mm respectively), then in 90s there is some decrease of rainfall (74 mm) and like March highest rainfall for April is also found during 2000 to 2007 (107 mm). The average rainfall (of all stations) for 58 years during this month is 79 mm.

In May there is a decreasing trend of averge rainfall from 50s to 70s (154, 151 and 141 mm respectively), then in 80s increase of rainfall has been observed, which is found to be the highest value of the average rainfall (236 mm) for this month and during 90s and during 2000 to 2007 average rainfall are 202 mm and 211 mm respectively. The average rainfall (of all stations) during 58 years for this month is 198 mm.

In June there is a decreasing trend of averge rainfall from 50s to 70s (448, 324 and 296 mm respectively), then from 80s to the period of 2000 to 2007 rainfall follows an increasing trend (302, 317 and 410 mm respectively). The average rainfall (of all stations) during 58 years for this month is 351 mm.

In July there is a decreasing trend of averge rainfall from 50s to 70s (417, 382 and 368 mm respectively), then in 80s increase of rainfall has been observed, which is found to be the highest value of the average rainfall (442 mm) for this month and during 90s and during 2000 to 2007 average rainfall are 411 mm and 380 mm respectively. The average rainfall (of all stations) during 58 years for this month is 405 mm.

In August during 50s average rainfall (of all stations) is found to be 363 mm, then rainfall has been decreased in the following decade. From 60s to 90s average rainfall shows an increasing trend (277, 285, 311 and 357 mm respectively). Again during the period of 2000 to 2007 there is some decrease of average rainfall (234 mm) and the average rainfall (of all stations) during 58 years for this month is 300 mm.

In september average rainfall (of all stations) show an increasing trend from 50s to 90s (189, 222, 250, 296 and 389 mm). During 2000 to 2007 there is some decrease of rainfall (312 mm) and for 58 year average rainfall (of all stations) for this month is 300 mm.

In October during 50s average rainfall (of all stations) is 175 mm. An increasing trend of the average rainfall has been observed in the following decades from 60s to the period of 2000 to 2007 (120, 121, 121, 138 and 214 mm). Highest average rainfall for this month is found in the recent eight years. The average rainfall (of all stations) during 58 years for this month is 151 mm.

In November average rainfall (of all stations) show an increasing trend from 50s to 90s (9, 10, 11, 11 and 13 mm). During 2000 to 2007 there is some decrease of rainfall (7 mm) and for 58 year average rainfall (of all stations) for this month is 11 mm.

In December average rainfall (of all stations) show an increasing trend from 50s to 80s (0, 1, 7 and 13 mm). There is some decrease of average rainfall in the following years. During 90s and during 2000 to 2007 average rainfall are 10 mm and 4 mm respectively. During 58 years average rainfall (of all stations) in this month is 7 mm.

For North-Central, North-East, South-West, South-Central, South-East, Eastern Hilly, and Rivers and Estuary regions Bar charts have been shown in Appendix B.1, B.2, B.3, B.4, B.4, B.5, B.6 and B.7 respectively.

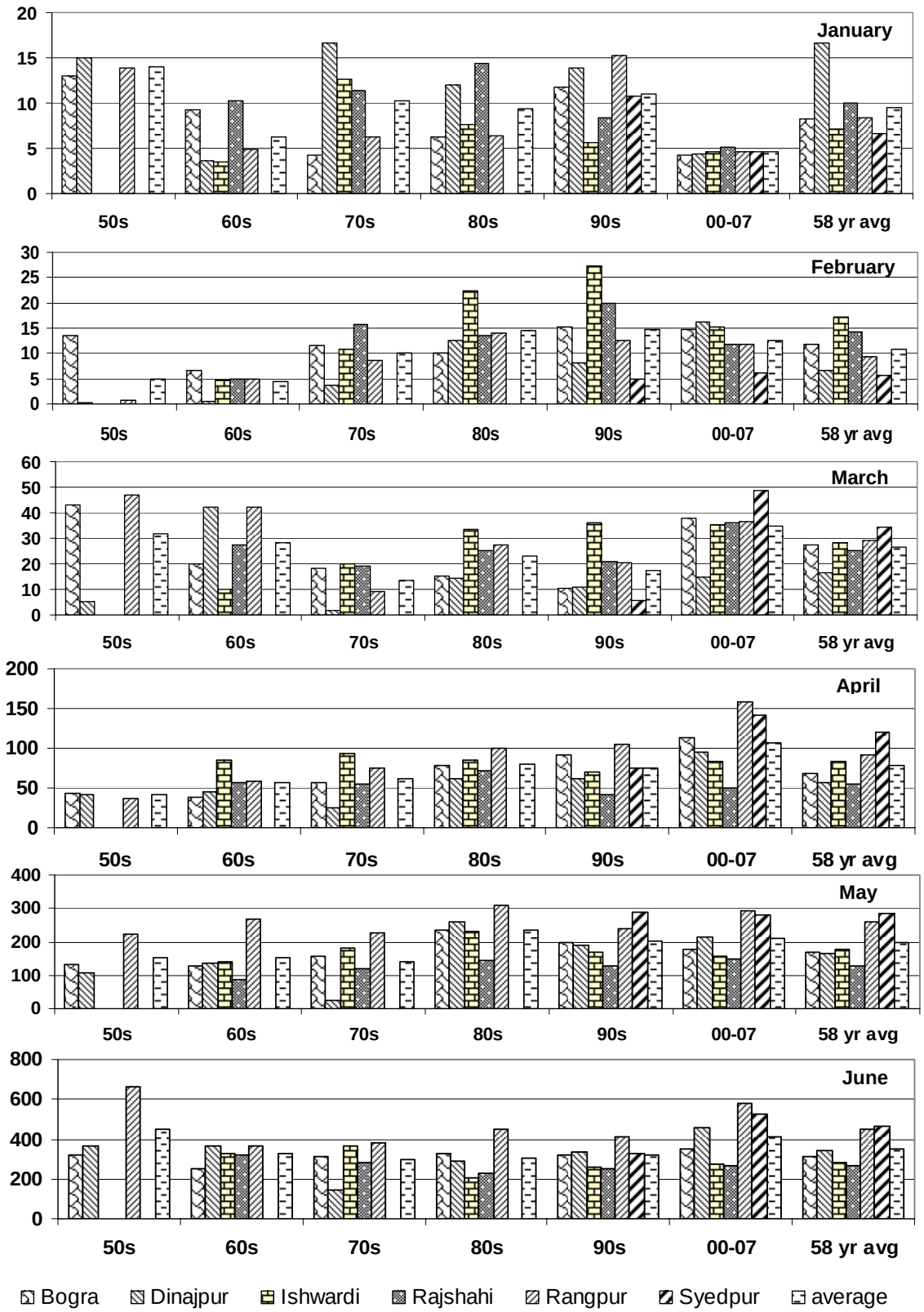


Figure 4.5: Decadal Monthly average rainfall (mm) of North-West Region

Continued…

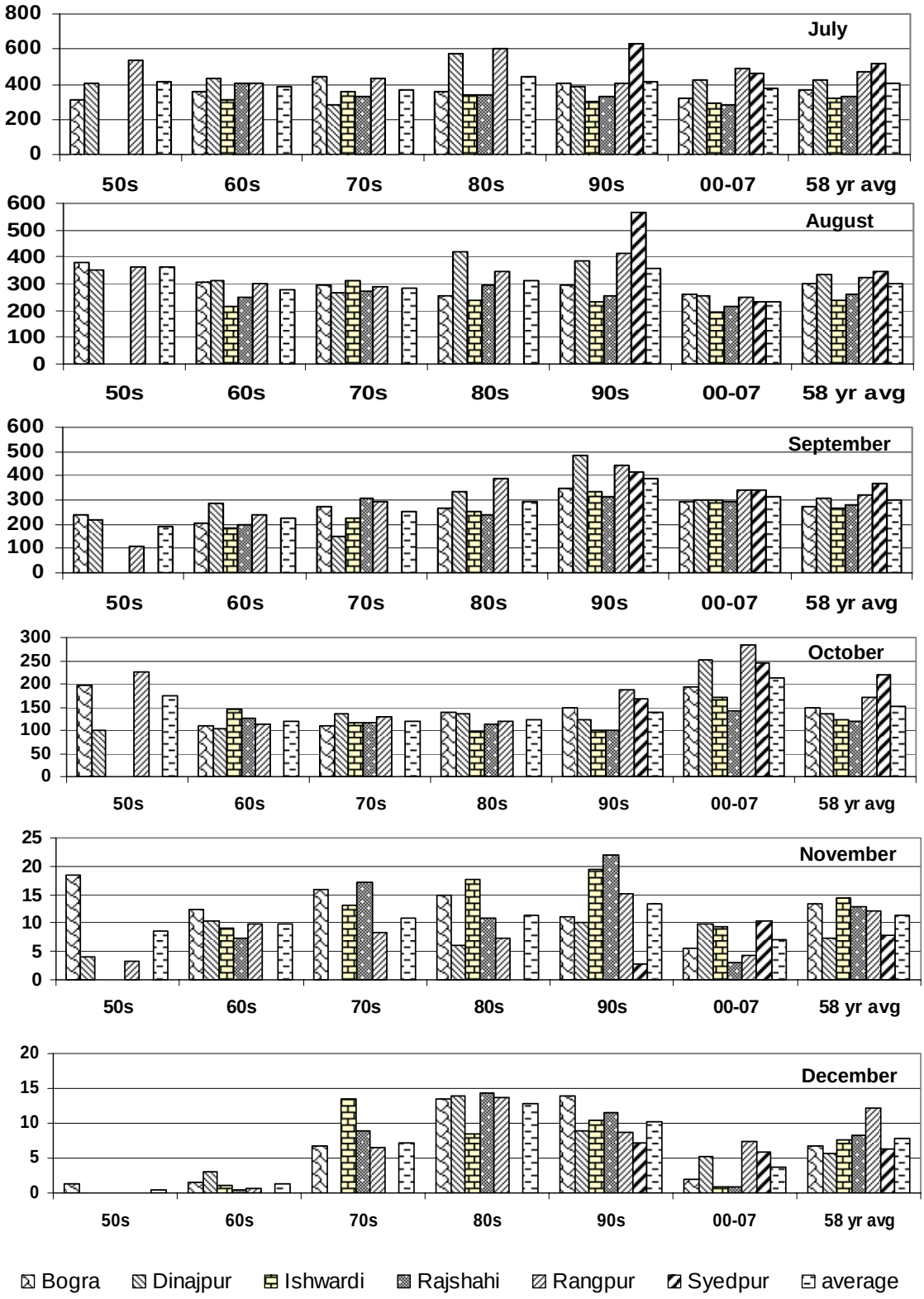


Figure 4.5: Decadal Monthly average rainfall (mm) of North-West Region

North Central Region

From the analysis for North-Central region shown in Appendix B.1, it can be observed that average rainfall (of all stations) follows an decreasing trend from 50s to 70s (19, 5 and 4 mm respectively) in January. During the time periods of 80s, 90s, 2000 to 2007 and for 58 years average rainfall (of all stations) are 4, 10, 5 and 8 mm, respectively.

In February during 50s average rainfall (of all stations) is 24 mm. From 60s to 80s average rainfall follows an increasing trend (10, 19 and 28 mm, respectively). During 90s, 2000 to 2007 and for 58 years average rainfall (of all stations) are 28, 15 and 21 mm, respectively.

In March there is a decreasing trend of averge rainfall (of all stations) from 50s to 70s (53, 44 and 21 mm). From 80s to the period of 2000 to 2007 average rainfall follows an increasing trend (39, 49 and 59 mm, respectively). The highest rainfall (59 mm) for this month is observed during 2000 to 2007and for 58 years average rainfall is found to be 46 mm.

In April there is an increasing trend from 50s to 80s (80, 95, 102 and 169 mm respectively), then in 90s there is some decrease of rainfall (112 mm) and during 2000 to 2007 average rainfall is found to be 148 mm. The average rainfall (of all stations) for 58 years during this month is 120 mm.

In May there is an increasing trend from 50s to 80s (213, 236, 287 and 333 mm respectively), then in 90s there is some decrease of rainfall (300 mm) and during 2000 to 2007 average rainfall is 281 mm. The average rainfall (of all stations) during 58 years for this month is 276 mm.

In June there is a decreasing trend from 50s to 90s (434, 391, 349, 332 and 326 mm respectively), but during 2000 to 2007 some increase of average rainfall (399 mm) has been observed. The average rainfall (of all stations) during 58 years for this month is 356 mm.

In July no significant trend is found during 50s to 70s for the average rainfall considering all the stations of the region (349, 408 and 319 mm). From the figure it can be observed that from 80s to the period of 2000 to 2007 average rainfall (of all stations) follows a decreasing trend (427, 400 and 369 mm). The average rainfall (of all stations) during 58 years for this month is 372 mm.

In August there is a decreasing trend from 50s to 70s (391, 345 and 267mm respectively), then some increase of rainfall has been observed during 80s and 90s (288 and 319 mm). During 2000 to 2007 average rainfall (of all stations) is 264 mm and during 58 years average rainfall for this month is 299 mm.

In September average rainfall (of all stations) during 50s and 60s are 271 and 282 mm respectively. Then some decrease of rainfall has been observed in the following decade, again it shows an increasing trend from 70s to the period of 2000 to 2007 (230, 317, 329 and 356 mm). During 58 year average rainfall (of all stations) in this month is 305 mm.

In October during 50s average rainfall (of all stations) is 201 mm. An increasing trend of the average rainfall has been observed in the following decades from 60s to the period of 2000 to 2007 (135, 148, 177, 188 and 216 mm). Highest average rainfall for this month is found in the recent period. The average rainfall (of all stations) during 58 years for this month is 176 mm.

In November no significant trend is observed for average rainfall considering all stations. For decades 50s to the period of 2000 to 2007 average rainfall values are 25, 22, 22, 37, 26 and 26 mm respectively and for 58 year average rainfall (of all stations) for this month is 27 mm.

In December there is no significant trend for average rainfall considering all stations. For decades 50s to the period of 2000 to 2007 average rainfall values are 2, 1, 10, 17, 12 and 4 mm respectively and for 58 year average rainfall (of all stations) for this month is 8 mm.

North East Region

From the analysis for North-East region shown in Appendix B.2, it can be observed that in January average rainfall (of all stations) follows an decreasing trend from 50s to 80s (15, 14, 8 and 3 mm respectively). Then some increase of average rainfall has been observed in the following periods. During the time periods of 90s, 2000 to 2007 and for 58 years average rainfall (of all stations) are 6, 8 and 9 mm, respectively.

In February during 50s and 60s average rainfall (of all stations) are 37 and 52 mm respectively. From 70s to 90s average rainfall follows an increasing trend (22, 25 and

39 mm respectively). During 2000 to 2007 and for 58 years average rainfall (of all stations) are 37 and 36 mm respectively.

In March during 50s and 60s average rainfall (of all stations) are 65 and 77 mm respectively. From 70s to 90s average rainfall follows an increasing trend (67, 112 and 138 mm respectively). During 2000 to 2007 and for 58 years average rainfall (of all stations) are 107 and 98 mm respectively.

In April there is an increasing trend from 50s to 80s (207, 216, 247 and 337 mm respectively), then in 90s there is some decrease of rainfall (216 mm) and the highest average rainfall for this month has been observed during 2000 to 2007 (347 mm). The average rainfall (of all stations) for 58 years during this month is 265 mm.

In May during 50s average rainfall (of all stations) is 598 mm. Then some decrease of rainfall has been observed in the following decade. From 60s to 80s average rainfall follows an increasing trend (330, 396 and 499 mm respectively). During the periods 90s and 2000 to 2007 average rainfall (of all stations) are 467 and 551 mm respectively. The average rainfall (of all stations) for 58 years during this month is 459 mm.

In June no significant trend is observed during 50s to 70s for average rainfall considering all stations (705, 630, and 644 mm respectively). From 80s to the period of 2000 to 2007 average rainfall follows an increasing trend (533, 576 and 667 mm respectively). For 58 years average rainfall (of all stations) is 624 mm.

In July there is an increasing trend from 50s to 70s (431, 534 and 626 mm respectively), then some decrease of average rainfall has been observed in the following decade. In 80s, 90s and the period of 2000 to 2007 average rainfall (of all stations) shows no significant trend (573, 594 and 575 mm). The average rainfall (of all stations) during 58 years for this month is 571 mm.

In August there is a decreasing trend from 50s to 70s (490, 478 and 407 mm respectively), then some increase of rainfall has been observed during 80s (491 mm). During 90s and during 2000 to 2007 average rainfall (of all stations) are 427 and 445 mm respectively. For 58 years average rainfall in this month is 460 mm.

In September average rainfall (of all stations) during 50s is 354 mm. Then some decrease of rainfall has been observed in the following decade, again it shows an increasing trend from 60s to 80s (311, 316 and 452 mm). During 90s and during 2000 to 2007 average rainfall are 416 and 371 mm respectively. For 58 years average rainfall (of all stations) in this month is 377 mm.

In October no significant trend has been found during 50s and 60s for average rainfall (243 and 148 mm respectively). From 70s to 90s a decreasing trend has been observed (220, 202 and 160mm respectively) for average rainfall (of all stations). During 2000 to 2007 average rainfall is found to be 191mm and for 58 years average rainfall in this month is 191 mm.

In November no significant trend is observed for average rainfall considering all stations. For decades 50s to the period of 2000 to 2007 average rainfall values are 30, 20, 40, 31, 38 and 33 mm respectively and for 58 years average rainfall (of all stations) for this month is 34 mm.

In December there is no significant trend for average rainfall considering all stations. For decades 50s to the period of 2000 to 2007 average rainfall values are 4, 3, 8, 13, 7 and 6 mm respectively and for 58 year average rainfall (of all stations) for this month is 7 mm.

South West Region

From the analysis for South-West region shown in Appendix B.3, it can be observed that in January during 50s average rainfall (of all stations) is 10 mm. From 60s to 90s average rainfall follows an increasing trend (5, 6, 13 and 15 mm respectively). During 2000 to 2007 and for 58 years average rainfall (of all stations) are 6 and 9 mm respectively.

In February during 50s average rainfall (of all stations) 10 mm. From 60s to 90s average rainfall follows an increasing trend (10, 17, 33 and 41 mm respectively). During 2000 to 2007 and for 58 years average rainfall (of all stations) are 18 and 23 mm respectively. In March during 50s and 60s average rainfall (of all stations) are 23 and 42 mm respectively. From 70s to 90s average rainfall follows an increasing trend (26, 44 and 60 mm respectively). During 2000 to 2007 average rainfall is found to be 42 mm and for 58 years average rainfall in this month is 42 mm.

In April no significant trend is observed for average rainfall considering all stations. For decades 50s to the period of 2000 to 2007 average rainfall values are 50, 78, 52, 104, 62 and 67 mm respectively and for 58 years average rainfall (of all stations) for this month is 66 mm.

In May during 50s average rainfall (of all stations) is 151 mm. Then some decrease of rainfall has been observed in the following decade. From 60s to 80s average rainfall follows an increasing trend (106, 145 and 193 mm respectively). During the periods 90s and 2000 to 2007 average rainfall (of all stations) are 165 and 179 mm respectively. The average rainfall (of all stations) for 58 years during this month is 164 mm.

In June there is a decreasing trend of average rainfall from 50s to 70s (316, 307 and 251 mm respectively), then some increase of average rainfall has been observed in the following decade (during 80s 336 mm). During 90s and 2000 to 2007, average rainfall (of all stations) are 278 and 334 mm, respectively. For 58 years average rainfall (of all stations) is 306 mm.

In July no significant trend has been found from 50s to 70s (350, 276 and 356 mm respectively), then some decrease of average rainfall has been observed in the following decade. From 80s to the period of 2000 to 2007 average rainfall (of all stations) shows an increasing trend (277, 351 and 408 mm). The average rainfall (of all stations) during 58 years for this month is 355 mm.

In August there is an increasing trend of average rainfall (of all stations) from 50s to 80s (250, 279, 283 and 331 mm respectively), then some decrease of average rainfall has been observed in the following decades (308 mm during 90s and 246 mm during 2000 to 2007). For 58 years average rainfall (of all stations) in this month is 276 mm.

In September average rainfall (of all stations) during 50s is 218 mm. From 60s to the period of 2000 to 2007 average rainfall follows an increasing trend (208, 238, 250, 289 and 360 mm respectively). For 58 years average rainfall (of all stations) is 292 mm.

In October during 50s and 60s average rainfall (of all stations) are 143 and 152 mm respectively. From 70s to the period of 2000 to 2007 an increasing trend has been observed (111, 119, 137 and 203 mm respectively) for average rainfall (of all stations). For 58 years average rainfall in this month is 158 mm.

In November average rainfall (of all stations) during 50s is 32 mm. From 60s to 90s average rainfall follows an increasing trend (10, 13, 33 and 39 mm respectively). During the period of 2000 to 2007 and for 58 years average rainfall (of all stations) for this month are 29 and 27 mm respectively.

In December during 50s and 60s average rainfall (of all stations) are 1 and 1 mm respectively. From 70s to the period of 2000 to 2007 a decreasing trend of average rainfall (of all stations) has been observed (14, 13, 6 and 3 mm respectively). For 58 years average rainfall in this month is 6 mm.

South Central Region

From the analysis for South-Central region shown in Appendix B.4, it can be observed that in January during 50s and 60s average rainfall (of all stations) are 14 and 5 mm respectively. From 70s to 90s average rainfall follows an increasing trend (4, 7 and 10 mm respectively). During 2000 to 2007 and for 58 years average rainfall (of all stations) are 9 and 8 mm respectively.

In February during 50s and 60s average rainfall (of all stations) are 14 and 15 mm respectively. From 70s to 90s average rainfall follows an increasing trend (13, 23 and 38 mm, respectively). During 2000 to 2007 and for 58 years average rainfall (of all stations) are 16 and 22 mm respectively.

In March during 50s and 60s average rainfall (of all stations) are 34 and 70 mm respectively. From 70s to 90s average rainfall follows an increasing trend (24, 42 and 85 mm respectively). During 2000 to 2007 average rainfall is found to be 41 mm and for 58 years average rainfall in this month is 50 mm.

In April during 50s average rainfall (of all stations) is 89 mm. For decades 60s to 80s average rainfall follows an increasing trend (84, 96 and 138 mm respectively). During the periods 90s and 2000 to 2007 average rainfall (of all stations) are 125 and 80 mm respectively. The average rainfall (of all stations) for 58 years during this month is 106 mm.

In May during 50s average rainfall (of all stations) is 213 mm. Then some decrease of rainfall has been observed in the following decade. From 60s to 80s average rainfall follows an increasing trend (128, 240 and 270 mm respectively). During the periods 90s

and 2000 to 2007 average rainfall (of all stations) are 236 and 224 mm respectively. The average rainfall (of all stations) for 58 years during this month is 231 mm.

In June during 50s average rainfall (of all stations) is 420 mm. Then some decrease of rainfall has been observed in the following decade. From 60s to 80s average rainfall follows an increasing trend (344, 404 and 455 mm respectively). During the periods 90s and 2000 to 2007 average rainfall (of all stations) are 405 and 466 mm respectively. The average rainfall (of all stations) for 58 years during this month is 426 mm.

In July during 50s average rainfall (of all stations) is 423 mm. From 60s to 90s average rainfall follows an increasing trend (409, 436, 461 and 485 mm respectively). Then some decrease of average rainfall has been observed in the following period of 2000 to 2007 (477 mm). The average rainfall (of all stations) during 58 years for this month is 461 mm.

In August there is an increasing trend of average rainfall (of all stations) from 50s to 80s (330, 381, 384 and 434 mm respectively), then some decrease of average rainfall has been observed in the following periods (400 mm during 90s and 317 mm during 2000 to 2007). For 58 years average rainfall (of all stations) in this month is 378 mm.

In September average rainfall (of all stations) during 50s is 288 mm. From 60s to 80s average rainfall follows an increasing trend (279, 299 and 321 mm respectively), then some decrease of average rainfall has been observed in the following decade (288 mm during 90s). During the period of 2000 to 2007 average rainfall (of all stations) is 380 mm. For 58 years average rainfall (of all stations) in this month is 319 mm.

In October there is a decreasing trend of average rainfall (of all stations) from 50s to 80s (212, 189, 168 and 154 mm respectively), then from 80s to the period of 2000 to 2007 rainfall follows an increasing trend (154, 202 and 242 mm respectively). The average rainfall (of all stations) during 58 years for this month is 195 mm.

In November average rainfall (of all stations) during 50s and 60s are 30 and 26 mm. From 70s to the period of 2000 to 2007 average rainfall follows a decreasing trend (54, 53, 51 and 37 mm respectively). For 58 years average rainfall (of all stations) for this month are 46 mm.

In December there is an increasing trend of average rainfall (of all stations) from 50s to 70s (0, 7 and 14 mm respectively), then from 70s to the period of 2000 to 2007 rainfall follows a decreasing trend (14, 9, 8 and 5 mm respectively). The average rainfall (of all stations) during 58 years for this month is 7 mm.

South East Region

From the analysis for South-East region shown in Appendix B.5, it can be observed that in January from 50s to 70s average rainfall (of all stations) follows an decreasing trend (16, 5 and 4 mm respectively). From 70s to the period of 2000 to 2007 average rainfall follows no significant trend (4, 8, 5 and 8 mm respectively). For 58 years average rainfall (of all stations) is 7 mm.

In February during 50s average rainfall (of all stations) is 18 mm. From 60s to 90s average rainfall follows an increasing trend (7, 18, 18 and 39 mm respectively). During 2000 to 2007 and for 58 years average rainfall (of all stations) are 15 and 21 mm respectively.

In March from 50s to 70s average rainfall follows a decreasing trend (49, 45 and 34 mm respectively). Then some increase of average rainfall has been observed in the following period. From 70s to 90s average rainfall follows an increasing trend (34, 53 and 100 mm respectively). During 2000 to 2007 and for 58 years average rainfall (of all stations) are 58 and 59 mm respectively.

In April from 50s to 80s average rainfall (of all stations) follows no significant trend (107, 119, 92 and 198 mm respectively). Then some decrease of average rainfall has been observed in the following period. From 80s to the period of 2000 to 2007 average rainfall follows a decreasing trend (198, 153 and 114 mm respectively). The average rainfall (of all stations) for 58 years during this month is 137 mm.

In May during 50s average rainfall (of all stations) is 275 mm. Then some decrease of rainfall has been observed in the following decade. From 60s to 80s average rainfall follows an increasing trend (203, 229 and 365 mm respectively). During the periods 90s and 2000 to 2007 average rainfall (of all stations) are 309 and 327 mm respectively. The average rainfall (of all stations) for 58 years during this month is 296 mm.

In June from 50s to 70s average rainfall (of all stations) follows a decreasing trend (613, 502 and 396 mm, respectively). Then some increase of average rainfall has been observed in the following decade. From 70s to the period of 2000 to 2007 average rainfall follows no significant trend (396, 436, 423 and 514 mm respectively). The average rainfall (of all stations) for 58 years during this month is 463 mm.

In July from 50s to 70s average rainfall (of all stations) follows no significant trend (520, 529 and 473 mm respectively). Then some increase of average rainfall has been observed in the following period. From 80s to the period of 2000 to 2007 average rainfall follows a decreasing trend (624, 569 and 494 mm respectively). The average rainfall (of all stations) for 58 years during this month is 540 mm.

In August there is a decreasing trend of average rainfall (of all stations) from 50s to 70s (482, 480 and 309 mm respectively), then some increase of average rainfall has been observed in the following period (517 mm during 80s). From 80s to the period of 2000 to 2007 average rainfall again follows a decreasing trend (517, 451 and 355 mm respectively). The average rainfall (of all stations) for 58 years during this month is 424 mm.

In September from 50s to the period of 2000 to 2007 average rainfall (of all stations) follows no significant trend (336, 343, 213, 327, 298 and 353 mm respectively). For 58 years average rainfall (of all stations) in this month is 305 mm.

In October there is a decreasing trend of average rainfall (of all stations) from 50s to 80s (228, 212, 162 and 150 mm respectively), then from 80s to the period of 2000 to 2007 average rainfall follows an increasing trend (150, 183 and 207 mm respectively). The average rainfall (of all stations) during 58 years for this month is 183 mm.

In November from 50s to the period of 2000 to 2007 average rainfall (of all stations) follows no significant trend (54, 24, 59, 34, 58 and 33 mm respectively). For 58 years average rainfall (of all stations) in this month is 44 mm.

In December from 50s to the period of 2000 to 2007 average rainfall (of all stations) follows no significant trend (2, 8, 7, 7, 12 and 6 mm respectively). For 58 years average rainfall (of all stations) in this month is 8 mm.

Eastern Hills Region

From the analysis for Eastern Hilly region shown in Appendix B.6, it can be observed that in January from 50s to 70s average rainfall (of all stations) follows a decreasing trend (7, 6 and 1 mm respectively). From 70s to 90s average rainfall follows an inreasing trend (1, 4 and 7 mm respectively). During 2000 to 2007 and for 58 years average rainfall (of all stations) are 4 and 5 mm respectively.

In February from 50s to 70s average rainfall (of all stations) follows a decreasing trend (12, 8 and 6 mm respectively). From 70s to 90s average rainfall follows an inreasing trend (6, 13 and 40 mm respectively). During 2000 to 2007 and for 58 years average rainfall (of all stations) are 10 and 18 mm respectively.

In March from 50s to 70s average rainfall follows a decreasing trend (48, 38 and 8 mm respectively). Then some increase of average rainfall has been observed in the following decades. From 70s to 90s average rainfall follows an increasing trend (8, 24 and 77 mm respectively). During 2000 to 2007 and for 58 years average rainfall (of all stations) are 34 and 40 mm respectively.

In April from 50s to 80s average rainfall (of all stations) follows an increasing trend (42, 79, 85 and 121 mm respectively). Then some decrease of average rainfall has been observed in the following period. From 80s to the period of 2000 to 2007 average rainfall follows a decreasing trend (121, 93 and 85 mm respectively). The average rainfall (of all stations) for 58 years during this month is 89 mm.

In May during 50s and 60s average rainfall (of all stations) are 221 and 230 mm respectively. From 70s to the period of 2000 to 2007 average rainfall follows an increasing trend (197, 229, 322 and 394 mm respectively). The average rainfall (of all stations) for 58 years during this month is 277 mm.

In June during 50s and 60s average rainfall (of all stations) are 535 and 691 mm respectively. Then some decrease of average rainfall has been observed in the following decade (531 mm in 70s). From 70s to the period of 2000 to 2007 average rainfall follows an increasing trend (531, 641, 714 and 735 mm respectively). The average rainfall (of all stations) for 58 years during this month is 685 mm.

In July during 50s and 60s average rainfall (of all stations) are 594 and 811 mm respectively. From 70s to 90s average rainfall follows an increasing trend (620, 757 and 865 mm respectively). During 2000 to 2007 and for 58 years average rainfall (of all stations) are 778 and 785 mm respectively.

In August during 50s and 60s average rainfall (of all stations) are 519 and 611 mm respectively. From 70s to 90s average rainfall follows an increasing trend (516, 573 and 651 mm respectively). During 2000 to 2007 and for 58 years average rainfall (of all stations) are 552 and 601 mm respectively.

In September there is a decreasing trend of average rainfall (of all stations) from 50s to 70s (352, 309 and 266 mm respectively), then from 70s to the period of 2000 to 2007 average rainfall follows an increasing trend (266, 321, 339 and 380 mm respectively). The average rainfall (of all stations) during 58 years for this month is 336 mm.

In October there is a decreasing trend of average rainfall (of all stations) from 50s to 70s (260, 236 and 135 mm respectively), then from 70s to the period of 2000 to 2007 average rainfall follows an increasing trend (135, 167, 203 and 256 mm respectively). The average rainfall (of all stations) during 58 years for this month is 209 mm.

In November during 50s average rainfall (of all stations) is 32 mm. Then some decrease of rainfall has been observed in the following decade (16 mm in 60s). From 60s to 80s average rainfall follows an increasing trend (16, 57 and 80 mm respectively). From 80s to the period of 2000 to 2007 average rainfall follows a decreasing trend (80, 79 and 54 mm respectively). The average rainfall (of all stations) during 58 years for this month is 63 mm.

In December during 50s and 60s average rainfall (of all stations) are 9 and 17 mm respectively. From 70s to 90s average rainfall follows an increasing trend (6, 10 and 17 mm respectively). During 2000 to 2007 and for 58 years average rainfall (of all stations) are 7 and 10 mm respectively.

Rivers and Estuary Region

From the analysis for Rivers and Estuary region shown in Appendix B.7, it can be observed that for two stations of this region (Hatiya and Sandwip) data for 50s is not available. In January from 60s to 80s average rainfall (of all stations) follows an

increasing trend (1, 3 and 6 mm respectively) in this region. During 90s and 2000 to 2007, average rainfall are 4 and 12 mm respectively. For 58 years average rainfall (of all stations) is 6 mm respectively.

In February from 60s to the period of 2000 to 2007 average rainfall (of all stations) follows no significant trend (4, 18, 14, 40 and 18 mm respectively). For 58 years average rainfall (of all stations) is 20 mm.

In March from 60s to 90s average rainfall follows an increasing trend (41, 42, 53 and 94 mm respectively). During 2000 to 2007 and for 58 years average rainfall (of all stations) are 46 and 56 mm respectively.

In April from 60s to 80s average rainfall (of all stations) follows an increasing trend (107, 136 and 201 mm respectively). Then some decrease of average rainfall has been observed in the following period. From 80s to the period of 2000 to 2007 average rainfall follows a decreasing trend (201, 108 and 96 mm respectively). The average rainfall (of all stations) for 58 years during this month is 135 mm.

In May during 60s and 70s average rainfall (of all stations) are 157 and 298 mm respectively. From 80s to the period of 2000 to 2007 average rainfall follows an increasing trend (274, 275 and 486 mm respectively). The average rainfall (of all stations) for 58 years during this month is 308 mm.

In June during 60s average rainfall (of all stations) is 584 mm. From 70s to 90s average rainfall follows a decreasing trend (662, 564 and 556 mm respectively). During 2000 to 2007 and for 58 years average rainfall (of all stations) are 871 and 646 mm respectively.

In July From 60s to 80s average rainfall follows an increasing trend (729, 766 and 773 mm respectively). During 90s and during 2000 to 2007 average rainfall (of all stations) are 627 and 946 mm respectively. Highest average rainfall (of all stations) has been observed in the recent period. For 58 years average rainfall (of all stations) is 770 mm.

In August during 60s average rainfall (of all stations) is 700 mm. From 70s to 90s average rainfall follows a decreasing trend (712, 607 and 527 mm respectively). During 2000 to 2007 and for 58 years average rainfall (of all stations) are 554 and 615 mm respectively.

In September there is a decreasing trend of average rainfall (of all stations) from 60s to 90s (507, 412, 397 and 331 mm respectively). The highest average rainfall (of all stations) has been observed in the recent period (611 mm during 2000 to 2007). For 58 years average rainfall (of all stations) is 435 mm.

In October there is an increasing trend of average rainfall (of all stations) from 60s to 80s (129, 199 and 232 mm respectively), then some decrease of average rainfall has been observed in the following decade (191mm during 90s). The highest average rainfall (of all stations) is found in the recent period (399 mm during 2000 to 2007) and for 58 years average rainfall is 233 mm.

In November during 60s average rainfall (of all stations) is 6 mm. Then some increase of rainfall has been observed in the following decade (91 mm during 70s). From 70s to 90s average rainfall follows a decreasing trend (91, 53 and 39 mm respectively). During 2000 to 2007 and for 58 years average rainfall (of all stations) are 66 and 57 mm respectively.

In December from 60s to 80s average rainfall (of all stations) follows a decreasing trend (26, 10 and 6 mm respectively). Then some increase of average rainfall has been observed during 90s (20 mm). During 2000 to 2007 and for 58 years average rainfall (of all stations) are 7 and 12 mm respectively.

4.5 Comparison between Average Monthly Rainfall for recent years relative to long term average for eight hydrological regions of Bangladesh

The normalized change of average rainfall in eight hydrological regions for recent 12 years (1996 to 2007) relative to long term rainfall of 58 years (1950 to 2007) for each month of a year has been calculated. The normalized change has been described by five criteria, namely significant increase of rainfall (overall increase and at least 40% increase in one station of a particular region), increase of rainfall (overall increase in more than 50% stations of a particular region), mixture of increase and decrease of rainfall (simultaneously significant increase and decrease of rainfall in the stations of a particular region), Decrease of rainfall (overall decrease in more than 50% stations of the region) and significant decrease of rainfall (overall decrease and at least 40% decrease in one station of a particular region)

From this analysis, it can be observed that in January there is significant increase of rainfall in SC region (increase of 78% in Barisal, 64% in Khepupara, 54% in Bhola, 44% in Faridpur and decrease of only 0.7% in Patuakhali) and in RE region (increase of 92% in Sandwip and 42% in Htiya); mixture of increase and decrease of rainfall in NC region (increase of 18% in Tangail, 4% in Dhaka and decrease of 62% in Mymensingh); in SW region (increase of 21% in Satkhira, 8% in Jessore and decrease of 5% in Khulna); in SE region (increase of 48% in Comilla, 42% in Feni, 21% in Chandpur and decrease of 14 % in Maijdee court) and in EH region (increase of 64% in Rangamati, 22% in Chittagong and decrease of 68% in Teknaf, 56% in Kutubdia, 38% in Cox's Bazar) and significant decrease of rainfall has been observed in NW region (decrease of 46% in Rajshahi, 43% in Bogra, 39% in Dinajpur, 34% in Ishurdi and 31% in Rangpur) and in NE region (decrease of 46% in Sylhet and 15% in Srimangal).

In February there is mixture of increase and decrease of rainfall in NW region (increase of 99% in Dinajpur, 19% in Bogra, 8% in Rangpur and decrease of 8% in Rajshahi,, 2% in Ishurdi); in SW region (increase of 9% in Satkhira and decrease of 27% in Jessore, 1% in Khulna); in SC region (increase of 16% in Faridpur and decrease of 33% in Bhola, 27% in Patuakhali, 18% in Barisal, 8% in Khepupara) and in EH region (increase of 53% in Chittagong, 16% in Cox's Bazar and decrease of 28% in Kutubdia, 15% in Rangamati, 4% in Teknaf); decrease of rainfall in NE region (decrease of 17% in Sylhet and 8% in Srimangal) and in RE region (decrease of 12% in Htiya and 10% in Sandwip) and significant decrease of rainfall has been observed in NC region (decrease of 42% in Dhaka, 38% in Tangail and 17% in Mymensingh) and in SE region (decrease of 59% in Feni, 17% in Comilla, 16 % in Maijdee court and increase of 5% in Chandpur).

In March there is significant increase of rainfall in SW region (increase of 40% in Khulna, 35% in Satkhira and 11% in Jessore), increase of rainfall in NC region (increase of 19% in Dhaka, 14% in Tangail and 3% in Mymensingh); in NE region (increase of 15% in Srimangal and 13% in Sylhet) and in SE region (increase of 38% in Comilla, 31% in Feni, 15% in Maijdee court and decrease of 5% in Chandpur), and mixture of increase and decrease of rainfall has been observed in NW region (increase of 26% in Bogra, 21% in Rajshahi,, 21% in Ishurdi, 1% in Rangpur and decrease of 26% in Dinajpur); in SC region (increase of 51% in Bhola, 26% in Barisal, 19% in

Patuakhali and decrease of 21% in Khepupara and 5% in Faridpur); in EH region (increase of 59% in Rangamati and decrease of 38% in Kutubdia, 30% in Teknaf, 16% in Chittagong and 10% in Cox's Bazar) and in RE region (increase of 8% in Sandwip and decrease of 60% in Htiya).

In April there is significant increase of rainfall in NW region (increase of 87% in Bogra, 66% in Rangpur, 57% in Dinajpur and decrease of 13% in Rajshahi, 1% in Ishurdi); in NC region (increase of 58% in Mymensingh, 5% in Dhaka and decrease of 4% in Tangail); increase of rainfall in NE region (increase of 11% in Srimangal and 10% in Sylhet); mixture of increase and decrease of rainfall in SW region (increase of 29% in Satkhira, 3% in Jessore and decrease of 8% in Khulna) and in SC region (increase of 5% in Barisal and decrease of 12% in Faridpur, 9% in Khepupara and 7% in Bhola) and decrease of rainfall has been observed in SE region (decrease of 31% in Chandpur, 21% in Feni, 5% in Maijdee court and 1% in Comilla); in EH region (decrease of 31% in Teknaf, 12% in Rangamati, 10% in Cox's Bazar and 3% in Kutubdia and increase of 5% in Chittagong) and in RE region (decrease of 38% in Sandwip and 23% in Htiya).

In May there is Significant increase of rainfall in EH region (increase of 45% in Cox's Bazar, 41% in Teknaf, 38% in Chittagong, 36% in Rangamati, and 30% in Kutubdia) and in RE region (increase of 53% in Sandwip and 32% in Htiya); increase of rainfall in NE region (increase of 21% in Srimangal and 3% in Sylhet) and in SW region (increase of 23% in Satkhira, 14% in Jessore and 3% in Khulna) and mixture of increase and decrease of rainfall has been observed in NW region (increase of 19% in Dinajpur, 6% in Rangpur, 4% in Rajshahi, 3% in Bogra and decrease of 10% in Ishurdi); in NC region (increase of 3% in Mymensingh, 3% in Dhaka and decrease of 6% in Tangail); in SC region (increase of 13% in Khepupara and decrease of 8% in Faridpur, 7% in Barisal, 5% in Patuakhali and 4% in Bhola) and in SE region (increase of 15% in Maijdee court, 12% in Comilla, 2% in Chandpur and decrease of 4% in Feni).

In June there is increase of rainfall in RE region (increase of 28% in Htiya and 16% in Sandwip); mixture of increase and decrease of rainfall in NW region (increase of 23% in Dinajpur, 13% in Rangpur, 5% in Bogra and decrease of 6% in Ishurdi and 2% in Rajshahi); in SW region (increase of 3% in Satkhira, 1% in Jessore and decrease of 5% in Khulna); in SC region (increase of 5% in Patuakhali, 4% in Khepupara, 1% in Bhola and decrease of 11% in Faridpur and 7% in Barisal); in SE region (increase of 5% in

Feni and decrease of 3% in Comilla, 3% in Chandpur and 2% in Maijdee court) and in EH region (increase of 16% in Rangamati and decrease of 5% in Chittagong, 4% in Teknaf, 4% in Kutubdia and 3% in Cox's Bazar) and decrease of rainfall has been observed in NC region (decrease of 5% in Dhaka and 4% in Tangail) and in NE region (decrease of 3% in Sylhet and 1% in Srimangal).

In July there is increase of rainfall in NC region (increase of 10% in Dhaka, 7% in Mymensingh and decrease of 1% in Tangail); in NE region (increase of 26% in Srimangal and decrease of 1% in Sylhet); in SW region (increase of 26% in Jessore, 15% in Khulna and 11% in Satkhira); in SC region (increase of 14% in Khepupara, 10% in Patuakhali, 8% in Bhola and decrease of 1% in Barisal); in EH region (increase of 12% in Teknaf, 8% in Kutubdia, 5% in Cox's Bazar, 5% in Rangamati and 1% in Chittagong) and in RE region (increase of 21% in Htiya and 16% in Sandwip) and mixture of increase and decrease of rainfall has been observed in NW region (increase of 4% in Rangpur, 3% in Dinajpur and decrease of 2% in Bogra, 2% in Rajshahi and 1% in Ishurdi) and in SE region (increase of 11% in Chandpur, 7% in Feni, 6% in Comilla and decrease of 8% in Maijdee court).

In August there is mixture of increase and decrease of rainfall in NC region (increase of 4% in Tangail and decrease of 7% in Mymensingh); in SE region (increase of 11% in Feni and decrease of 25% in Comilla, 15% in Maijdee court, 9% in Chandpur); in EH region (increase of 26% in Kutubdia, 7% in Teknaf, 5% in Cox's Bazar and decrease of 3% in Chittagong and 2% in Rangamati) and in RE region (increase of 8% in Htiya and decrease of 3% in Sandwip); decrease of rainfall has been observed in NW region (decrease of 10% in Ishurdi, 4% in Dinajpur, 2% in Bogra, 1% in Rajshahi and and increase of 3% in Rangpur); in NE region (decrease of 7% in Srimangal and 6% in Sylhet); in SW region (decrease of 14% in Jessore and 1% in Khulna) and in SC region (decrease of 19% in Barisal, 11% in Bhola, 6% in Patuakhali and increase of 2% in Khepupara).

In September there is significant increase of rainfall in SW region (increase of 45% in Khulna, 33% in Jessore and 19% in Satkhira); increase of rainfall in NW region (increase of 18% in Ishurdi, 17% in Dinajpur, 14% in Rajshahi, 8% in Rangpur and 3% in Bogra); in SC region (increase of 21% in Khepupara, 16% in Bhola, 9% in Patuakhali, 8% in Barisal and 3% in Faridpur); in SE region (increase of 21% in Chandpur, 9% in

Feni, 5% in Comilla, and 5% in Maijdee court); in EH region (increase of 21% in Chittagong, 19% in Cox's Bazar, 19% in Kutubdia, 17% in Rangamati and 10% in Teknaf) and in RE region (increase of 29% in Htiya and 14% in Sandwip); mixture of increase and decrease of rainfall has been observed in NC region (increase of 22% in Dhaka, 12% in Mymensingh and decrease of 6% in Tangail) and in NE region (increase of 11% in Srimangal and decrease of 7% in Sylhet).

In October there is significant increase of rainfall in NW region (increase of 66% in Dinajpur, 59% in Rangpur, 30% in Ishurdi, 26% in Bogra and 13% in Rajshahi); in EH region (increase of 41% in Teknaf, 24% in Kutubdia, 16% in Chittagong, 12% in Cox's Bazar and 2% in Rangamati) and in RE region (increase of 58% in Htiya and 41% in Sandwip); increase of rainfall in NC region (increase of 23% in Dhaka, 22% in Mymensingh and 2% in Tangail); in SW region (increase of 37% in Satkhira, 34% in Khulna and 28% in Jessore); in SC region (increase of 29% in Bhola, 28% in Patuakhali, 25% in Khepupara, 8% in Faridpur and decrease of 7% in Barisal); in SE region (increase of 22% in Chandpur, 3% in Maijdee court and 1% in Feni); mixture of increase and decrease of rainfall has been observed and in NE region (increase of 11% in Srimangal and decrease of 13% in Sylhet).

In November there is increase of rainfall in SW region (increase of 33% in Khulna, 26% in Jessore and 17% in Satkhira); mixture of increase and decrease of rainfall in NE region (increase of 20% in Sylhet and decrease of 44% in Srimangal); in SE region (increase of 7% in Chandpur and decrease of 31% in Comilla, 13% in Maijdee court and 7% in Feni) and in RE region (increase of 18% in Htiya and decrease of 33% in Sandwip); decrease of rainfall has been observed in NC region (decrease of 11% in Dhaka, 9% in Tangail and 7% in Mymensingh) and in EH region (decrease of 37% in Kutubdia, 30% in Teknaf, 27% in Cox's Bazar, 14% in Chittagong, and 13% in Rangamati); significant decrease of rainfall in NW region (decrease of 57% in Rangpur, 53% in Bogra, 34% in Rajshahi, 22% in Ishurdi and 5% in Dinajpur) and in SC region (decrease of 41% in Patuakhali, 25% in Khepupara, 14% in Barisal, 7% in Bhola and increase of 5% in Faridpur).

In December there is significant increase of rainfall in EH region (increase of 67% in Chittagong, 37% in Cox's Bazar, 20% in Rangamati, 13% in Kutubdia and 10% in Teknaf,); mixture of increase and decrease of rainfall in NE region (increase of 22% in

Srimangal and decrease of 45% in Sylhet) and in RE region (increase of 14% in Htiya and decrease of 56% in Sandwip); decrease of rainfall has been observed in SE region (decrease of 22% in Maijdee court, 11% in Chandpur, 8% in Comilla and 4% in Feni); significant decrease of rainfall in NW region (decrease of 72% in Rajshahi, 72% in Ishurdi, 49% in Bogra and increase of 16% in Dinajpur); in NC region (decrease of 65% in Tangail, 38% in Dhaka and 24% in Mymensingh); in SW region (decrease of 59% in Jessore, 46% in Satkhira and 21% in Khulna) and in SC region (decrease of 72% in Patuakhali, 57% in Barisal, 48% in Faridpur, 44% in Bhola and 10% in Khepupara).

Figure 4.6 shows the normalized change of average rainfall in eight hydrological regions for recent 12 years (1996 to 2007) relative to long term rainfall of 58 years (1950 to 2007) for the months of December, January, April and May. December and January are considered here to correspond as dry season and April and May are considered to correspond as wet season. The normalized change of average rainfall in eight hydrological regions for recent 12 years (1996 to 2007) relative to long term rainfall of 58 years (1950 to 2007) for the rest of the months have been shown in Appendix C.1.

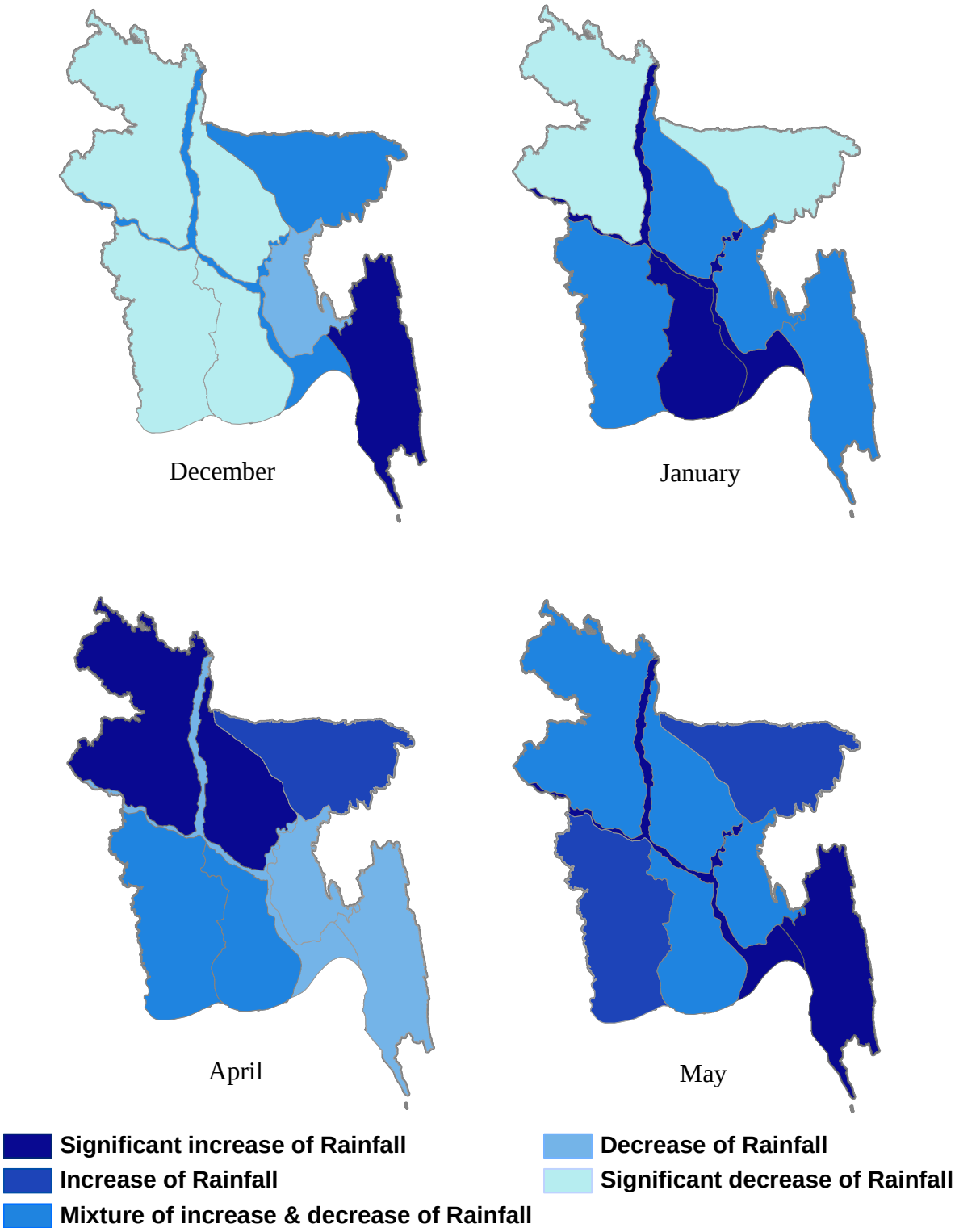


Figure 4.6: Normalized change of average rainfall in eight hydrological regions for recent 12 years (1996 to 2007) relative to long term rainfall of 58 years (1950 to 2007)

CHAPTER 5

RAINFALL CONTRIBUTION IN MEETING CROP WATER REQUIREMENT

5.1 General

In this chapter area occupied for production of three categories of rice and wheat as well as their yield has been analyzed over four decades in Bangladesh. Contribution of rainwater in meeting Crop water requirement for three varieties of Rice and for Wheat have been compared for recent 12 years (1996 to 2007) considering long term rainfall data of 58 years (1950 to 2007).

5.2 Production Area of rice and wheat and their yield

Area under different categories of rice (Aus, Aman and Boro) over last four decades in Bangladesh has been shown in Figure 5.1. It illustrates that area under Aman production remained more or less constant during this period, while area under Boro production increased by almost five times and area under Aus production became one third during the same period.

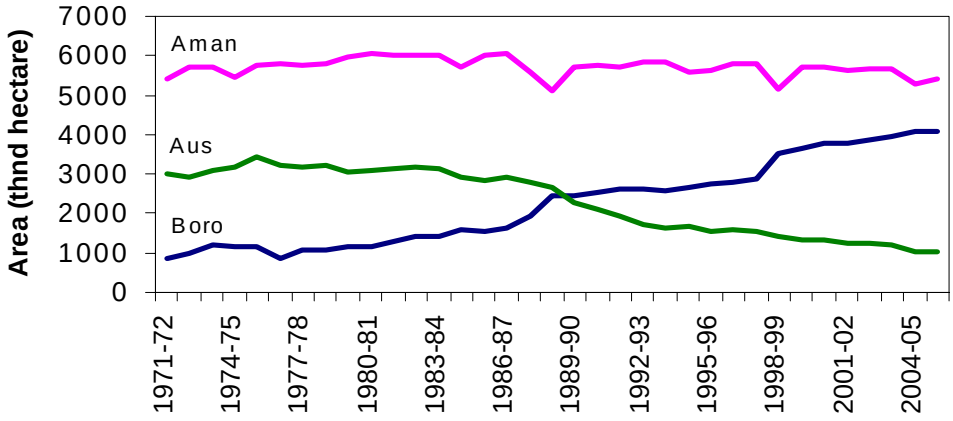


Figure 5.1: Area under different categories of rice

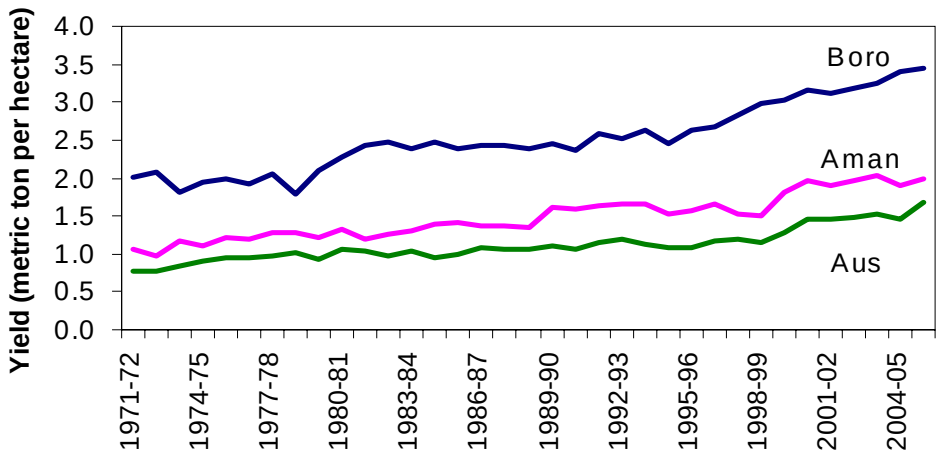


Figure 5.2: Yield (metric ton per hectare) of different categories of rice over last four decades (1971 to 2005)

Figure 5.2 shows the yield under different categories of rice (Aus, Aman and Boro) over last four decades in Bangladesh. From the figure it can be observed that yield of these three varieties of rice slowly increased by about two times during the last four decades.

To assess the present conditions of yield, which may have been influenced by altered rainfall due to climate change impacts, spatial variation of yield of three varieties of rice and wheat is obtained for eight hydrological regions as well as for the whole country using GIS. As shown in Table 5.1 during 2001-2002, minimum 2000 kg/Ha yield of Boro, Aman, Aus and wheat was observed in 97%, 50%, 10% and 55% area of Bangladesh respectively. 100% area of NW, NE, SE, SW, EH, RE regions show minimum 2000 kg/Ha yield of Boro crop whereas SC and NC regions show 70% and 52% area with minimum 2000 kg/Ha yield. In EH, NW and NC regions, area coverage of Aman with minimum 2000 kg/Ha yield are 100%, 56% and 52% respectively. In NW region, 43% area show minimum 2000 kg/Ha yield of Aus crop. Similar yield of wheat is observed in 95% area of NW, 72% area of NC, 53% area of SW and 43% area of EH region.

Table 5.1: Percentage of area with yield at least 2000 kg/Ha of three varieties of rice and wheat in different hydrological regions of Bangladesh (2001-2002)

Zones		**NW**	**NC**	**NE**	**SW**	**SC**	**SE**	**EH**	**RE**	**BD**
Crops										
Rice	**Boro**	100	52	100	100	70	100	100	100	97
	Aman	56	52	36	46	0	41	100	21	50
	Aus	43	0	0	0	0	0	0	0	10
Wheat		95	72	21	53	31	13	43	41	55

From the above table it appears that Aus, Aman and Wheat show relatively low yield relative to that for Boro.

5.3 Comparative contribution of rainwater in meeting Crop water requirement considering long term rainfall data

The comparative contribution of rainwater in meeting Crop water requirement (Rainfall×100/ETc) for three varieties of rice (Boro, Aman and Aus) and Wheat has been made considering long term rainfall data (1950 to 2007) over their cropping period. For this purpose, difference of rainfall contribution in meeting Crop water requirement over recent 12 years (1996-2007) and that of for 58 years (1950-2007) has been calculated and this difference is normalized with respect to the rainfall contribution over 58 years. The normalized changes in contribution of rainfall for different months of the cropping periods have been analyzed here for each variety of crop considering all of the BMD stations located in eight hydrological regions of the country.

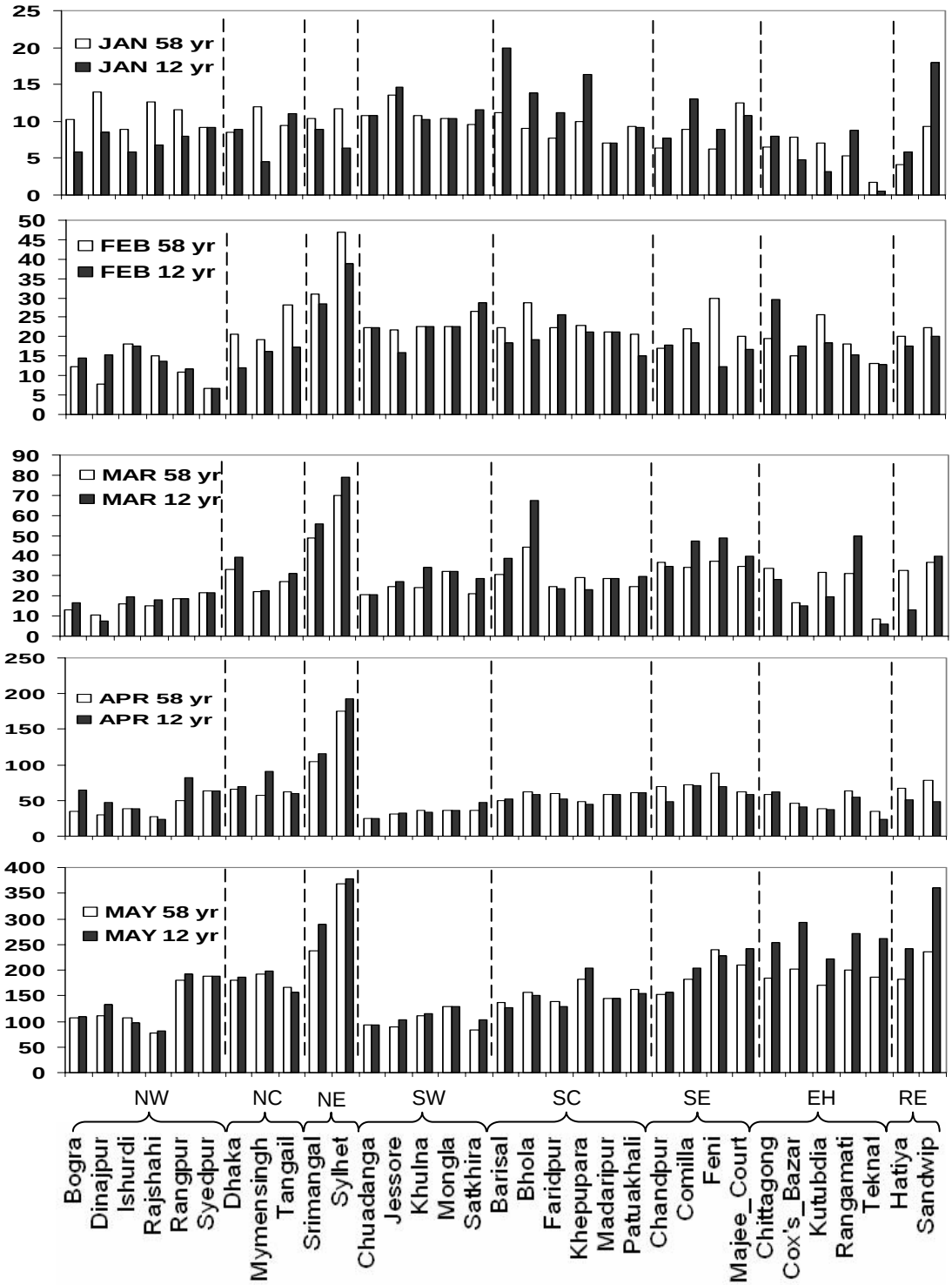


Figure 5.3: Rainfall contribution in meeting Crop water requirement (Rainfall × 100/ETc) over recent 12 years (1996-2007) with respect to 58 years (1950-2007) for Boro rice

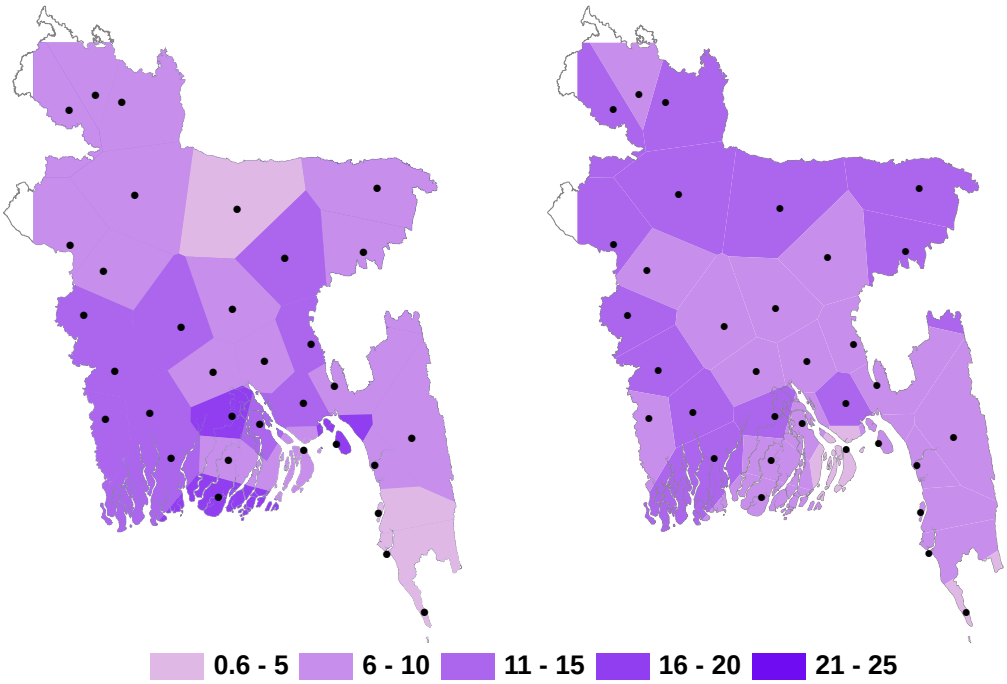
The comparative contribution of rainwater in meeting Crop water requirement for Boro over its cropping period (January to May) considering long term rainfall data (1950 to 2007) is shown in Figure 5.3. After making normalization of changes in contribution it was observed that in January, there is 4% (Dhaka) to 18% (Tangail) increase in contribution of rainfall in NC region with exception of Mymensingh (62% decrease), by 8% (Jessore) to 21% (Satkhira) increase in SW region with exception of Khulna (4% decrease), by 44% (Faridpur) to 78% (Barisal) increase in SC region with exception of Patuakhali (1% decrease), by 21% (Chandpur) to 48% (Comilla) increase in SE region with exception of Maijdee court (14% decrease) and by 42% (Hatiya) to 92% (Sandwip) increase in RE region. During the same period, contribution of rainfall has decreased by 31% (Rangpur) to 46% (Rajshahi) in NW region, by 15% (Srimangal) to 45% (Sylhet) in NE region, by 38% (Cox's Bazar) to 68% (Teknaf) in EH region with exception of Rangamati (64% increase) and Chittagong (22% increase).

In February, there is 8% (Rangpur) to 99% (Dinajpur) increase in contribution of rainfall in NW region with exception of Rajshahi (8% decrease) and Ishurdi (2% decrease). During the same period, contribution of rainfall has decreased by 17% (Mymensingh) to 42% (Dhaka) in NC region, by 8% (Srimangal) to 17% (Sylhet) in NE region, by 1% (Khulna) to 27% (Jessore) in SW region with exception of Satkhira (9% increase), by 8% (Khepupara) to 33% (Bhola) in SC region with exception of Faridpur (16% increase), by 16% (Maijdee court) to 59% (Feni) in SE region with exception of Chandpur (5% increase), by 4% (Teknaf) to 28% (Kutubdia) in EH region with exception of Chittagong (53% increase), Cox's Bazar (16% increase) and by 10% (Sandwip) to 12% (Htiya) decrease in RE region.

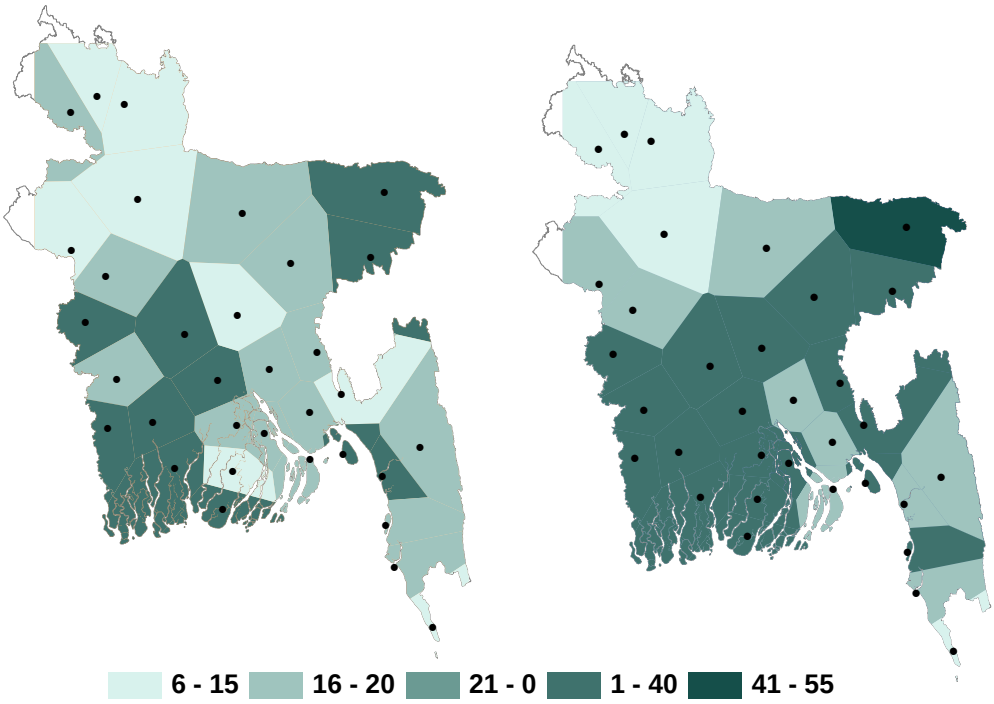
In March, there is increase in contribution of rainfall in NW region by 1% (Rangpur) to 26% (Bogra) with exception of Dinajpur (26% decrease), by 3% (Mymensingh) to 19% (Dhaka) in NC region, by 13% (Sylhet) to 15% (Srimangal) in NE region, by 11% (Jessore) to 40% (Khulna) in SW region, by 19% (Patuakhali) to 51% (Bhola) in SC region with exception of Khepupara (21% decrease), Faridpur (5% decrease), by 15% (Maijdee court) to 38% (Comilla) in SE region with exception of Chandpur (5% decrease). During the same period, contribution of rainfall has decreased by 10% (Cox's Bazar) to 38% (Kutubdia) in EH region with exception of Rangamati (59% increase) and by 60% (Hatiya) in RE region with exception of Sandwip (8% increase).

In April, there is increase in contribution of rainfall in NW region by 57% (Dinajpur) to 87% (Bogra) with exception of Rajshahi (13% decrease), Ishurdi (1% decrease), by 5% (Dhaka) to 58% (Mymensingh) in NC region with exception of Tangail (4% decrease), by 10% (Sylhet) to 11% (Srimangal) in NE region, by 3% (Jessore) to 29% (Satkhira) in SW region with exception of Khulna (8% decrease). During the same period, contribution of rainfall has decreased by 7% (Bhola) to 12% (Faridpur) in SC region with exception of Barisal (5% increase), by 1% (Comilla) to 31% (Chandpur) in SE region, by 3% (Kutubdia) to 31% (Teknf) in EH region with exception of Chittagong (5% increase) and by 23% (Hatiya) to 38% (Sandwip) in RE region.

In May, there is increase in contribution of rainfall by 3% (Bogra) to 19% (Dinajpur) in NW region with exception of Ishurdi (10% decrease), by 3% (Dhaka and Mymensingh) in NC region with exception of Tangail (6% decrease), by 3% (Sylhet) to 21% (Srimangal) in NE region, by 3% (Khulna) to 23% (Satkhira) in SW region, by 2% (Chandpur) to 15% (Maijdee court) in SE region with exception of Feni (4% decrease), by 30% (Kutubdia) to 45% (Cox's Bazar) in EH region, by 32% (Htiya) to 53% (Sandwip) in RE region. During the same period, contribution of rainfall has decreased by 4% (Bhola) to 8% (Faridpur) in SC region with exception of Khepupara (13% increase). GIS maps have also been developed to show comparative differences of contribution of rainwater for Boro from recent 12 years and past 58 years (Figure 5.4).



January, 12 year January, 58 year



February, 12 year February, 58 year

Figure 5.4: Comparison of contribution of Rainfall for Crop water requirement (Rainfall × 100/ETc) for Boro

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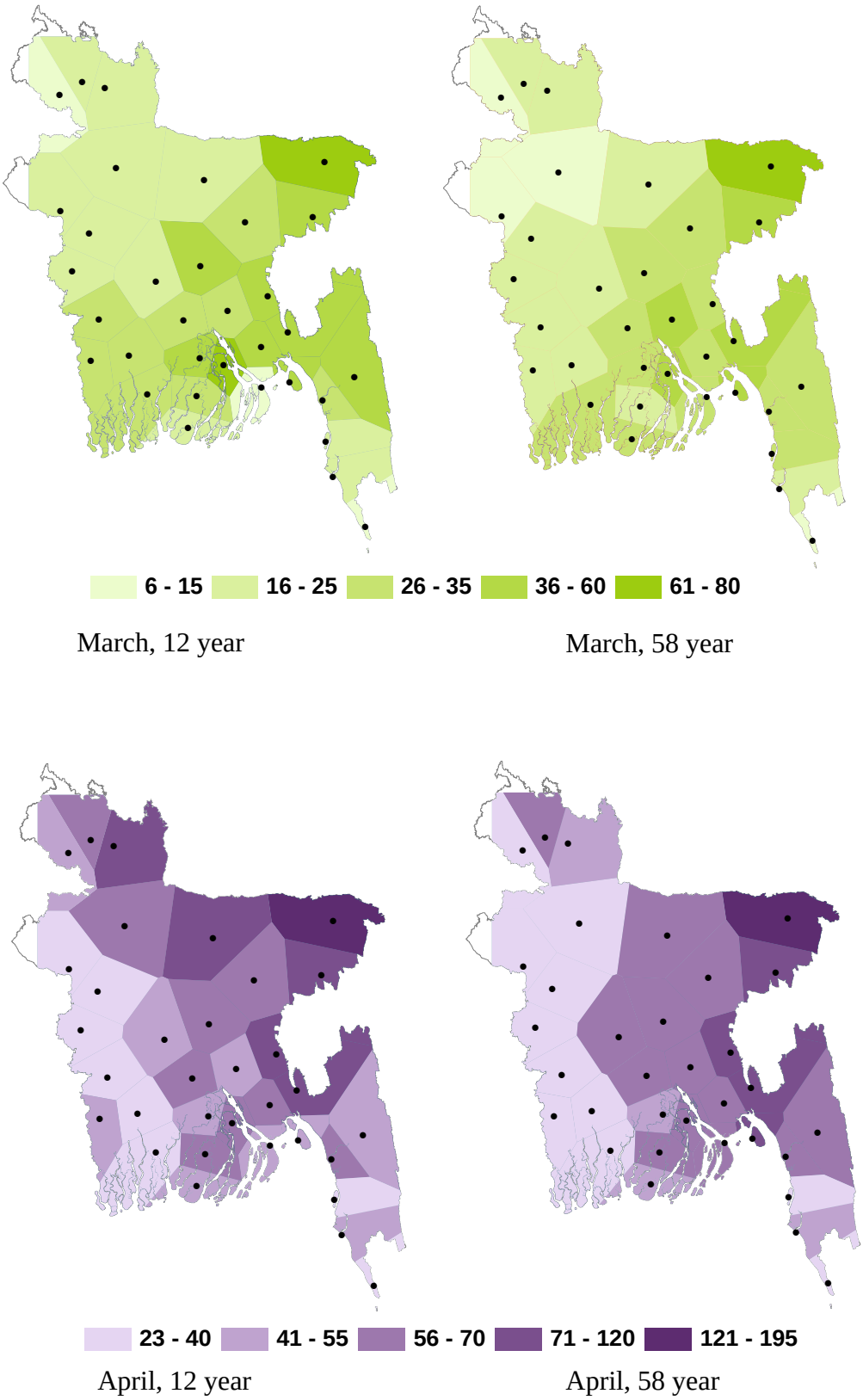

Figure 5.4: Comparison of contribution of Rainfall for Crop water requirement (Rainfall × 100/ETc) for Boro

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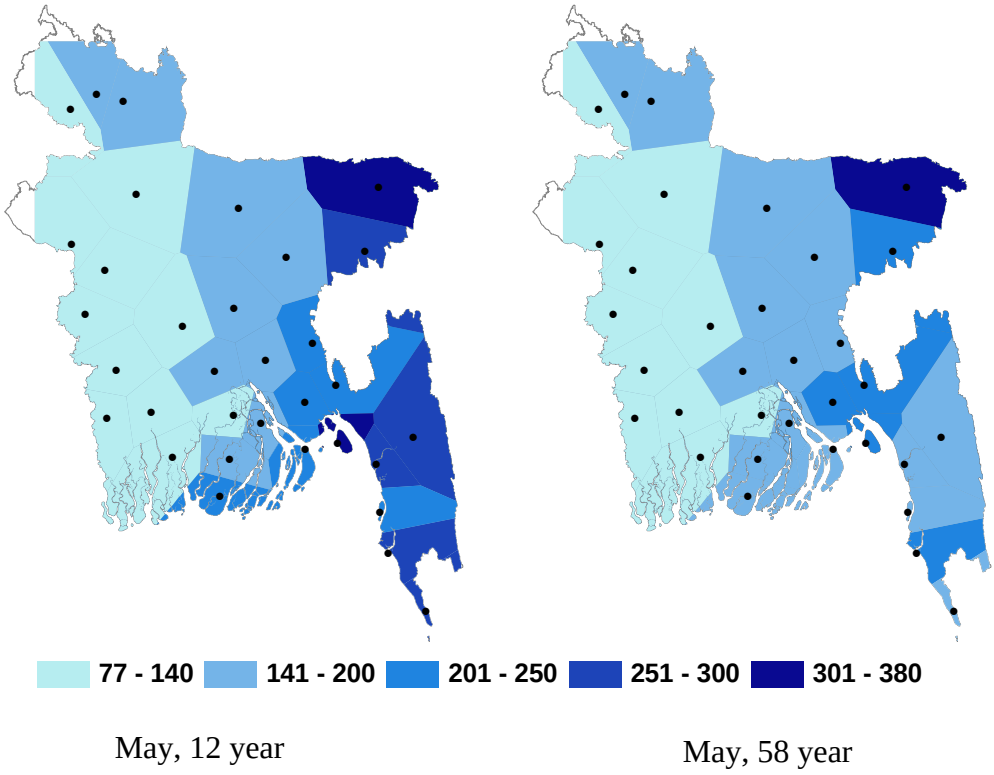


Figure 5.4: Comparison of contribution of Rainfall for Crop water requirement (Rainfall×100/ETc) for Boro

The comparative contribution of rainwater in meeting Crop water requirement for Aman over its cropping period (July to November) considering long term rainfall data (1950 to 2007) is shown in Figure 5.5. After making normalization of changes in contribution it was observed that in July, there is increase in contribution of rainfall by 7% (Mymensingh) to 10% (Dhaka) in NC region with exception of Tangail (1% decrease), by 26% (Srimangal) in NE region with an exception of Sylhet (1% decrease), by 11% (Satkhira) to 26% (Jessore) in SW region, by 8% (Bhola) to 14% (Khepupara) in SC region with exception of Barisal (1% decrease), by 6% (Comilla) to 11% (Chandpur) in SE region with exception of Maijdee court (8% decrease), by 1% (Chittagong) to 12% (Teknaf) in EH region and by 16% (Sandwip) to 21% (Htiya) in RE region. During the same period, contribution of rainfall has decreased by 1% (Ishurdi) to 2% (Bogra and Rajshahi) in NW region with exception of Rangpur (4% increase), Dinajpur (3% increase).

In August, there is increase in contribution of rainfall by 5% (Cox's Bazar) to 26% (Kutubdia) in EH region with exception of Chittagong (3% decrease), Rangamati (2% decrease) and by 8% (Htiya) in RE region with exception of Sandwip (3% decrease). During the same period, contribution of rainfall has decreased by 1% (Rajshahi) to 10% (Ishurdi) in NW region with exception of Rangpur (3% increase), by 7% (Mymensingh) in NC region with exception of Tangail (4% increase), by 6% (Sylhet) to 7% (Srimangal) in NE region, by 1% (Khulna) to 14% (Jessore) in SW region, by 6% (Patuakhali) to 19% (Barisal) in SC region with exception of Khepupara (2% increase) and by 9% (Chandpur) to 25% (Comilla) in SE region with exception of Feni (11% increase).

In September, there is increase in contribution of rainfall by 3% (Bogra) to 18% (Ishurdi) in NW region, by 12% (Mymensingh) to 22% (Dhaka) in NC region with exception of Tangail (6% decrease), by 11% (Srimangal) in NE region with exception of Sylhet (7% decrease), by 19% (Satkhira) to 45% (Khulna) in SW region, by 3% (Faridpur) to 21% (Khepupara) in SC region, by 5% (Comilla and Maijdee court) to 21% (Chandpur) in SE region, by 10% (Teknaf) to 21% (Chittagong) in EH region and by 14% (Sandwip) to 29% (Htiya) in RE region.

In October, there is increase in contribution of rainfall by 13% (Rajshahi) to 66% (Dinajpur) in NW region, by 2% (Tangail) to 23% (Dhaka) in NC region, by 28% (Jessore) to 37% (Satkhira) in SW region, by 8% (Faridpur) to 29% (Bhola) in SC region with exception of Barisal (7% decrease), by 1% (Feni) to 22% (Chandpur) in SE region, by 2% (Rangamati) to 41% (Teknaf) in EH region and by 41% (Sandwip) to 58% (Htiya) in RE region. During the same period, contribution of rainfall has decreased by 13% (Sylhet) in NE region with exception of Srimangal (11% increase).

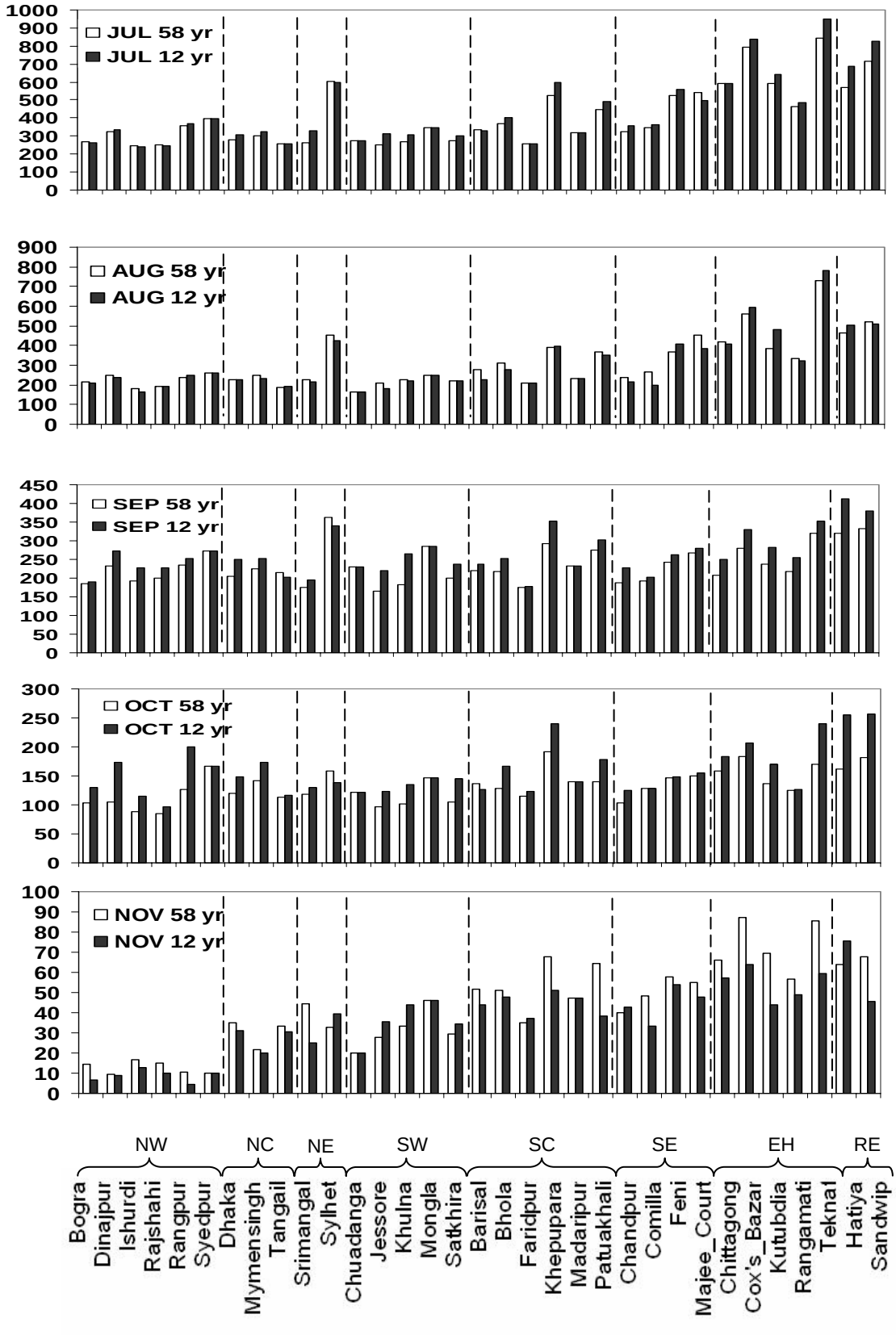
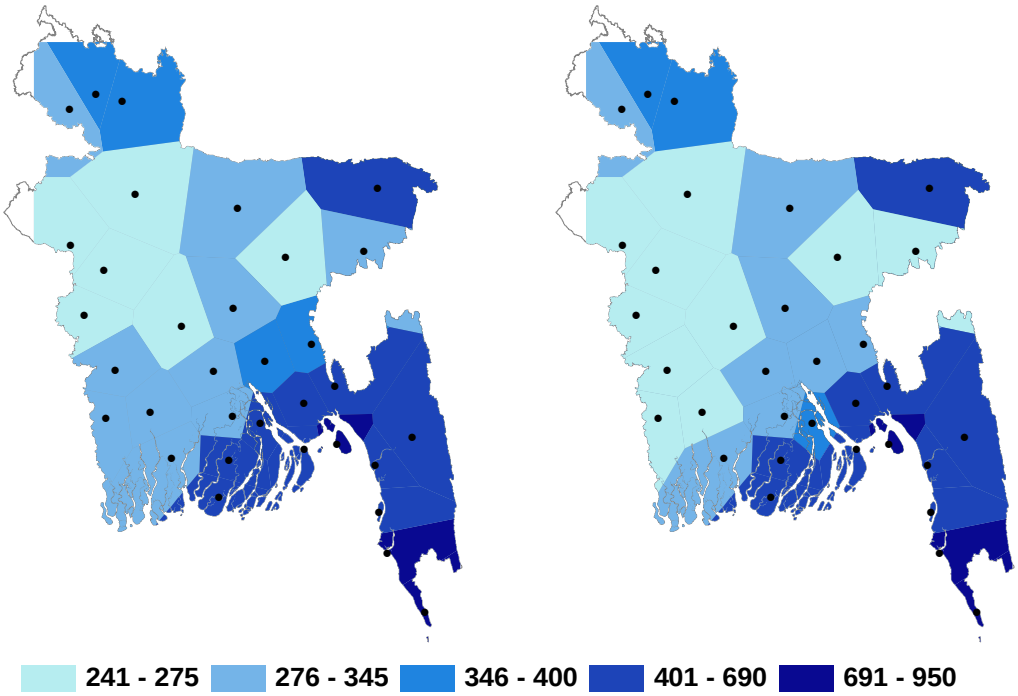


Figure 5.5: Rainfall contribution in meeting Crop water requirement (Rainfall×100/ETc) over recent 12 years (1996-2007) with respect to 58 years (1950-2007) for Aman rice

In November, there is increase in contribution of rainfall by 17% (Satkhira) to 33% (Khulna) in SW region. During the same period, contribution of rainfall has decreased by 5% (Dinajpur) to 57% (Rangpur) in NW region, by 7% (Mymensingh) to 11% (Dhaka) in NC region, by 44% (Srimangal) in NE region with exception of Sylhet (20% increase), by 7% (Bhola) to 41% (Patuakhali) in SC region with exception of Faridpur (5% increase), by 7% (Feni) to 31% (Comilla) in SE region with exception of Chandpur (7% increase), by 13% (Rangamati) to 37% (Kutubdia) in EH region and by 33% (Sandwip) in RE region with exception of Htiya (18% increase). GIS maps have also been developed to show comparative differences of contribution of rainwater for Aman from recent 12 years and past 58 years (Figure 5.6).



July, 12 year

July, 58 year

Figure 5.6: Comparison of contribution of Rainfall for Crop water requirement (Rainfall×100/ETc) for Aman

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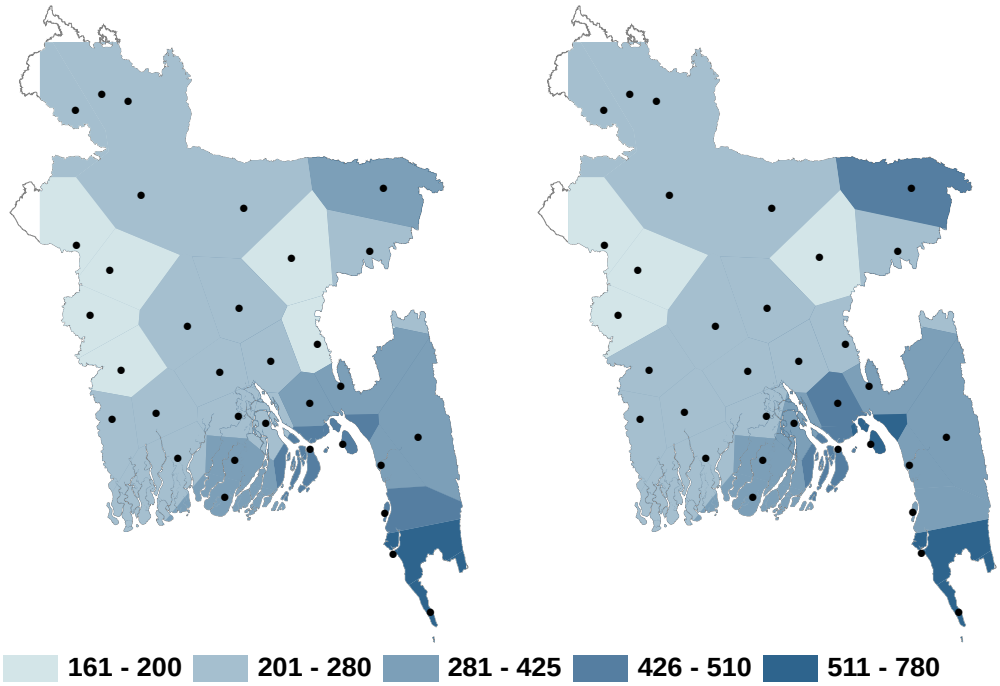
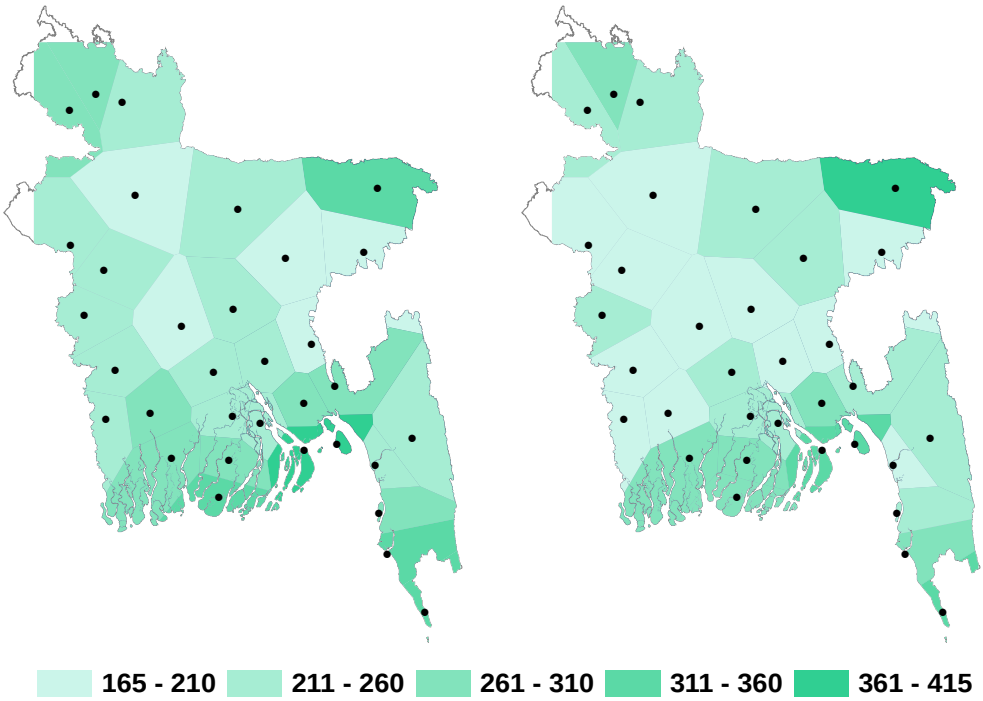


August, 12 year August, 58 year



September, 12 year September, 58 year

Figure 5.6: Comparison of contribution of Rainfall for Crop water requirement (Rainfall×100/ETc) for Aman

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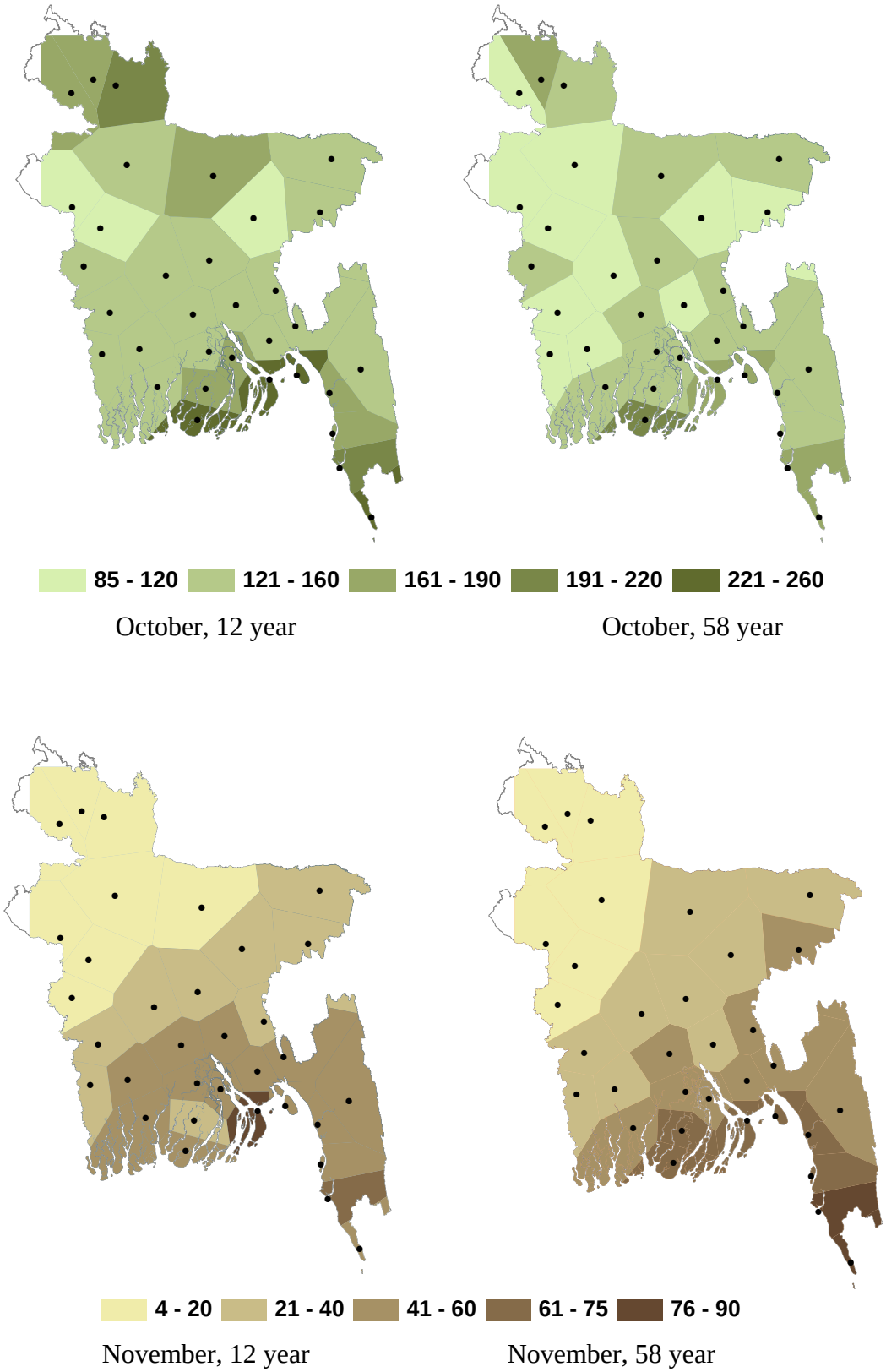

Figure 5.6: Comparison of contribution of Rainfall for Crop water requirement (Rainfall×100/ETc) for Aman

The comparative contribution of rainwater in meeting Crop water requirement for Aus over its cropping period (March to July) considering long term rainfall data (1950 to 2007) is shown in Appendix D.1. After making normalization of changes in contribution (change in contribution of rainfall from recent 12 years to past 58 years×100/contribution over 58 years) it was observed that in March, there is increase in contribution of rainfall in NW region by 1% (Rangpur) to 26% (Bogra) with exception of Dinajpur (26% decrease), by 3% (Mymensingh) to 19% (Dhaka) in NC region, by 13% (Sylhet) to 15% (Srimangal) in NE region, by 11% (Jessore) to 40% (Khulna) in SW region, by 19% (Patuakhali) to 51% (Bhola) in SC region with exception of Khepupara (21% decrease), Faridpur (5% decrease), by 15% (Maijdee court) to 38% (Comilla) in SE region with exception of Chandpur (5% decrease). During the same period, contribution of rainfall has decreased by 10% (Cox's Bazar) to 38% (Kutubdia) in EH region with exception of Rangamati (59% increase) and by 60% (Hatiya) in RE region with exception of Sandwip (8% increase).

In April, there is increase in contribution of rainfall in NW region by 57% (Dinajpur) to 87% (Bogra) with exception of Rajshahi (13% decrease), Ishurdi (1% decrease), by 5% (Dhaka) to 58% (Mymensingh) in NC region with exception of Tangail (4% decrease), by 10% (Sylhet) to 11% (Srimangal) in NE region, by 3% (Jessore) to 29% (Satkhira) in SW region with exception of Khulna (8% decrease). During the same period, contribution of rainfall has decreased by 7% (Bhola) to 12% (Faridpur) in SC region with exception of Barisal (5% increase), by 1% (Comilla) to 31% (Chandpur) in SE region, by 3% (Kutubdia) to 31% (Teknf) in EH region with exception of Chittagong (5% increase) and by 23% (Hatiya) to 38% (Sandwip) in RE region.

In May, there is increase in contribution of rainfall by 3% (Bogra) to 19% (Dinajpur) in NW region with exception of Ishurdi (10% decrease), by 3% (Dhaka and Mymensingh) in NC region with exception of Tangail (6% decrease), by 3% (Sylhet) to 21% (Srimangal) in NE region, by 3% (Khulna) to 23% (Satkhira) in SW region, by 2% (Chandpur) to 15% (Maijdee court) in SE region with exception of Feni (4% decrease), by 30% (Kutubdia) to 45% (Cox's Bazar) in EH region, by 32% (Htiya) to 53% (Sandwip) in RE region. During the same period, contribution of rainfall has decreased by 4% (Bhola) to 8% (Faridpur) in SC region with exception of Khepupara (13% increase).

In June, there is increase in contribution of rainfall by 5% (Bogra) to 23% (Dinajpur) in NW region with exception of Ishurdi (6% decrease), Rajshahi (2% decrease), by 1% (Jessore) to 3% (Satkhira) in SW region with exception of Khulna (5% decrease), by 1% (Bhola) to 5% (Patuakhali) in SC region with exception of Faridpur (11% decrease), Barisal (7% decrease), by 16% (Sandwip) to 28% (Htiya) in RE region. During the same period, contribution of rainfall has decreased by 4% (Tangail) to 5% (Dhaka) in NC region, by 1% (Srimangal) to 3% (Sylhet) in NE region, by 2% (Maijdee court) to 3% (Chandpur and Comilla) in SE region with exception of Feni (5% increase), by 3% (Cox's Bazar) to 5% (Chittagong) in EH region with exception of Rangamati (16% increase).

In July, there is increase in contribution of rainfall by 7% (Mymensingh) to 10% (Dhaka) in NC region with exception of Tangail (1% decrease), by 26% (Srimangal) in NE region with an exception of Sylhet (1% decrease), by 11% (Satkhira) to 26% (Jessore) in SW region, by 8% (Bhola) to 14% (Khepupara) in SC region with exception of Barisal (1% decrease), by 6% (Comilla) to 11% (Chandpur) in SE region with exception of Maijdee court (8% decrease), by 1% (Chittagong) to 12% (Teknaf) in EH region and by 16% (Sandwip) to 21% (Htiya) in RE region. During the same period, contribution of rainfall has decreased by 1% (Ishurdi) to 2% (Bogra and Rajshahi) in NW region with exception of Rangpur (4% increase), Dinajpur (3% increase).

GIS maps have also been developed to show comparative differences of contribution of rainwater for Aus from recent 12 years to past 58 years (Appendix E.1).

Comparative contribution of rainwater in meeting Crop water requirement for Wheat over its cropping period (November to March) considering long term rainfall data (1950 to 2007) is shown in Appendix D.2. After making normalization of changes in contribution it was observed that in November, there is increase in contribution of rainfall by 17% (Satkhira) to 33% (Khulna) in SW region. During the same period, contribution of rainfall has decreased by 5% (Dinajpur) to 57% (Rangpur) in NW region, by 7% (Mymensingh) to 11% (Dhaka) in NC region, by 44% (Srimangal) in NE region with exception of Sylhet (20% increase), by 7% (Bhola) to 41% (Patuakhali) in SC region with exception of Faridpur (5% increase), by 7% (Feni) to 31% (Comilla) in SE region with exception of Chandpur (7% increase), by 13% (Rangamati) to 37%

(Kutubdia) in EH region and by 33% (Sandwip) in RE region with exception of Htiya (18% increase).

In December, there is increase in contribution of rainfall by 10% (Teknaf) to 67% (Chittagong) in EH region. During the same period, contribution of rainfall has decreased by 49% (Bogra) to 72% (Ishurdi and Rajshahi) in NW region with exception of Dinajpur (16% increase), by 24% (Mymensingh) to 65% (Tangail) in NC region, by 45% (Sylhet) in NE region with exception of Srimangal (22% increase), by 21% (Khulna) to 59% (Jessore) in SW region, by 10% (Khepupara) to 72% (Patuakhali) in SC region, by 4% (Feni) to 22% (Maijdee court) in SE region and by 56% (Sandwip) in RE region with exception of Htiya (14% increase).

In January, there is 4% (Dhaka) to 18% (Tangail) increase in contribution of rainfall in NC region with exception of Mymensingh (62% decrease), by 8% (Jessore) to 21% (Satkhira) increase in SW region with exception of Khulna (4% decrease), by 44% (Faridpur) to 78% (Barisal) increase in SC region with exception of Patuakhali (1% decrease), by 21% (Chandpur) to 48% (Comilla) increase in SE region with exception of Maijdee court (14% decrease) and by 42% (Hatiya) to 92% (Sandwip) increase in RE region. During the same period, contribution of rainfall has decreased by 31% (Rangpur) to 46% (Rajshahi) in NW region, by 15% (Srimangal) to 45% (Sylhet) in NE region, by 38% (Cox's Bazar) to 68% (Teknaf) in EH region with exception of Rangamati (64% increase) and Chittagong (22% increase).

In February, there is 8% (Rangpur) to 99% (Dinajpur) increase in contribution of rainfall in NW region with exception of Rajshahi (8% decrease), Ishurdi (2% decrease). During the same period, contribution of rainfall has decreased by 17% (Mymensingh) to 42% (Dhaka) in NC region, by 8% (Srimangal) to 17% (Sylhet) in NE region, by 1% (Khulna) to 27% (Jessore) in SW region with exception of Satkhira (9% increase), by 8% (Khepupara) to 33% (Bhola) in SC region with exception of Faridpur (16% increase), by 16% (Maijdee court) to 59% (Feni) in SE region with exception of Chandpur (5% increase), by 4% (Teknaf) to 28% (Kutubdia) in EH region with exception of Chittagong (53% increase), Cox's Bazar (16% increase) and by 10% (Sandwip) to 12% (Htiya) decrease in RE region.

In March, there is increase in contribution of rainfall in NW region by 1% (Rangpur) to 26% (Bogra) with exception of Dinajpur (26% decrease), by 3% (Mymensingh) to 19% (Dhaka) in NC region, by 13% (Sylhet) to 15% (Srimangal) in NE region, by 11% (Jessore) to 40% (Khulna) in SW region, by 19% (Patuakhali) to 51% (Bhola) in SC region with exception of Khepupara (21% decrease), Faridpur (5% decrease), by 15% (Maijdee court) to 38% (Comilla) in SE region with exception of Chandpur (5% decrease). During the same period, contribution of rainfall has decreased by 10% (Cox's Bazar) to 38% (Kutubdia) in EH region with exception of Rangamati (59% increase) and by 60% (Hatiya) in RE region with exception of Sandwip (8% increase).

GIS maps have also been developed to show comparative differences of contribution of rainwater for Wheat from recent 12 years and past 58 years (Appendix E.2).

CHAPTER 6
POTENTIAL OF RAINWATER TO MITIGATE WATER SCARCITY PROBLEMS

6.1 General

In this chapter water scarcity due to ground water depletion has been analyzed considering ground water level data of consecutive five years (1998 to 2002) over Bangladesh. Areas of the country having water scarcity problem due to arsenic and iron contamination with ground water has been identified. Water availability problem due to salinity intrusion in coastal areas of the country has been discussed. Finally the potential of rainwater harvesting in eight hydrological regions of Bangladesh has been analyzed considering water scarcity problems.

6.2 Water scarcity due to ground water depletion

Groundwater level maps have been analyzed to assess its availability during different cropping periods in Figure 6.1. A total of 5.92% area of Bangladesh show ground water depletion (GW level below 7 meter) during Kharif I period (March to July), 4.69% area is affected in Rabi season (November to April) and 1.38% area during Kharif II period (July to December).

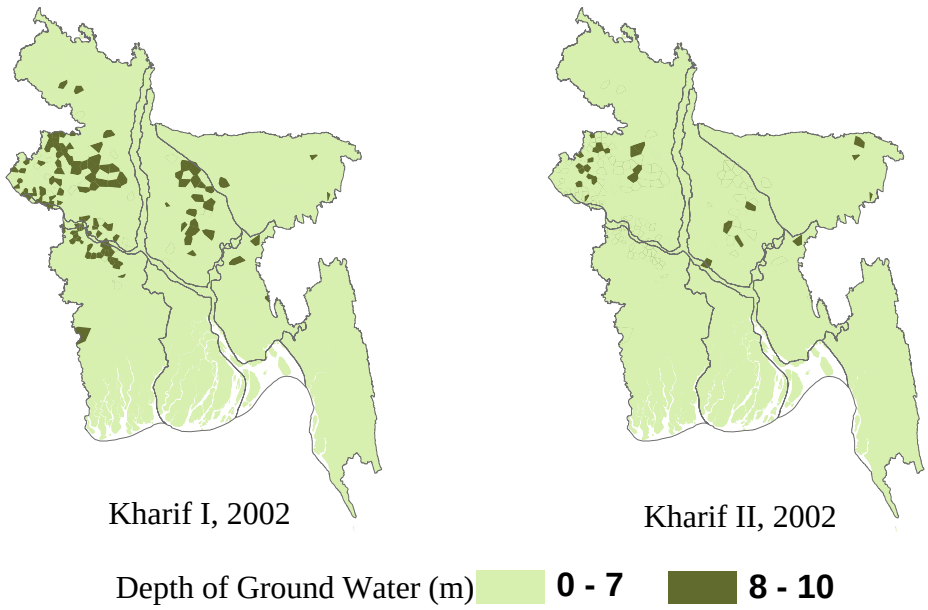

Figure 6.1: Ground water level for three cropping periods during 2002

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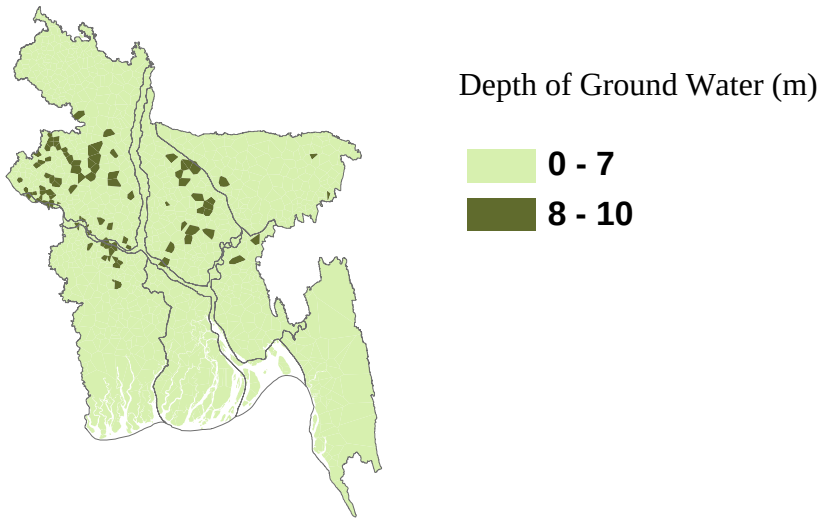


Rabi, 2002

Figure 6.1: Ground water level for three cropping periods during 2002

In Kharif I period 14.4% area of NW region, 12.1% area of NC region and 5.1% in SW region show ground water level equal or below 7 m in 2002, whereas in Rabi period ground water level is equal or below 7 m in 11.4% area of NW region, 11.7% area of NC region and 2.7% area of SW region. During Kharif II period ground water level is equal or below 7 m in 3.7% area of NW region, 2.8% area of NC region and 1.1% area of SW region.

Among the three distinct cropping periods, Kharif I shows severe condition of ground water level. Figure 6.2 shows the depth of groundwater level during Kharif I period for consecutive five years (1998 to 2002). The Figures indicating the depth of ground water level during periods of Kharif II and Rabi have been shown in Appndix F.1 and Appendix F.2 respectively. As shown in Table 6.1, a total of 11.3% area of Bangladesh is affected due to ground water level depletion (>=7 m) in 2002. Dhaka city shows the most severe condition for groundwater (in 1998 up to 34 m and in 2002 up to 53 m) which is due to extensive extraction to meet the water demand of high population.

So more difficulty in extracting ground water is faced during Kharif I period, which may affect irrigation for Boro during March to May. During Rabi period irrigation for Boro and Wheat can be affected for difficulty with extraction of ground water.

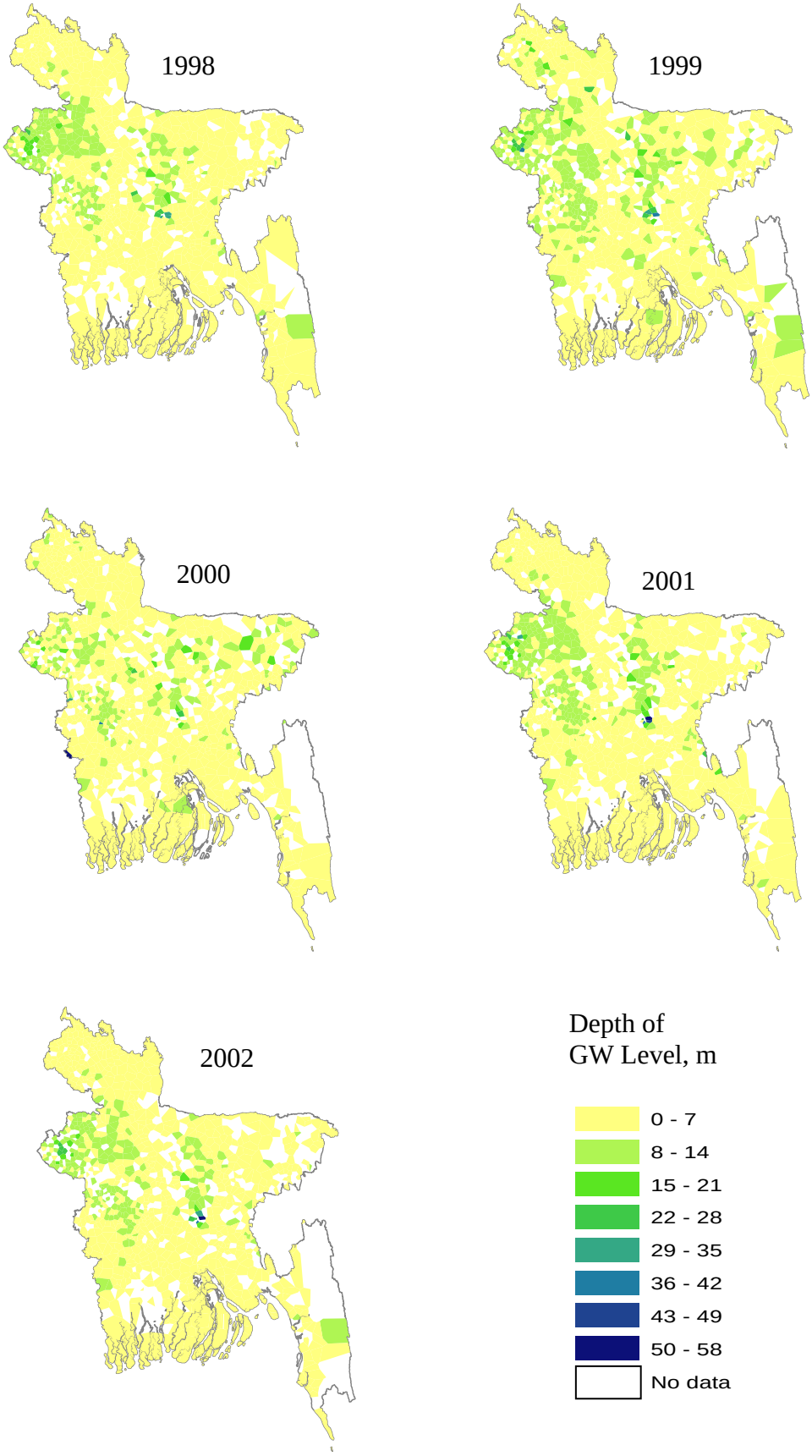
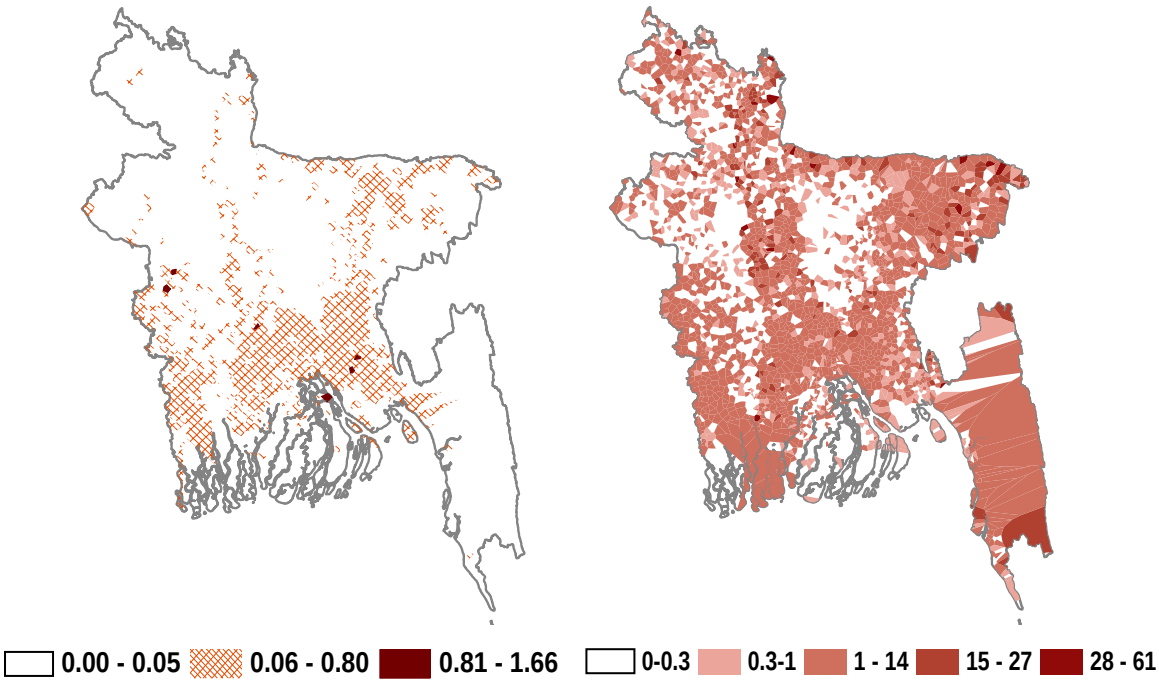


Figure 6.2: Ground water level in Kharif I Period for consecutive five years

6.3 Water scarcity due to contamination of Arsenic and Iron with ground water



Arsenic concentration, (mg/liter)

Iron concentration, mg/liter

Figure 6.3: Arsenic and Iron concentration of ground water in Bangladesh
(Data obtained from Bangldesh Country Almanac, 2002)

Figure 6.3 shows Arsenic (As.) and Iron (Fe) affected areas of Bangladesh. Point data of tubewells having arsenic and iron concentration over the country has been obtained from Bangladesh Country Almanac (2002). Significant Arsenic contamination, exceeding Bangladesh standards (0.05 mg/liter) is observed in SE (69% area), SW (38% area), SC (26% area), NE (25% area) and NC (18% area) regions. Some areas of NW (6% area) region also show existence of Arsenic. Overall 21.2% area of Bangladesh is affected by As. (Table 6.1).

Significant Iron contamination, exceeding 1 mg/liter is observed in SE (87% area), RE (85% area), EH (81% area), NE (73% area), and SW (66% area), NC (51% area), SC (45% area) and NW (39% area) regions. Overall 55% area of Bangladesh is affected by Iron (Table 6.1).

6.4 Water scarcity due to salinity problem in Coastal areas of Bangladesh

Salinity prone areas of Bangladesh have been shown in Figure 6.4. The map is developed using salinity information from Bangladesh Country Almanac (2002). The figure shows that most of the areas of the SC (70% area) and SW (55% area) regions suffer due to salinity problem. Some of the coastal areas of the EH (6% area) region and RE region also show salinity problem. Salinity has been detected in 16.85% area of Bangladesh (Table 6.1).

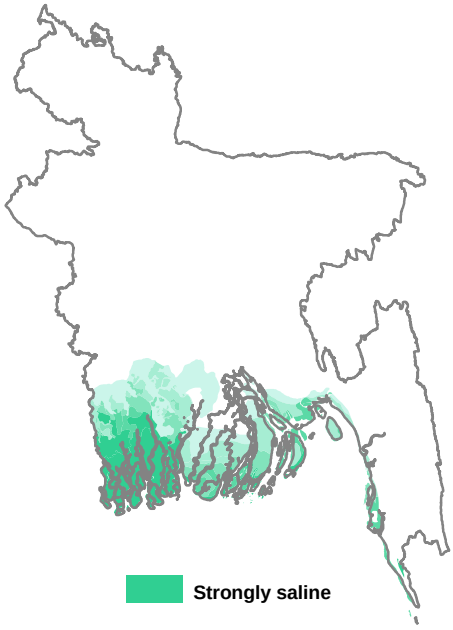


Figure 6.4: Salinity prone areas in Bangladesh
(Data obtained from Bangldesh Country Almanac, 2002)

Table 6.1: Comparison of areas under As., Iron, salinity and ground water problems along with cropping areas in Bangladesh

Criteria regarding water availability problem	Arsenic (>=0.05mg/L)	Iron (>=1mg/L)	Salinity (detected)	Ground Water Depth(>=7m) 2002		
				Kharif I	Kharif II	Rabi
% Area of Bangladesh	21.2	55	16.85	11.3	4.26	4.72

6.5 Mitigation of Water scarcity through Rainwater harvesting

Table 6.2 shows different problems related to water availability for eight hydrological regions of Bangladesh. From the table it can be found that in NW region ground water depletion in different cropping periods especially in Kharif I and Rabi is the main problem. Iron concentration also exceeds the tolerable limit in some places of the region. Arsenic problem is relatively low in this region.

In NC region ground water depletion, iron and arsenic contamination have been experienced. In NE region Iron and arsenic contamination are found to be the main problems. In SW region iron and arsenic contamination are experienced. There are also ground water depletion and salinity problem in this region. In SC region mainly salinity problem associated with iron and arsenic problems are found. In SE region iron and arsenic contamination are found to be main problems. In EH and RE regions iron contamination is detected as the main water related problem. Figure 6.5 shows Arsenic, Iron and Salinity prone areas in eight hydrological regions of Bangladesh.

Table 6.2: Comparison of areas under As., Iron, salinity and ground water problems along with cropping areas for eight regions of Bangladesh

Criteria regarding water availability problem	% area with Ground water depletion (>= 7 m) in 2002			% area with Arsenic (>= 0.05 mg/l)	% area with Iron (>= 1 mg/l)	% area with Salinity (Detected)
Regions	**Karif I** Mar-Jul	**Karif II** Jul-Dec	**Rabi** Nov-Apr			
NW	14	4	11	6	39	-
NC	12	3	12	18	51	-
NE	-	-	-	25	73	-
SW	5	1	3	38	66	55
SC	-	-	-	26	45	70
SE	-	-	-	69	87	-
EH	-	-	-	-	81	6
RE	-	-	-	-	85	-

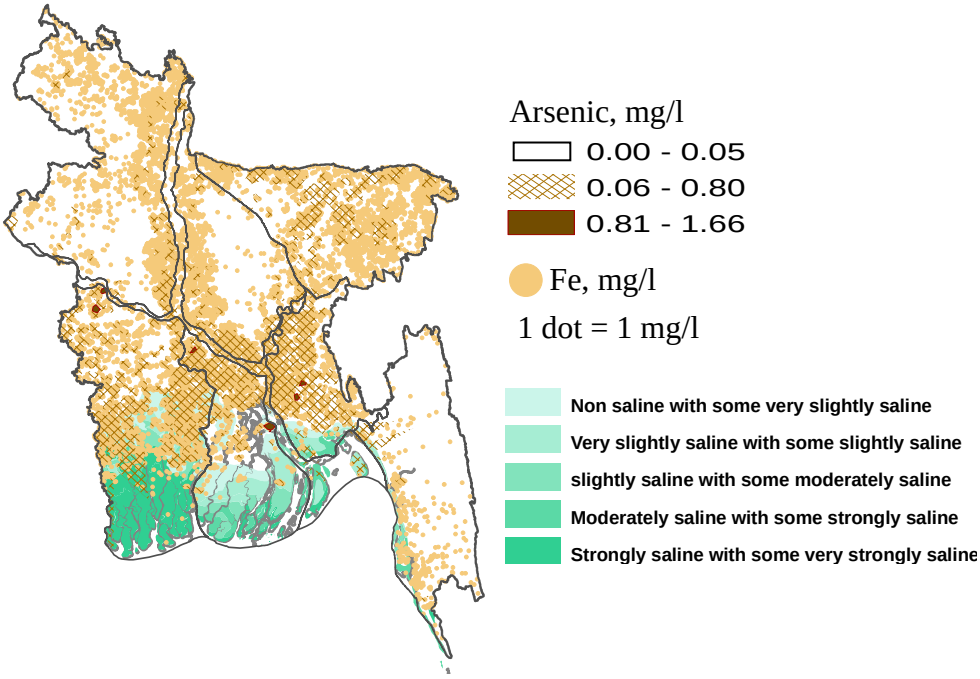


Figure 6.5: Arsenic, Iron and Salinity prone areas in eight Hydrological regions of Bangladesh.

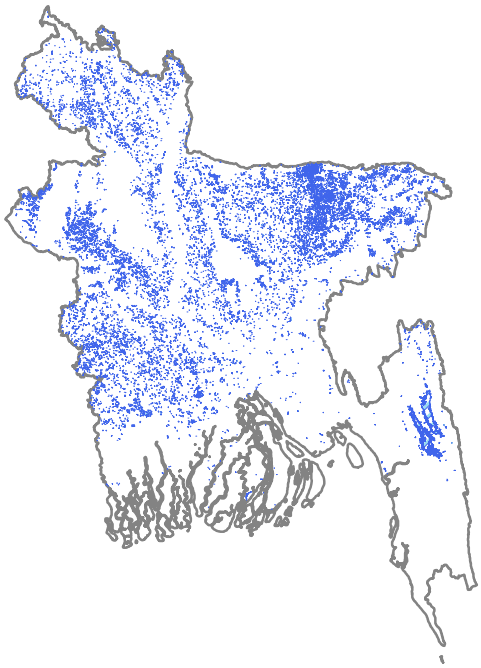


Figure 6.6: Surface water bodies of Bangladesh.

Figure 6.6 shows surface water bodies in Bangladesh. Only 1.33% area of Bangladesh is occupied by surface water bodies except the river surfaces.

In the coastal areas of SW and SC regions where salinity is very high and ground water is polluted by As., the option for surface water is not available either because of the scarcity of surface water bodies in those areas. As already mentioned in these areas there is increase in rainfall during the recent past, RWH remains as the only source of water for drinking and irrigation purposes. NE region also shows As. contamination and this region show high rainfall in recent years. In NW region ground water remains in a very low level, so RWH can be used as an adaptive option for source of water.

CHAPTER 7

POTENTIAL OF RAINWATER HARVESTING IN DHAKA CITY

7.1 General

This chapter aims to find out the potential of rainwater harvesting in an urban area. For this analysis Dhaka city has been considered. Considering water demand of Dhaka city and present water supply status, long term rainfall analysis and contribution of rainwater in meeting water demand of Dhaka city have been analyzed in this chapter. Finally form roof size distribution of different wards of Dhaka city, a method has been presented to identify the potential areas where RWH can be adopted for partially meeting the water demand.

7.2 Population density and respective water demand of Dhaka city

Dhaka, the capital of Bangladesh is one of the most populated cities in the world with a population of 10 million in an area of 1528 sq. km. (Rajuk, 2004). Many people from the whole country are forced to move from rural areas to the urban areas due to natural disasters like river erosion, cyclone and dry spells. For massive migration of people towards urban areas, population density in Dhaka city is increasing day by day, thereby putting enormous pressures on urban infrastructure, economy and service delivery systems of the city.

A comparison of urban population density of Bangladesh between 1991 and 2004 is shown in Figure 7.1. From this figure it can be observed that even though population density is very high in Dhaka City Corporation, growth rate is highest in Dhaka Mega city (12.4%) compared to Dhaka City Corporation (4.1%) and for the whole country (3.0%). In 2007 Dhaka was ranked as the 11th most populous city in the world (World Bank, 2007).

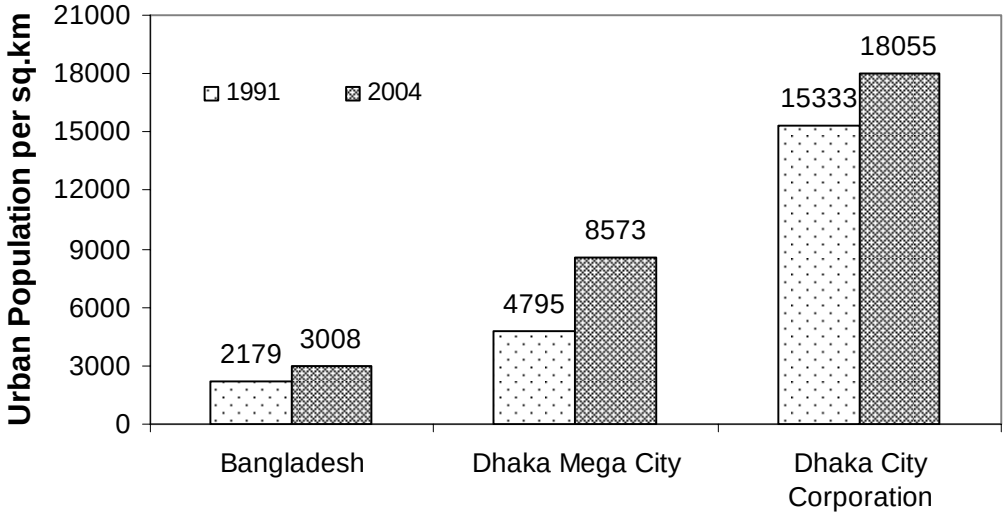


Figure 7.1: Urban population density of Bangladesh

About 198 crore liters of water was required daily for more than ten million people of Dhaka city during 2007, while Dhaka WASA supplied 166 crore liters per day (CLD) in that year, of which 139 crore liters came from underground source through 465 deep tubewells and 27 crore liters using surface water. There was water deficit of 32 CLD during 2007 (DWASA, 2010). Deficit in water supply causes frequent sufferings to the city dwellers. Contribution of different sources of water Supply of Dhaka city during 2007 is shown with their relative amount in a pie chart of Figure 7.2. The Figure shows that 70% of water demand is met up through ground water extraction and 13% from surface water treatment. Water deficit is found to be 16% of the total water demand. Water of the rivers around the city is heavily polluted and is not in general suitable for treatment. So, City water supply needs to be augmented in order to fill in the deficit, as well as to meet the increased demand in the future.

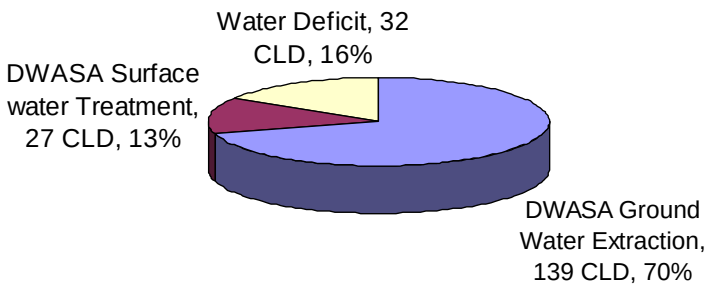


Figure 7.2: Water Supply in Dhaka City

(Data obtained from Dhaka WASA, 2010)

As shown in Figure 7.3 there is a decreasing trend in water deficit between years 1995 to 2007 (DWASA, 2010) but it is creating immense pressure on ground water, which is not an unlimited resource.

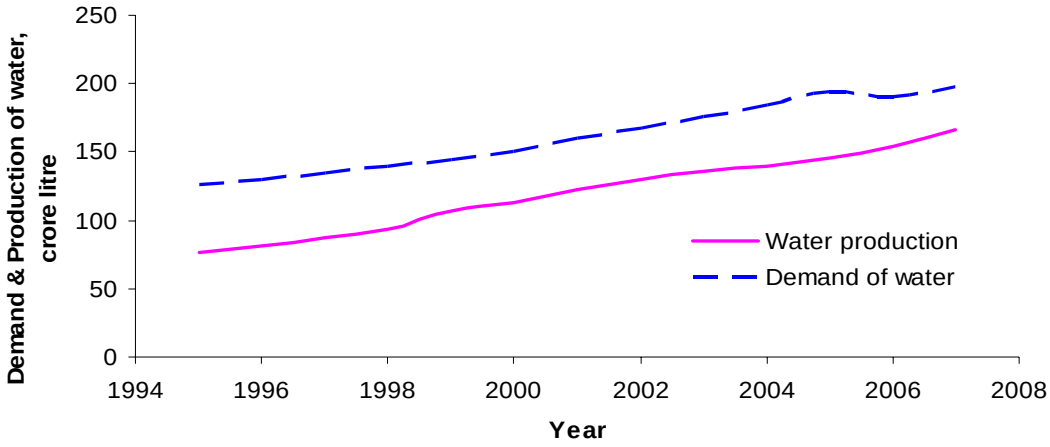


Figure 7.3: Water demand and production in Dhaka City

(Data obtained from Dhaka WASA, 2010)

Continuous lowering of groundwater table day by day can cause geological imbalance. For water availability bore-wells in the city have to go deeper and deeper. Current annual withdrawal of groundwater in the city is in excess of annual recharge of the aquifers. Withdrawal rate in the city should be, in fact, reduced to prevent further lowering of the water table. So, new sources for additional water need to be identified and there is an urgent need to find ways of saving, reusing and recycling water.

7.3 Rainfall analysis of Dhaka city considering long term rainfall data

To evaluate the potential of rainwater harvesting (RWH) in Dhaka city in terms of quantity of rainfall, variation of annual rainfall during the last 55 years (1953-2007) has been analyzed, as shown in Figure 7.4 (The data source is Bangladesh Meteorological Department). From the figure it clearly appears that there is an increasing tendency in annual rainfall at Dhaka. Interestingly, except during 2007, rainfall is not significantly high during the high flood years of 1987, 1988, 1998 and 2004. Average rainfall of these 55 years is found to be 2073 mm.

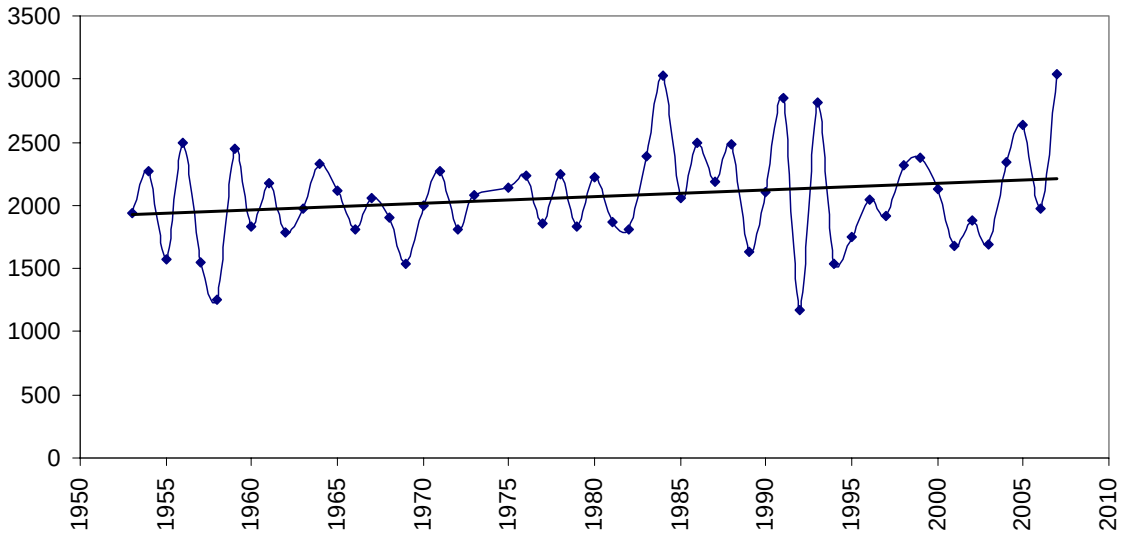


Figure 7.4: Variation of annual rainfall (mm) during 55 years (1953-2007) in Dhaka city

Figure 7.5 shows cumulative of annual rainfall considering 55 year duration (1953-2007) for Dhaka city. In the same figure cumulative of average annual rainfall (2073 mm) over this time period is also plotted through dotted line. It can be noticed from this figure that cumulative of average annual rainfall is relatively higher than the cumulative of annual rainfall during late 50s to middle of 80s and after that cumulative of annual rainfall maintains relatively steeper slope. Thus difference between the cumulative of annual rainfall with cumulative of average annual rainfall becomes less, which indicates that there is relatively higher annual rainfall during the recent decades (80s, 90s and 2000 to 2007) than the previous decades (50s, 60s and 70s). Figure 7.6 represents the variation of 5 year (moving) average annual rainfall considering 55 year duration (1953-2007) for the city. In this figure 55 year average annual rainfall as well as the variation of annual rainfall over this period has also been shown. From this figure it has been found that from 1980 to 2005, five year (moving) average annual rainfall is higher than 55 year average annual rainfall during 62% of the years, whereas from 1953 to 1979 only 15% of the years show higher 5 year (moving) average annual rainfall than 55 year average. It is also evident from this figure that there is an increasing trend of 5 year (moving) average rainfall during this period for Dhaka city.

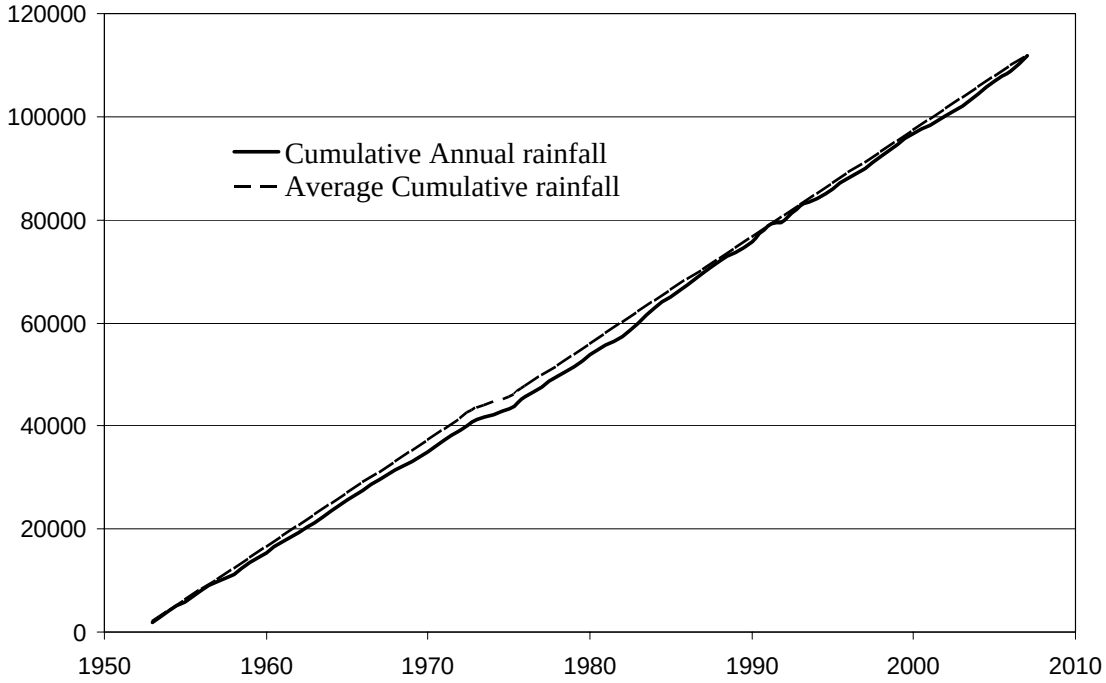


Figure 7.5: Cumulative Annual rainfall (mm) considering 55 year duration (1953-2007) for Dhaka city

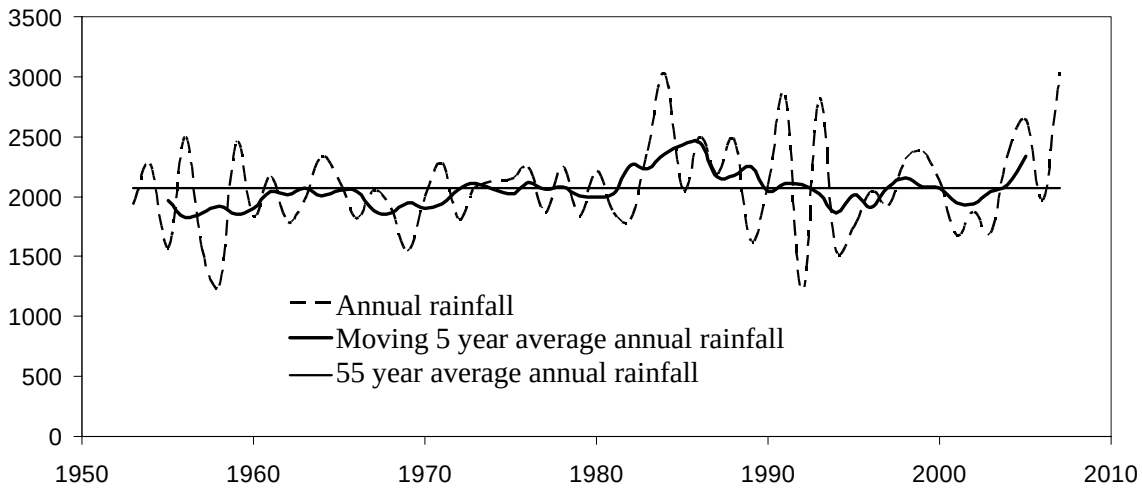


Figure 7.6: Variation of Moving 5 year Average Annual Rainfall (mm) considering 55 year duration (1953-2007) for Dhaka city

Figure 7.7, Figure 7.8 and Figure 7.9 represent the variation of 5 year (moving) average monthly rainfall during March, May and September, respectively considering 55 year duration (1953-2007) for Dhaka city. In these figures 55 year average monthly rainfall as well as the variation of monthly rainfall over this period have also been shown.

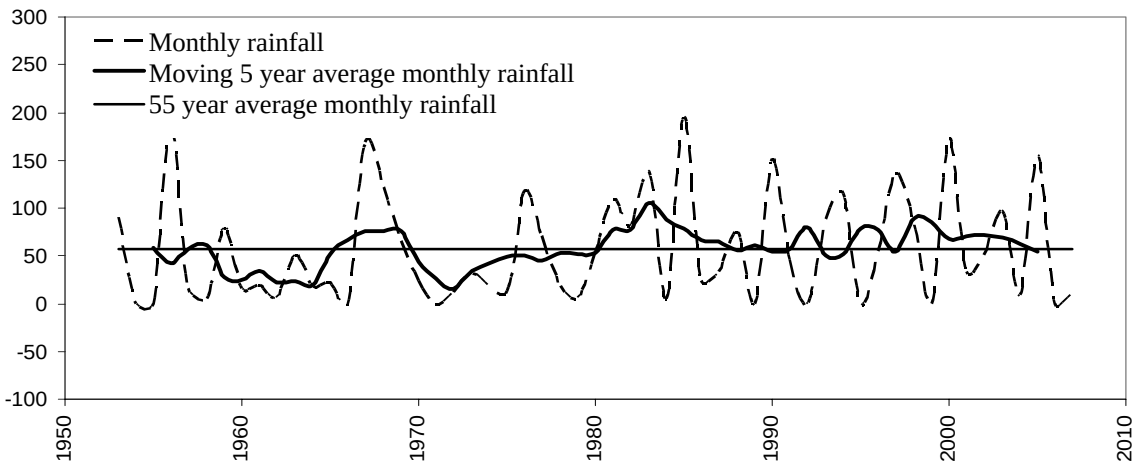


Figure 7.7: Variation of Moving 5 year Average Rainfall (mm) during March considering 55 year duration (1953-2007) for Dhaka city

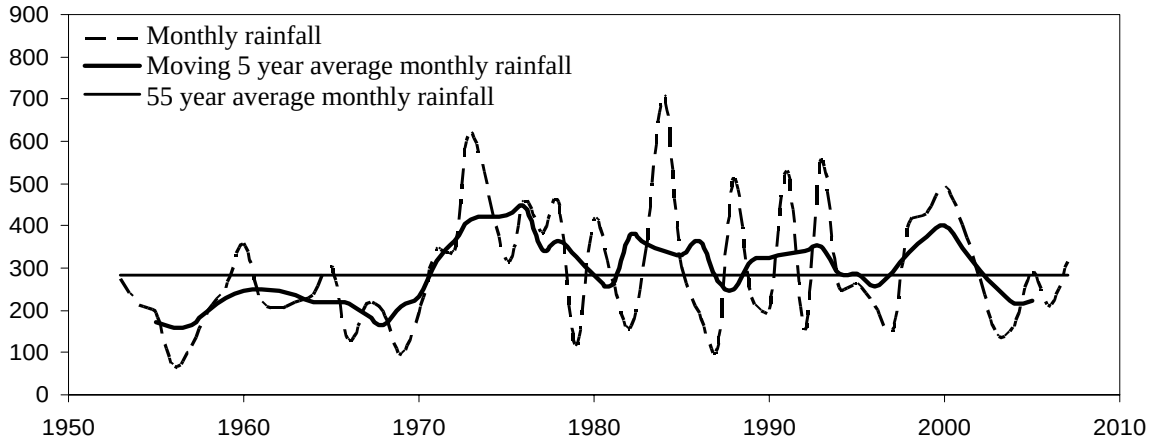


Figure 7.8: Variation of Moving 5 year Average Rainfall (mm) during May considering 55 year duration (1953-2007) for Dhaka city

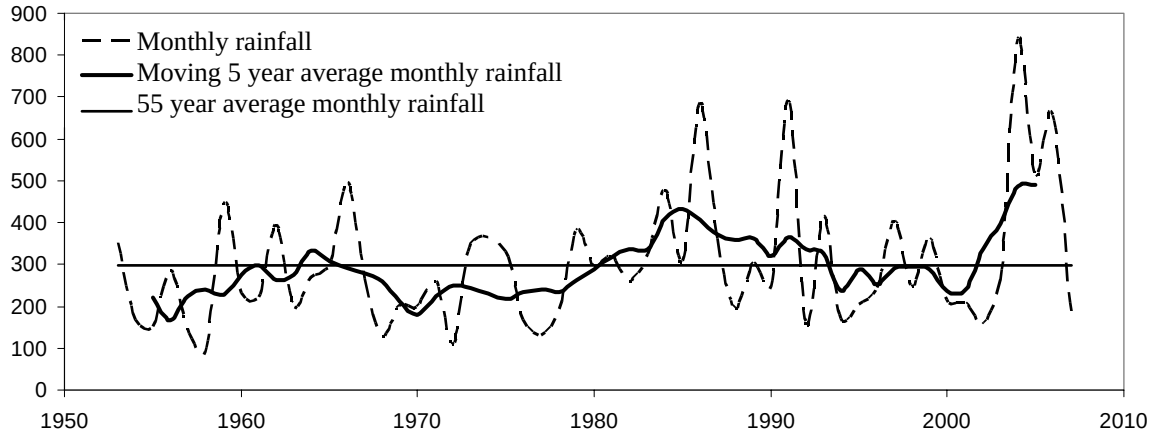


Figure 7.9: Variation of Moving 5 year Average Rainfall (mm) during September considering 55 year duration (1953-2007) for Dhaka city

Again from Figures 7.7, 7.8 and 7.9, it has been found that from 1980 to 2005, five year (moving) average monthly rainfall is higher than 55 year average monthly rainfall in 73% of the years during March, 69% of the years during May and 65% of the years during September, whereas from 1953 to 1979, higher five year (moving) average monthly rainfall respective to 55 year average has been observed in 27% of the years during March, 31% of the years during May and 8% of the years during September. It is also evident from these figures that there is an increasing trend of 5 year (moving) average monthly rainfall for these three months (March, May and September) during this period for Dhaka city.

Decadal average rainfall of Dhaka city has been shown considering rainfall data of 55 years in Figure 7.10 for 5 consecutive decades (50s, 60s, 70, 80s and 90s) and for the period of 2000 to 2007. Average rainfall of these 55 years is 2073 mm. This Figure shows that there is an increasing trend of rainfall in Dhaka city showing the highest value of 2215 mm for decade 80.

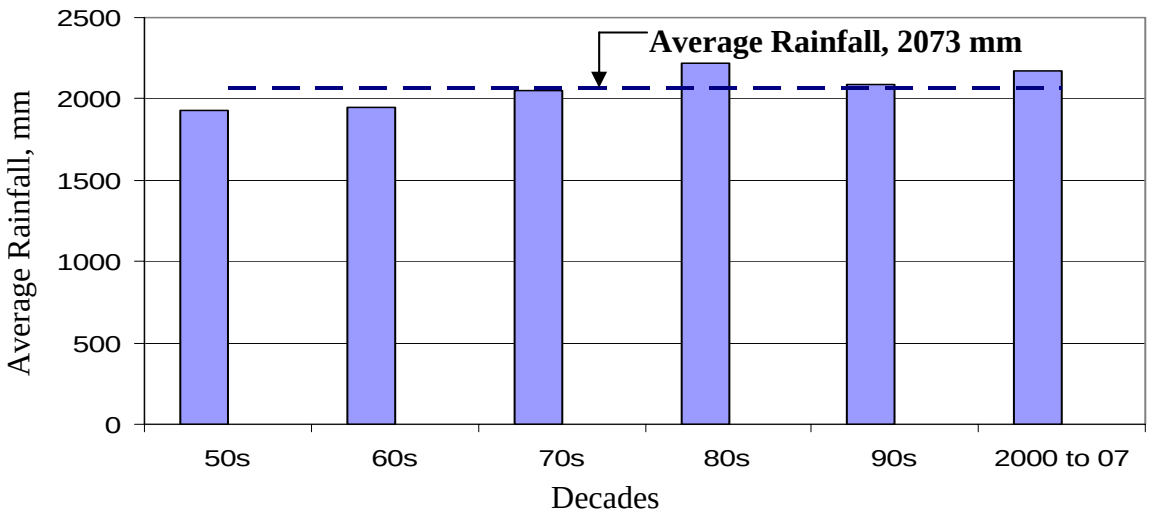


Figure 7.10: Decadal Average of Rainfall considering 55 year duration (1953-2007) for Dhaka city

Figure 7.11 shows the percentage of normalized change of decadal average rainfall of Dhaka city relative to the average rainfall for 55 years, which is illustrated in equation 3.4. It can be observed that there is an increasing trend of rainfall in the recent decades.

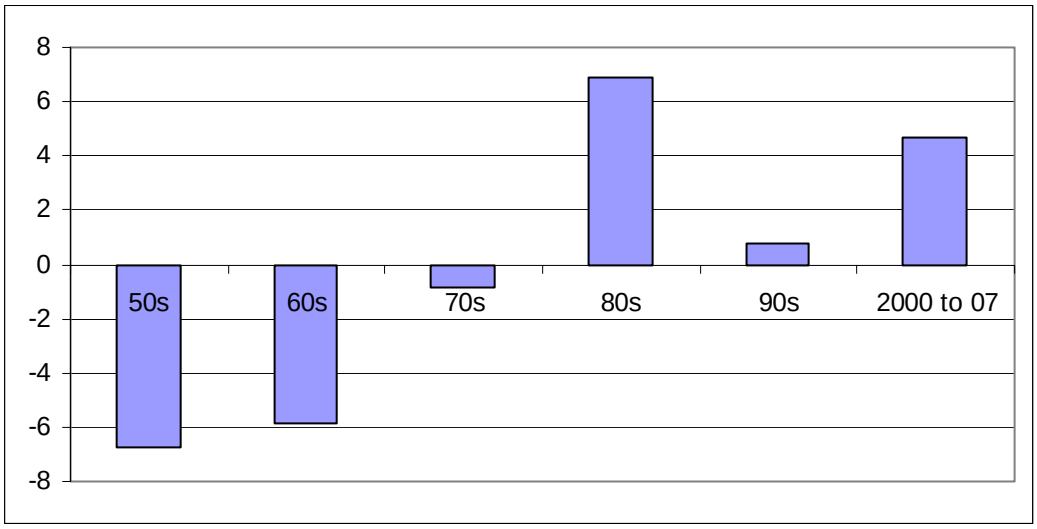


Figure 7.11: Percentage Normalized value of decadal Average Rainfall of Dhaka city

From Figure 7.12, the average annual rainfall of Dhaka city for twelve consecutive years (1996 to 2007) is found to be 2166 mm, which can be considered to be good enough for storing water for later use.

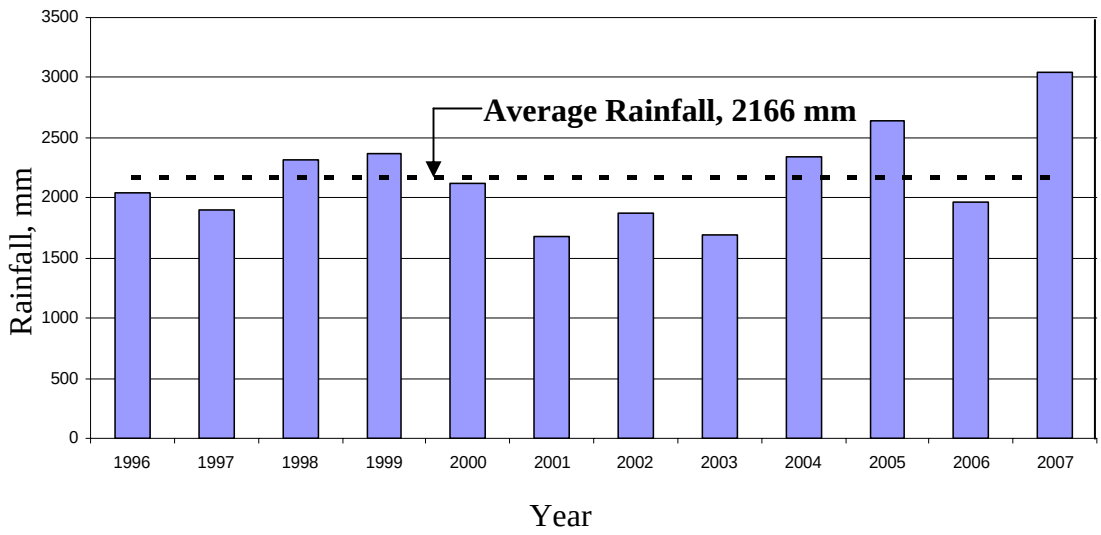


Figure 7.12: Variation of annual rainfall of 12 year (1996-2007) duration of Dhaka city

The monthly distribution of average rainfall of 12 years (1996-2007) in Dhaka city is shown in Figure 7.13. This Figure shows the highest rainfall of 408 mm for the month of July.

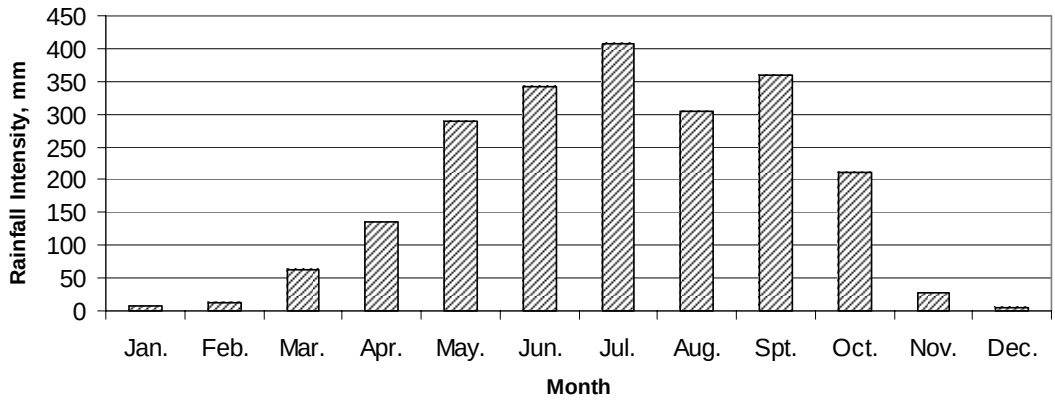


Figure 7.13: Monthly Distribution of average rainfall of 12 year (1996-2007) duration of Dhaka city

7.4 Contribution of rainwater in meeting water demand of Dhaka city

From the average monthly rainfall data of twelve consecutive years (1996 to 2007), a mass curve for Dhaka has been developed, as shown in Figure 7.14. Cumulative distribution showed that maximum excess water of 0.25 m^3 is available during October and maximum deficit occurs during the month of April, which is 0.38 m^3. Ahmed (1999) developed a mass curve for the whole country and it was found that maximum excess water was 0.24 m^3 in October and maximum deficit of water was 0.48 m^3 in April. For full utilization of rainwater potential, a storage tank of capacity 0.63 m^3 that is 39 per cent of the available rainwater is required for uninterrupted water supply at a constant rate throughout the year.

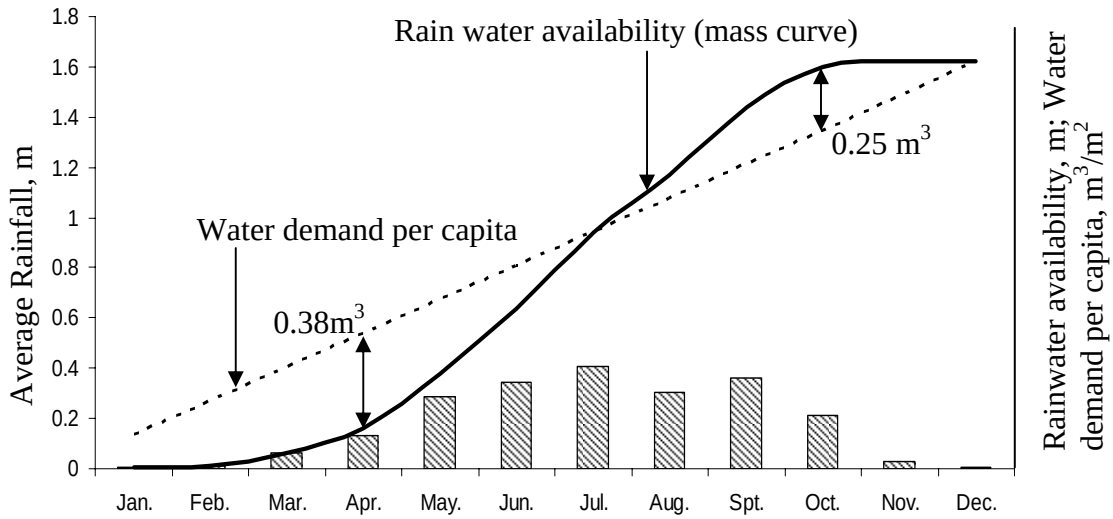


Figure 7.14: Monthly rainfall intensity, cumulative rainfall availability (mass curve) and Water demand per capita of Dhaka city

7.4.1 Analysis of water availability in urban context

A number of simplified analyses have been done to evaluate the water demand against the water availability of Dhaka city.

Gross area requirement for RWH in Dhaka

As the population of Dhaka city is 10 million, with a gross water demand of 180 lpcd, water requirement becomes 180000 m^3 per day and 65700000 m^3 per year. The calculated average annual rainfall of Dhaka is 2166 mm (1996 to 2007), and employing a moderate runoff coefficient of 25%, effective rainfall is found to be 1624.5 mm. Catchment area that would be needed to capture the required water is obtained as (65700000 /1.6245=) 40.44 km^2. As the area of Dhaka city is 1,529 sq. km., only 2.6% of the total area of the city is required as catchment area for adopting RWH system.

Individual harvesting system

An investigation, carried out in Bangladesh Agricultural University, Mymensingh, showed that about 160 thousand liters of water might be available from a roof area of 100 sqm, in an average year in Dhaka city (Khan, M.H, 2005). This is equivalent to the amount of water required by an 8-person family for about 130 days. In the present study, the percentage of water demand that can be met from rainwater considering a roof area of 100 sq.km. has been calculated. With 2166 mm of rainfall per annum, a building with a terrace of 100 sq meter area can harvest about 129960 liters of water at 60% efficiency (2.166×100×1000×0.6 liter). The loss of rain water may be due to evaporation from the rooftop and first flush which may be lost to the drainage system. This translates into water availability of about 356 liters per day (129960/365). With same water demand (180 lpcd) a family of 6 members will require 1080 liter (180×6) of water per day. This indicates that around 33% of the water demand can be met by RWH with individual harvesting system (356/1080×100).

Community based harvesting system

In a multistoried building with a terrace area of 500 square meters, the rainwater harvesting potential is 649800 liters per annum (2.166×500×1000×.6 liters) at 60% efficiency. Assuming that the building has 16 flats and considering same number of family members, per day availability of water per flat will be about 111 liters

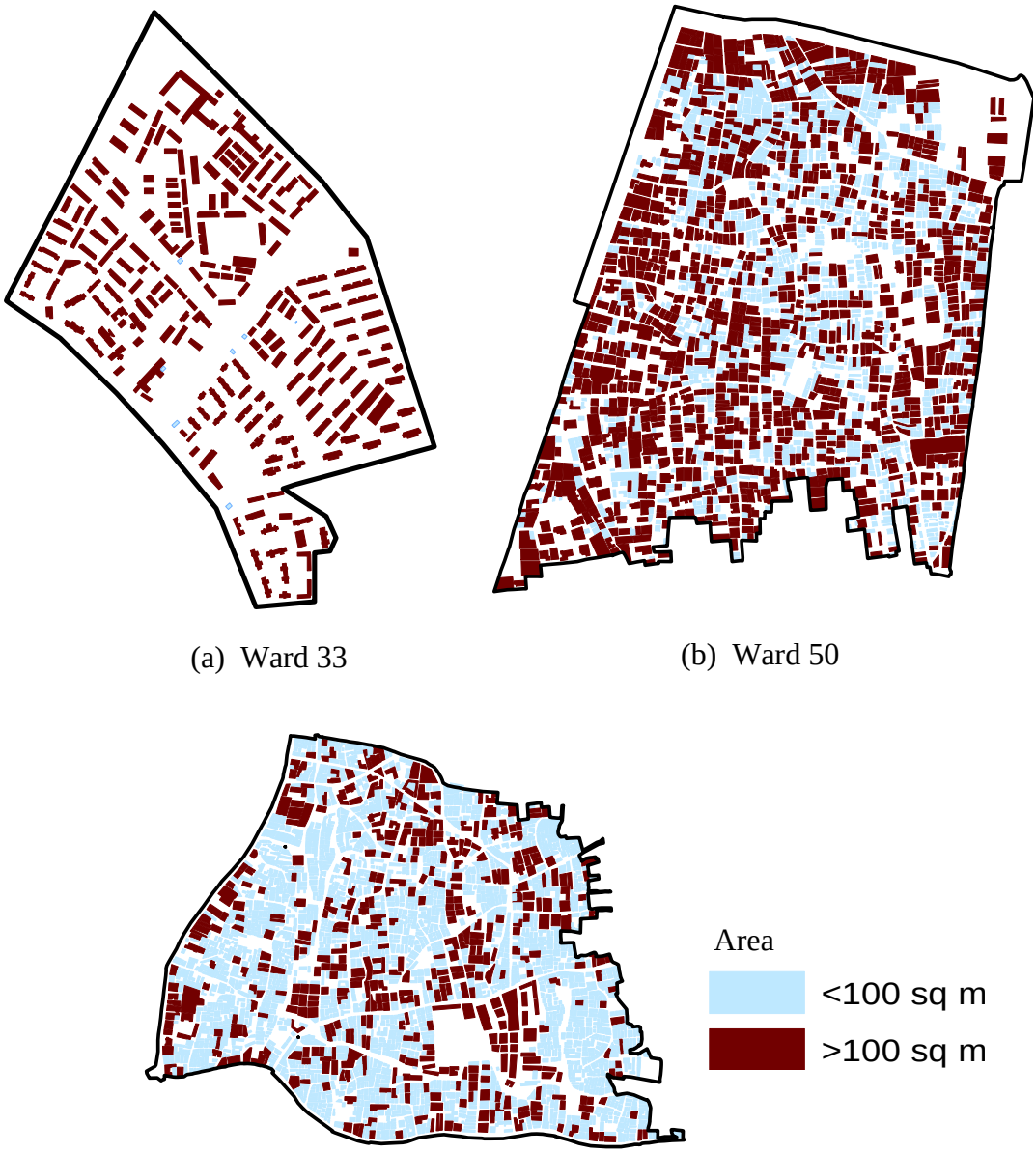
(649800/365/16). This would mean that rain water availability is 10% of the water demand (111/1080×100) through this system.

7.4.2 Analysis of roof size distribution of different wards of Dhaka city to provide catchment area for RWH

The Roof size distribution from building area of different wards of Dhaka city have been mapped using Arc GIS 9.2. The GIS data has been obtained from GSRC (Geographical Solutions Research Center), where data from only 29 wards are available out of 90 wards. Table 7.2 shows the Percent of buildings with roof size greater than 100 m^2 in 29 wards of Dhaka city. From information of 29 wards of Dhaka city, 97% buildings of ward 33 have more than 100 m^2 area (maximum), while ward 50 has 44% (average) and ward 69 has 14% (minimum). The GIS maps of these three wards are shown in Figure 7.15.

Table 7.1: Percent of buildings with roof size >100 m^2 in 29 wards of Dhaka city.

Zone	Ward number	Total no. of building	% of buildings with Area > 100 m^2
	74	2643	28.9
	67	1561	30.5
	68	1676	23.7
Zone 2	***69***	***3297***	***14.1***
	71	1533	21.1
	72	1195	27.2
	73	945	56.2
	78	1548	24.5
	79	2128	25.6
	49	2252	83.5
	50	***2549***	***43.5***
	52	1434	73.8
Zone 5	53	2062	72.8
	54	3258	37.5
	55	2778	44.5
	56	915	76.6
	22	4932	27.5
	23	2573	38.2
	24	2824	32.0
	26	2209	22.5
	28	2896	38.6
Zone 4	29	2438	38.8
	31	1222	45.9
	32	1546	50.9
	33	***236***	***96.6***
	34	1872	44.3
	35	2189	34.6
	36	1867	63.5
Zone 9	20	3161	40.0



(a) Ward 33

(b) Ward 50

(c) Ward 69

Figure 7.15: GIS maps of three wards of Dhaka city having roof area more than 100 sq. meters (a) ward 33 with 97%, (b) ward 50 with 44%, (c) ward 69 with 14% of the buildings

From Figure 7.15, it can be observed that ward 33 having 97% buildings with area greater than 100 m^2 may be suitable for providing enough catchment area in favor of adopting rainwater harvesting, whereas ward 69 having only 14% buildings with area greater than 100 m^2 may not be suitable for adopting rainwater harvesting. So these information of buildings with larger roof area along with population of the respective ward can be useful to plan RWH systems for different wards of Dhaka city.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

The overall objective of the present study was to substantiate rainwater harvesting as an alternate source of water for climate change adaptation. The followings are the major conclusions of the study:

1. Long term rainfall data has been analyzed to identify the changes in rainfall distribution in the country considering temporal as well as spatial distribution. It has been observed that average annual rainfall of total 58 years (1950-2007) is 2371 mm; while that of the recent 12 years (1996-2007) is 2505 mm.

   i) From the decadal average rainfall analysis for each of the months, it has been observed that during the months of January, February, November and December average rainfall for all of the decades is below 50 mm and during June and July more than 400 mm of average rainfall is observed in all of the decades. Again, during the recent three decades of 80s, 90s and 2000 to 2007, average rainfall in July is found to be higher than 500 mm.

   ii) Decadal average rainfall has been compared for each month at different stations within eight hydrological regions. Increasing trend of regional average decadal rainfall is evident in NW region for the months of April and September; in NE region during April and in SW region during September. Regional average rainfall during the recent three decades are higher than that of previous three decades as well as 58 year average in NW region during February and May, in NC region during September; in SW region during May; in SC region during July and in SE region during May.

   iii) The normalized changes of rainfall are categorized into five criteria through the comparison of average monthly rainfall in eight hydrological regions for recent 12 years relative to long term rainfall of 58 years.

2. Analysis on contribution of rainwater in meeting crop water requirement suggests that for Boro, rainwater contribution has increased significantly in SC and RE regions during January, SW region during March, NW and NC regions during April, EH and RE regions during May, and rainwater contribution has decreased significantly in NW and NE regions during January, NC and SE regions during February. For Aman, rainwater contribution has increased significantly in SW region during September, NW, EH and RE regions during October, and rainwater contribution has decreased significantly in NW, SC and EH regions during November. So, in general, for Boro, during the initial stage (January and February) rainwater contribution appears to be decreasing. For Aman, rainwater contribution is increasing during October but decreasing in November. This suggests that rainwater can be stored in october for irrigation in later months.

   i) For each month normalized change of rainfall resembles to the change of rainwater contribution in meeting crop water requirement during different months of cropping period for three varieties of rice and wheat.

   ii) From spatial variation of yield of three varieties of rice and wheat for eight hydrological regions as well as for the entire country, it has been observed that percentage of area with yield at least 2000 kg/Ha for Boro is relatively high in all of the regions and large area of NW region show higher yield than the other regions during 2001-2002. For the entire country larger area show higher yield of Boro than for Aman.

3. Potential areas where rainwater may also be used as an alternate source of water for drinking purposes have been identified taking into consideration of ground water depletion, arsenic, iron and salinity problems.

   i) From groundwater level assessment it has been found that among three cropping periods, Kharif I and Rabi show worse condition specially in NW and NC regions. During April there is significant increase of rainfall in NW region, so ground water recharge schemes can be implemented in this region.

   ii) SE is the most vulnerable region due to arsenic and iron contamination with ground water. From rainfall analysis in this region, it has been noticed that

during May the recent three decades show higher rainfall relative to that for previous three decades as well as 58 year average. This rainfall may be harvested to mitigate the arsenic problem.

iii) Salinity problem is experienced in the coastal areas of SC and SW regions most. As there is significant increase in rainfall during September in the SW region where rainwater may be helpful to overcome the soil salinity problem in these regions.

4. In the present study, potential of rainwater harvesting in Dhaka city has been assessed where long term average annual rainfall of 55 years (1953 to 2007) is found to be 2073 mm and that for recent 12 years (1996 to 2007) is 2166 mm. It has been found that there is an increasing trend of annual rainfall in the recent decades. The amount of rainfall may be considered to be adequate for adopting RWH system in the city for partial coverage of water supply.

   i) Variation of 5 year (moving) average annual rainfall as well as average monthly rainfall during March, May and September has been analyzed for Dhaka city considering 55 year duration (1953-2007) and, it is compared with 55 year average rainfall. It has been found that from 1980 to 2005, five year (moving) average annual rainfall is higher than 55 year average annual rainfall during 62% of the years, whereas from 1953 to 1979 only 15% of the years show higher 5 year (moving) average annual rainfall than 55 year average. Again five year (moving) average monthly rainfall is higher than 55 year average monthly rainfall in 73% of the years during March, 69% of the years during May and 65% of the years during September.

   ii) From the mass curve analysis of Dhaka city, it is found that the maximum excess water of $0.25m^3$ is available during the month of October and maximum deficit of $0.38m^3$ water occurs during April. Thus excess water obtained during rainy season can be stored in a proper way for the use in dry season. Rainwater capture systems should be installed which will harvest rainwater from the roof, and channel it into a storage device.

iii) As much as 33% of water demand can be met by RWH with individual harvesting system and up to 10% water demand can be met with community based RWH system. So in Dhaka, RWH can be used in conjunction with conventional water supply system to improve the present water scarcity.

iv) Finally an analysis of roof size distribution of different wards of Dhaka city has been made to find out suitable catchment area that can be used for RWH.

8.2 Recommendations

Future studies may consider the followings recommendations:

- In case of regional (e.g. hydrological region) rainfall analyses, future studies should employ Thiessen polygon method and compare the trend in rainfall distribution at different decades. This method may produce a better investigation.

- Only average data of rainfall is considered for long term rainfall analysis. Future studies may employ other statistical methods (e.g. maximum, minimum, standard deviation) and should also focus on the trend of rainfall intensity for some more interesting outcome.

- For determining the contribution of rainwater in meeting crop water requirement, monthly PET (potential evapotranspiration) data has been considered. In this case, weekly PET data may be used and it may represent the real situation of crop water requirement.

- Average groundwater level data of each cropping period has been considered for the analysis of groundwater level at three cropping periods. For further analysis, data for each month instead of average data of cropping period may impart better understanding of the severity of groundwater level depletion.

- Roof size distribution, to provide catchment area for RWH in Dhaka city, has been analyzed for only available 29 wards out of total 90 wards. Further analyses should be performed after information regarding all the wards is available.

- To promote rainwater utilization, basic policies, implementation strategies, technology development and networking are required. Public awareness and education are essential in order to improve acceptance of rainwater collection and utilization. Developing incentive programs to encourage the incorporation of rainwater harvesting systems into the design and construction of new residential, commercial, and industrial facilities in urban areas may promote people to adopt rain water harvesting.

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APPENDICES

Appendix A

Figures of Decadal average rainfall of different months

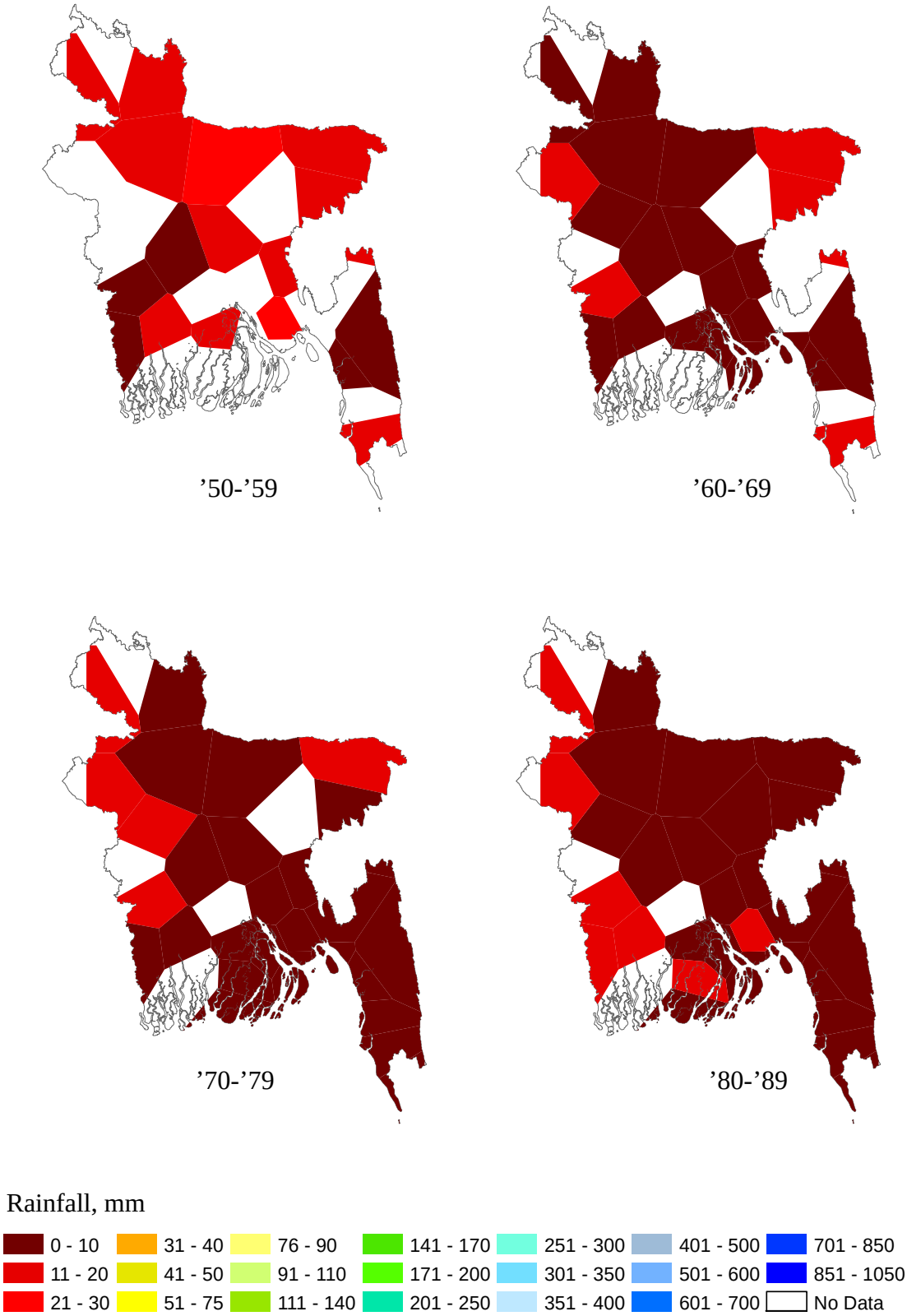
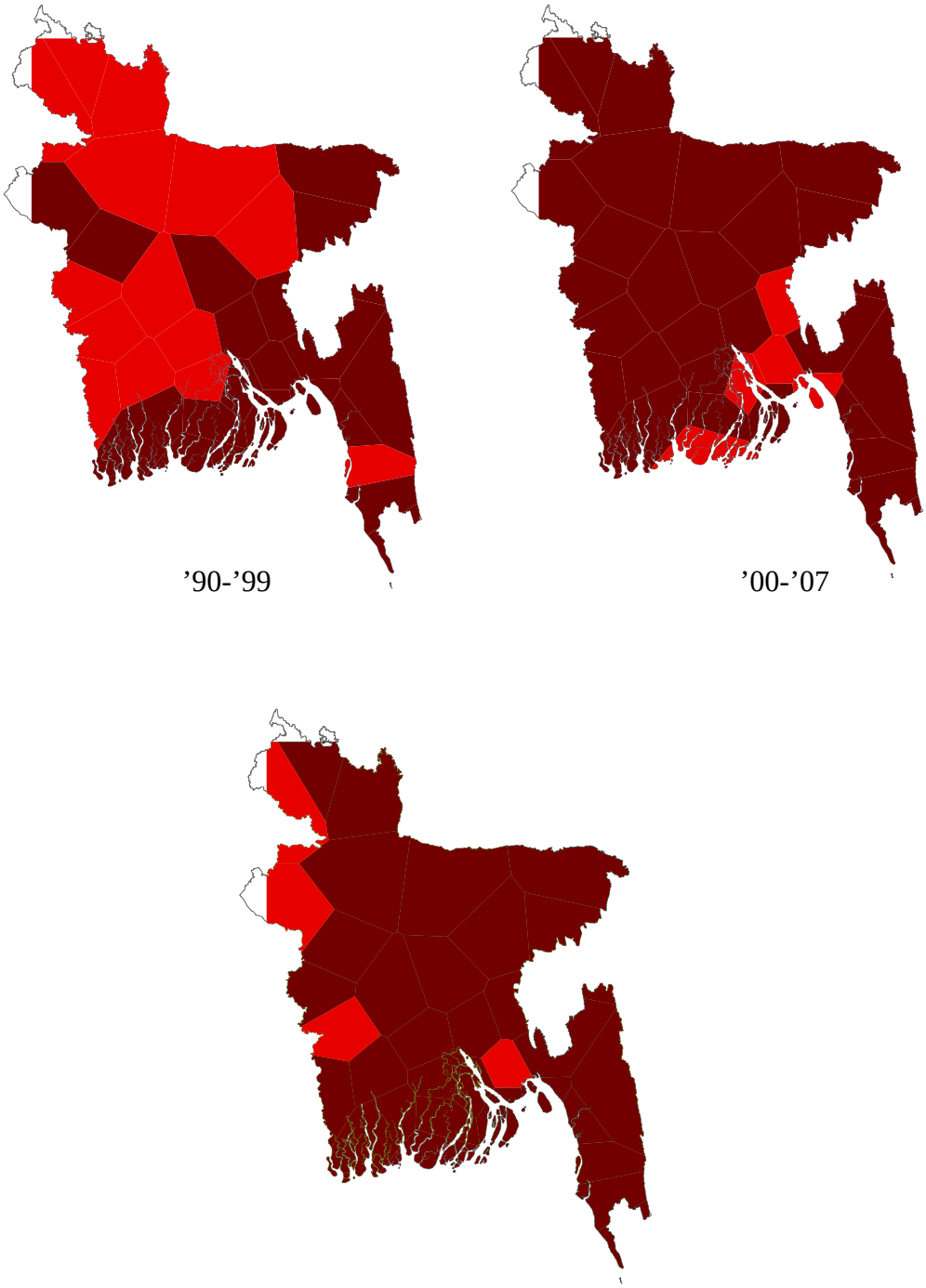


Figure A.1: Decadal average rainfall of January for 58 years (1950-2007)

Continued…



Average rainfall of 58 years (50-’07)

Rainfall, mm

0 - 10	31 - 40	76 - 90	141 - 170	251 - 300	401 - 500	701 - 850
11 - 20	41 - 50	91 - 110	171 - 200	301 - 350	501 - 600	851 - 1050
21 - 30	51 - 75	111 - 140	201 - 250	351 - 400	601 - 700	No Data

Figure A.1: Decadal average rainfall of January for 58 years (1950-2007)

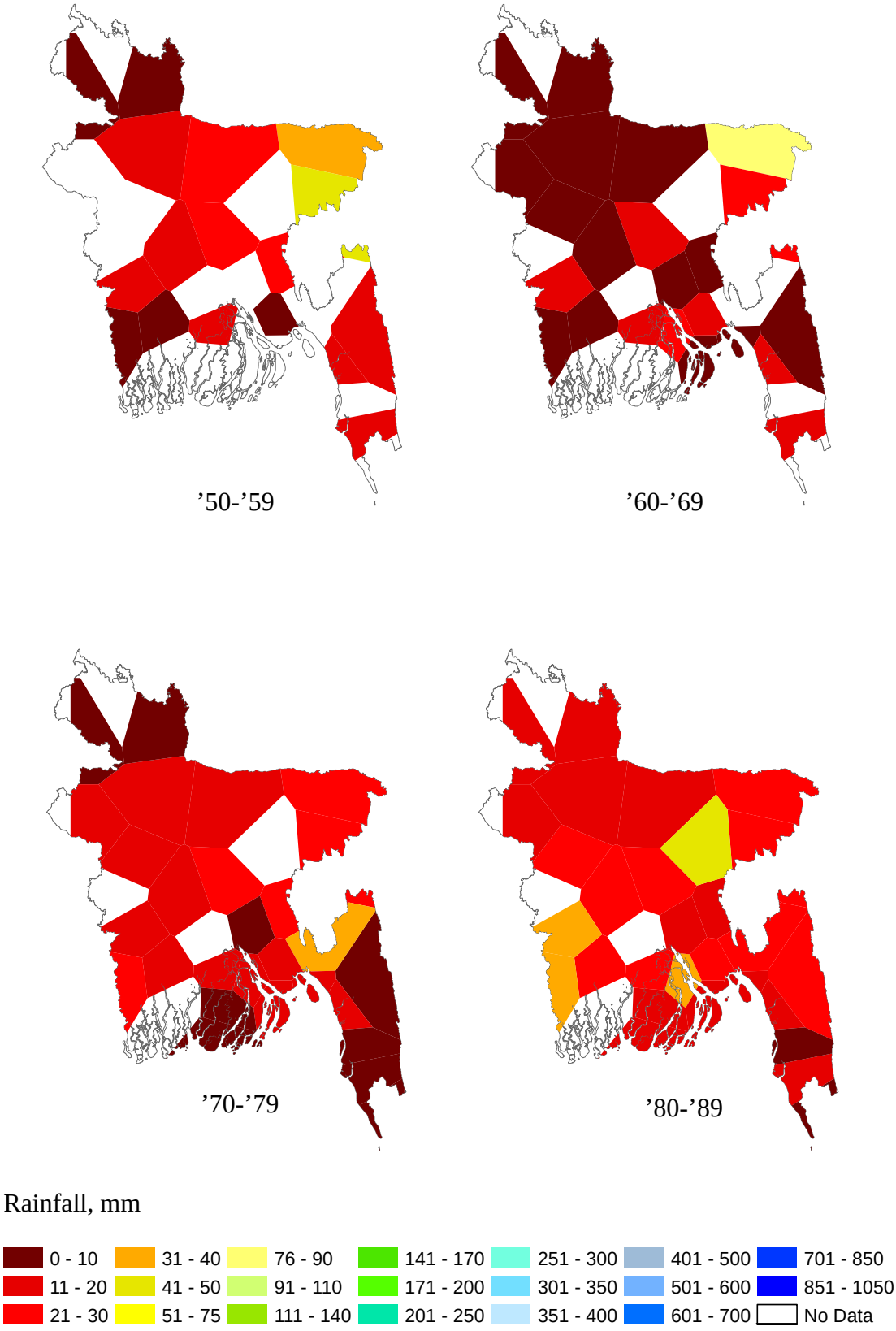


Figure A.2: Decadal average rainfall of February for 58 years (1950-2007)

Continued…

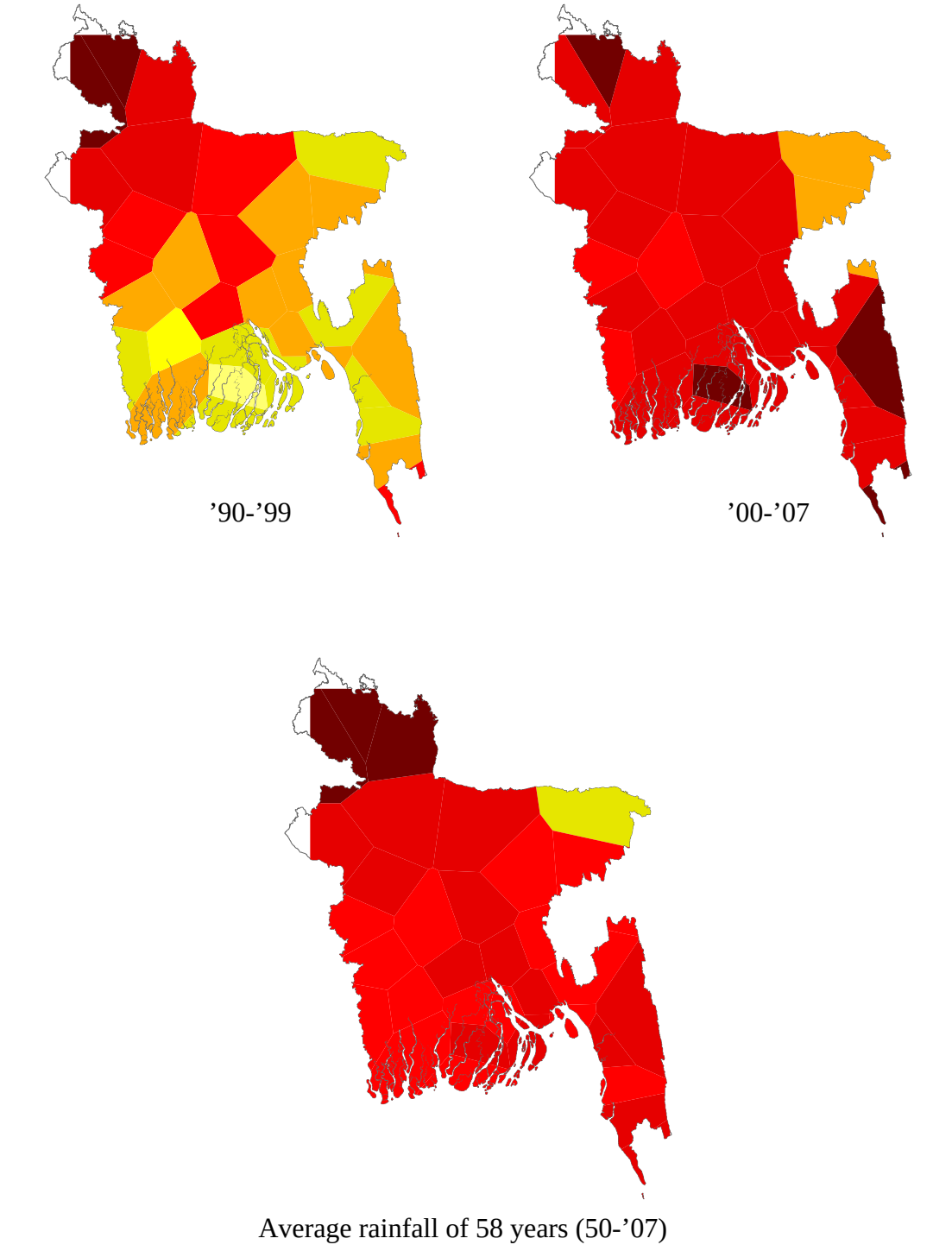


Figure A.2: Decadal average rainfall of February for 58 years (1950-2007)

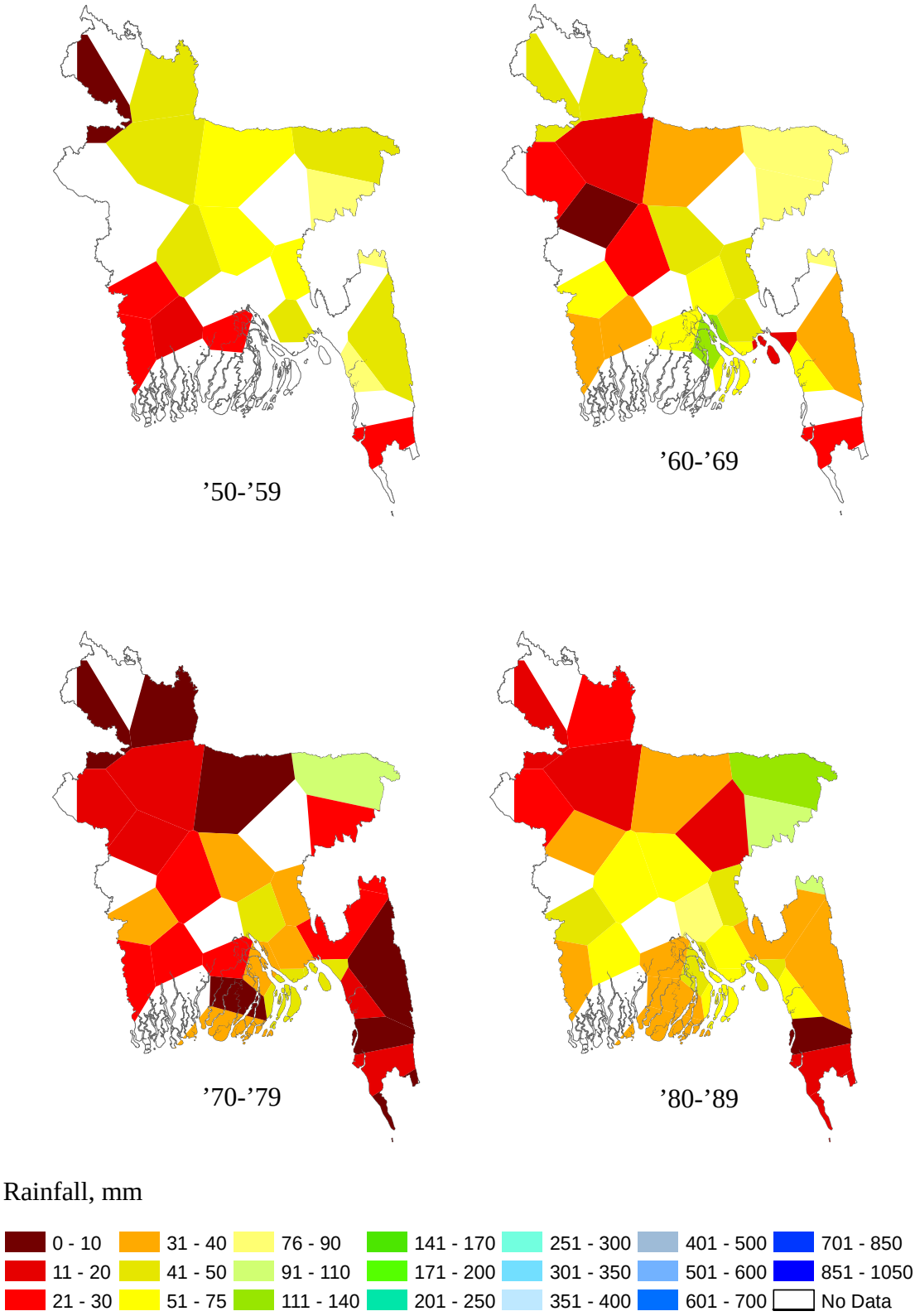


Figure A.3: Decadal average rainfall of March for 58 years (1950-2007)

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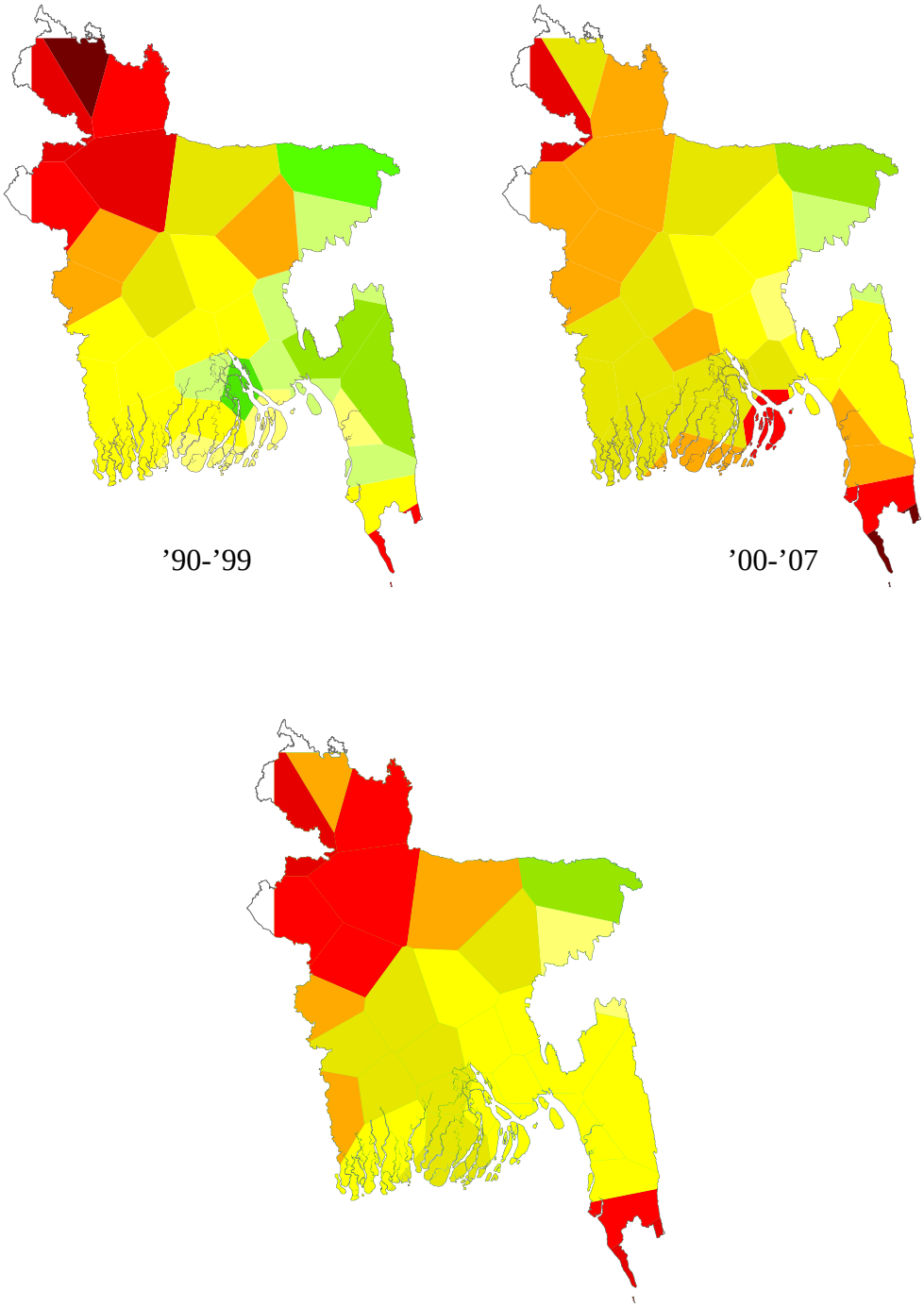


Figure A.3: Decadal average rainfall of March for 58 years (1950-2007)

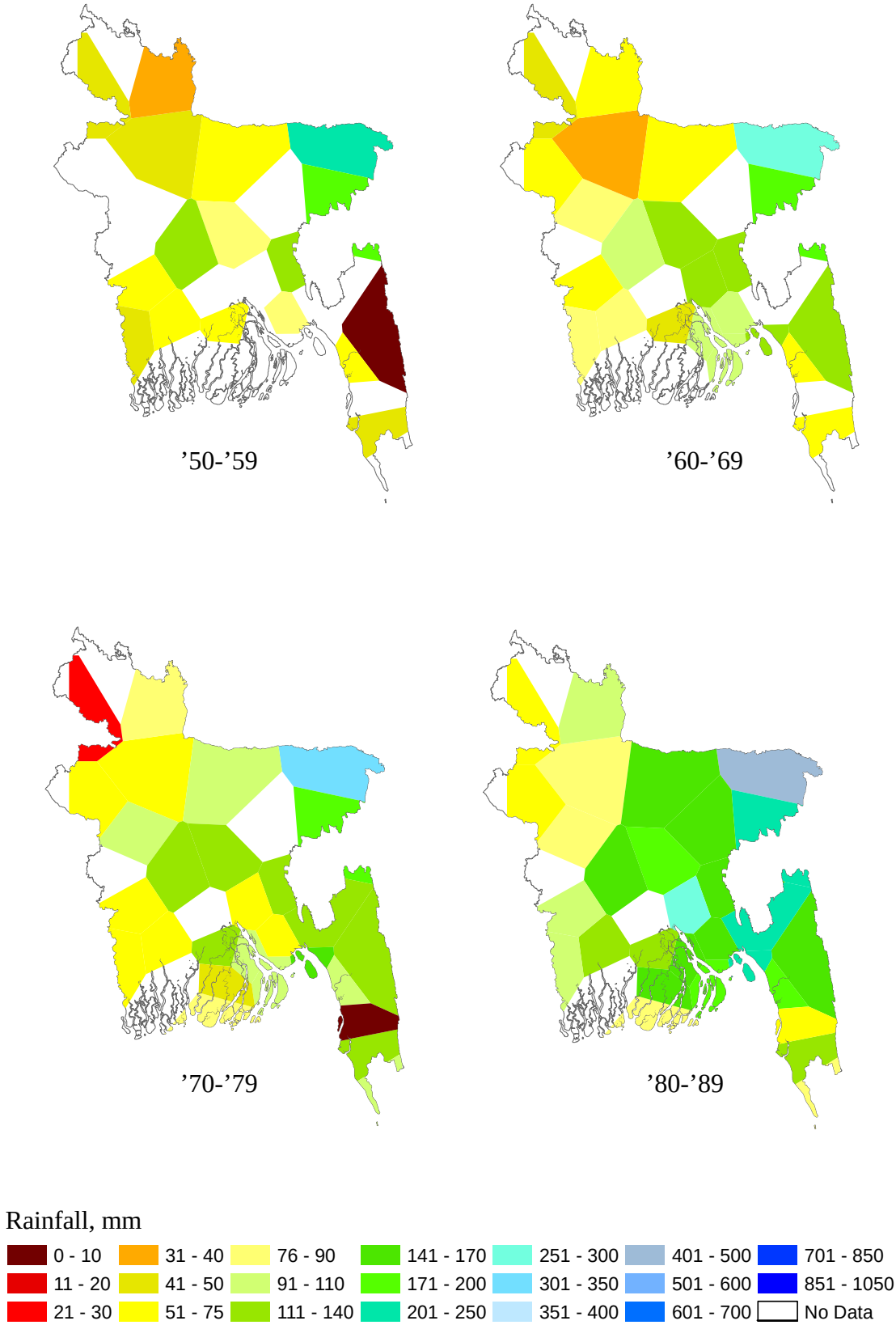
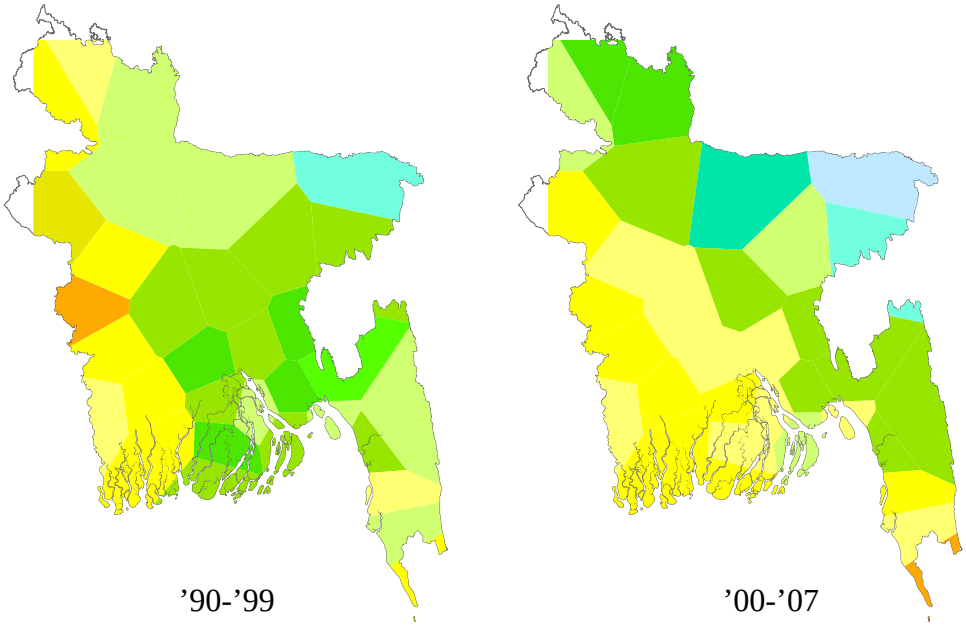
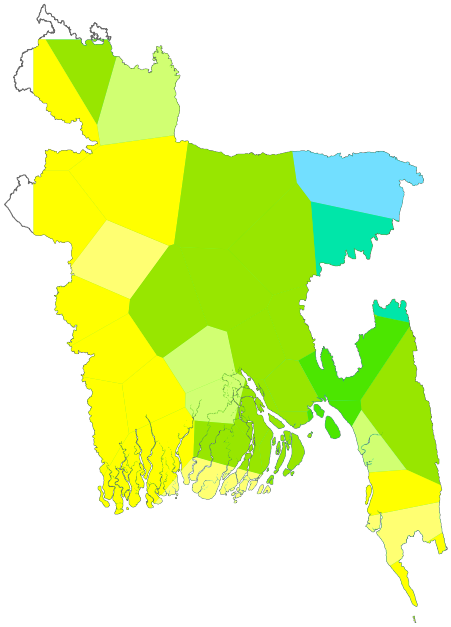


Figure A.4: Decadal average rainfall of April for 58 years (1950-2007)

Continued…





Average rainfall of 58 years (50-’07)

Rainfall, mm

0 - 10	31 - 40	76 - 90	141 - 170	251 - 300	401 - 500	701 - 850
11 - 20	41 - 50	91 - 110	171 - 200	301 - 350	501 - 600	851 - 1050
21 - 30	51 - 75	111 - 140	201 - 250	351 - 400	601 - 700	No Data

Figure A.4: Decadal average rainfall of April for 58 years (1950-2007)

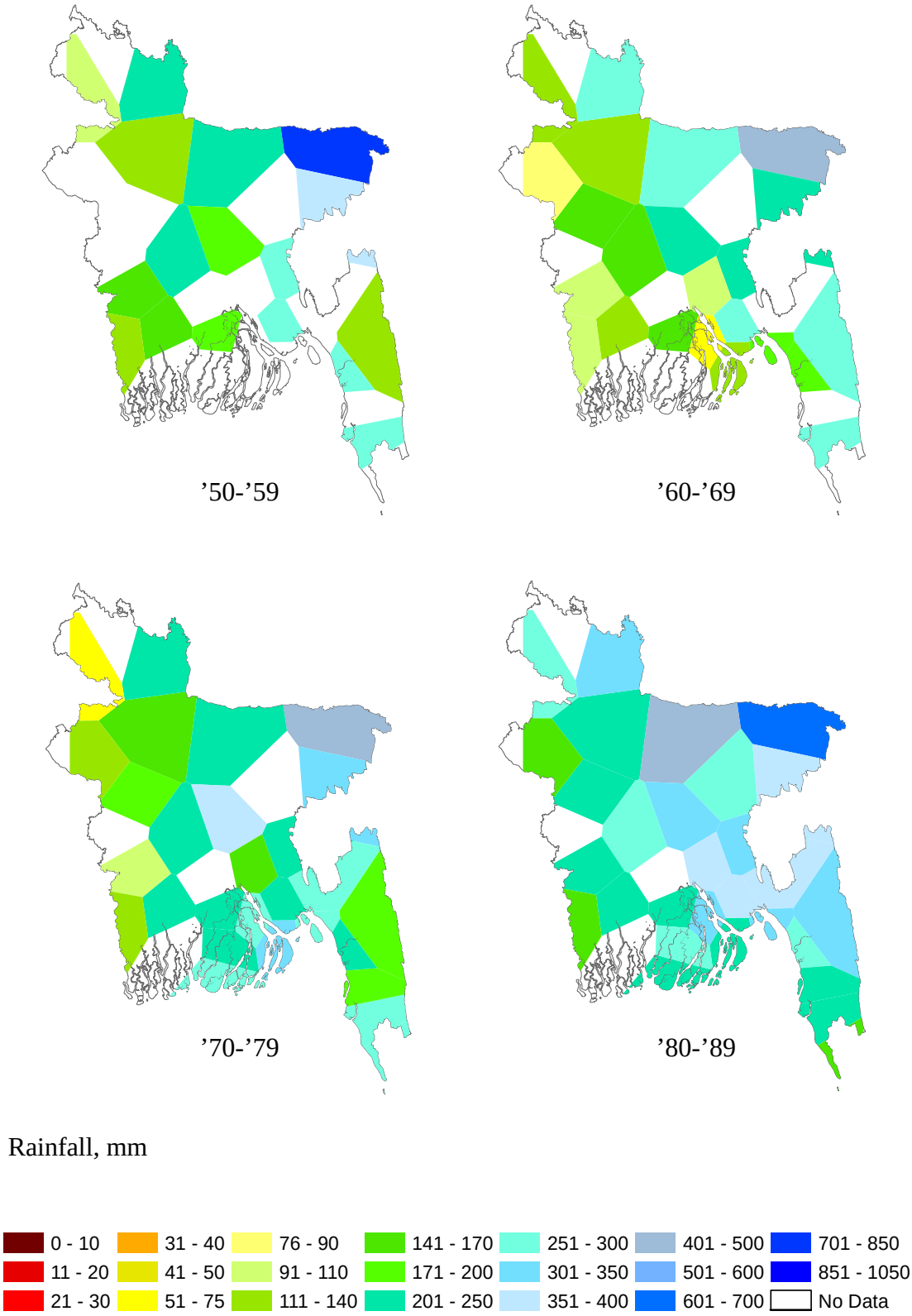


Figure A.5: Decadal average rainfall of May for 58 years (1950-2007)

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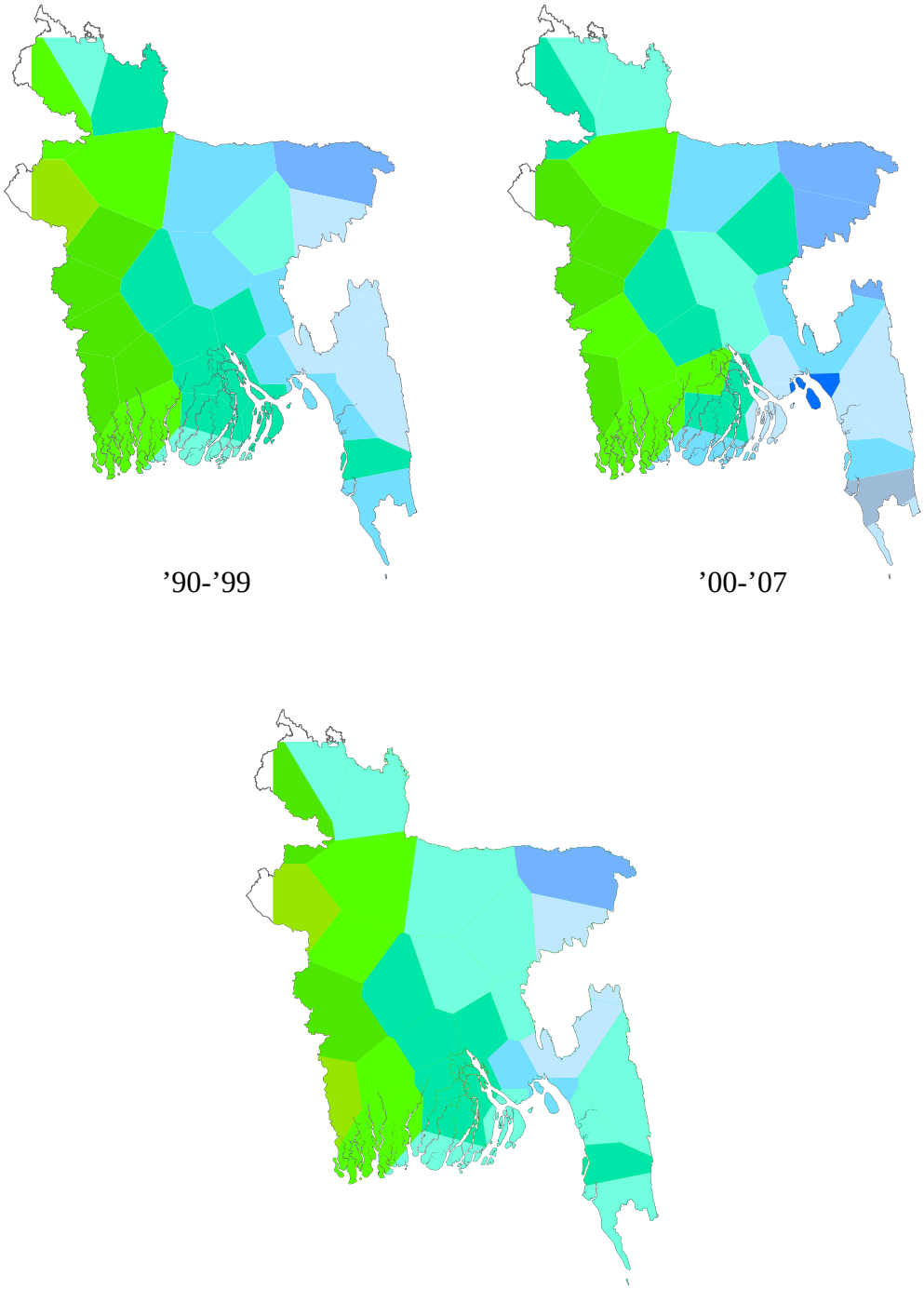


Figure A.5: Decadal average rainfall of May for 58 years (1950-2007)

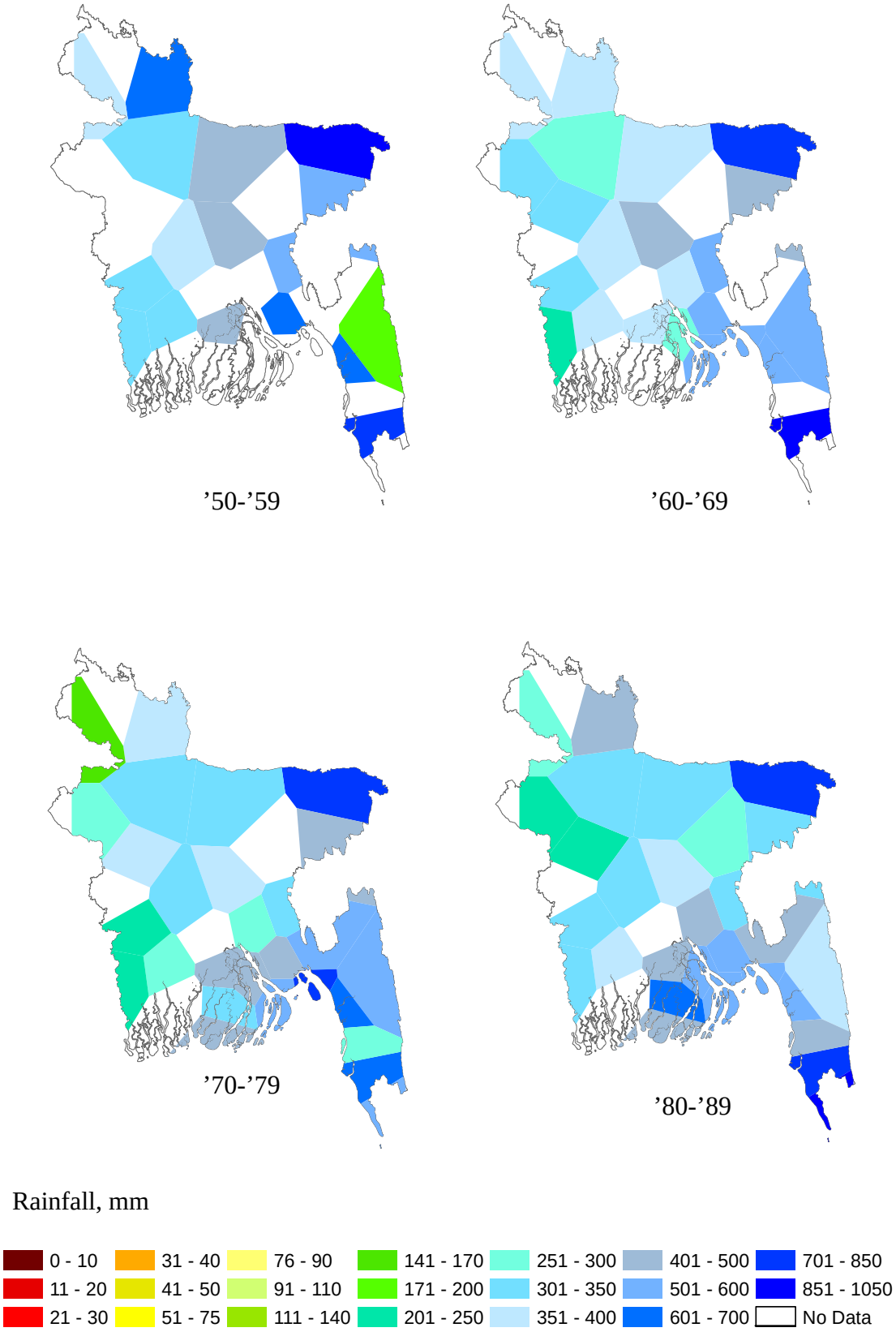
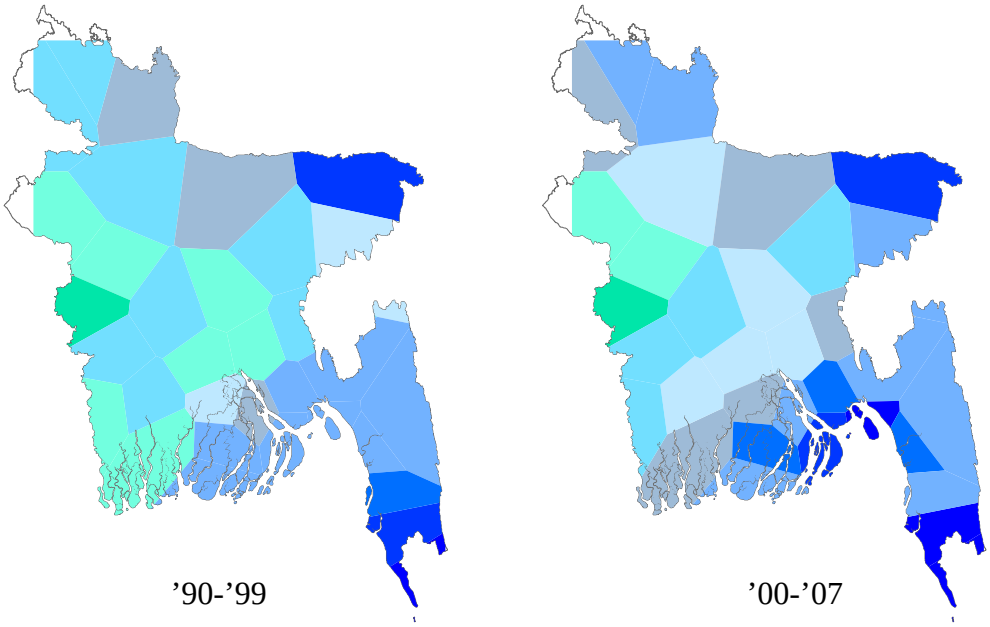
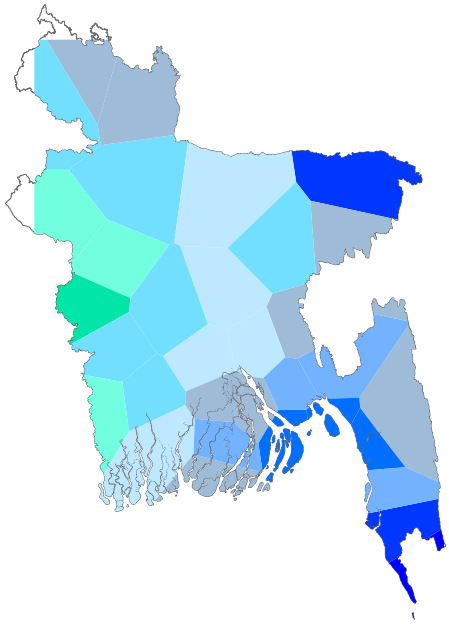


Figure A.6: Decadal average rainfall of June for 58 years (1950-2007)

Continued…





Average rainfall of 58 years (50-’07)

Rainfall, mm

0 - 10	31 - 40	76 - 90	141 - 170	251 - 300	401 - 500	701 - 850
11 - 20	41 - 50	91 - 110	171 - 200	301 - 350	501 - 600	851 - 1050
21 - 30	51 - 75	111 - 140	201 - 250	351 - 400	601 - 700	No Data

Figure A.6: Decadal average rainfall of June for 58 years (1950-2007)

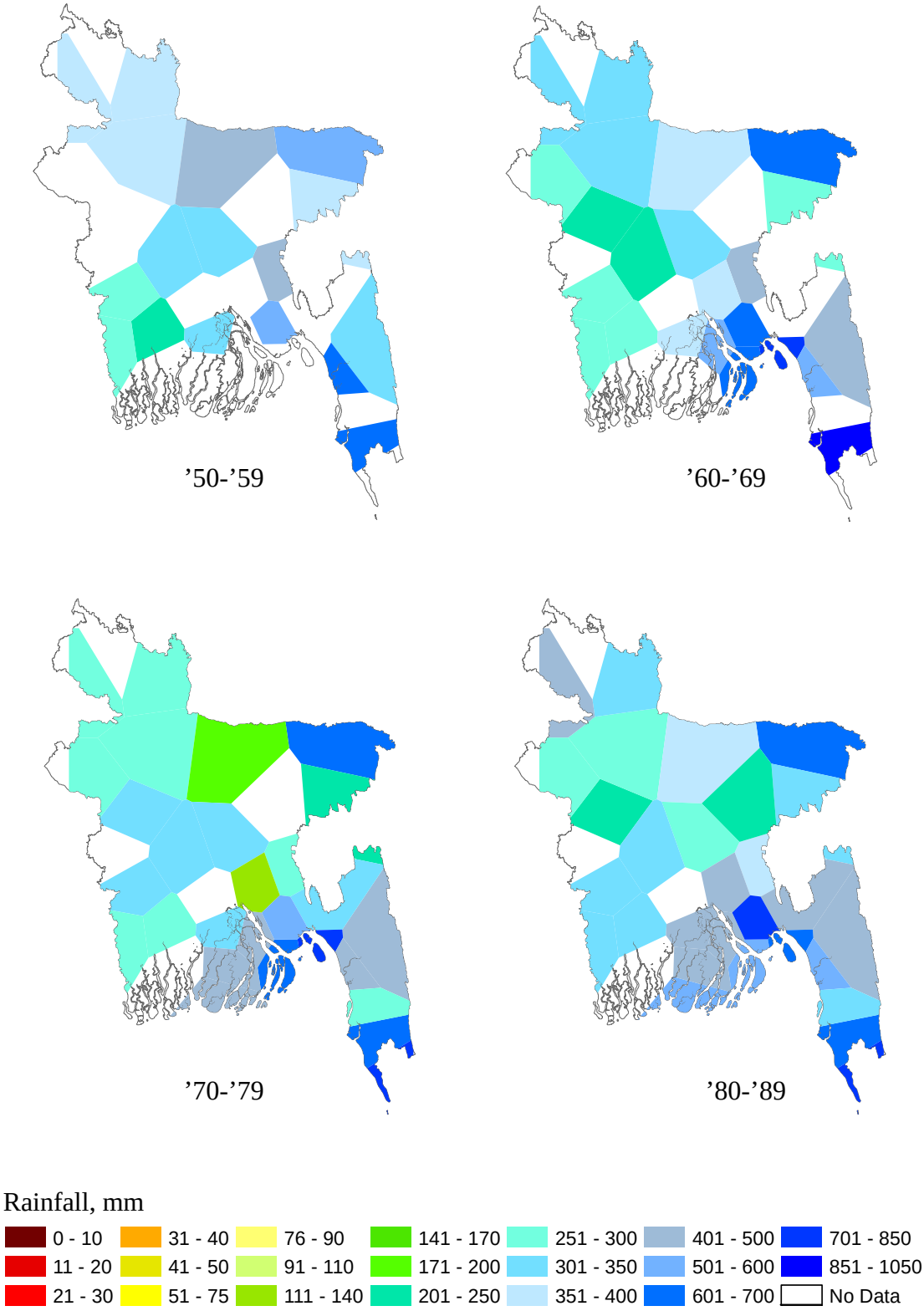
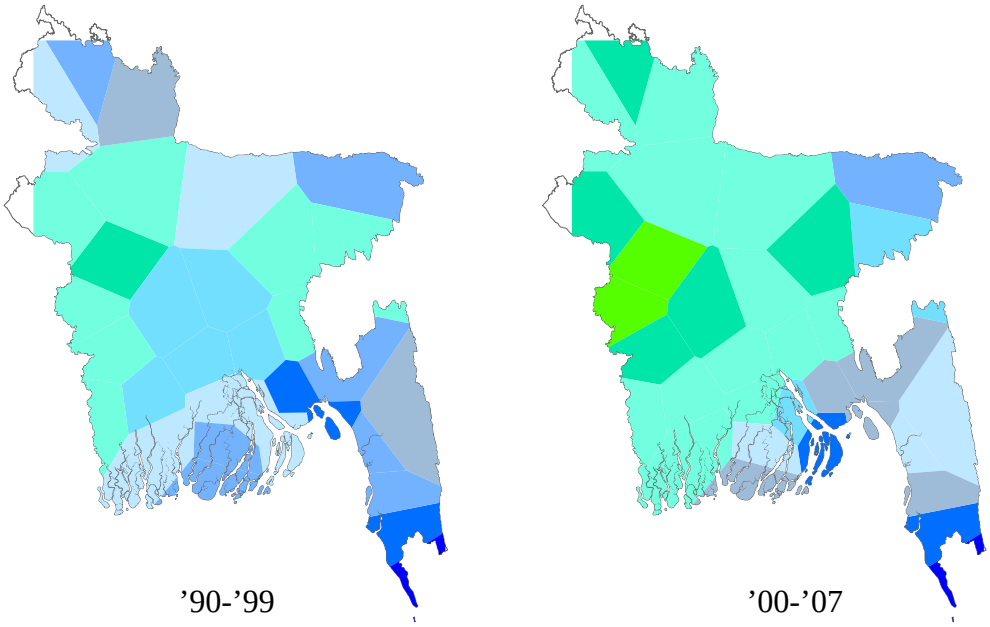
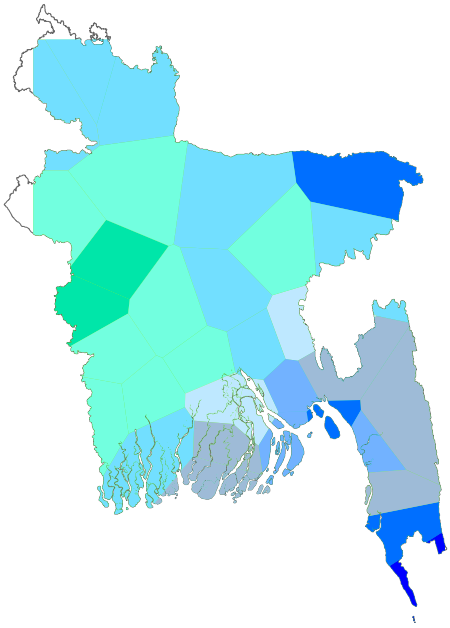


Figure A.7: Decadal average rainfall of August for 58 years (1950-2007)

Continued…





Average rainfall of 58 years (50-’07)

Rainfall, mm

0 - 10	31 - 40	76 - 90	141 - 170	251 - 300	401 - 500	701 - 850
11 - 20	41 - 50	91 - 110	171 - 200	301 - 350	501 - 600	851 - 1050
21 - 30	51 - 75	111 - 140	201 - 250	351 - 400	601 - 700	No Data

Figure A.7: Decadal average rainfall of August for 58 years (1950-2007)

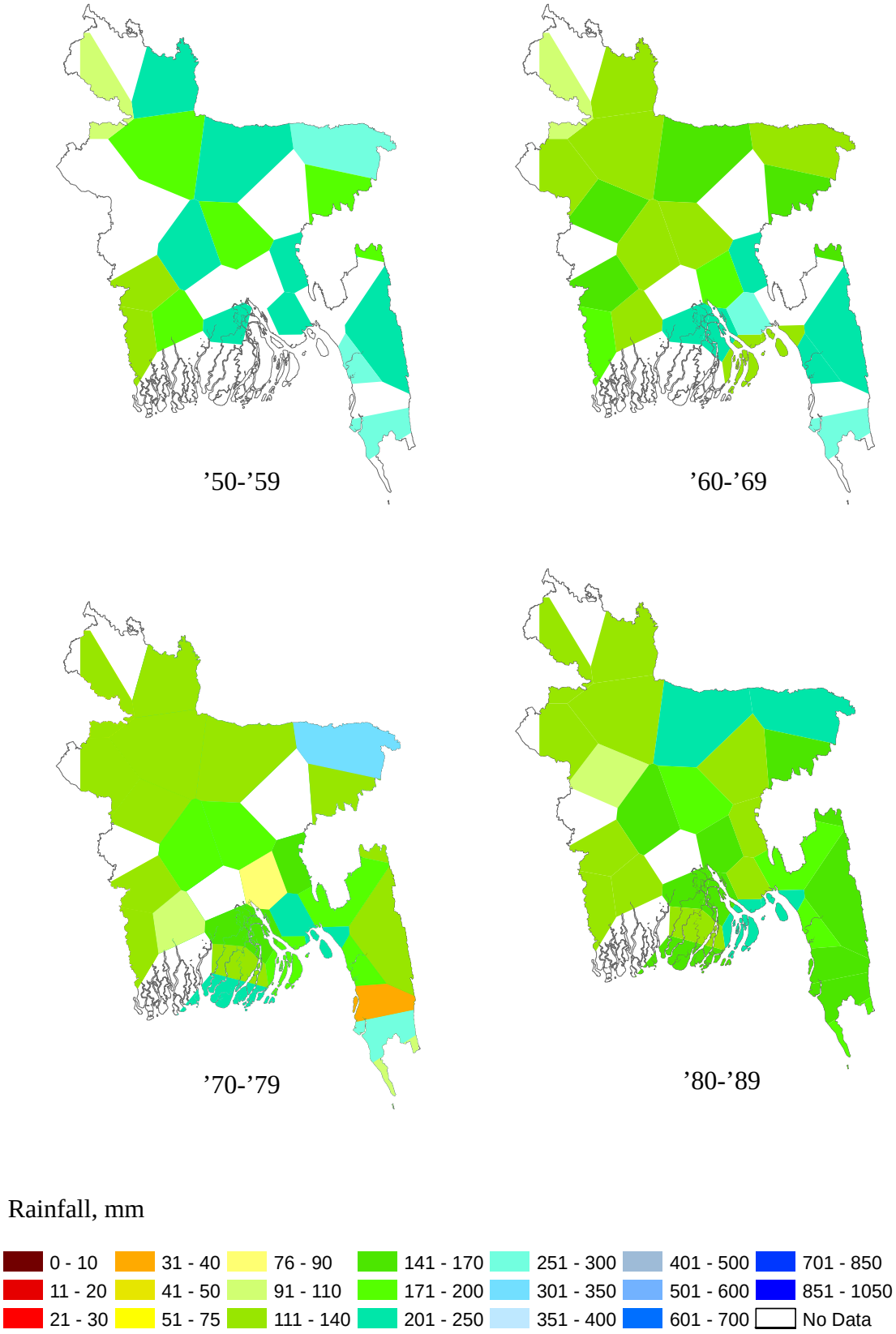
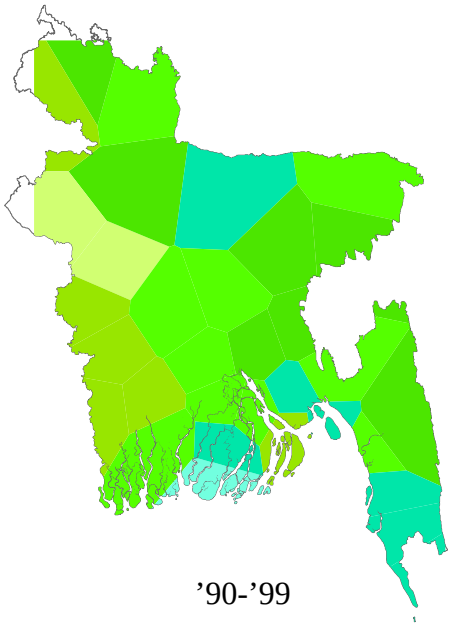
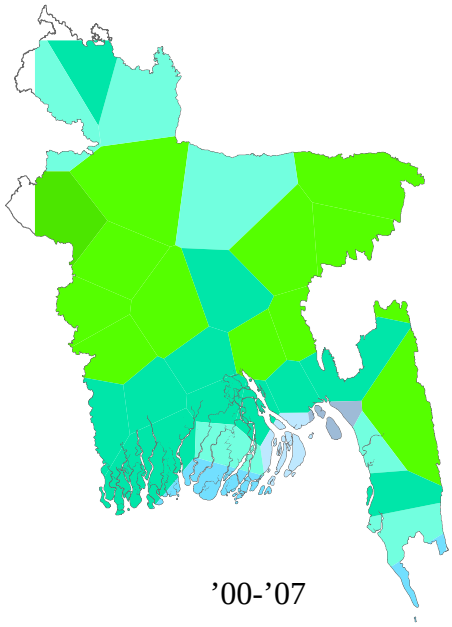


Figure A.8: Decadal average rainfall of October for 58 years (1950-2007)

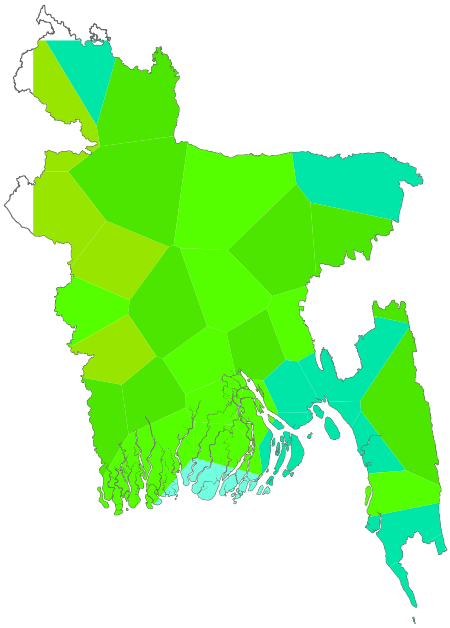
Continued…



’90-’99



’00-’07



Average rainfall of 58 years (50-’07)

Rainfall, mm

0 - 10	31 - 40	76 - 90	141 - 170	251 - 300	401 - 500	701 - 850
11 - 20	41 - 50	91 - 110	171 - 200	301 - 350	501 - 600	851 - 1050
21 - 30	51 - 75	111 - 140	201 - 250	351 - 400	601 - 700	No Data

Figure A.8: Decadal average rainfall of October for 58 years (1950-2007)

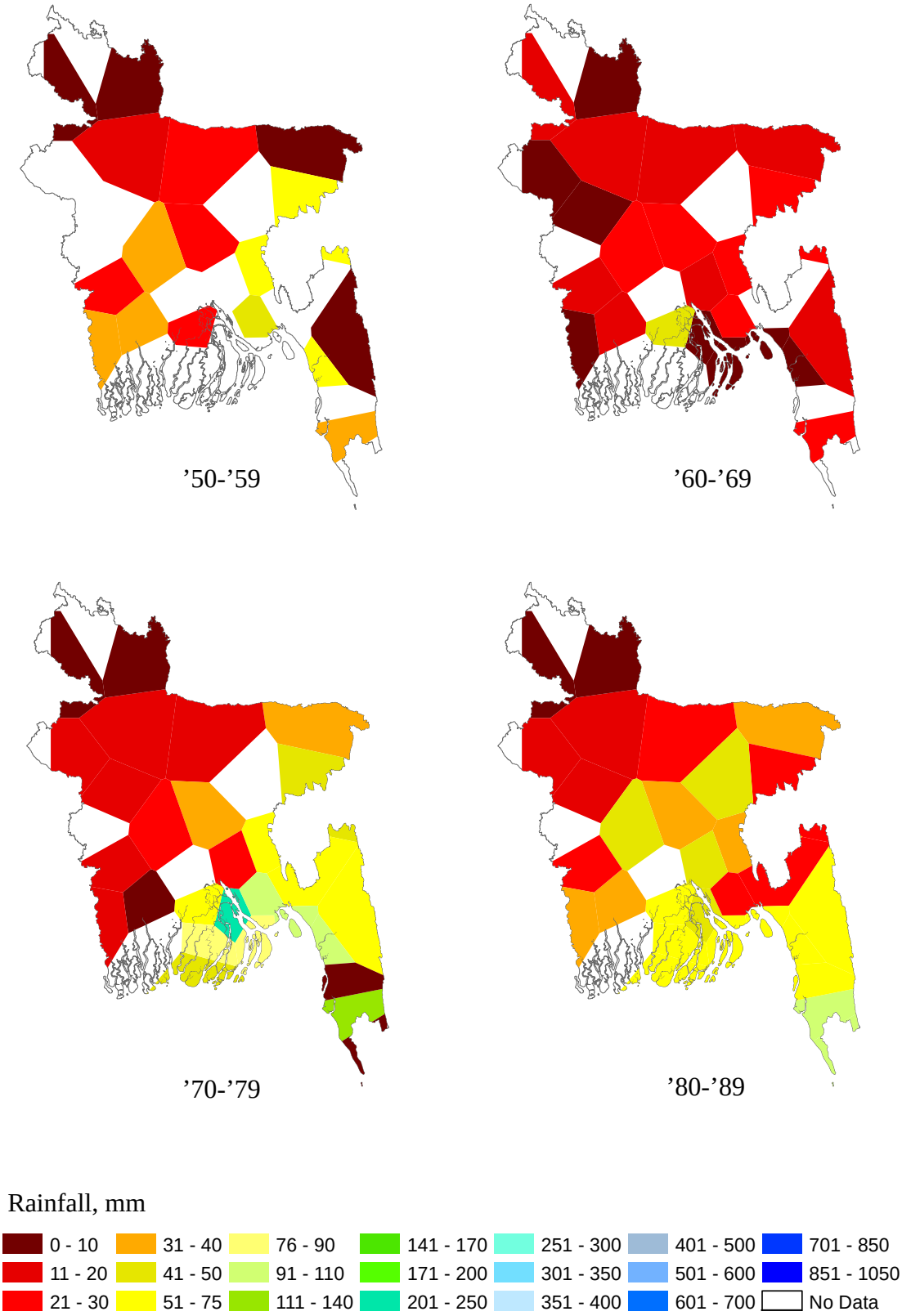
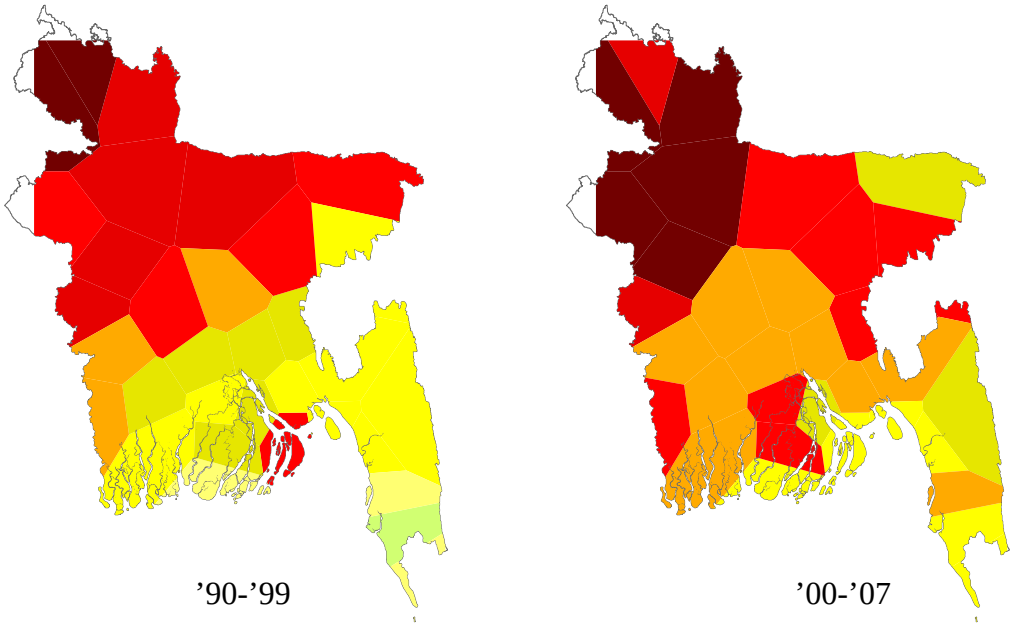
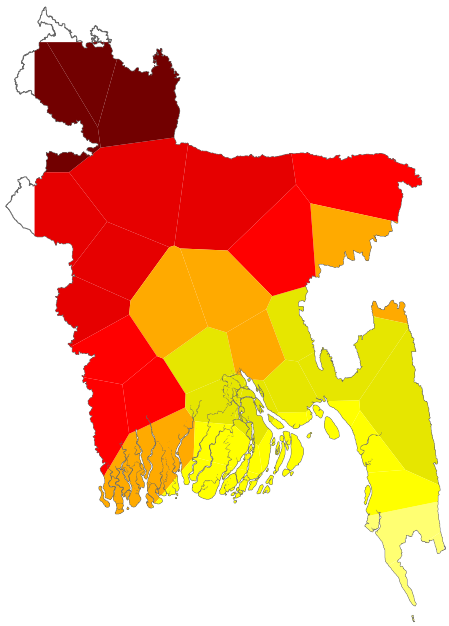


Figure A.9: Decadal average rainfall of November for 58 years (1950-2007)

Continued…





Average rainfall of 58 years (50-’07)

Rainfall, mm

0 - 10	31 - 40	76 - 90	141 - 170	251 - 300	401 - 500	701 - 850
11 - 20	41 - 50	91 - 110	171 - 200	301 - 350	501 - 600	851 - 1050
21 - 30	51 - 75	111 - 140	201 - 250	351 - 400	601 - 700	No Data

Figure A.9: Decadal average rainfall of November for 58 years (1950-2007)

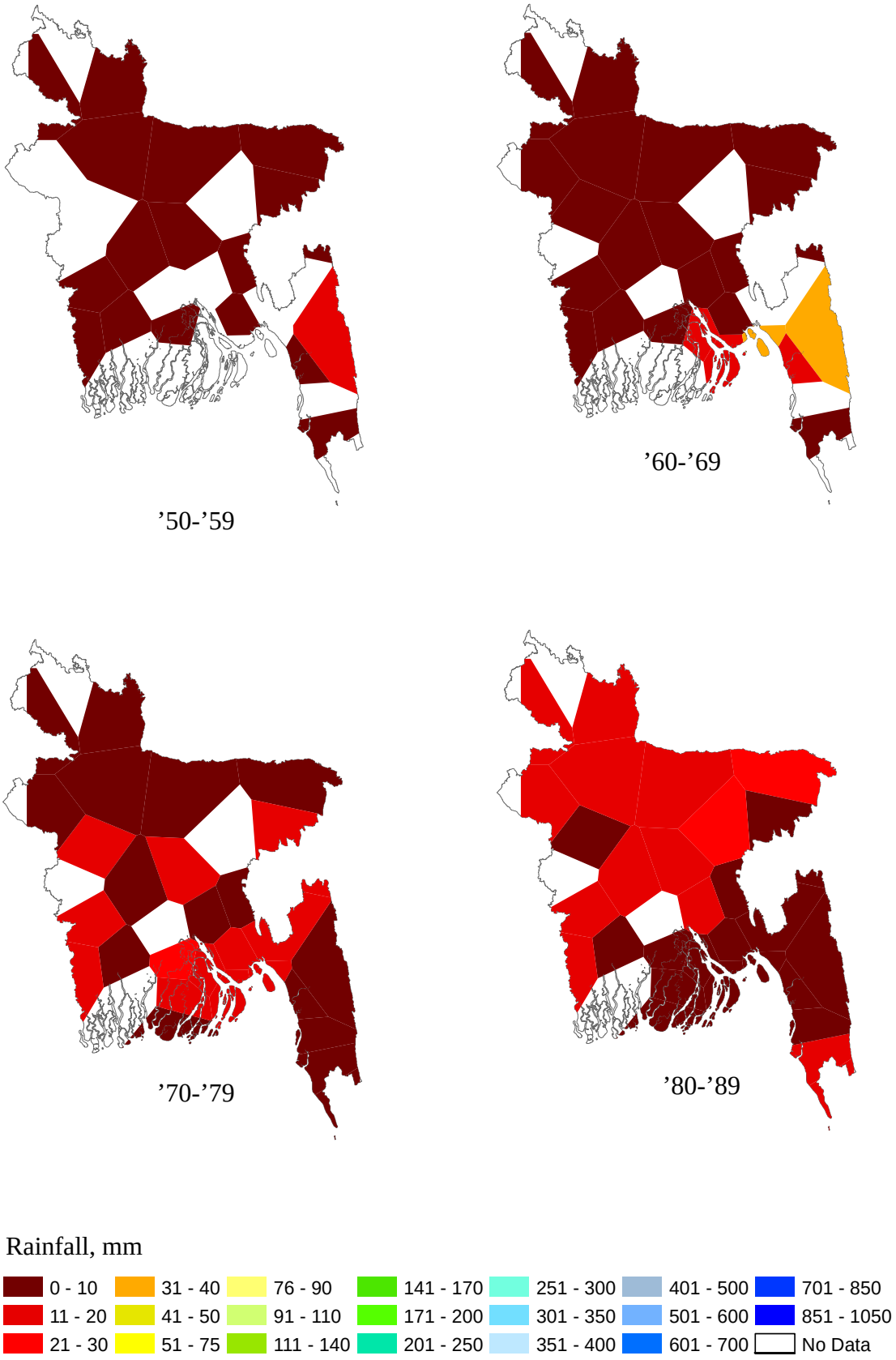


Figure A.10: Decadal average rainfall of December for 58 years (1950-2007)

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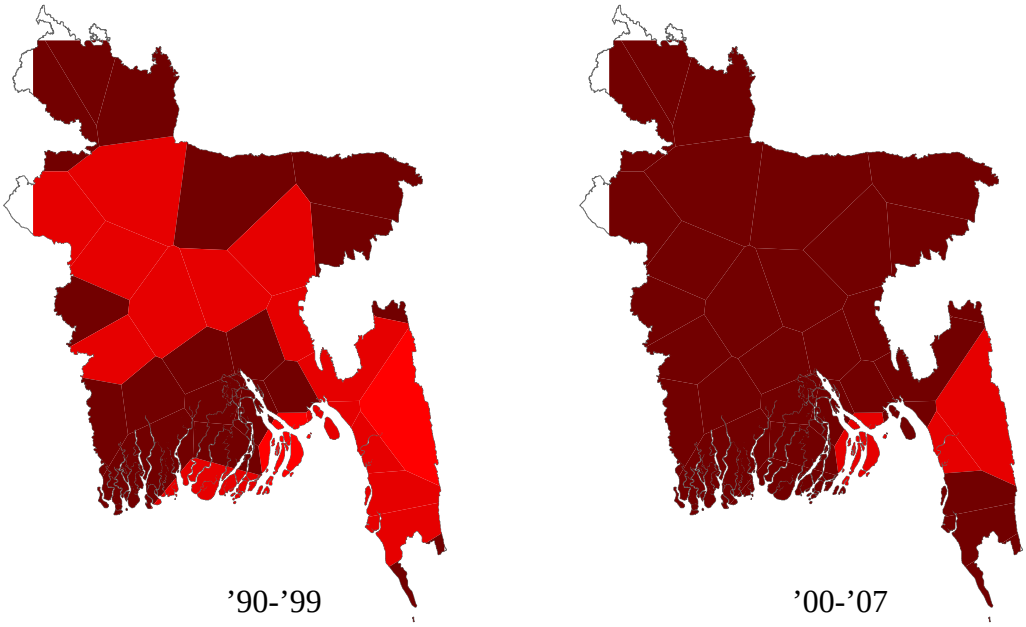

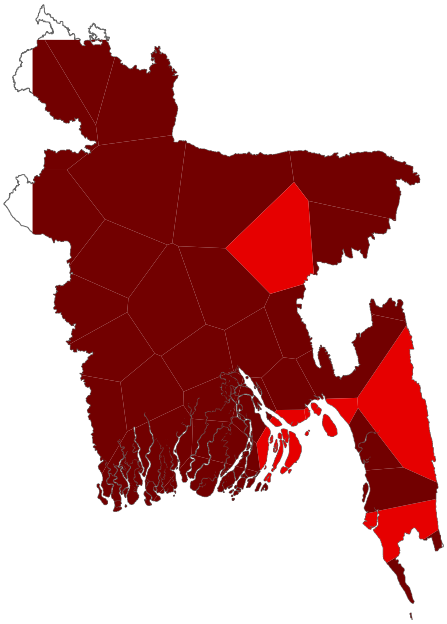

Average rainfall of 58 years (50-’07)

Rainfall, mm

0 - 10	31 - 40	76 - 90	141 - 170	251 - 300	401 - 500	701 - 850
11 - 20	41 - 50	91 - 110	171 - 200	301 - 350	501 - 600	851 - 1050
21 - 30	51 - 75	111 - 140	201 - 250	351 - 400	601 - 700	No Data

Figure A.10: Decadal average rainfall of December for 58 years (1950-2007)

Appendix B

Bar charts of Decadal Monthly average rainfall of Different Hydrological Regions of Bangladesh

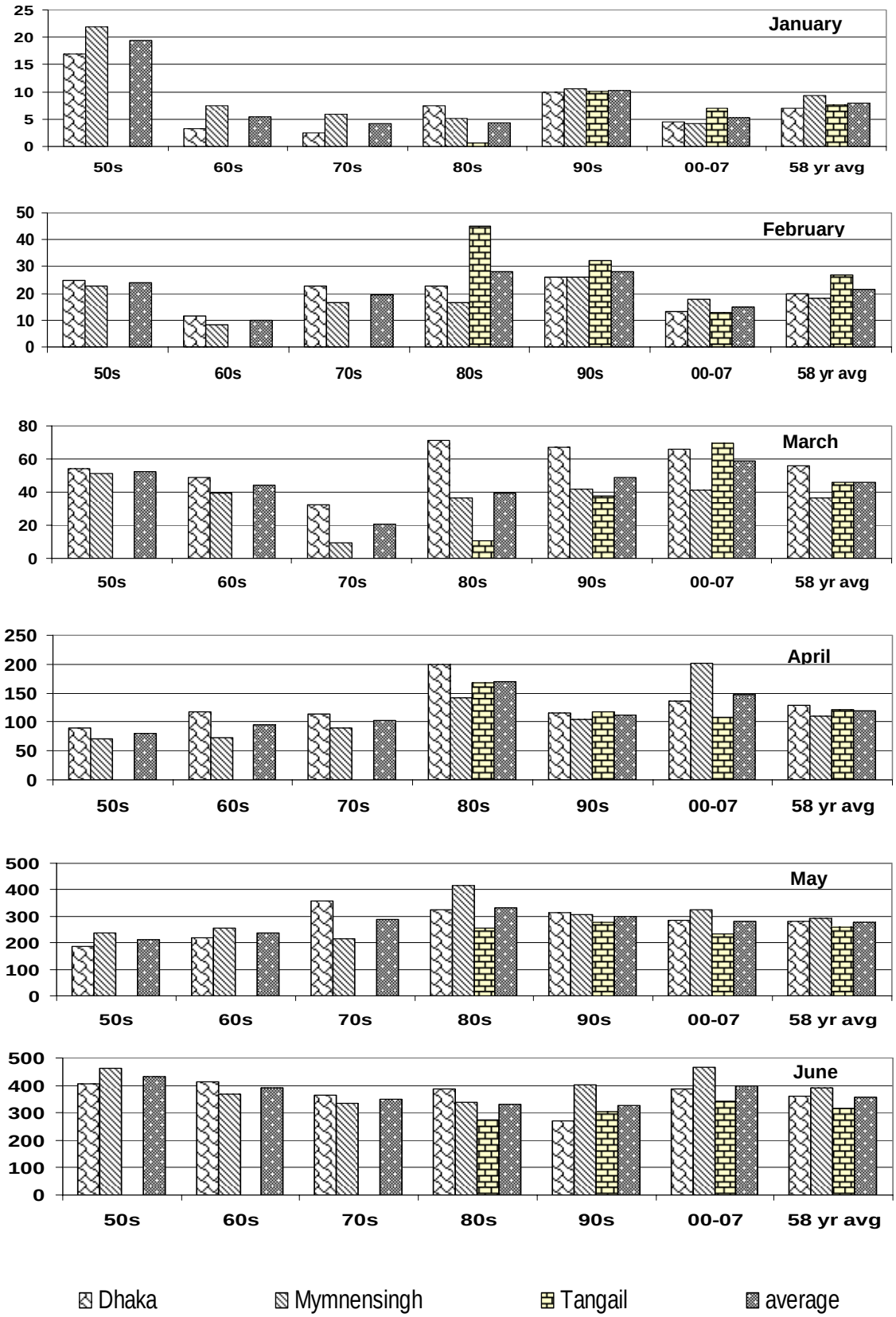

Figure B.1: Decadal Monthly average rainfall (mm) of North-Central Region

Continued…

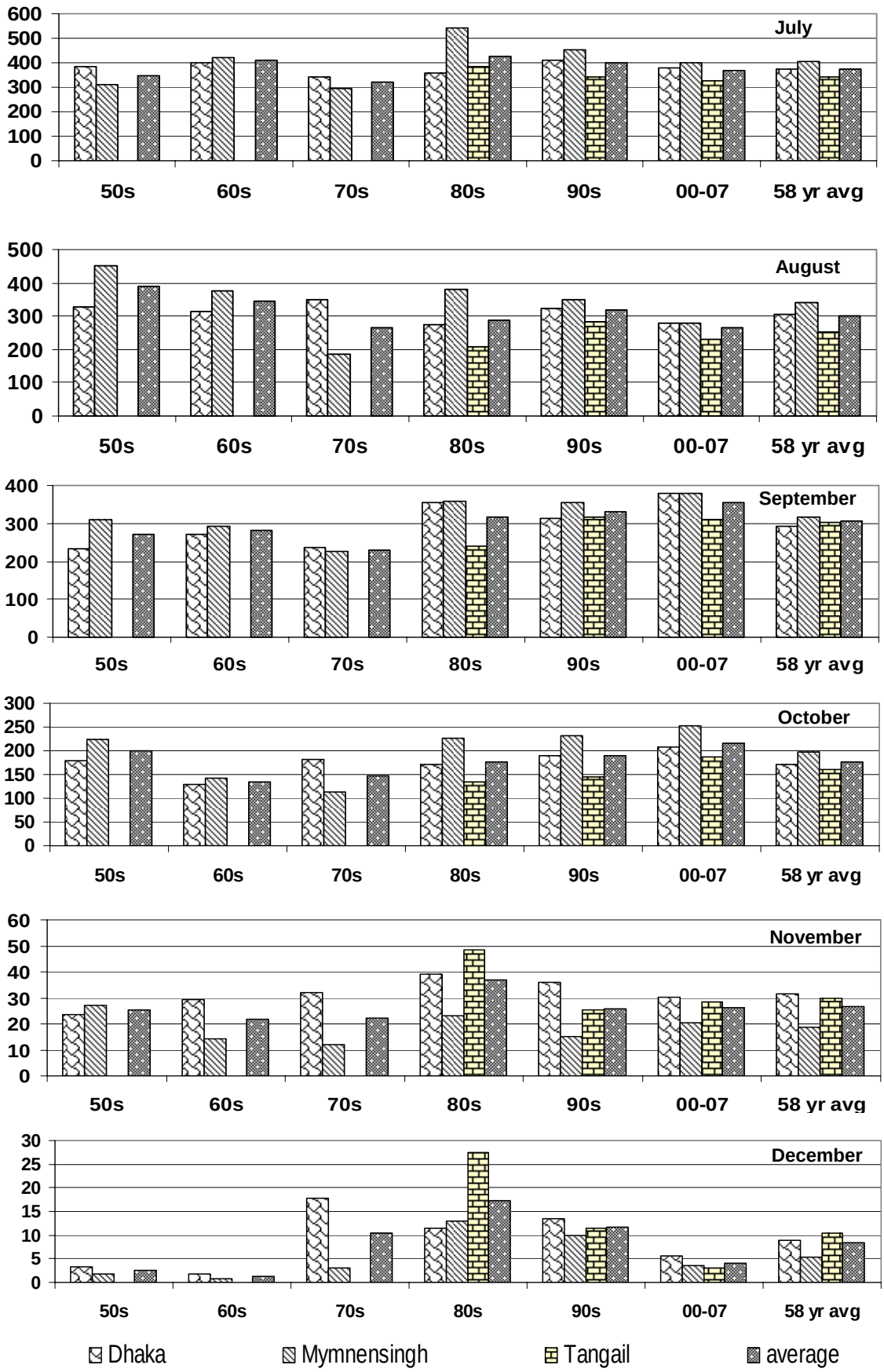

Figure B.1: Decadal Monthly average rainfall (mm) of North-Central Region

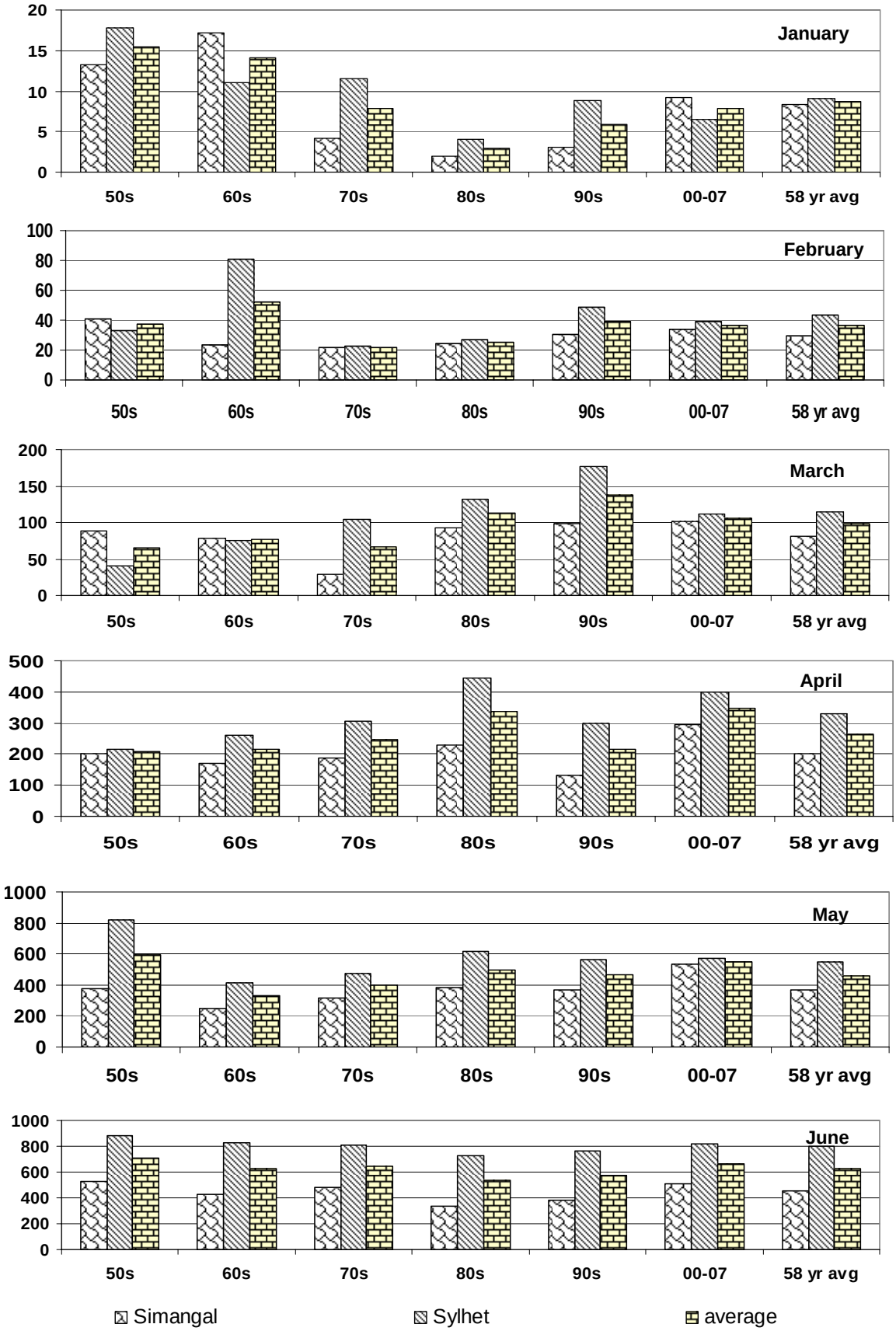

Figure B.2: Decadal Monthly average rainfall (mm) of North-East Region

Continued…

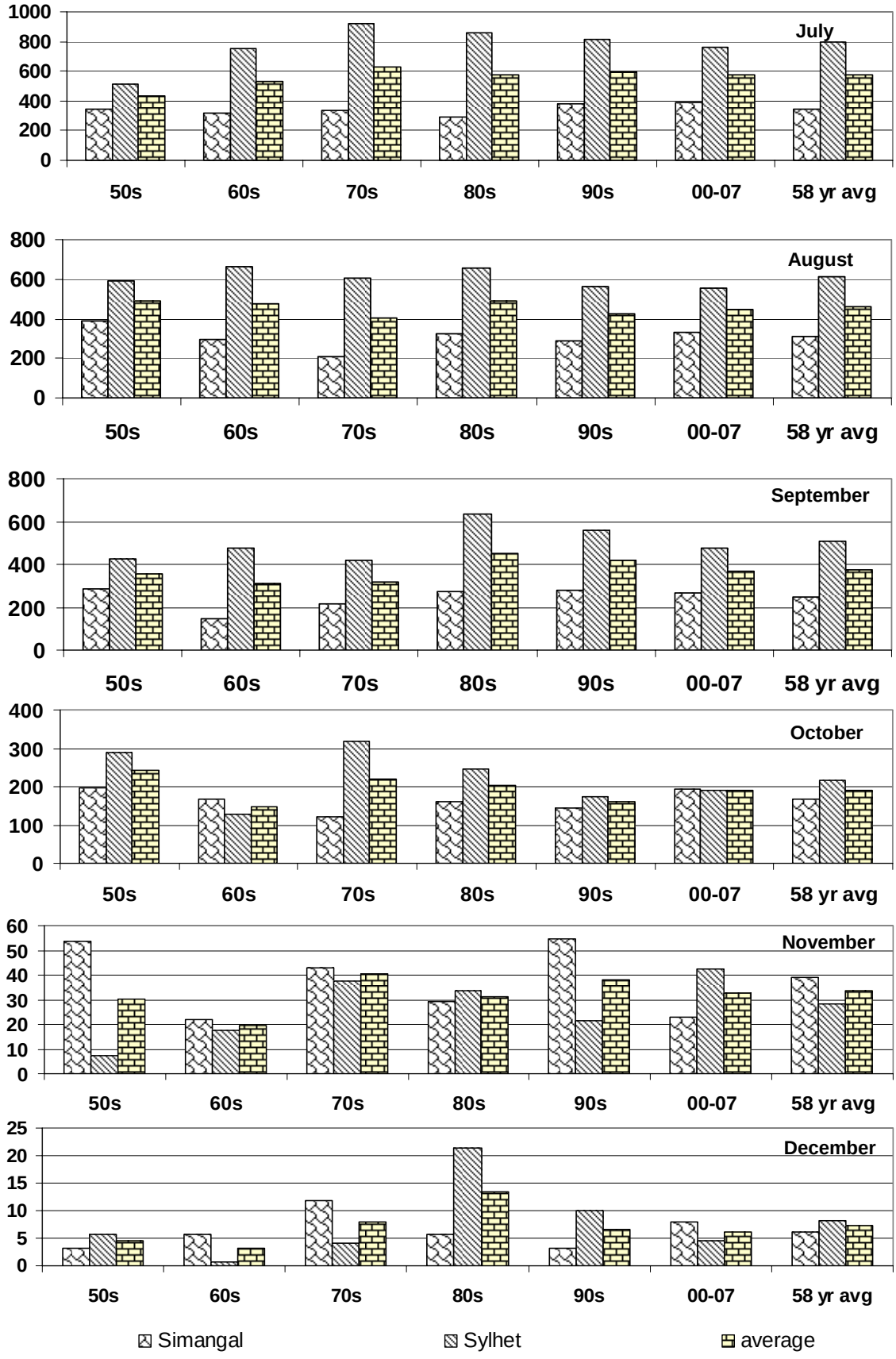

Figure B.2: Decadal Monthly average rainfall (mm) of North-East Region

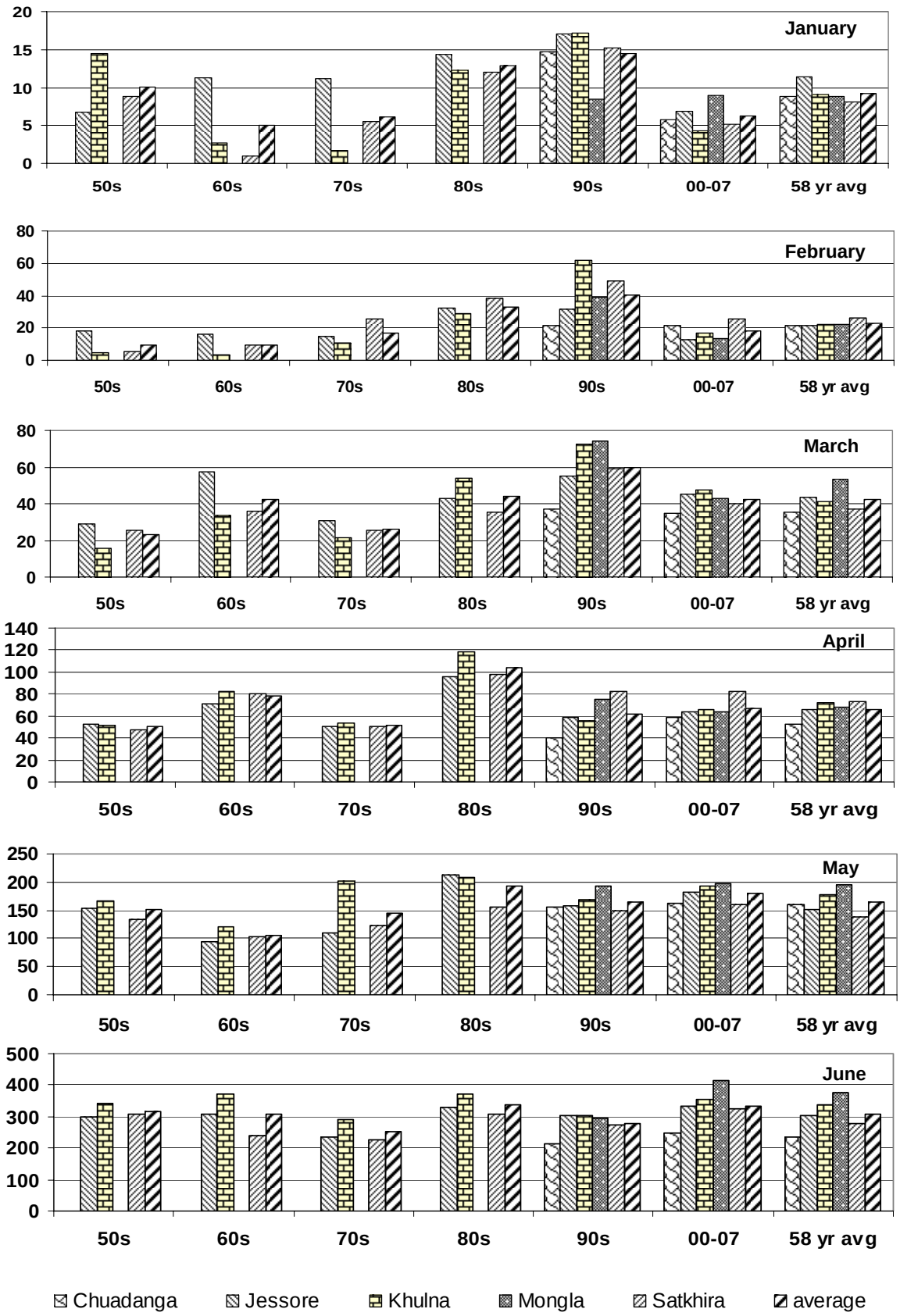

Figure B.3: Decadal Monthly average rainfall (mm) of South-West Region

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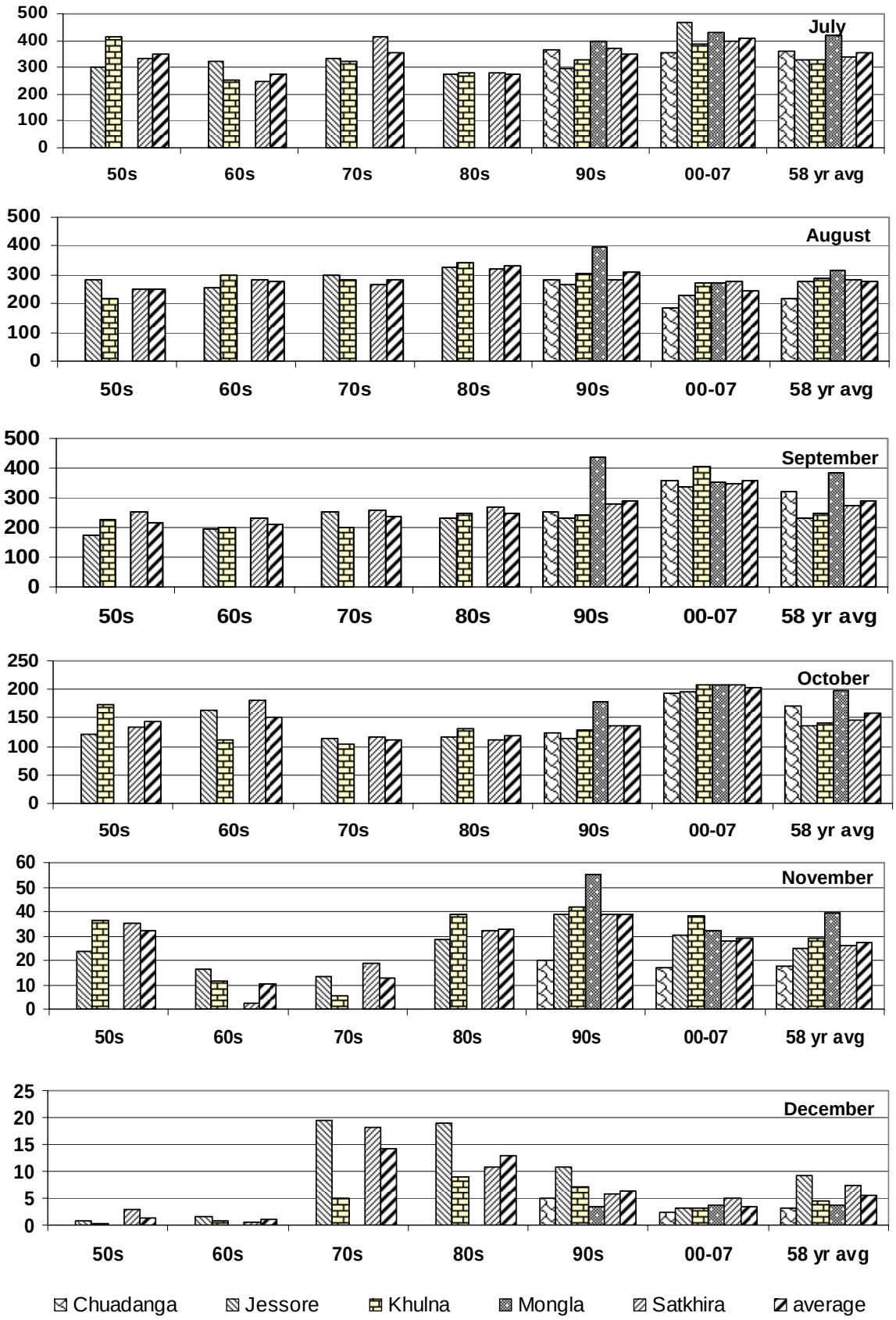


Figure B.3: Decadal Monthly average rainfall (mm) of South-West Region

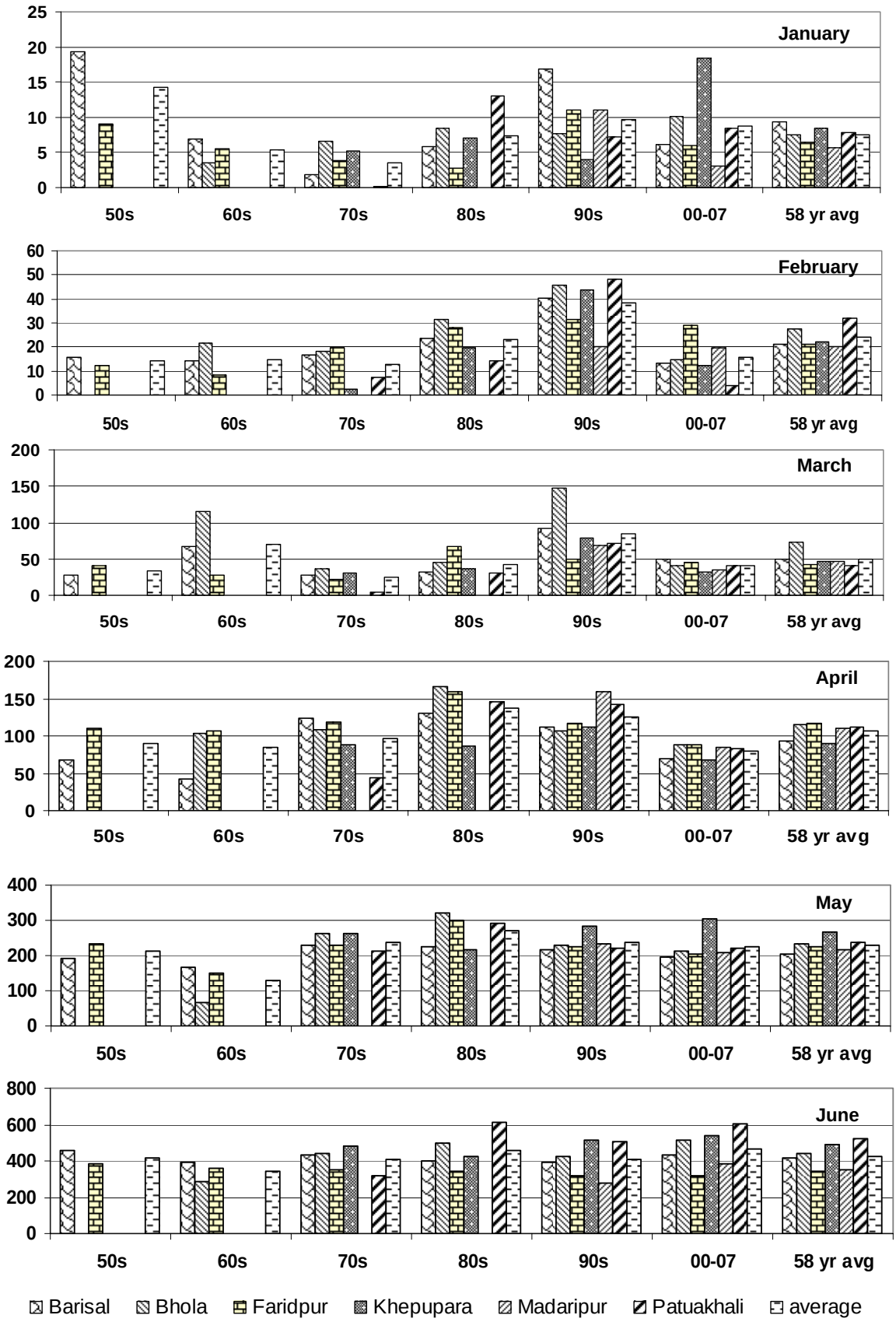


Figure B.4: Decadal Monthly average rainfall (mm) of South-Central Region

Continued…

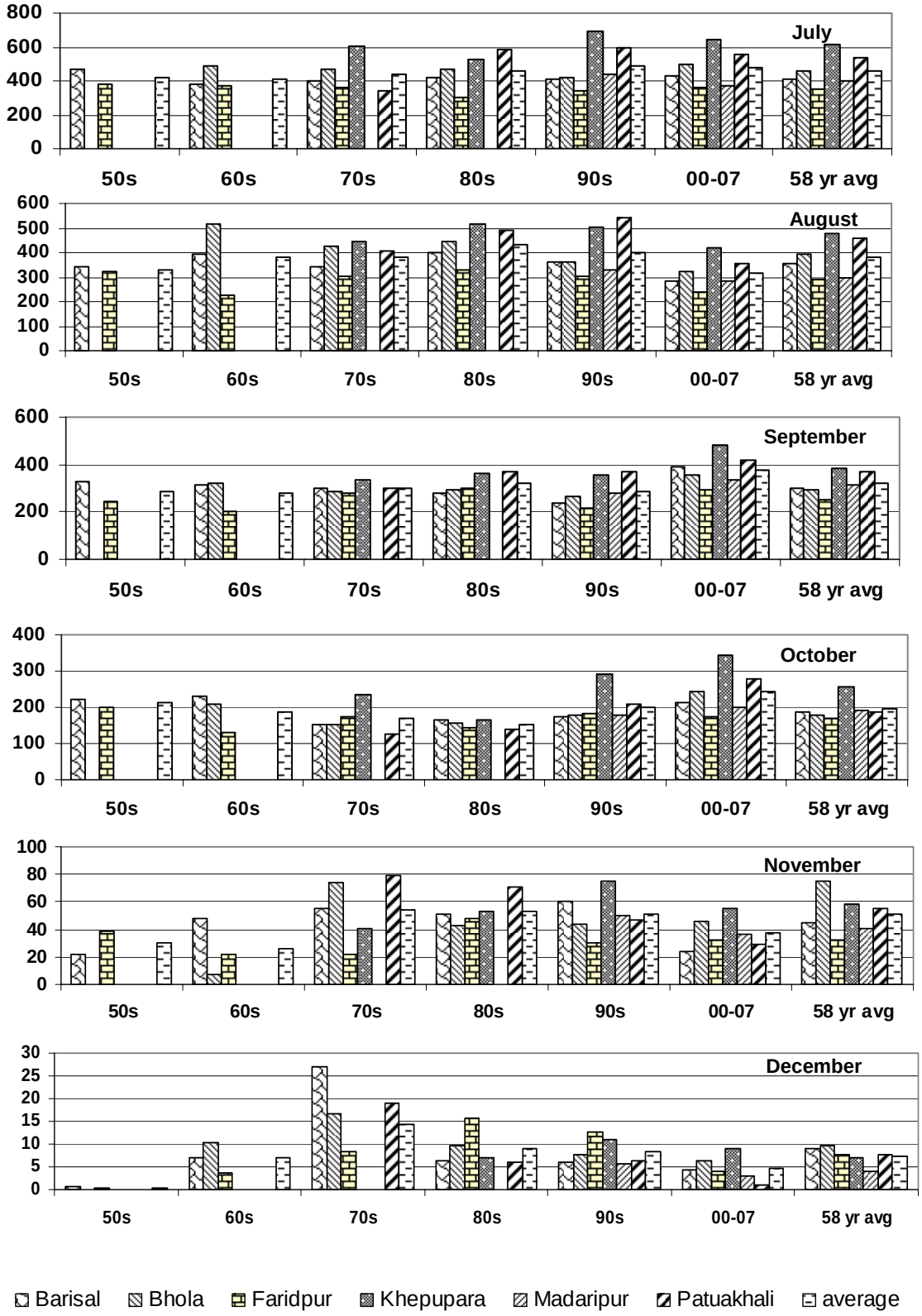


Figure B.4: Decadal Monthly average rainfall (mm) of South-Central Region

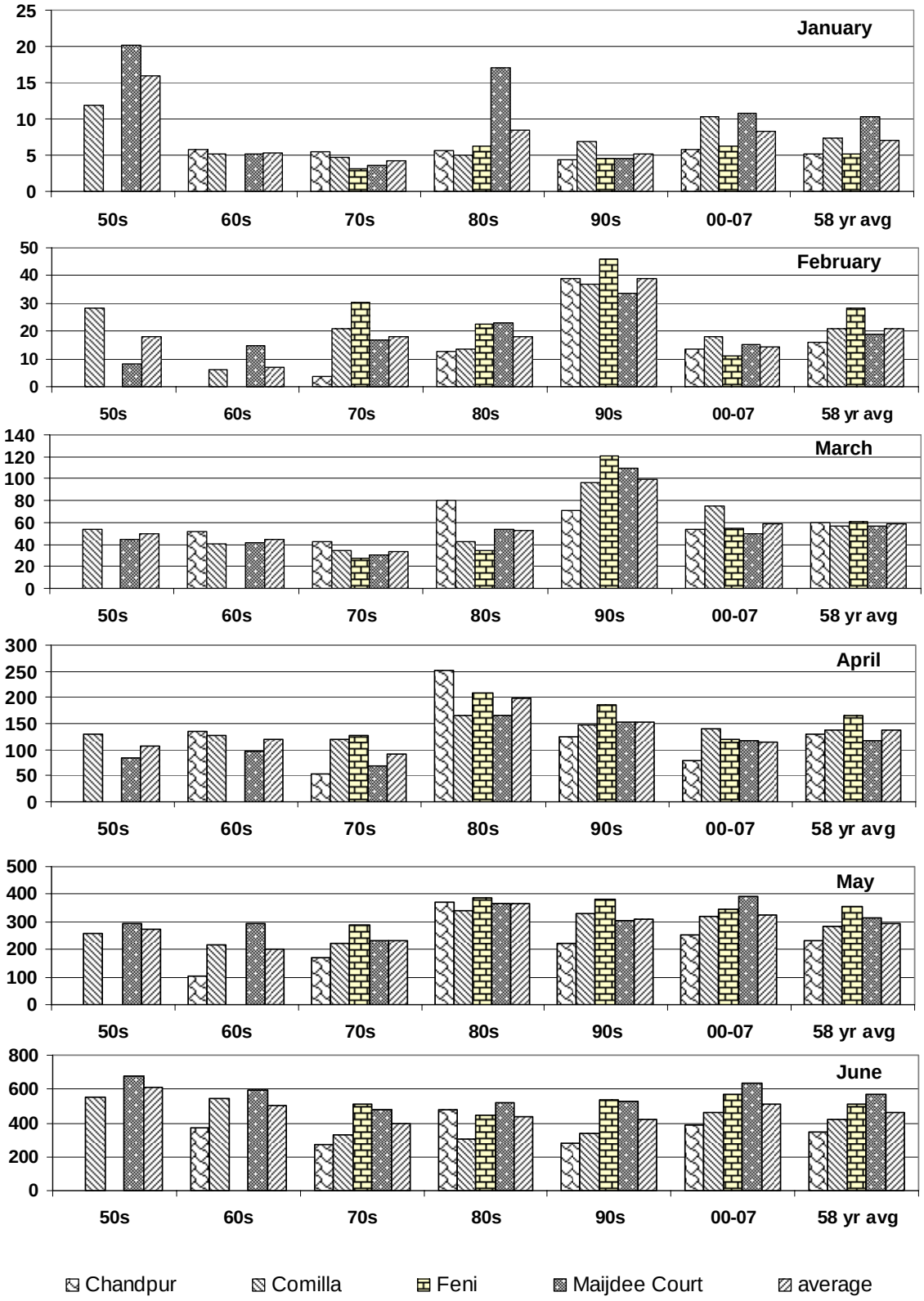


Figure B.5: Decadal Monthly average rainfall (mm) of South-East Region

Continued…

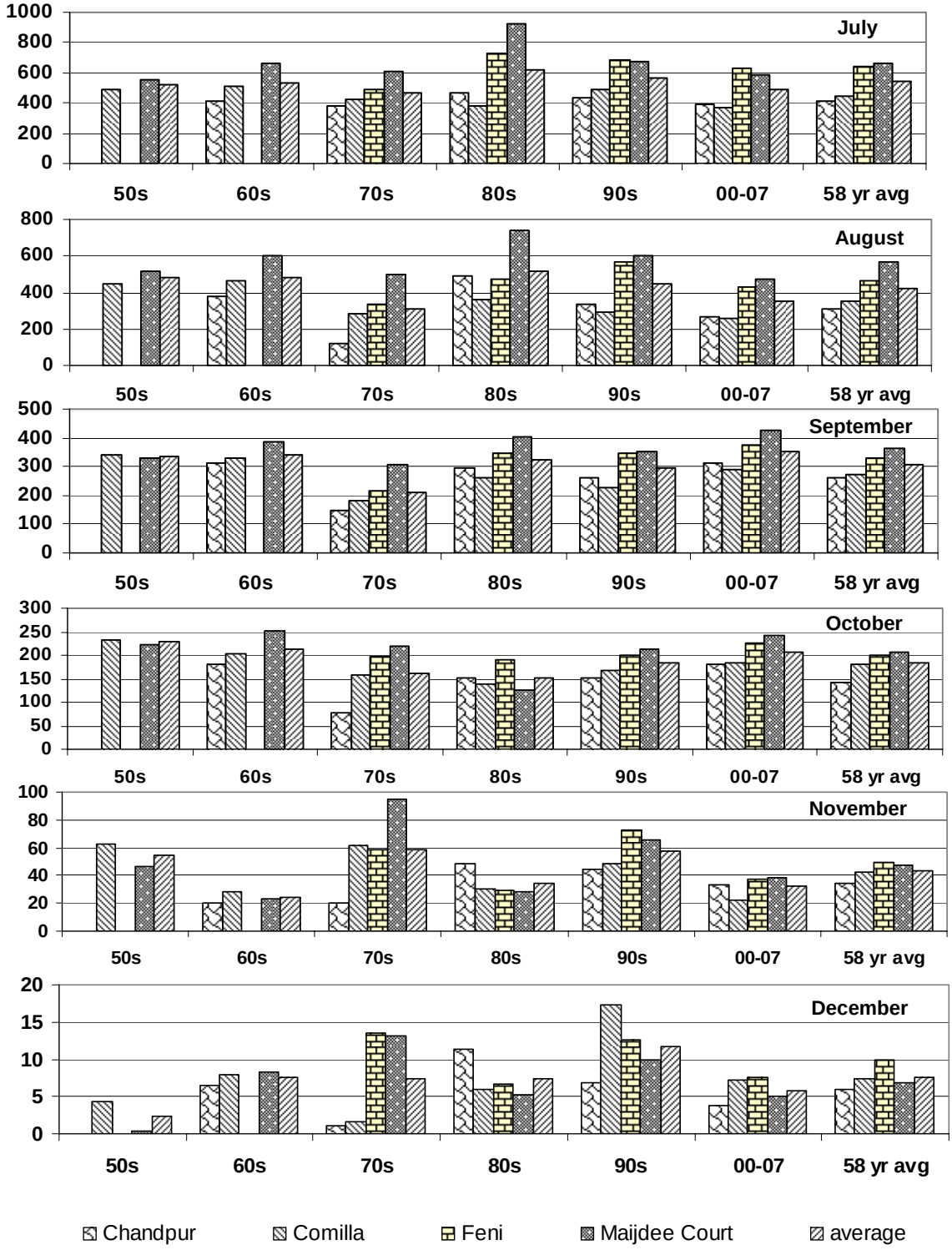


Figure B.5: Decadal Monthly average rainfall (mm) of South-East Region

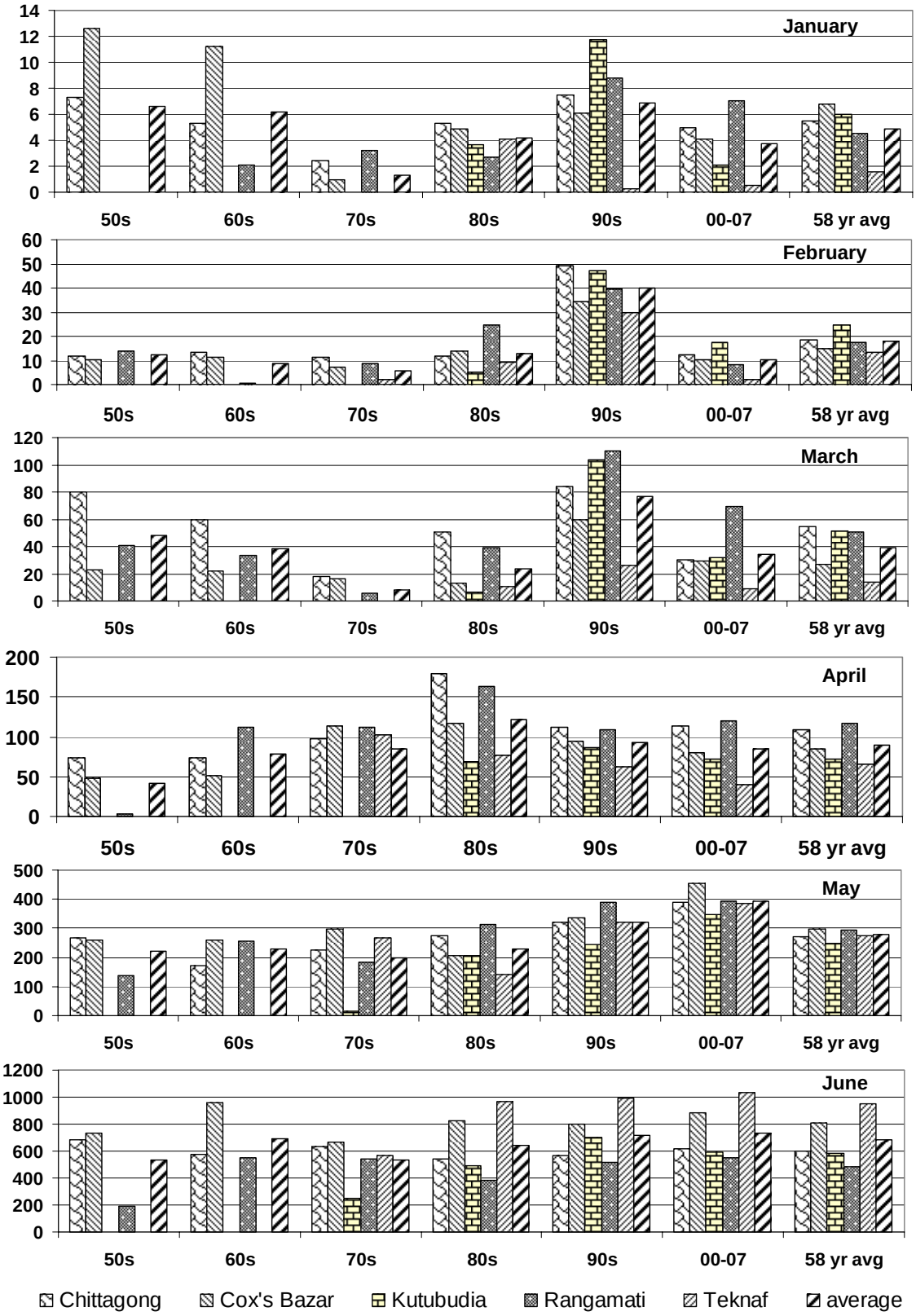


Figure B.6: Decade wise Monthly average rainfall (mm) of Eastern Hilly Region

Continued…

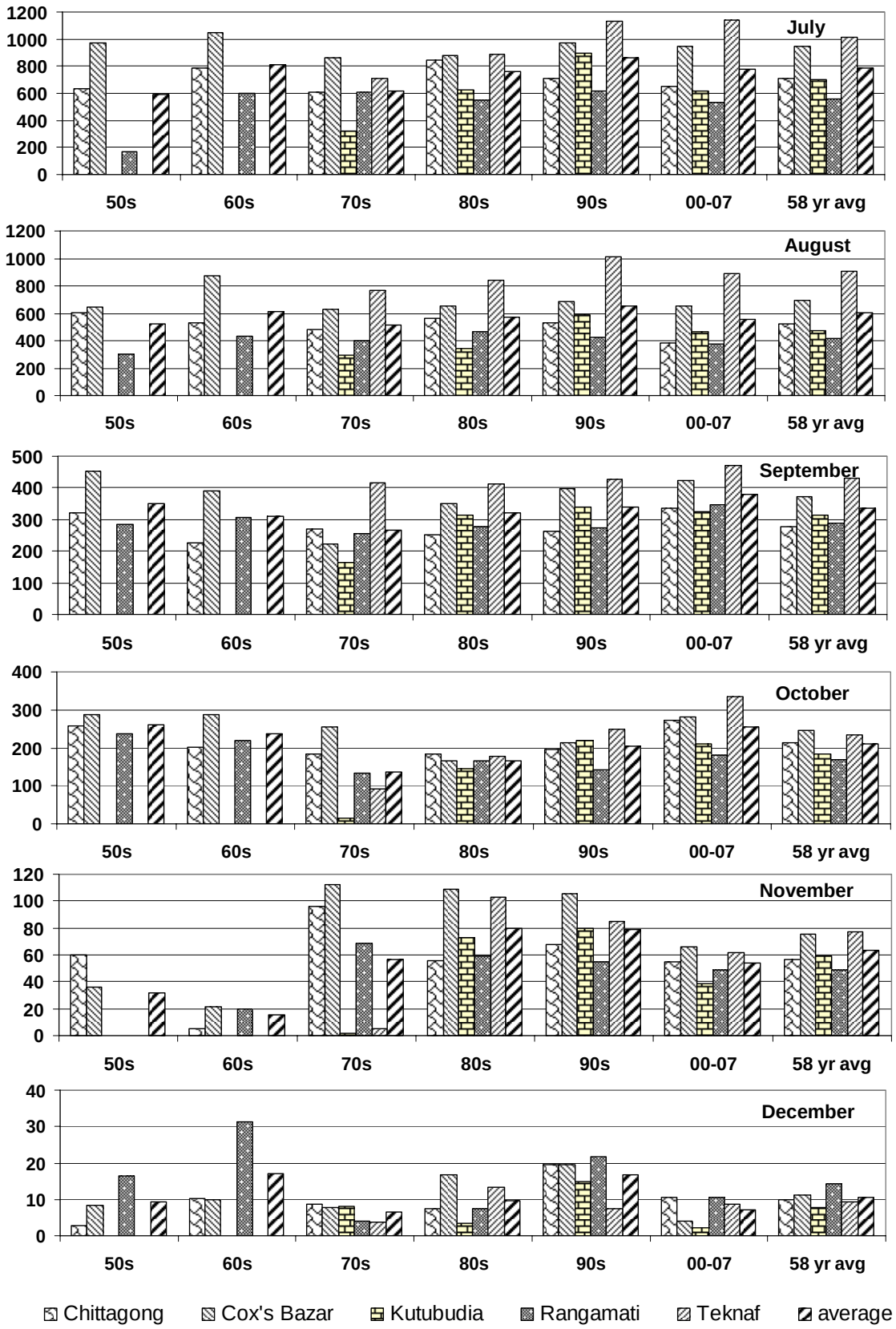


Figure B.6: Decade wise Monthly average rainfall (mm) of Eastern Hilly Region

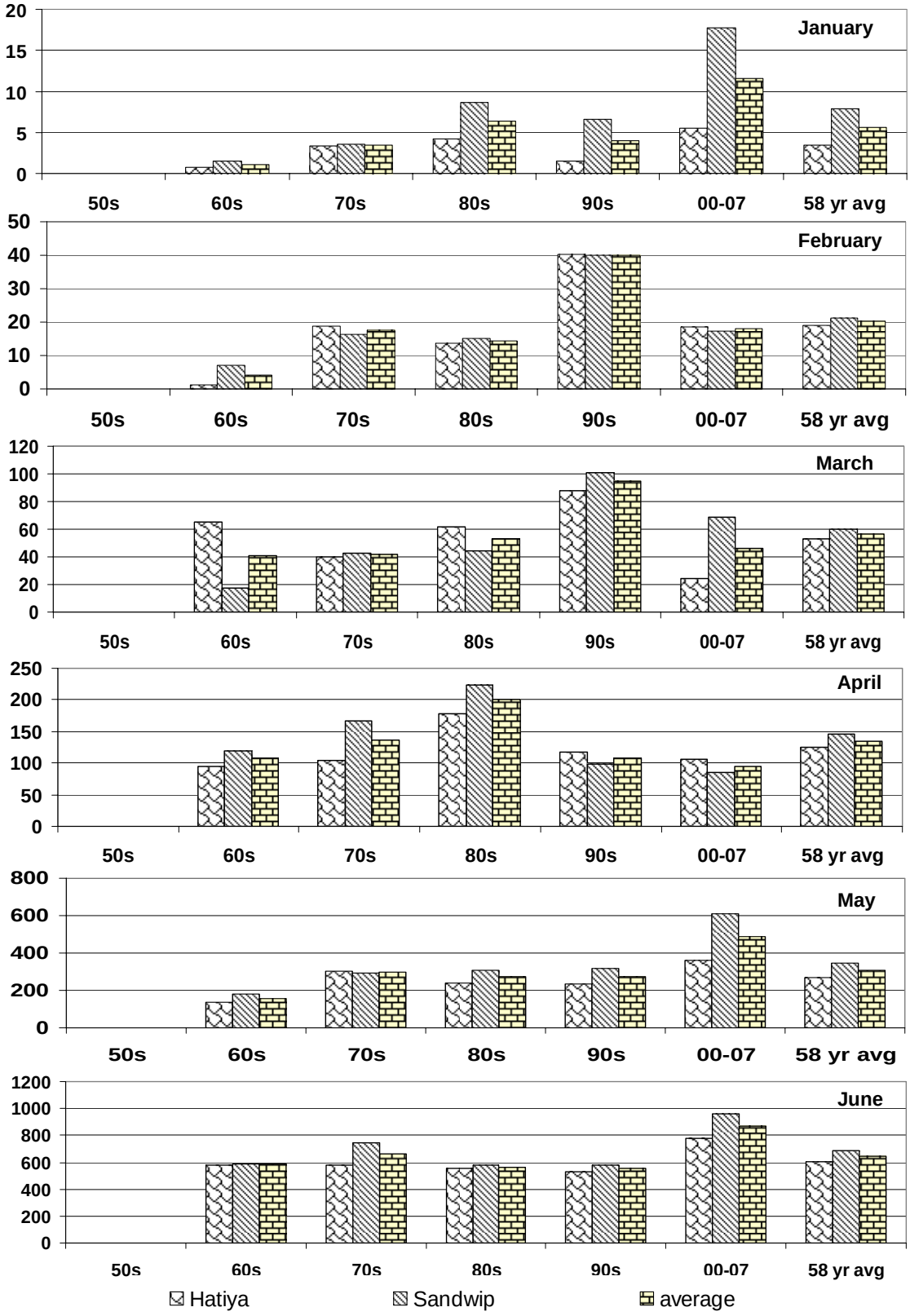


Figure B.7: Decadal Monthly average rainfall (mm) of Rivers and Estuary Region

Continued…

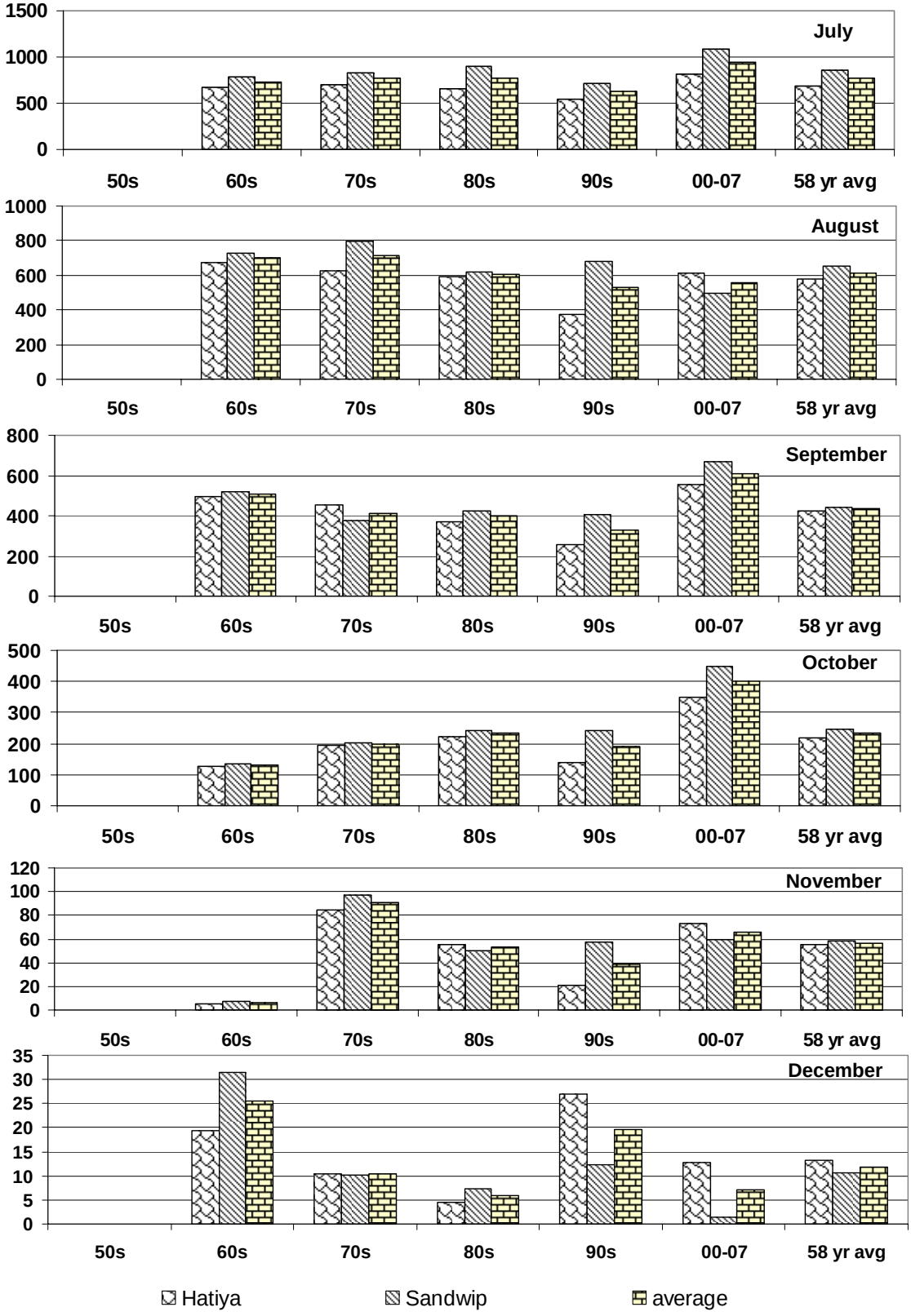


Figure B.7: Decadal Monthly average rainfall (mm) of Rivers and Estuary Region

Appendix C

Figure of Normalized change of average rainfall in eight Hydrological regions for recent 12 years (1996 to 2007) relative to long term rainfall of 58 years (1950 to 2007)

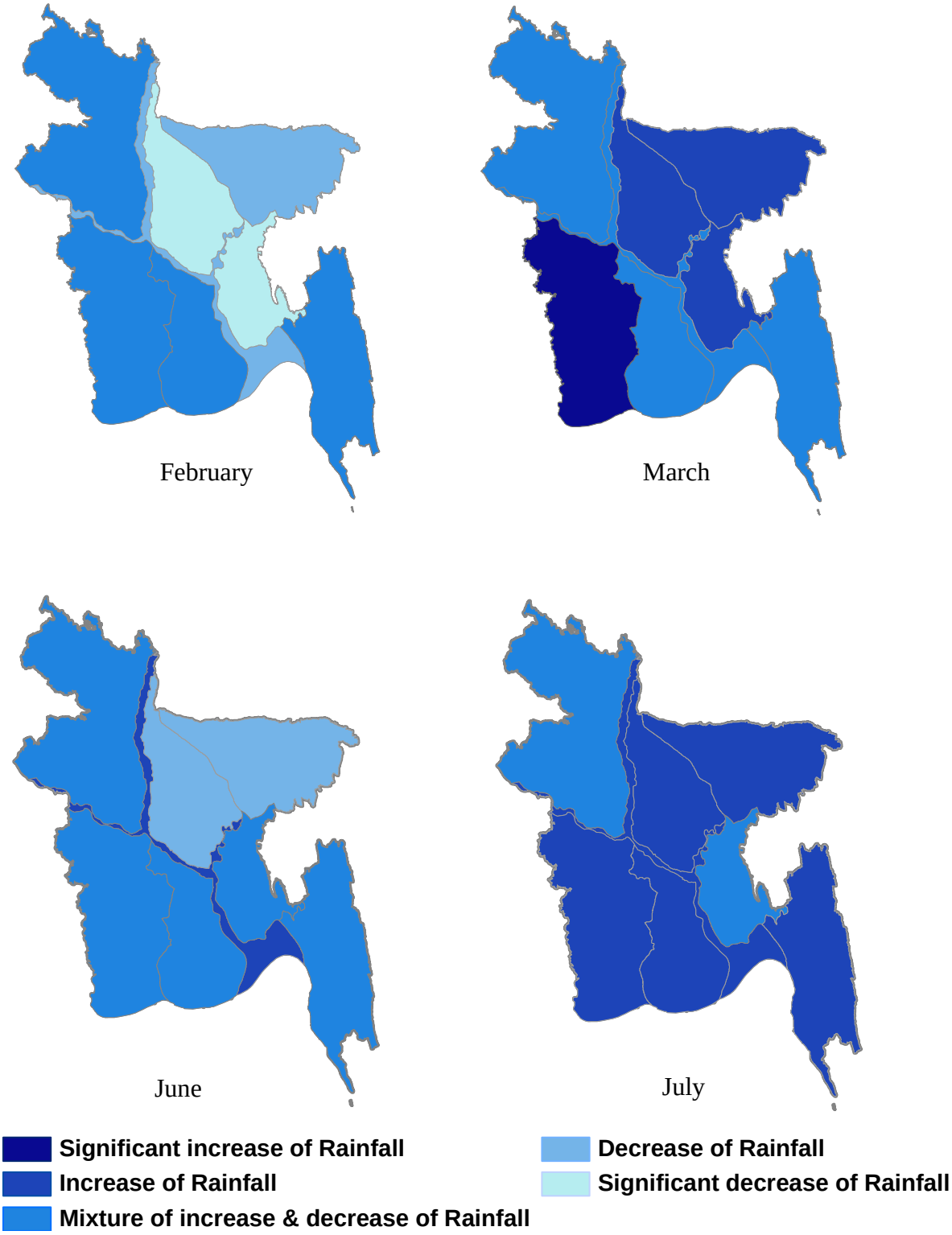


Figure C.1: Normalized change of average rainfall in eight hydrological regions for recent 12 years (1996 to 2007) relative to long term rainfall of 58 years (1950 to 2007)

Continued…

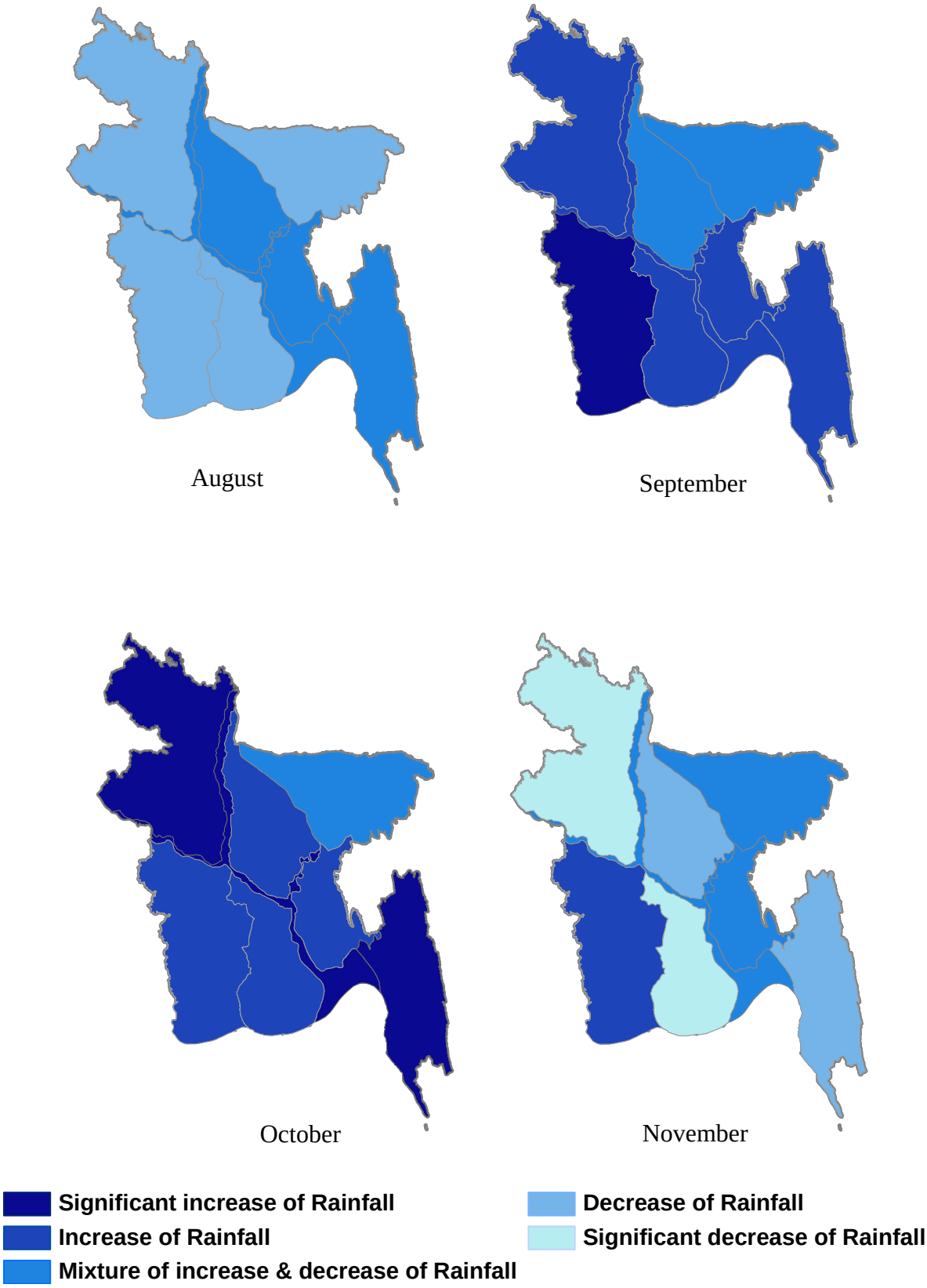


Figure C.1: Normalized change of average rainfall in eight hydrological regions for recent 12 years (1996 to 2007) relative to long term rainfall of 58 years (1950 to 2007)

Appendix D

Bar charts of Rainfall contribution in meeting Crop water requirement over recent 12 years (1996-2007) with respect to 58 years (1950-2007) for Aus rice and Wheat

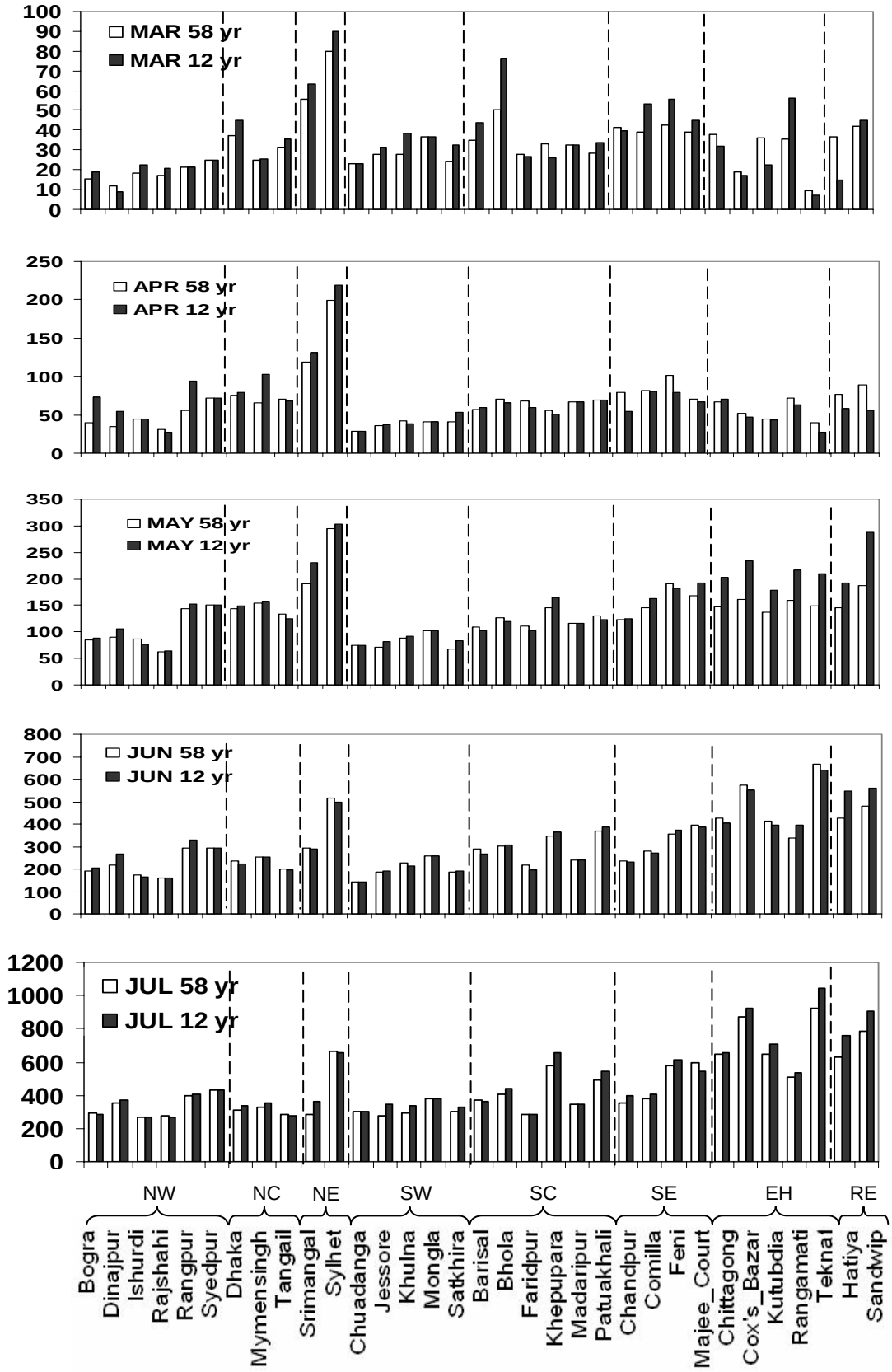


Figure D.1: Rainfall contribution in meeting Crop water requirement (Rainfall×100/ETc) over recent 12 years (1996-2007) with respect to 58 years (1950-2007) for Aus rice

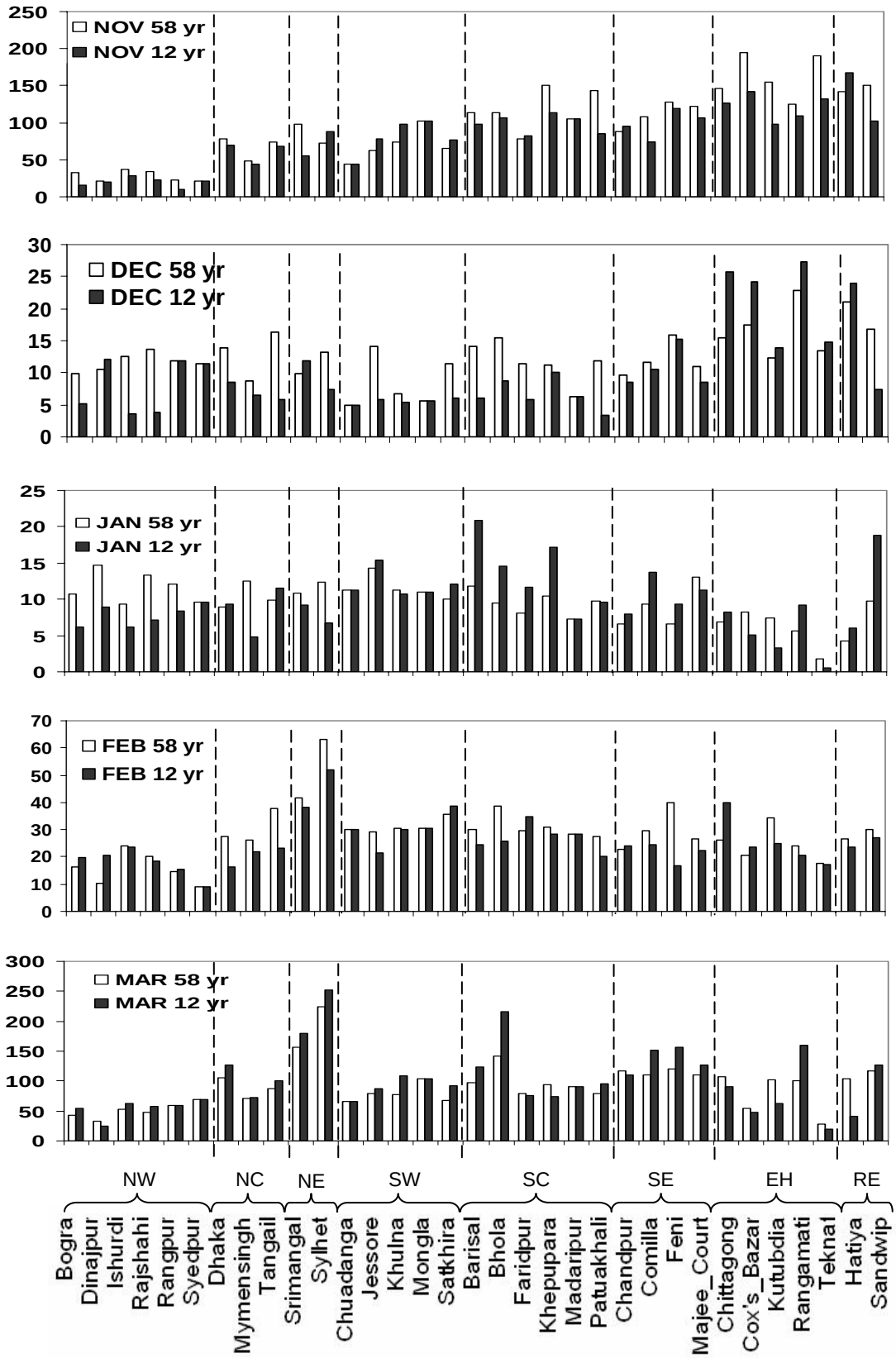
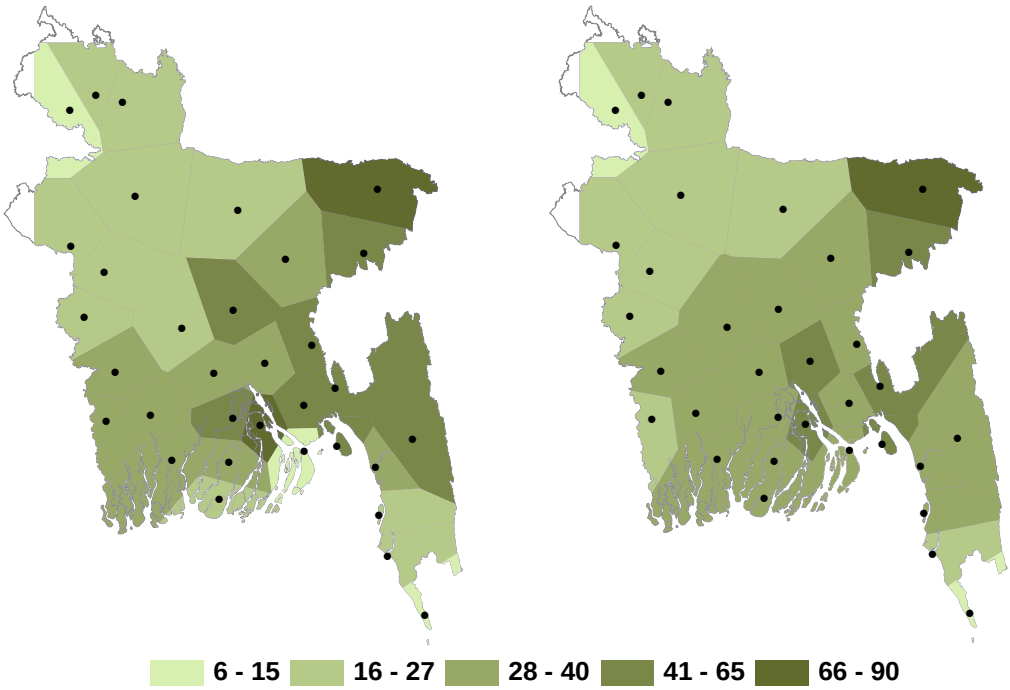


Figure D.2: Rainfall contribution in meeting Crop water requirement (Rainfall×100/ETc) over recent 12 years (1996-2007) with respect to 58 years (1950-2007) for Wheat

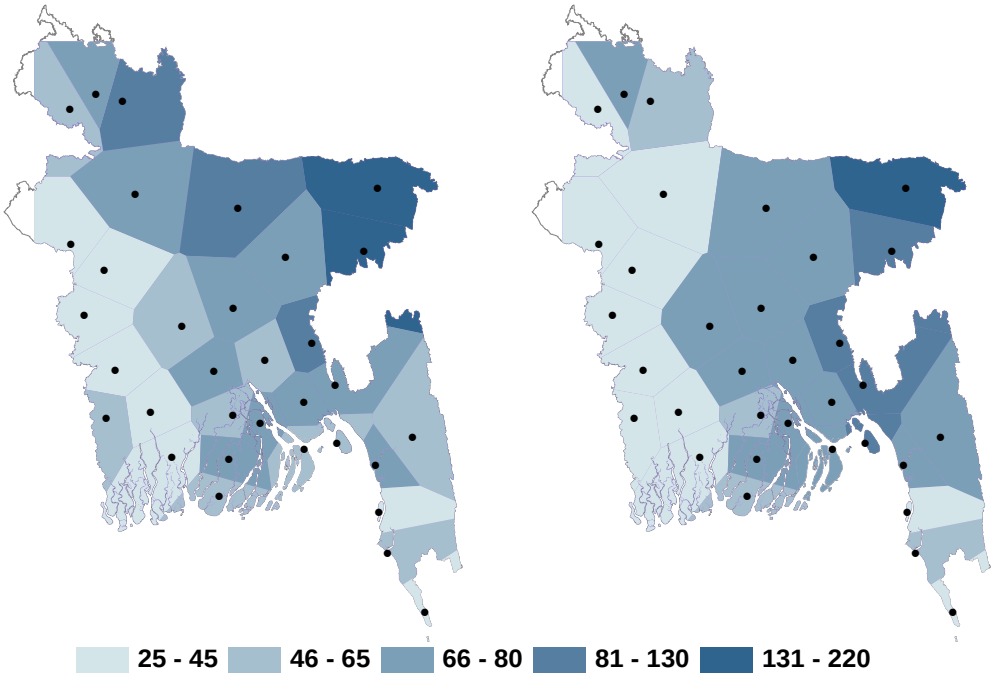
Appendix E

Figures of Rainfall contribution in meeting Crop water requirement over recent 12 years (1996-2007) with respect to 58 years (1950-2007) for Aus rice and Wheat



Mar, 12 year

Mar, 58 year



April, 12 year

April, 58 year

Figure E.1: Contribution of Rainfall (Rainfall×100/ETc) for Crop water requirement for Aus

Continued…

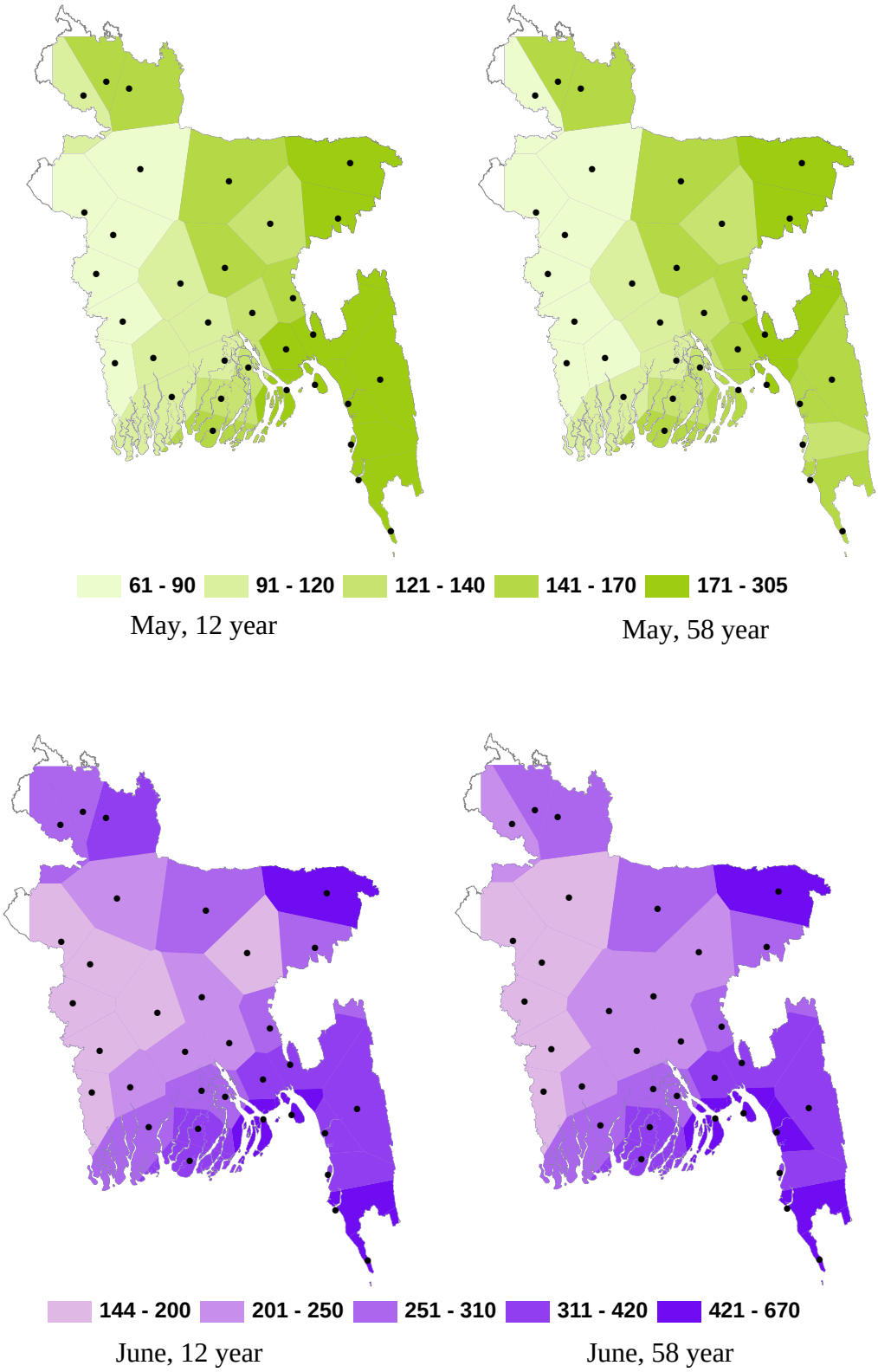


Figure E.1: Contribution of Rainfall for Crop water requirement (Rainfall×100/ETc) for Aus

Continued…

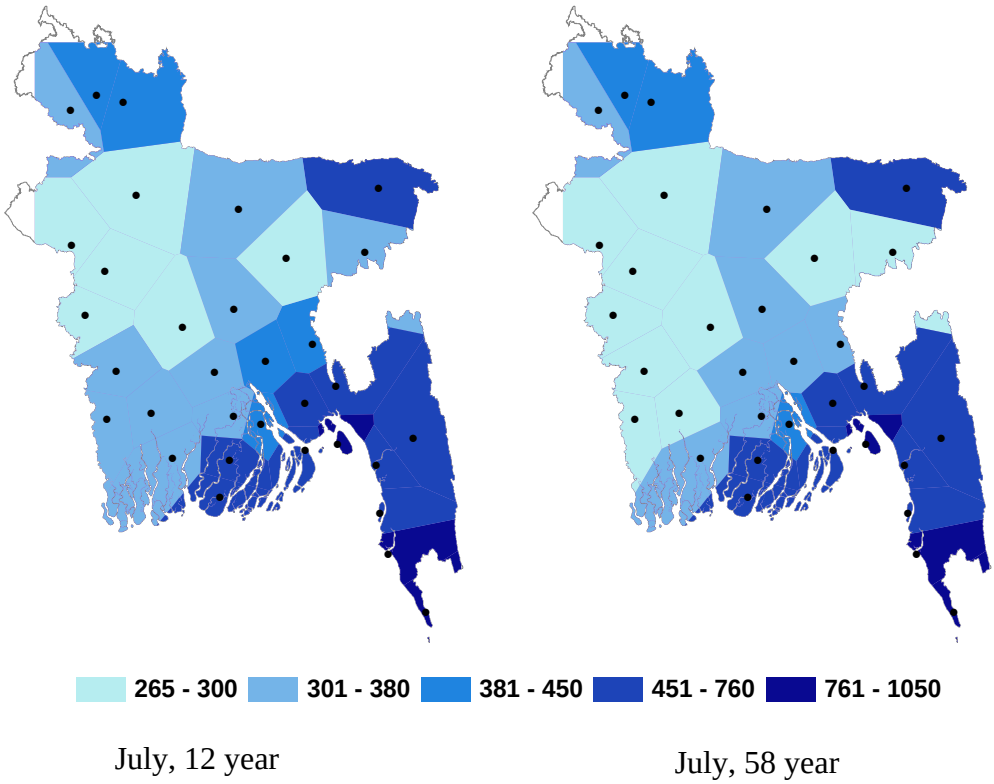


Figure E.1: Contribution of Rainfall for Crop water requirement (Rainfall×100/ETc) for Aus

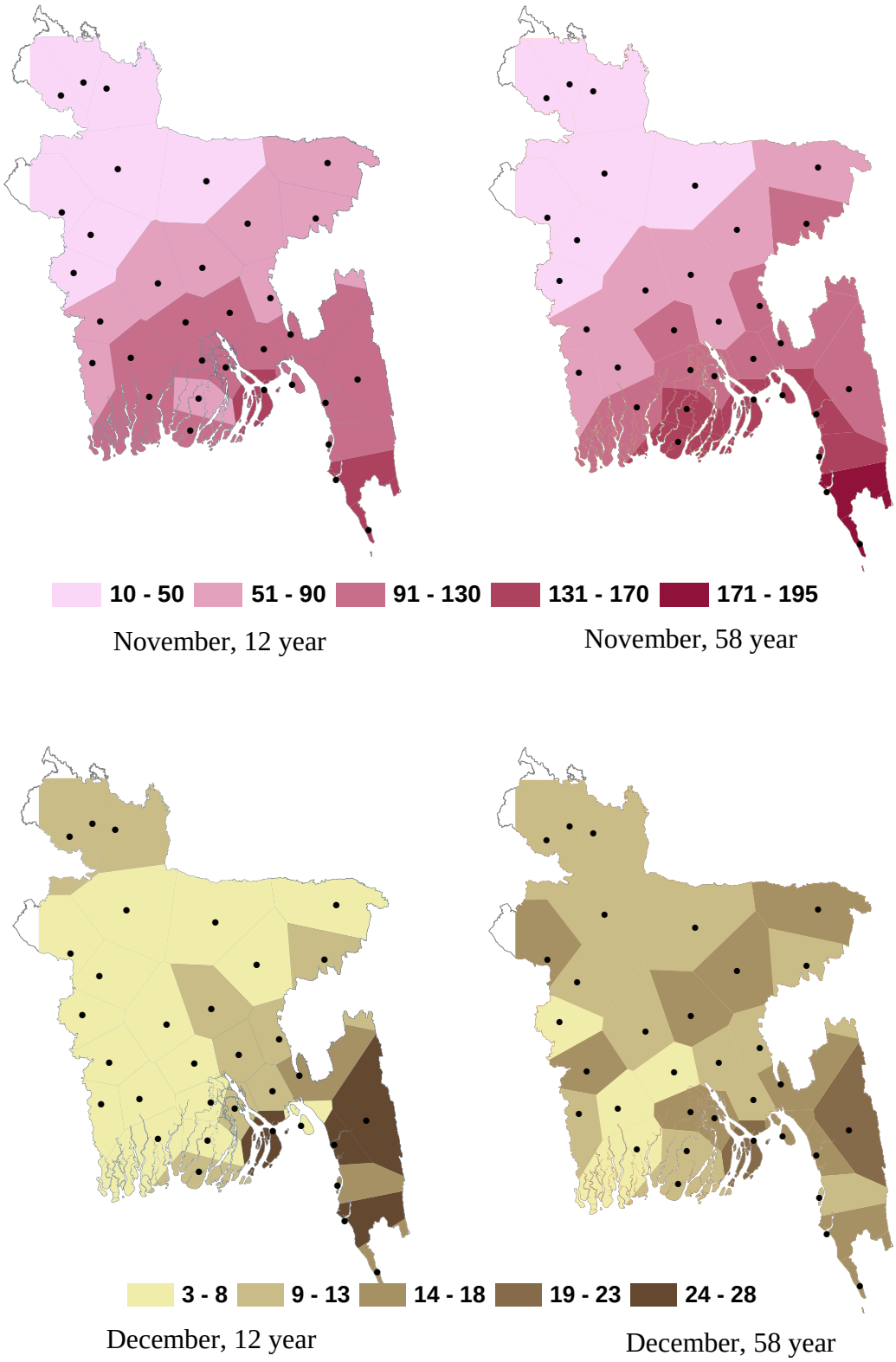


Figure E.2: Contribution of Rainfall for Crop water requirement (Rainfall×100/ETc) for Wheat

Continued…

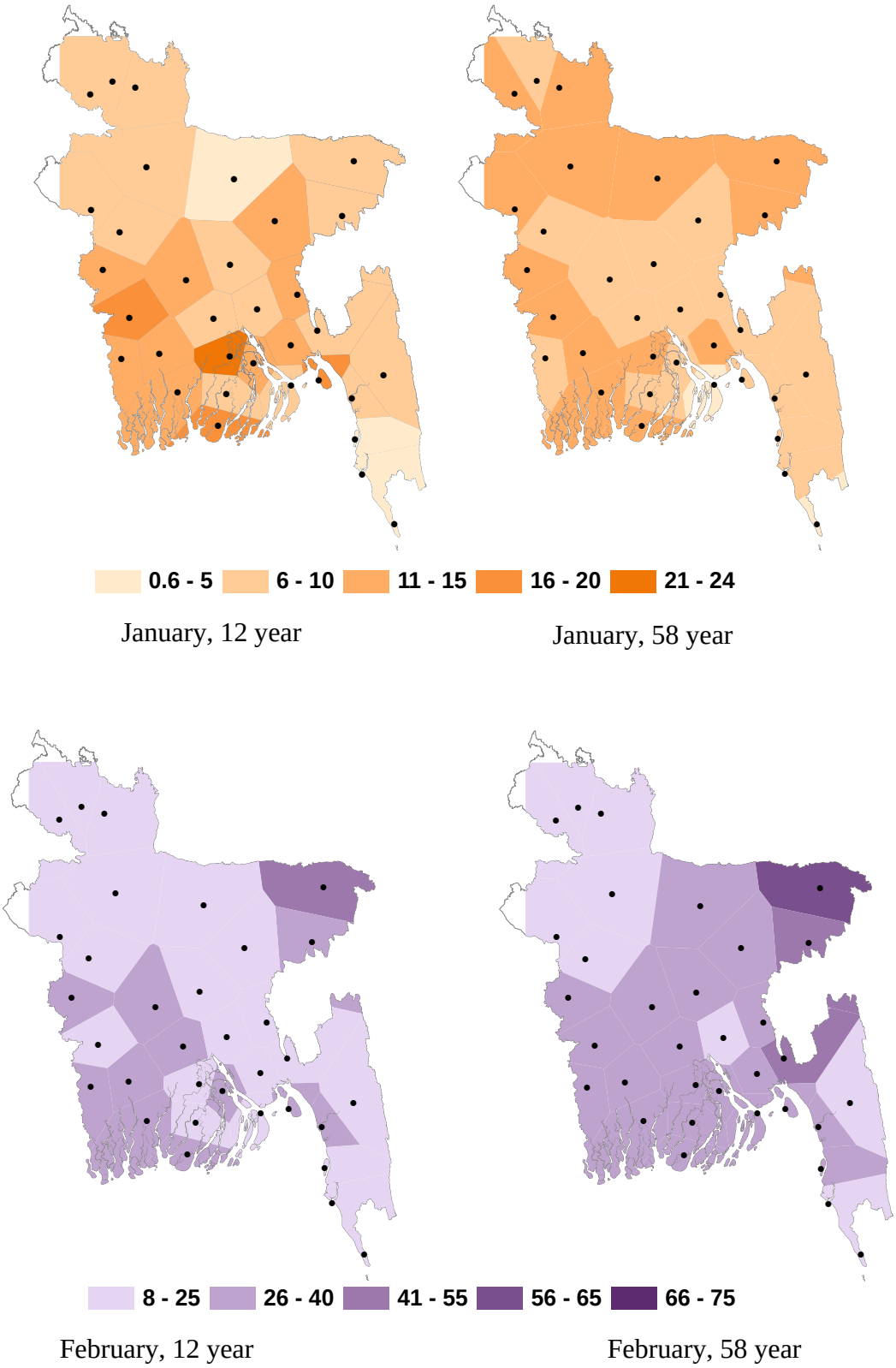


Figure E.2: Contribution of Rainfall for Crop water requirement (Rainfall×100/ETc) for Wheat

Continued…

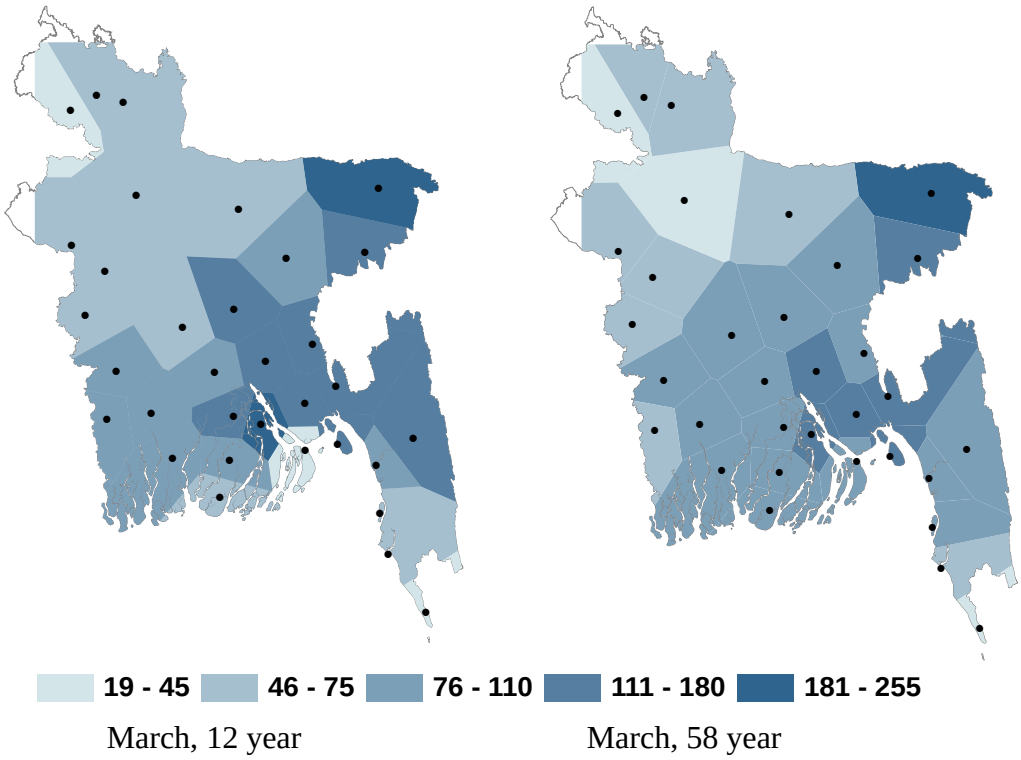


Figure E.2: Contribution of Rainfall for Crop water requirement (Rainfall×100/ETc) for Wheat

Appendix F

Figures showing Ground water level in Cropping periods of Kharif II and Rabi for consecutive five years

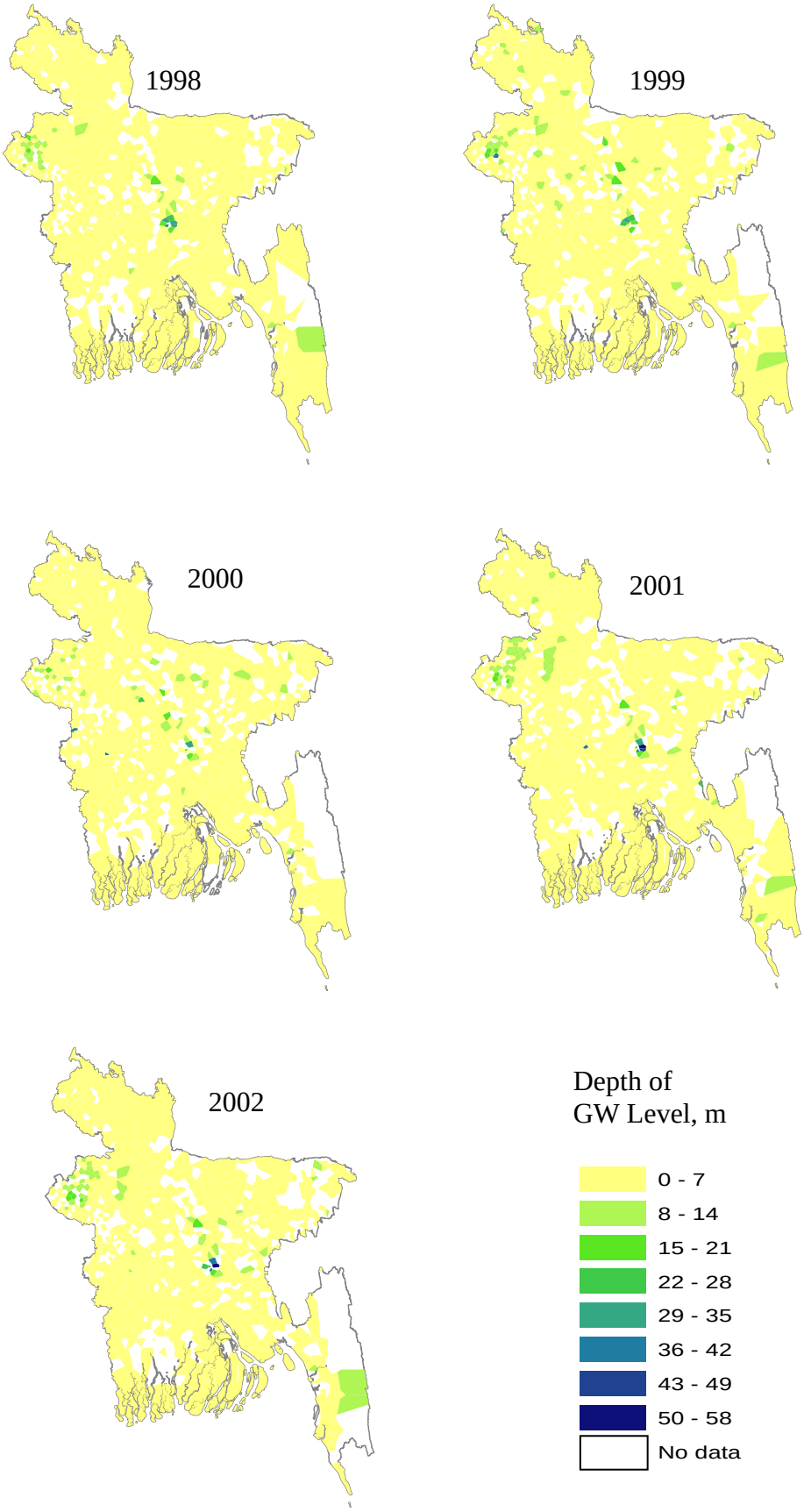


Figure F.1: Ground water level in Kharif II for consecutive five years

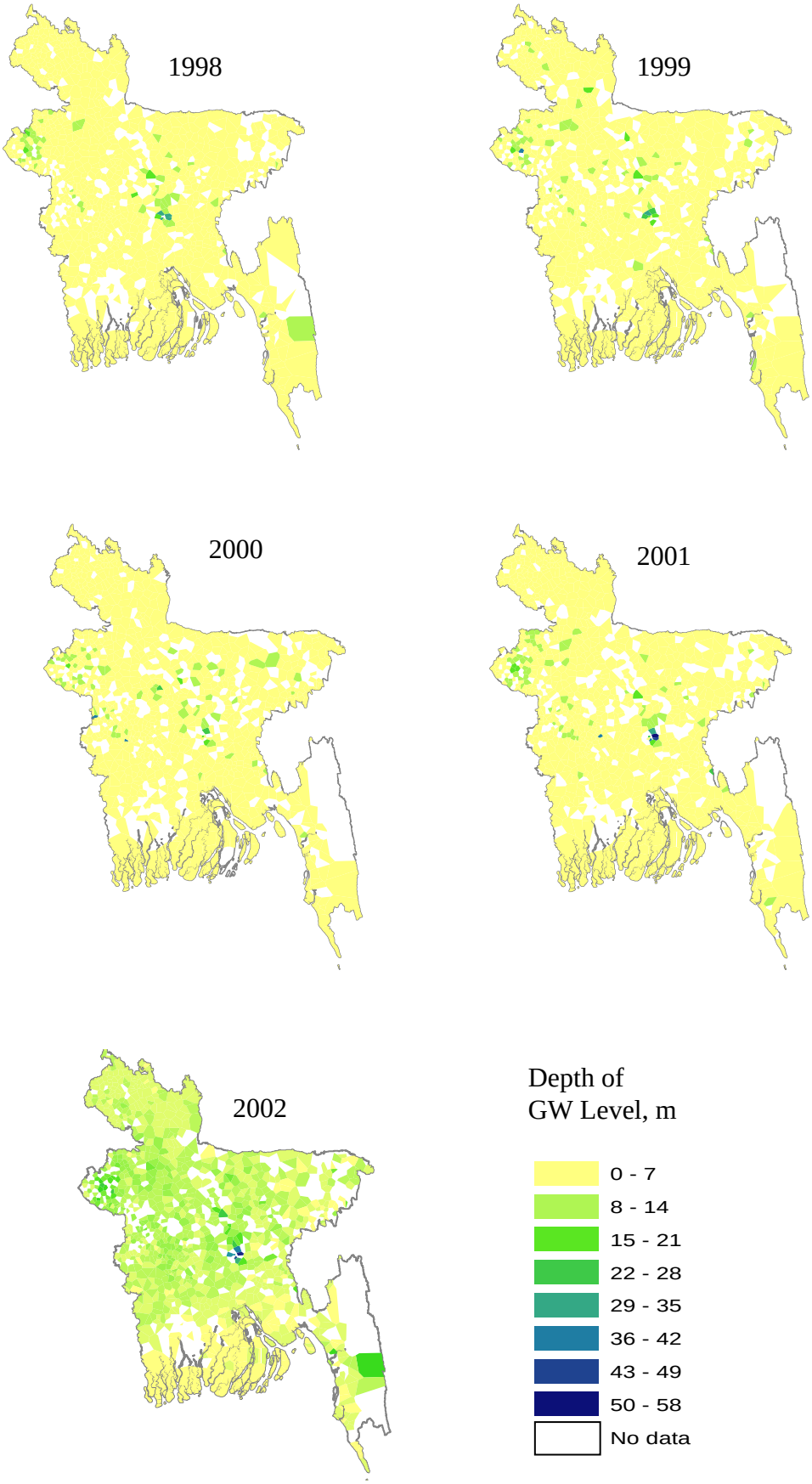


Figure F.2: Ground water level in Rabi for consecutive five years