# Physical Assessment of the Brahmaputra River

## Ecosystems for Life: A Bangladesh-India Initiative

DIALOGUE FOR SUSTAINABLE MANAGEMENT OF TRANS-BOUNDARY WATER REGIMES IN SOUTH ASIA

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Cover: A mesmerizing view of the Brahmaputra. Photo by IUCN

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# Preface

*Ecosystems for Life: a Bangladesh-India Initiative* is a civil society led multi-stakeholder dialogue process to promote better understanding and improved management of natural resources in Bangladesh and India.

Bangladesh and India share some of the world's most intricate and complex river systems. The Ganges, Brahmaputra and Meghna Rivers, along with their tributaries, drain an area of about 1.75 million square kilometres and directly impact about 620 million people. These great rivers are inseparable from the history and legends of the region, and from the people who depend upon them for their well-being. At the same time, the rivers face significant issues related to pollution, biodiversity loss, navigability and flooding, and these are exacerbated by the challenges inherent in managing trans-boundary resources.

Ecosystems for Life was designed to help deal with these issues by encouraging Track III multi-stakeholder dialogues among civil society actors. This has allowed representatives of civil society, academia, the private sector and other organizations from both countries to engage in extensive dialogue and information sharing and to produce a number of recommendations which will ultimately be fed into advocacy and policy approaches.

Specifically, the project works to develop a shared vision and understanding of food, livelihood and water security issues through collaborative research, the creation of a knowledge hub, developing research-based policy options, and enhancing the capacity of civil society stakeholders to participate in the management of natural resources.

Ecosystems for Life has been guided by a Project Advisory Committee which includes prominent professionals, legislators, diplomats, researchers and academics from Bangladesh and India who act as a bridge for the dialogue process between government and civil society at the regional level.

To date, Ecosystems for Life has focused on five main themes: the links between food security and water productivity for poverty alleviation; the impacts of climate change, adaptation methods and mitigation strategies; convergence of inland navigation and integrated water resource management; the links between economic development and environmental security; and improving understanding of ecosystems and habitats, leading to the improved conservation of flagship species.

The first phase of the project concentrated on creating 'situation analyses' for each thematic area to identify core issues and their significance within the India-Bangladesh geographic focus, research gaps and, ultimately, priority areas for joint research. The process included authors discussing and sharing their research, with the resulting material further circulated among multiple stakeholders in both countries. This analysis and consultation provided a clear agenda for meaningful joint research to be conducted by Joint Research Teams (JRT) consisting of Bangladeshi and Indian researchers.

The JRT process was an important contribution to building dialogue between the two countries, allowing researchers to present their respective points of view and build consensus and shared understanding about issues in the thematic areas. Researchers were carefully selected through an extensive and transparent process, and their diverse backgrounds led to important sharing and reflective learning. They worked with a common approach and mutually agreed methodology, communicating through the internet and face to face in workshops facilitated by the project.

This joint research study analyses available climatic and hydrological data to carry out a physical assessment of the Brahmaputra River Basin. The Brahmaputra is one of the world's largest trans-boundary river systems and provides a rich diversity of resources.

Despite its size and importance in the region, it is one of the most under-investigated and underdeveloped basins.

The main objective of this assessment was to determine the water regime and the potential climate change impacts on water availability in selected sites of the Basin. The analysis also looks at possible climate change impacts on temperature, evapotranspiration, rainfall and river flows.

Key findings from the analysis of 22 General Circulation Models (GCMs) suggest that climate change will lead to a gradual increase in temperature and evapotranspiration rates throughout the Basin. In terms of rainfall, it is projected that there will be a decrease during the winter, but an increase in the monsoon season.

The outputs from this climate modelling study were also used to simulate changes in river flows of the Brahmaputra under different emission scenarios. Preliminary results suggest that there will be a net increase in river flows over the next 50 to 100 years. This concurs with the common understanding of climate change impacts on the Brahmaputra Basin. However, the continued increase in flows by 2100 goes against the common understanding that a reduction in glacier contributions over the long term would decrease river flows.

While these outputs are projections, they provide likely indications of the direction and magnitude of change in flows of the Brahmaputra. Unlike previous assessments which used only a single GCM, the fact that the study was based on 22 GCMs rather than a single model provides policy makers with a broad picture of potential impacts.

Ecosystems for Life has successfully demonstrated fruitful research collaboration between India and Bangladesh in the field of water resources. For international river basins such as the Brahmaputra, joint research projects like this one can lead to a better understanding of water resource systems and of the way they can change under climate change scenarios.

This report also opens the ways ahead for further study of the Brahmaputra River Basin, particularly in the areas of snowmelt research, additional joint modelling studies, and including water demand projections in the basin model. There is clear scope for future collaborative research in these areas, which can benefit the unique ecosystems and dependent livelihoods in the region.

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# Executive Summary

The Brahmaputra River is one of the largest river systems in the world. Yet it is also one of the most under-investigated, underdeveloped basins. This study analyzed available climatic , and hydrologic data to carry out a physical assessment of the basin. The analysis also looked at possible climate change impacts on temperature, evapotranspiration, rainfall, and river flows in the basin.

By analyzing the outputs from twenty two General Circulation Models (GCMs), it was found that:

- Temperatures are expected to increase from 1.3°C to 2.4°C by 2050, and from 2.0°C to 4.5°C by 2100 in the basin;
- Monthly evapotranspiration is likely to increase by 5% to 18% by 2050, and from 7% to 36% by 2100, especially in the months of winter;
- Average change in monthly rainfall are likely to vary from 14% decrease to 15 % increase by 2050, and 28 % decrease to 22 % increase by 2100;
- Average monthly flow at a downstream station at Chilmari in Bangladesh is expected to change by -1% to 15% by 2050, and by 5% to 20% by 2100; and
- Generally, A1B[1] and A2 impact predictions are similar, which tend to be more severe than impacts in the B1 emission scenario.

The predicted climatic changes derived from the GCMs were then used as inputs to a basin model, which was based on the MIKE Basin software package. The mathematical model was used to simulate the changes in river flows for the three emission scenarios. The overall increase in flows throughout the year is driven by significant increase in monsoon flows arising from increased rainfall, higher snow melt rates, and increased run off generating areas (as snow melt zone shifts to higher latitudes due to climate change, revealing more surface areas). During monsoon, the average increase in monthly flows may vary from 3% to 9% by 2050 across the three emission scenarios, and by 7% to 16% by 2100. In the dry season, the average increase in monthly flows varies by similar amounts (2% to 11% by 2050, and 8% to 15% by 2100). The increase in flows by 2050 concurs with common understanding of climate change impacts in the Brahmaputra Basin. However, the continued increase in flows indicated by 2100 does not support the common understanding that reduction in glacier contributions over the long term would have a decreasing impact on flows. This highlights the large uncertainties associated with long term climate change impact estimates. It is also important to note that apart from greenhouse gas emissions, there are other first-order drivers of climate change such as land use, and land cover changes that play significant roles. The numerous interactions between land, atmosphere, and human activities often make long-term projections undependable. However, our results are based on the collective projections of 22 GCMs, which give an indication of the possible direction, and magnitude of change in river flows.

When undertaking physical assessments of river systems, it is important to keep in mind contextual issues such as population growth, land use changes, dams, and diversions, etc. For international river basins such as theBrahmaputra Basin, joint research projects, and collaboration between scientists from riparian countries can lead to a better understanding of the water resources systems, and how it can change in the future. This project has successfully demonstrated that fruitful collaboration is possible between researchers of India, and Bangladesh in the field of water resources. It is recommended that further joint data collection, and analyses studies be undertaken.

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[1] A1B scenario assumes very rapid economic growth, a global population that peaks in mid-century and rapid introduction of new and more efficient technologies with balance across all energy sources – this scenario is considered as the most likely. A2 describes a very heterogeneous world with high population growth, slow economic development and slow technological change – this scenario is normally seen as worst case. B1 describes a convergent world, with the same global population as A1 but with more rapid changes in economic structures toward a service and information economy – the scenario is normally seen as best case.

# 1

# Introduction

## 1.1 Background

The project aims to improve integrated management of riverine ecosystems in South Asia through dialogue, research and advocacy efforts. The joint Project Advisory Committee (PAC) oversees implementation of the E4L initiative, and acts as a bridge for the dialogue process between government, and civil society at the regional level. The Ecosystems for Life: A Bangladesh-India Initiative is a project led by the IUCN to promote insights into transboundary issues across the three major river systems: the Ganges, the Brahmaputra, and the Meghna.

IWM is a Trust established by the Government of Bangladesh in December 1996, to function as a Centre of Excellence, and Learning in the field of Computational Hydraulics, Water Modelling, and Allied Sciences. IWM has more than 20 years of experience in mathematical modelling in the field of water resources, and in carrying out National Macro Level Planning Studies using Mathematical Modelling tools. IWM has successfully provided Support Services to National Flood Action Plan (FAP), Development of Flood Forecasting & Warning System of Bangladesh, and in the preparation of the National Water Management Plan (NWMP). IWM has developed a suite of mathematical models at the national, and at the level of Ganges-Brahmaputra-Meghna (GBM) region. These models are routinely used for planning, and management of water resources in Bangladesh. The model of the GBM region has been used for water resources assessment of the GBM basins, climate change impact studies, study of the impacts of different development scenarios in the basin on water availability, salinity intrusion, flooding, and river morphology. IWM is the single source of modelling technology, and expertise in Bangladesh. The government of Bangladesh has issued a circular to this effect.

Indian Institute of Technology (IIT) Guwahati is the premier institute of engineering, science, and technology in the north-eastern region of India, with a growing list of accolades earned nationally, and internationally. The Institute has eleven departments, and three inter-disciplinary academic centres, covering all the major engineering, science and humanities disciplines, offering BTech, BDes, MA, MDes, MTech, MSc and PhD programmes. IIT Guwahati has world class infrastructure for carrying out advanced research and has been equipped with state-of-the-art scientific and engineering instruments and laboratories. Water resources and hydraulics engineering are specialized research fields in the Department of Civil Engineering. Some of the particular research areas under this specialization include meso-scale distributed hydrological modelling, satellite remote sensing and GIS based water resources modelling and management, computational river hydraulics and its applications, watershed and irrigation management, flow through porous media, stochastic sub-surface hydrology, rainfall modelling, modelling & simulation in free surface flow, heuristic method in reservoir optimization, and dam break analysis.

## 1.2 Study Objectives

The main objective of this Physical Assessment is to determine the water regime and the potential climate change impacts on water availability, in selected sites of the Brahmaputra River Basin. Specific objectives include the following:

- Using existing data, identify current potential annual flow regime (amount and variability), identify types of water users, their annual water use and identify knowledge gaps where information are missing;
- Assess the water availability for a number of potential climate change projection[2] scenarios for both wet

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[2] “A climate projection is usually a statement about the likelihood that something will happen several decades to centuries in the future if certain influential conditions develop. In contrast to a prediction, a projection specifically allows for significant changes in the set of boundary conditions, such as an increase in greenhouse gases, which might influence the future climate. As a result, what emerge are conditional expectations (if this happens, then that is what is expected). For projections extending well out into the future, scenarios are developed of what could happen given various assumptions and judgments.” http://www.wmo.int/pages/themes/climate/climate_projections.php

and dry seasons;

- Identify the main potential climate change impacts on water availability;
- Technical assessment with model results, on climate change implications for various scenarios, to other groups responsible for assessment of food security, water productivity, poverty assessment and adaptation measures to mitigate the adverse impacts.

So far, existing GCM-centric studies have focused on one type of outputs but this study provides a composite appraisal. Policy-makers can have a broader picture compared to impacts of individual GCMs. Beneficiaries of this joint research study are mainly policy makers, researchers, etc.

## 1.3 Scope of Study

The scope of the study was:

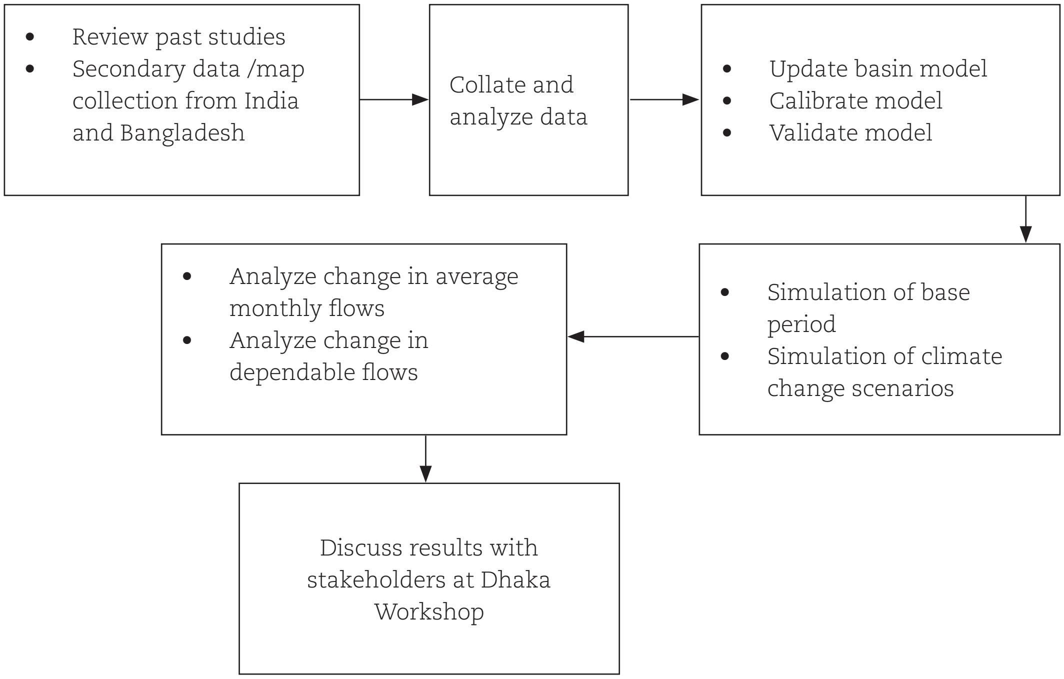
- Define the extent of the study area;
- Review of available data and literature relevant to physical assessment of the Brahmaputra Basin;
- Customization and updating of Brahmaputra River Basin model – which is a GIS-based hydrological water balance model;
- Formulation of climate change scenarios and model simulations; and
- Multi-stakeholder dialogue and reporting.

## 1.4 Study Approach and Methodology

The overall study approach and methodology is shown in Figure 1.1. The study is mainly based on basin level modelling, which is based on collection and analyses of secondary data. After setting up the model, several simulations were carried out for the base period (no climate change) and the scenarios with climate change. The physical assessment of the basin was then based on the change in average monthly flows and also variations in dependable flows. The key findings from this study were discussed at a workshop in Dhaka with stakeholders and researchers from other parts of the Ecosystems for Life project.

**Figure 1.1**

**Overall Study Approach and Methodology**



## 1.5 Report Structure

In the next section, the basin setting is described, with emphasis on its physical features. In Section 3, a review of the available literature is provided, with a focus on climate change related studies. The data collected and analyses undertaken are summarized in Section 4. Sections 5 and 6 provide a summary of climate change model predictions for temperature, rainfall and evapotranspiration in the Brahmaputra Basin. Section 7 describes the modelling work undertaken in this study. The model results are provided in Section 8, with relevant discussions. The final section provides conclusions and recommendations from this study.

# 2

# Basin Setting

## 2.1 Overview

The old Sanskrit name of the river Brahmaputra is Lauhitya; however the local name in Assam is *Luit*. The native inhabitants like the *Bodos* called the river *Bhullam-buthur* that means 'making a gurgling sound'. This name was later Sanskritized into Brahmaputra (www.srimanta.net). The Brahmaputra river of South Asia is the fourth largest river in the world in terms of annual discharge. Average discharge of the Brahmaputra is approximately 20,000$m^3/s$ (Immerzeel, 2008). The river has an average annual sediment load of about 735 million metric tonnes, and a specific flood discharge of 0.149 $m^3/s/km^2$ (Datta and Singh 2004).

The Brahmaputra valley in Assam (India) is long and narrow; it is 640 km long and the width varies from 64 km to 90 km (Datta and Singh 2004). The valley is bounded in the north by high Himalayan mountain ranges, in the east by the Patkai hill ranges, in the south by the lower (Assam) hill ranges and in the west, it is contiguous with the plains of Bangladesh. Figure 2.1 shows the Brahmaputra basin area. The Indian and Bangladesh portions of the basin are shown in more detail in Figure 2.2 and Figure 2.3, respectively.

The Brahmaputra River drains an area of around 580,000$km^2$, covering four countries (% of total catchment area in brackets): China (50.5%), India (33.6%), Bangladesh (8.1%) and Bhutan (7.8%). Its basin in India is shared by Arunachal Pradesh (41.88%), Assam (36.33%), Nagaland (5.57%), Meghalaya (6.10%), Sikkim (3.75%) and West Bengal (6.47%) (Singh et al 2004).

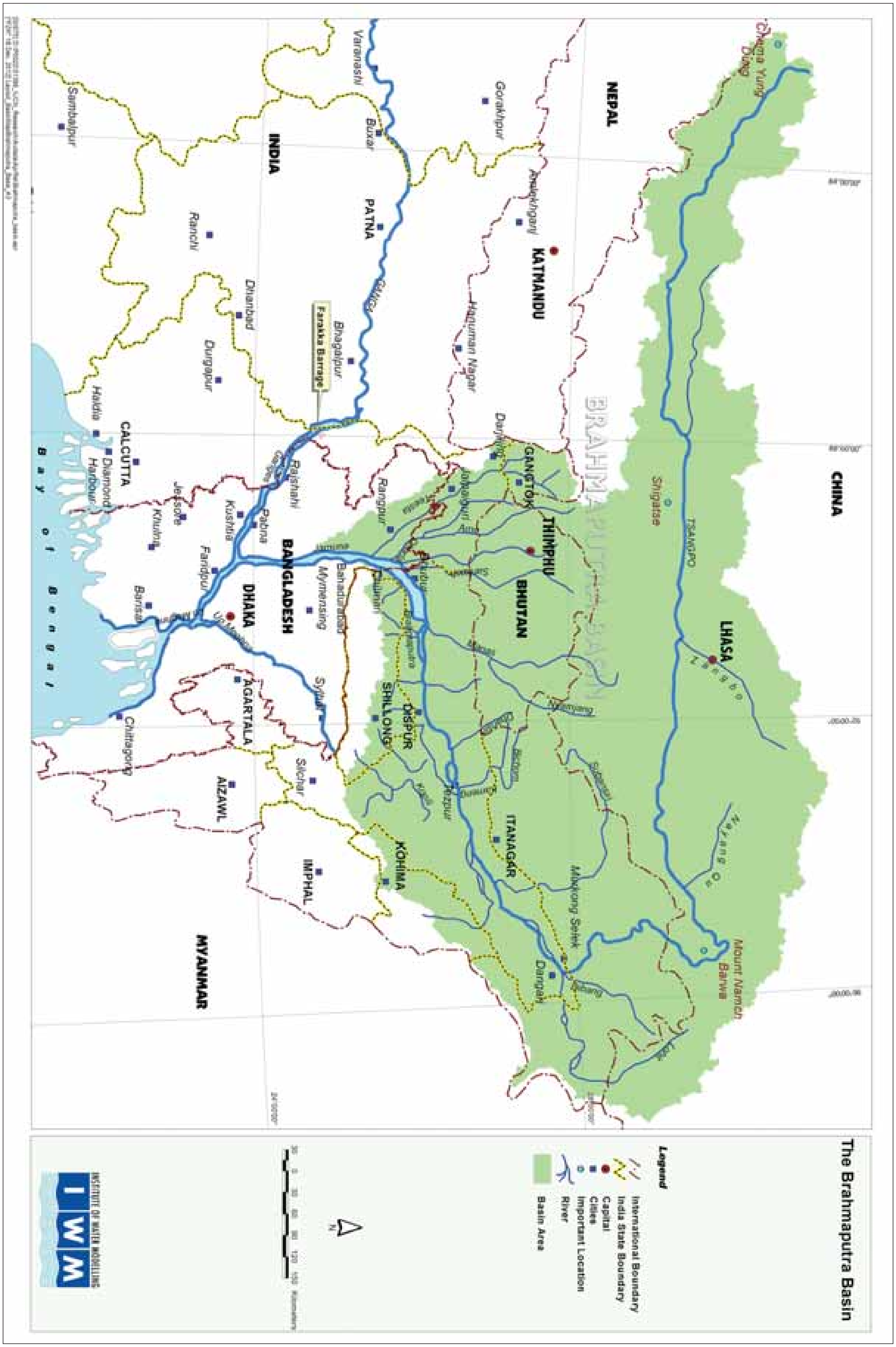


Figure 2.1
The Brahmaputra River Basin area

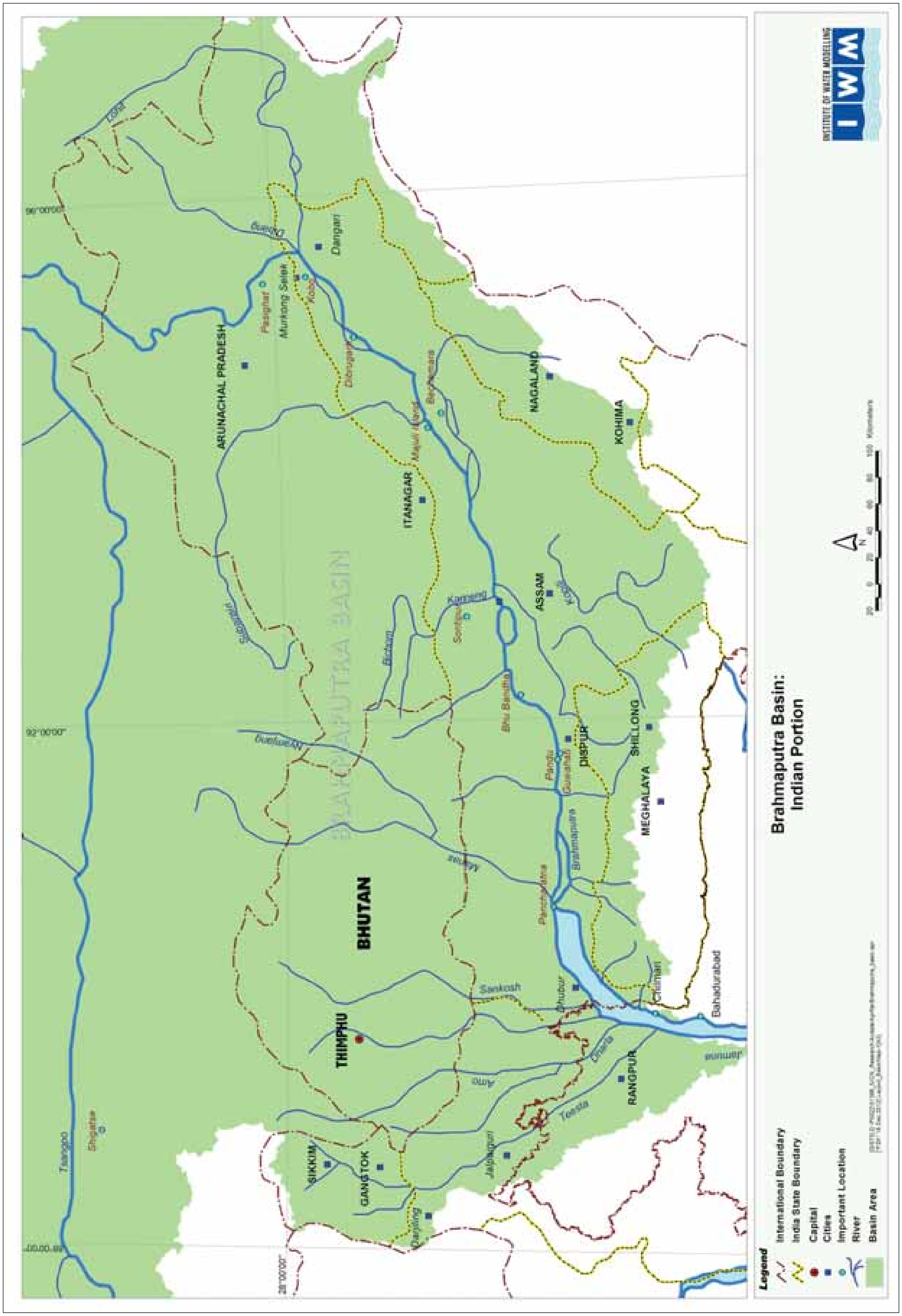


**Figure 2.2**
**The Brahmaputra River Basin – Indian Part**

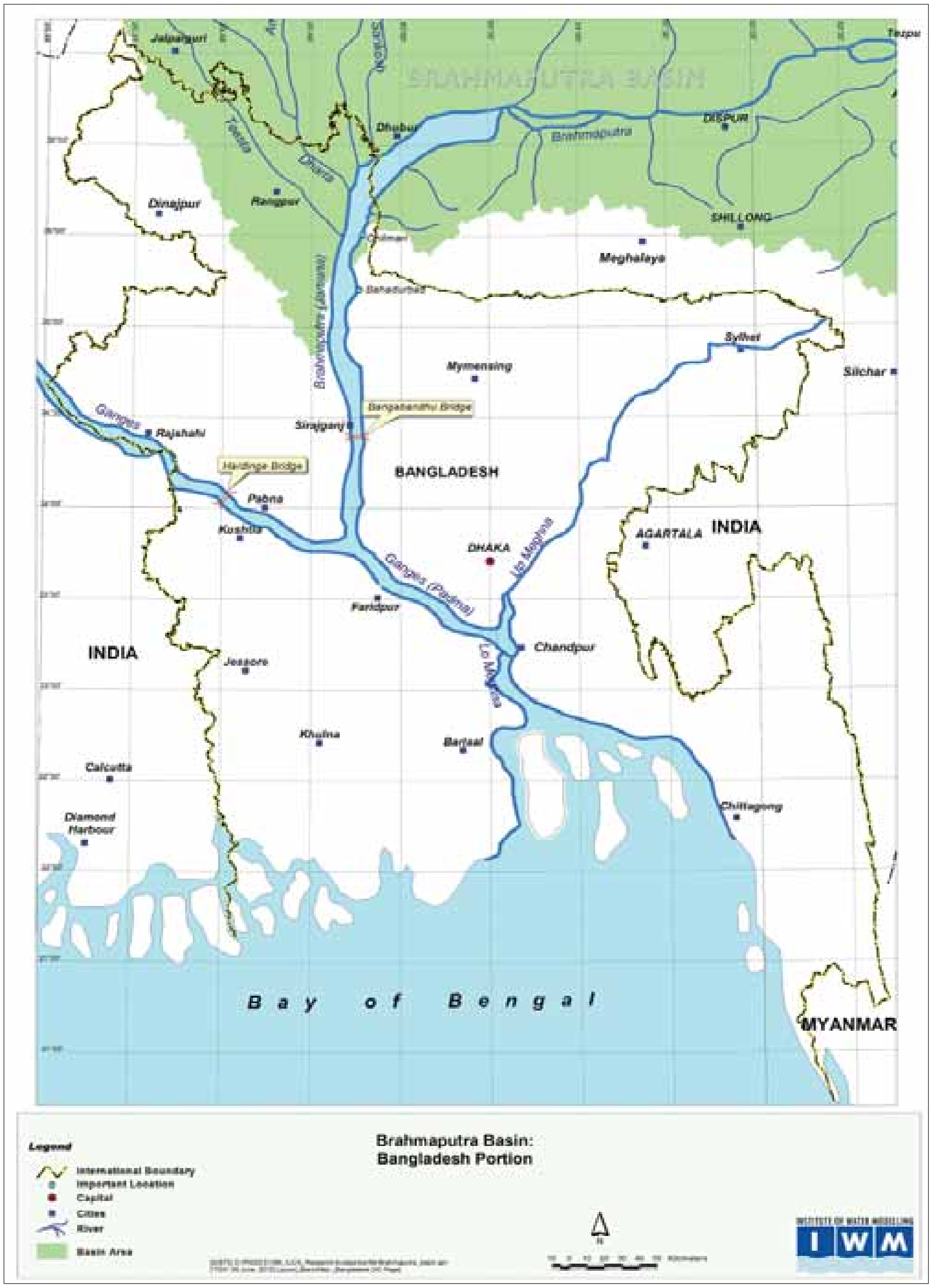
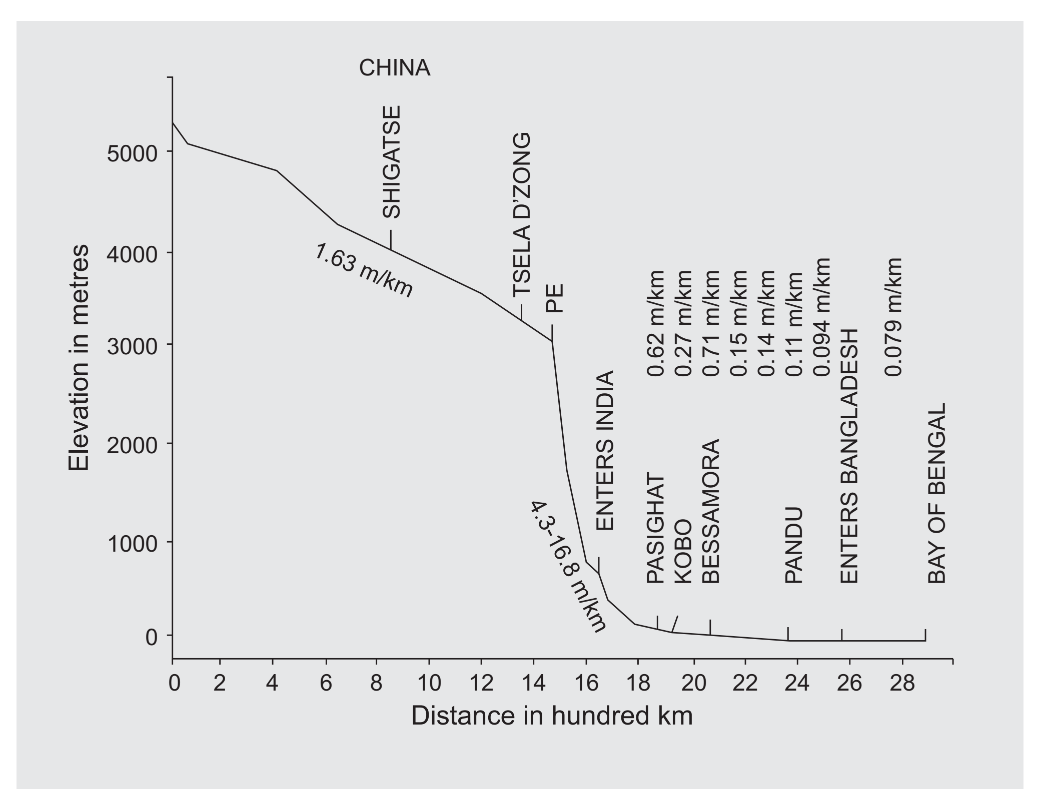


**Figure 2-3**
**The Brahmaputra River Basin – Bangladesh Part**

The main river channel traverses three different countries: China, India and Bangladesh. Originating from the great glacier mass of Chema-Yung-Dung in the Kailas range of southern Tibet at an elevation of 5,300m above sea level (a.s.l), the Brahmaputra river travels a total distance of 2,880km (1,625km in China, 918km in India and 337km in Bangladesh) before emptying into the Bay of Bengal through a joint channel with the Ganga (Ganges River). The long profile for the entire river course is shown in Figure 2.4. In China, the river is known as the Yarlung Tsangpo and flows east at an average height of 4,000m a.s.l. At its easternmost point, it bends around Mt. Namcha Barwa and forms the Yarlung Tsangpo Canyon, which is considered the deepest in the world.

**Figure 2.4**

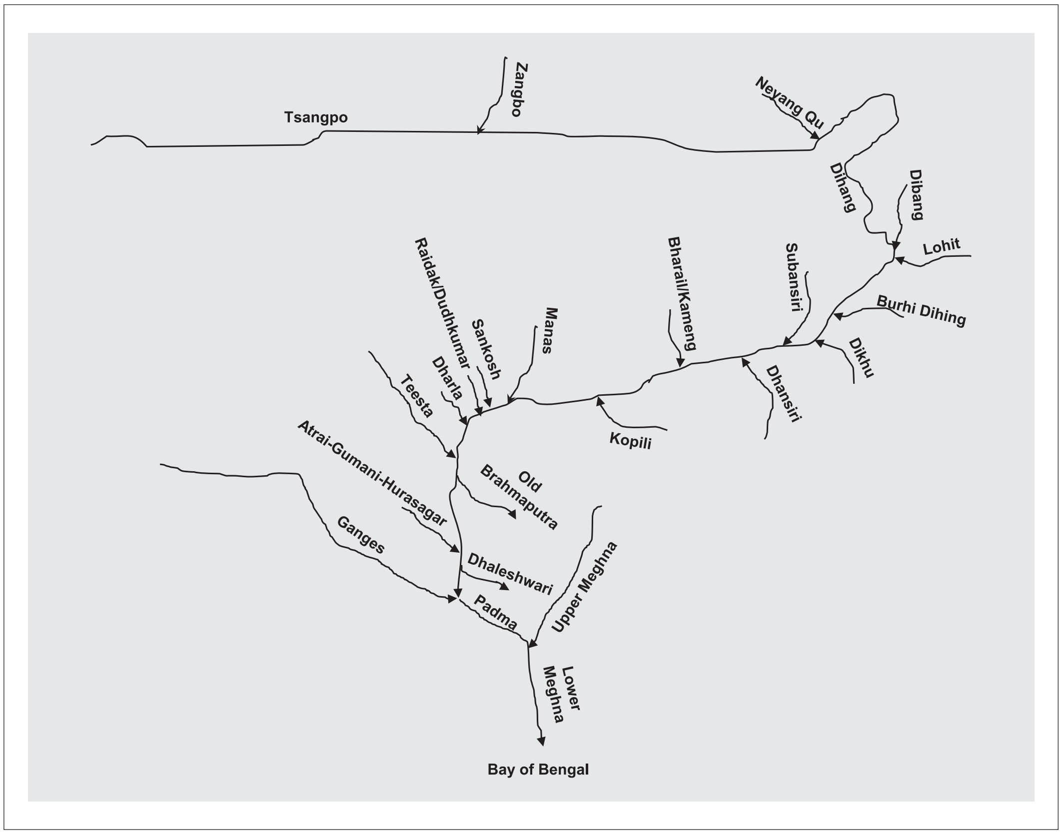
**Long Profile of the Brahmaputra River**



As the river enters Arunachal Pradesh (India), it makes a very rapid descend from its original height in Tibet, and finally appears in the plains, where it is called Dihang. It flows for about 35km and is joined by two other major rivers: Dibang and Lohit (see Figure 2.5, next page). From this confluence, the river becomes very wide and is called Brahmaputra. A few more tributaries join the main course of the river later on namely, BurhiDihing, Dikhou, Dhansiri and Kopili Rivers on the left bank and Subansiri, Kameng, Manas, Sankosh, Dudhkumar/Raidak, Jaldhaka/Dharla, Teesta, and Atrai Rivers on the right bank. In Assam, the river is sometimes as wide as 10 km or more. Between Dibrugarh, and Lakhimpur districts, the river divides into two channels-the northern Kherkutia channel and the southern Brahmaputra channel. The two channels join again about 100 km downstream, forming the Majuli island. At Guwahati, near the ancient pilgrimage centre of Hajo, the Brahmaputra cuts through the rocks of the Shillong Plateau, and is at its narrowest and is 1km wide. (Singh et al 2004).

**Figure 2.5**

**Schematic Profile of the Brahmaputra River**



In Bangladesh, the Brahmaputra splits into two branches: the much larger branch continues due south as the Jamuna (Jomuna) and flows into the Lower Ganges, locally called Padma (Pôdda), while the older branch curves southeast as the old Brahmaputra (Bromhoputro) and flows into the Upper Meghna. Both paths eventually reconverge near Chandpur in Bangladesh and flow out into the Bay of Bengal. Apart from the old Brahmaputra, the other main distributary (spill channel) is the Dhaleshwari River in Bangladesh.

The Brahmaputra basin represents an acutely flood-prone region, which act as a bottleneck to agricultural development and is one of the major reasons of economic backwardness of the state. The agricultural sector faces the greatest threat due to the flooding events (Table 2.1). As a consequence of flood, there is large scale erosion of riverbank soil and high flood season is synonymous with breach of embankment which are not sturdy enough to withstand heavy pressure of high flood water. Surge of water that inundates the cropfileds also brings silt and sandy soil, rendering the cultivatable lands unsuitable for immediate cultivation. Normally, flood occurs during the monsoon months of June to September. However, recent years have seen several spate of floods devastating the state, that offer continues for 6 to 7 months.

## Table 2.1

**Flood damage in Assam (1 lakh= 100,000)**

| Year | Area affected (lakh ha) | Cropped area damaged (lakh ha) | Value of crops damaged (lakh Rs.) | Population affected (in lakh) |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |
| 1954 | 29 | 3.05 | 1175.14 | 13.00 |
| 1955 | 13.5 | 0.73 | 238.43 | 1.77 |
| 1956 | 5.13 | 0.69 | 254.55 | 2.71 |
| 1957 | 3.95 | 0.25 | 100.71 | 3.16 |
| 1958 | 12.29 | 0.59 | 144.33 | 4.04 |
| 1959 | 7.58 | 1.44 | 486.59 | 11.72 |
| 1960 | 4.68 | 2.21 | 762.92 | 13.22 |
| 1961 | 1.89 | 0.13 | 29.9 | 2.21 |
| 1962 | 15.95 | 6.61 | 1848.57 | 39.08 |
| 1963 | 5.67 | 0.74 | 197.4 | 8.80 |
| 1964 | 6.02 | 1.23 | 238.07 | 7.65 |
| 1965 | 3.22 | 0.24 | 88.56 | 2.58 |
| 1966 | 15.11 | 3.69 | 2149.04 | 36.24 |
| 1967 | 2.45 | 0.88 | 133.44 | 4.50 |
| 1968 | 3.76 | 1.25 | 801.4 | 8.35 |
| 1969 | 10.63 | 0.69 | 335.73 | 8.90 |
| 1970 | 7.58 | 2.26 | 1042.52 | 18.91 |
| 1971 | 4.48 | 1.12 | 469.88 | 6.59 |
| 1972 | 9.97 | 3.59 | 2221.41 | 29.52 |
| 1973 | 24.09 | 1.64 | 1440.04 | 18.47 |
| 1974 | NA | NA | 1366.11 | NA |
| 1975 | 1.24 | 0.17 | 124.55 | 2.32 |
| 1976 | 2.52 | NA | 865.13 | 4.40 |
| 1977 | 10.24 | NA | 2654 | 45.49 |
| 1978 | 3.06 | NA | 393 | 9.17 |
| 1979 | 6.73 | NA | 2614 | 24.51 |
| 1980 | 10.6 | NA | 3237 | 33.59 |
| 1981 | 4.57 | NA | 701 | 13.58 |
| 1982 | 68.85 | NA | 469 | 14.24 |
| 1983 | 6.95 | 1.25 | 1032 | 21.21 |
| 1984 | 9.36 | 3.57 | 4899 | 38.79 |
| 1985 | 6.46 | 0.82 | 8290 | 24.66 |
| 1986 | 4.26 | 3.22 | 33,867 | 24.45 |
| 1987 | 25.73 | 10.7 | 36,859 | 94.60 |
| 1988 | 46.5 | 13.35 | 33,410 | 126.77 |
| 1989 | 8.8 | 1.00 | na | 28.00 |
| 1990 | 6.2 | 0.6 | 63.7 | 28.00 |
| 1991 | 12.7 | 0.9 | 115.6 | 108 |
| 1992 | 2.9 | 0.1 | 17.8 | 12 |
| 1993 | 17.2 | 6.6 | na | na |
| 1994 | 6.8 | 6.8 | na | na |
| 1995 | 9.2 | 10.6 | na | na |
| 1996 | 12.8 | 6.5 | na | na |
| 1997 | 9.6 | 2.7 | 19.5 | na |
| 1998 | 12.4 | 7.7 | 463.3 | na |

Modified after: Goswami et al. 2004; Goyari, 2005

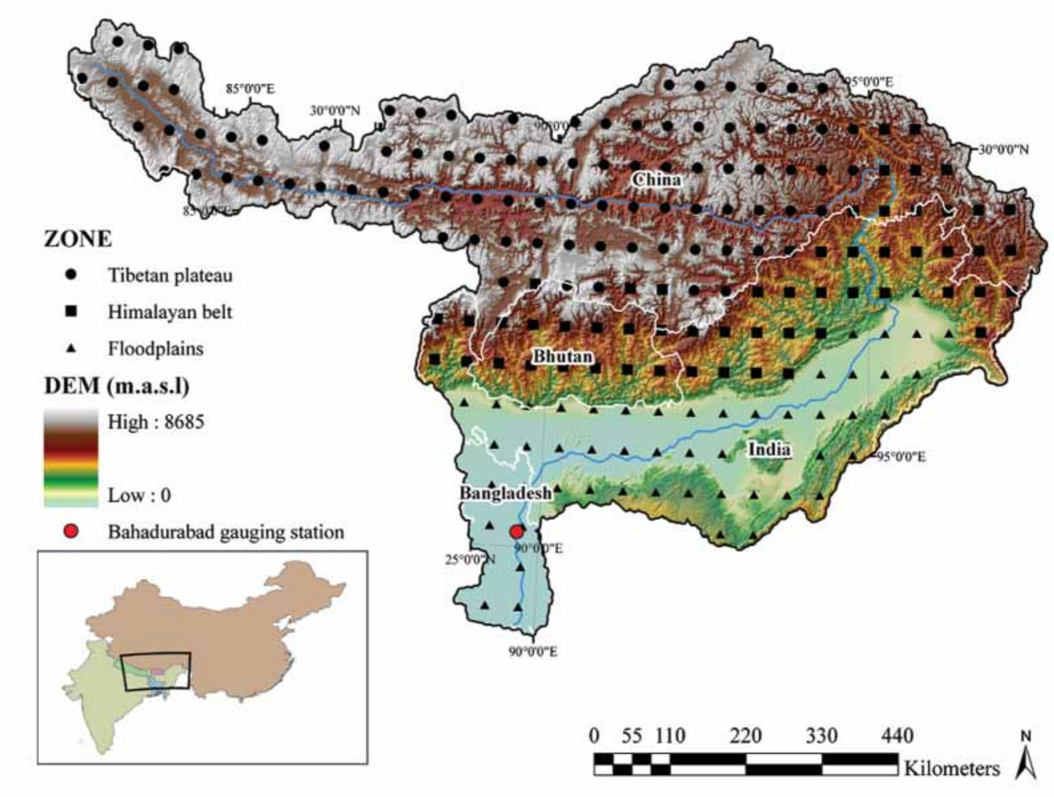
## 2.2 Topography

The basin is of irregular shape: the maximum east-west length is 1,540km and the maximum north-south width is 682 km. The basin lies between 23°N to 32°N latitude and 82°E to 97°50'E longitude. The part of the Tibetan plateau falling under the basin has an elevation varying from 3,000 to 5,000m a.s.l and is dotted with numerous glaciers (Singh et al 2004).

Immerzeel (2008) categorized the Brahmaputra basin into three different physiographic zones: Tibetan Plateau (TP), Himalayan Belt (HB), and the floodplain (FP) (see Figure 2.6). These zones respond differently to the anticipated climate change. TP covers 44.4% of the basin, with elevations of 3,500m a.s.l and above, whereas HB covers 28.6% of the basin with elevations ranging from 100m to 3,500m a.s.l. The area with an elevation of less than 100m a.s.l. is considered as FP and comprises about 27% of the entire basin.

**Figure 2.6**

**Physiographic Zones of the Brahmaputra Basin**



The Brahmaputra River drains diverse environments such as the cold dry plateau of Tibet, the rain-drenched Himalayan slopes, the alluvial plains of Assam and the vast deltaic lowlands of Bangladesh. The basin covers 5 topographic regions falling in 4 countries as given in Table 2.2.

Table 2.2

**Topographic Regions of the Brahmaputra River Basin**

| Topographic Region | Area (km²) | Geographical Location |
|---|---|---|
| High Tibetan Plateau | 293,000 | Southern Part of the Tibet province of China. |
| High Himalayan mountains | 137,050 | Part of Himalayan kingdom of Bhutan and 3 states of India: Arunachal Pradesh, West Bengal and Sikkim. |
| Brahmaputra Valley | 56,200 | Part of Assam State of India. |
| Lower (Assam) Mountainous Region | 37,200 | Part of 3 states of India: Nagaland, Assam and Meghalaya. |
| Plains | 56,550 | Part of West Bengal (India) and part of Bangladesh. |

*Source:www.nih.ernet.in/rbis/basin%20maps/brahmaputra_about.htm*

## 2.3 Climate

In the basin area, the year can be divided into four seasons: the relatively dry, cool winter from December through February; the dry, hot summer from March through May; the southwest monsoon from June through September when the predominating southwest maritime winds bring rains; and the retreating monsoon of October and November.

Frigid winds from the Himalayas can depress temperatures near the Brahmaputra River. The two Himalayan states in the east, Sikkim and Arunachal Pradesh, receive substantial snowfall. The extreme north of West Bengal, centred around Darjeeling, also experiences snowfall, but only rarely. Winter rainfall—and occasionally snowfall—is associated with large storm systems such as “Nor’westers” and “Western disturbances”; the latter are steered by westerlies towards the Himalayas.

Summer in the basin lasts from March to May. The southwest summer monsoon, when massive convective thunderstorms dominate the weather in the basin, originates from a high-pressure mass, centered over the southern Indian Ocean; attracted by a low-pressure region centered over South Asia, it gives rise to surface winds that ferry humid air into basin from the southwest. These inflows ultimately result from a northward shift of the local jet stream, which itself results from rising summer temperatures over Tibet and the Indian subcontinent. The void left by the jet stream, which switches from a route just south of the Himalayas to one tracking north of Tibet, attracts warm, humid air. The main factor behind this shift is the high summer temperature difference between Central Asia and the Indian Ocean. The hottest month for most of the basin is May. In cooler regions of North India, immense pre-monsoon squall-line thunderstorms, known locally as “Nor’westers”, commonly drop large hailstones. Most summer rainfall occurs during powerful thunderstorms associated with the southwest summer monsoon; occasional tropical cyclones also contribute to this.

The Bay of Bengal monsoon, moves northward in the Bay of Bengal and spreads over most of Assam (Brahmaputra and Meghna Basin) by the first week of June. On encountering the barrier of the Great Himalayan Range, it is deflected westward along the Indo-Gangetic Plain (i.e. over the Ganges basin) toward New Delhi (North-west of Ganges basin).

Further climatic details as per the three regions defined by Immerzeel (2008) are provided in the analyses section (4.1).

## 2.4 Hydrology

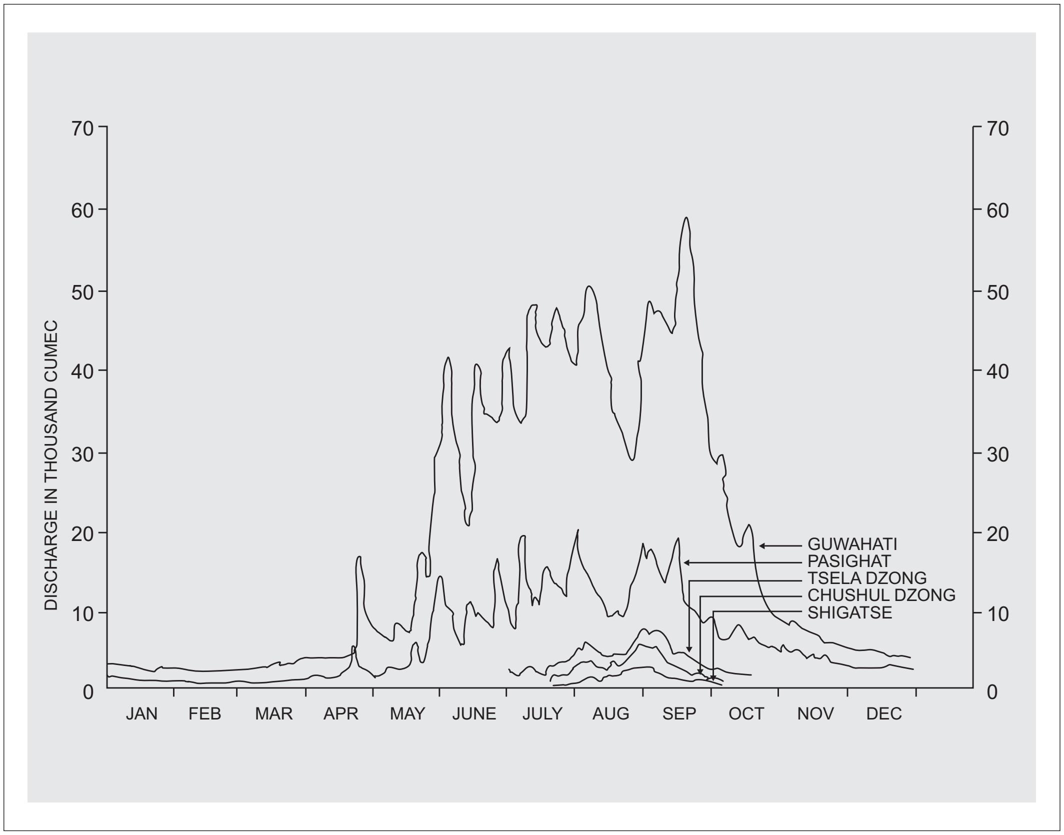
The hydrological regime of the Brahmaputra River is distinguished by extremely large and variable flows (Figure 2.7), significant rates of sediment discharge, rapid channel aggradations, accelerated rates of basin denudation and unique patterns of river morphology. The annual regime of river flow in Brahmaputra basin is controlled by climatic conditions. Rivers flowing from the Himalayas experience two high-water seasons, one in early summer caused by snow melt in the mountains, and one in late summer caused by runoff from monsoon rains.

With an average annual discharge of 19,830 m$^3$/s at its mouth, the Brahmaputra ranks fourth among the large rivers of the world (Goswami, 1998). The large variation in the river's daily discharge over different seasons is a unique feature of the river's flow regime.

The highest recorded daily discharge in the Brahmaputra at Pandu was 72,726 m$^3$/s August 1962 while the lowest was 1,757 m$^3$/s in February 1968. At Bahadurabad, the highest recorded peak flow was 102,534 m$^3$/s in 1998 (Mirza 2003) and the minimum was 3,280 m$^3$/s in 1960 (Barua 2010). The discharge in the river between summer high flows and winter low flows fluctuates, on an average, by 12 times, although in certain years it has been as high as 20 times (Goswami and Das 2003). At Pandu, the mean annual flood of the river, 48,200m$^3$/s, has a return period of 2.2 years, while the maximum recorded flood of 72,726 m$^3$/s likely to be repeated once in about every 133 years (Goswami and Das 2003). At Bahadurabad, the return period of a flood flow of 81,313 m$^3$/s has been decreasing (becoming more frequent) from 25 years to 5 years, based on analysis of flows from 1956-1981 and 1981-2007, respectively (IWM and CCC 2008).

**Figure 2.7**

**Discharge Hydrographs of the Brahmaputra River at Different Locations**



*Source: (Datta and Singh 2004)*

The different time lags and peaking characteristics of flows in different tributaries generate large and variable perturbations on the Brahmaputra's discharge hydrograph (see Figure 2.7). As shown in Table 2.3, the key tributaries are Dihang and Subansiri. However, contributions from other tributaries can combine to give major flood peaks. The Brahmaputra basin has a long history of major floods. For example in Assam, major floods have occurred in 1954, 1962, 1966, 1972, 1977, 1984, 1986, 1988, 1998 and 2002. After the major 8.7 Richter scale earthquake in 1950, the intensity, frequency and damage due to floods have increased. The 1988 and 1998 floods were the worst in recent history. Floods in the basin are caused by a combination of natural and man-made factors: the eastern Himalayas setting, highly potent monsoon regime, weak geological formation, active seismicity, accelerated erosion, rapid channel aggradation, massive deforestation, intense land-use pressure and high population growth, especially in the floodplain belt and ad hoc temporary flood control measures (Goswami and Das 2003).

**Table 2.3**

**Tributary Flow Contributions at Pandu**

| Tributary | Average Flow in MCM/yr | Percent contribution |
|---|---|---|
| Dihang (main stream) | 185,102 | 37.5% |
| Subansiri | 52,705 | 10.7% |
| Lohit | 46,964 | 9.5% |
| Dibang | 37,818 | 7.7% |
| JiaBharali | 28,844 | 5.8% |
| BurhiDihing | 11,906 | 2.4% |
| Kapili-Kalang | 9,023 | 1.8% |
| Other tributaries above Pandu | 121,938 | 24.7 |
| Brahmaputra at Pandu | 494,300 | 100.0 |

*Source: Brahmaputra Board (1995)*

## 2.5 Land Cover

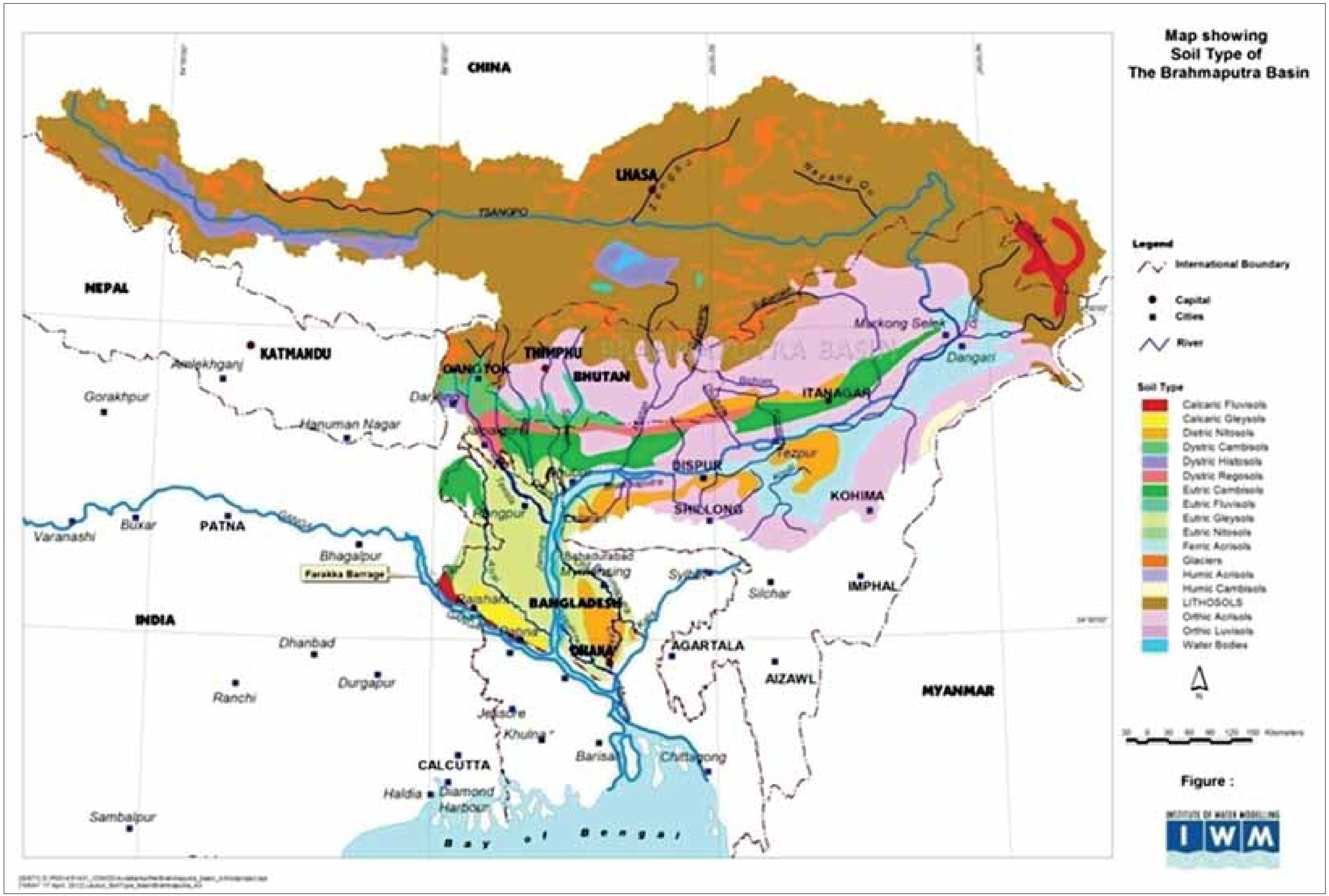
The Brahmaputra basin, as a whole, has a forest cover of about 14.5%, grasslands occupy about 44%, agricultural lands about 14%, cropland/natural vegetation mosaic 12.8%, barren/sparsely vegetated land 2.5%, water bodies 1.8%, snow and ice 11%, urban land 0.02% and permanent wetlands 0.05%. The total forest cover of the Brahmaputra basin in India is 1,14,894 km$^2$, i.e. 54% of the total area. The distribution of forest cover in the different Indian states within the Brahmaputra basin is as follows: Arunachal Pradesh (82.8%), Nagaland (68.9%), Meghalaya (63.5%), Sikkim (38.1%), West Bengal (21.4 %) and Assam (20.6 %). As a whole, the eastern Himalaya is more humid, its climate more conducive to tree growth with a relatively higher tree line (average 4,570m a.s.l) compared to the western and central Himalayas (Goswami and Das 2003).

The different soil types across the Basin are shown in Figure 2.8. In the Tibetan Plateau region, the soils are mainly Lithosols, (initial rocky soils), which are shallow soils developed in situ from various non carbonate hard rocks. These soils lack horizon development due to either steep slopes or parent materials that contain no permanent weatherable minerals. The steep slopes where these soils are normally found cause the flora on them to be sparse shrubs or grassland. In the Himalayan Belt region, the soils are mainly orthicacrisols, which are soils with a layer of clay accumulation. Under forest cover, these soils are porous surface soils but if the forest is cleared, the A-horizon degrades to form a hard surface crust. This crusting leads to surface erosion during rain showers.

In the Floodplain region of the Basin, the soils are mainly eutriccambisols and eutricgleysols. Cambisols have slight profile development due to moderate weathering of parent material. Eutriccambisols of the Temperate Zone are among the most productive soils on earth (Driessen and Deckers 2001). Gleysols are typically wetland soils that tend to be saturated with groundwater for long periods, leading to lack of aeration, poor conditions crop roots and for soil fauna (Driessen and Deckers 2001).

Figure 2.8

Soil Types of Brahmaputra Basin



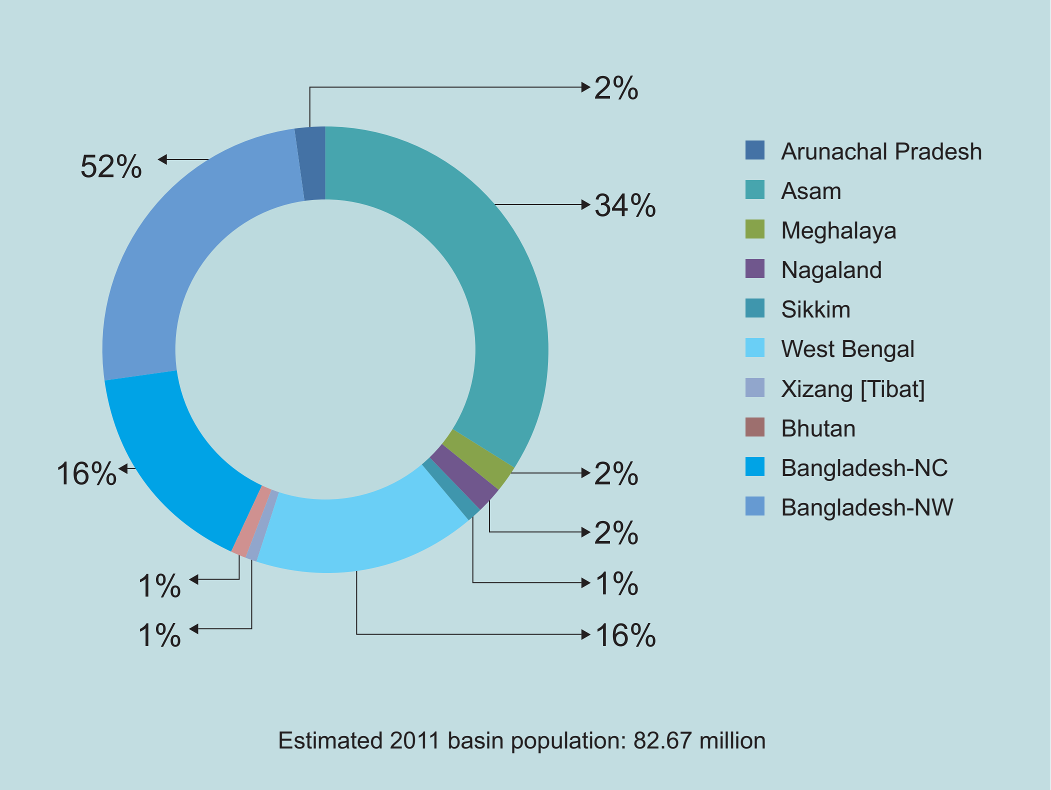
## 2.6 Population

The Brahmaputra basin, with a total population of about 83 million (across all four countries), is extremely rich in cultural diversity, with many ethnic, socio-cultural and linguistic groups. The distribution of the basin population across different administrative areas is shown in Figure 2.9. This has been calculated based on population data and areas obtained from www.citypopulation.de. About 41% of the basin's population resides in Bangladesh (north central and north western hydrological regions). Another 34% resides in Assam and a further 16% in the West Bengal part of the basin. The remaining 9% of the basin population can be found in Tibet, Bhutan and other northeastern states of India (Sikkim, Arunachal Pradesh, Meghalaya and Nagaland).

It is important to note that the above population distribution is up to the confluence point between the Ganges and Brahmaputra Rivers at Goalanda in Bangladesh. A much larger area and population depends on the combined flow, which flows to the bay via the Meghna River.

Figure 2.9

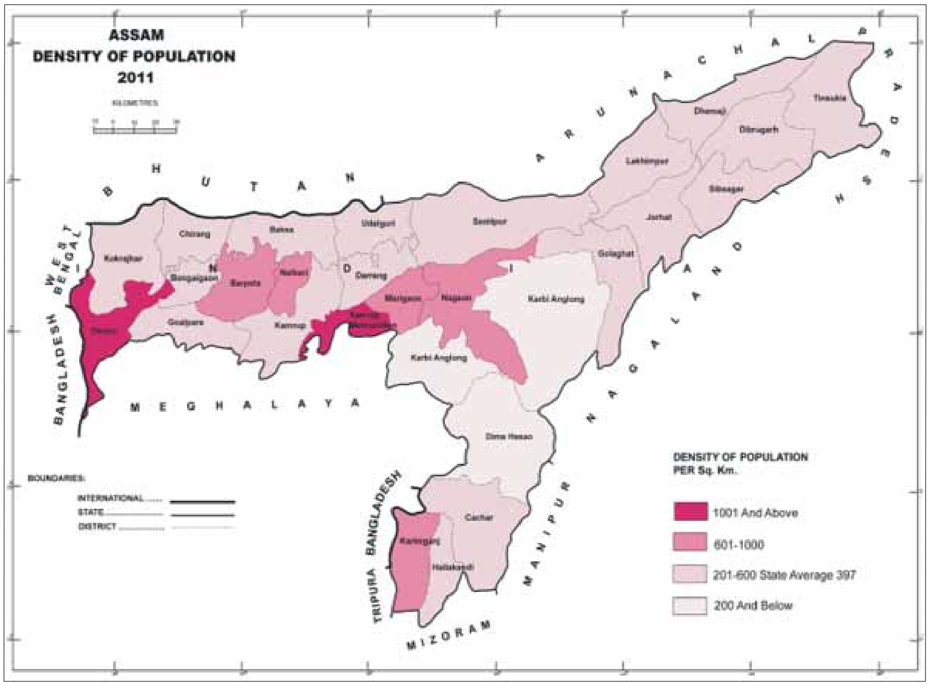
Basin Population Distributed by Administrative Areas



Population data source: www.citypopulation.de, all estimates are for 2011, except Bhutan data is for 2010

Figure 2.10

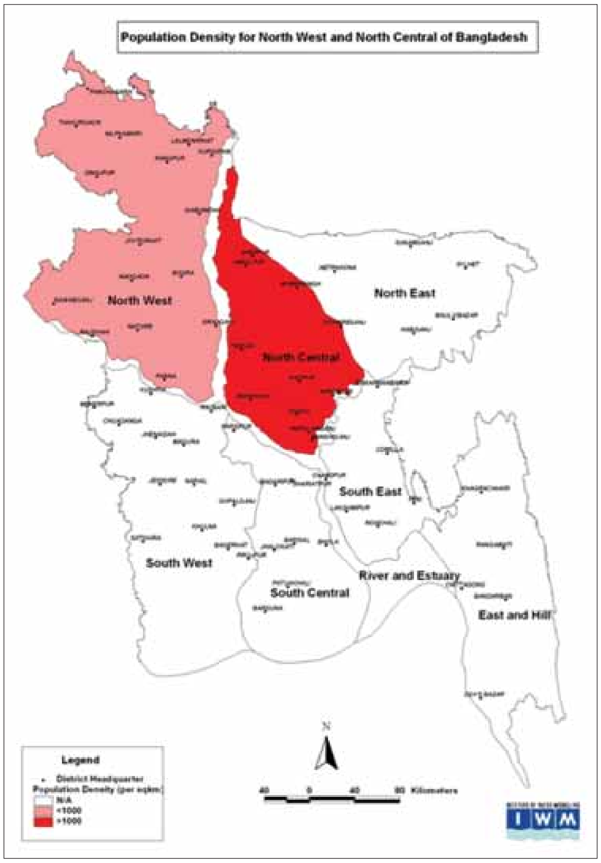
**Population Density in Assam**



*Source: http://online.assam.gov.in/*

Figure 2.11

**Population Density (2011) of Selected Regions in Bangladesh**



The spatial distribution and density of population is quite uneven in the basin, with the highest density of about 828 persons/km$^2$ in the Bangladesh portion, followed by India (143 persons/km$^2$), Bhutan (26 persons/km$^2$) and Tibet (6 persons/km$^2$) (Goswami and Das 2003). As an example, the varying population density in Assam and Bangladesh are shown in Figure 2.10 and Figure 2.11, respectively. In Assam, agricultural expansion and migration has been identified as one of the drivers of its varying population density (Shrivastava and Heinen 2005).

The population growth rate of Assam is about 1.6%/yr based on the 2011 and 2001 Indian Census data. In Arunachal Pradesh it is 2.3%/yr but the overall population is much lower (Table 2.4). Decadal growth of population and percentage contribution to total growth of India 1991-2001 and 2001-2011 has been highlighted in Table (2.5). In Bangladesh, the annual population growth rates for North Central and Northwest regions in the same period were 2.6%/yr and 1.2%/yr respectively. For the Xizang (Tibet) region, the annual growth rate was 1.4% for the period from 2001 to 2011. The annual population growth rate of Bhutan for the period 2005 to 2010 was 1.8%/yr.

**Table 2.4**

**Decadal growth of population and percentage contribution to total growth of India 1991-2001 and 2001-2011 (For the seven Northeastern states)**

| | Decadal Growth of Population | | Percentage contribution to total population growth of India | |
|---|---|---|---|---|
| **State** | **1991-2001** | **2001-2011** | **1991-2001** | **2001-2011** |
| Assam | 4241206 | 4513744 | 2.33 | 2.49 |
| Arunachal Pradesh | 233410 | 284643 | 0.13 | 0.16 |
| Manipur | 456747 | 427860 | 0.25 | 0.24 |
| Mizoram | 198817 | 202441 | 0.11 | 0.11 |
| Nagaland | 780490 | -9434 | 0.43 | -0.01 |
| Tripura | 441998 | 471829 | 0.24 | 0.26 |
| Meghalaya | 544044 | 645185 | 0.3 | 0.36 |
| Sikkim | 134394 | 66837 | 0.07 | 0.04 |

*Source: http://www.imaginmor.com/census-of-india-2011*

Table 2.5

**Distribution of Population, Decadal Growth Rate, Sex-Ratio and Population Density**

| State/ District | Population 2011 | | | Percentage decadal growth rate of population | | Sex-Ratio (Number of females per 1000 males) | | Population density per sq. km |
|---|---|---|---|---|---|---|---|---|
| | Persons | Male | Female | 1991-01 | 2001-11 | 2001 | 2011 | 2001 |
| Arunachal Pradesh | 1382611 | 720232 | 662379 | 27 | 25.92 | 893 | 920 | 13 |
| Tawang | 49950 | 29361 | 20589 | 37.6 | 28.33 | 782 | 701 | 18 |
| West Kameng | 87013 | 49568 | 37445 | 32.22 | 16.64 | 754 | 755 | 10 |
| East Kameng | 78413 | 38974 | 39439 | 13.46 | 37.14 | 985 | 1012 | 14 |
| Papumpare | 176385 | 90447 | 85938 | 67.56 | 44.57 | 901 | 950 | 35 |
| Upper Subansiri | 83205 | 41974 | 41231 | 10.5 | 50.34 | 960 | 982 | 8 |
| West Siang | 112272 | 58589 | 53683 | 15.55 | 8.04 | 912 | 916 | 12 |
| East Siang | 99019 | 50467 | 48552 | 21.61 | 13.3 | 931 | 962 | 24 |
| Upper Siang | 35289 | 18657 | 16632 | 20.1 | 5.77 | 848 | 891 | 5 |
| Changlang | 147951 | 77289 | 70662 | 31.29 | 17.96 | 906 | 914 | 27 |
| Tirap | 111997 | 57992 | 54005 | 17.33 | 11.63 | 910 | 931 | 42 |
| Lower Subansiri | 82839 | 41935 | 40904 | 29.15 | 48.65 | 960 | 975 | 16 |
| Kurung Kumey | 89717 | 44226 | 45491 | 6.24 | 111.01 | 1013 | 1029 | 7 |
| Dibang Valley | 7948 | 4396 | 3552 | 17.65 | 9.3 | 697 | 808 | 1 |
| Lower Dibang Valley | 53986 | 28127 | 25859 | 36.76 | 7.01 | 858 | 919 | 13 |
| Lohit | 145538 | 76544 | 68994 | 35.1 | 16.44 | 863 | 901 | 24 |
| Anjaw | 21089 | 11686 | 9403 | 7.84 | 13.77 | 816 | 805 | 3 |

*Source: http://www.indiagrowing.com/Arunachal_Pradesh*

## 2.7 Water Use and Requirements

The potential utilizable water resources of the basin are estimated at 50 km$^3$/yr, of which about 90% remains undeveloped (Mahanta 2006), which is about 0.6 m$^3$/person/yr (based on estimated 2011 population of 82.7 million people). Approximately 9.9 km$^3$/yr is used throughout the basin (Mahanta 2006). The main water use in the basin is for agriculture (81%), followed by domestic uses (10%) and industries (9%) (Amarasinghe et al 2004). It has been estimated that irrigated area in the Indian part is about 8,500km$^2$ and the potential irrigable area is about 42,600km$^2$ (Goswami and Das 2003).

In Bangladesh, total areas irrigated by surface water in 2009-2010 in Dhaka and Rajshahi Divisions were 2,500km$^2$ and 500km$^2$, respectively (BADC 2010).

In Bangladesh, some major irrigation projects dependent on Brahmaputra River (and tributary) flows include Teesta Project, Kurigram Project, Tangail Project, Pabna Project, Meghna-Dhonagoda Irrigation Project. Even irrigation projects in southern part of the country are dependent on flows from the Brahmaputra River, e.g. projects in Chandpur, Bhola and Barisal. 1989 estimates of surface water irrigation requirements in the Northwest and North Central regions of Bangladesh varied from 51 to 91 $m^3/s$ for April (WARPO 2001).

Groundwater availability at shallow depth (within 20m) is very high in the basin, especially in the valley areas. However, only 4.3% of the existing potential has been developed so far in the Indian part of the basin (Goswami and Das 2003). In Bangladesh, total areas irrigated by shallow tube wells in 2009-10 were 9,400$km^2$ (Dhaka Division) and 15,500$km^2$ (Rajshahi Division) (BADC 2010).

Environmental water uses in the basin has not been given due importance and the wetlands are already in danger of losing their ecological character, mainly due to eutrophication (Mahanta 2006). Smakhtin and Anputhas (2006) have provided estimates for a range of environmental flow requirements for the Brahmaputra River based on an estimated natural mean annual runoff of 585 BCM/yr at Pandu. The least acceptable environmental flow (that could lead to “largely modified” ecosystems) was estimated to be about 200 BCM/yr. This corresponds to about a 3 percentage points lateral shift (to the left) of the natural flow duration curve (Smakhtin and Anputhas 2006).

River navigation in the 890km long reach of the Brahmaputra from Sadiya to the Bangladesh border has been designated as the ‘National Waterway No. 2’ of India (Goswami and Das 2003).

The flow in the Brahmaputra River has an important bearing on salinity intrusion in coastal regions of Bangladesh. Based on a modelling study, Chowdhury and Haque (1990) estimated that the salinity levels in the Lower Meghna River will exceed acceptable levels if the total water withdrawal from the Brahmaputra and Ganges Rivers exceeds 2,200 $m^3/s$, based upon the 80% dependable flow. If salinity intrusion is not checked, many irrigation projects in Bangladesh will be adversely affected. Therefore, further development in the Ganges-Brahmaputra-Meghna basin needs to take into account the whole basin water requirements.

Based on the study objectives, the literature review focused on studies related to climate change and water resources development projects in the Brahmaputra Basin.

# 3

# Literature Review

## 3.1 Conceptual Prediction of Global Climate Change

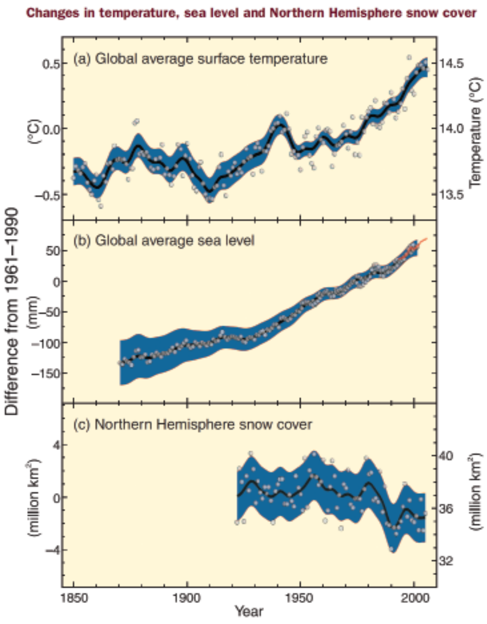
The Earth's climate has changed many times during the planet's history, with events ranging from ice ages to long periods of warmth. Historically, natural factors such as volcanic eruptions, changes in the Earth's orbit, and the amount of energy released from the Sun have affected the Earth's climate. Beginning late in the 18th century, human activities associated with the Industrial Revolution have also changed the composition of the atmosphere and may very likely influenced the Earth's climate. The term 'Climate change' refers to major changes in temperature, rainfall, snow, or wind patterns, lasting for decades or longer. Both human-made and natural factors contribute to climate change:

- Human causes include burning fossil fuels, cutting down of forests, and developing land for farms, cities, and roads. These activities all release greenhouse gases into the atmosphere.
- Natural causes include changes in the Earth's orbit, the sun's intensity, the circulation of the ocean and the atmosphere, and volcanic activity.

Although the Earth's climate has changed many times throughout its history, the rapid warming seen today cannot be explained by natural processes alone. Human activities are increasing the amount of greenhouse gases in the atmosphere. Some amount of greenhouse gases is necessary for life to exist on Earth—they trap heat in the atmosphere, keeping the planet warm and in a state of equilibrium. But this natural greenhouse effect is being strengthened as human activities (such as the combustion of fossil fuels) add more of these gases to the atmosphere, resulting in a shift in the Earth's equilibrium (www.epa.gov). Rising trend of global temperature analyzed by IPCC is shown in Figure 3.1.

**Figure 3.1**

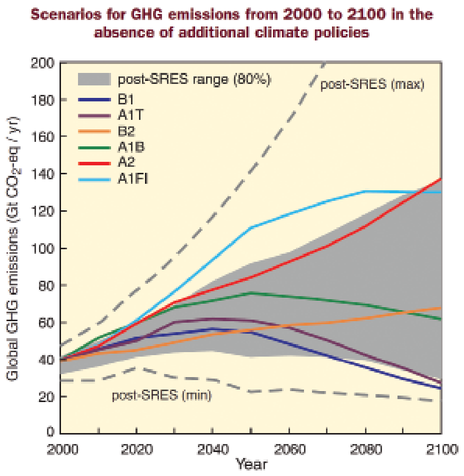
**Changes in Temperature, Sea Level and Northern Hemisphere Snow Cover**



Observed changes in (a) global average surface temperature; (b) global average sea level from tide gauge (blue) and satellite (red) data; and (c) Northern Hemisphere snow cover for March-April. All differences are relative to corresponding averages for the period 1961-1990. Smoothed curves represent decadal averaged values while circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from the time series (c) (IPCC AR4)

Figure 3.2

**Scenarios for GHG Emissions from 2000 to 2100**



Global GHG emissions (in GtCO2-eq per year) in the absence of additional climate policies: six illustrative SRES marker scenarios (coloured lines) and 80th percentile range of recent scenarios published since SRES (post-SRES) (gray shaded area). Dashed lines show the full range of post- SRES scenarios. The emissions include CO$^2$, CH4, N$^2$O and F-gases (IPCC AR4).

According to IPCC, there is high agreement and much evidence that with current climate change mitigation policies and related sustainable development practices, global GHG emissions will continue to grow over the next few decades (Figure 3.2 shown above). For the next two decades, a warming of about 0.2°C per decade is projected for a range of emissions scenarios. Even if the concentrations of all GHGs and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1°C per decade would be expected. Afterwards, temperature projections increasingly depend on specific emissions scenarios. The IPCC Special Report on Emissions Scenarios (Nakicenovic and Swart 2000) are grouped into four scenario families (A1, A2, B1 and B2) that explore alternative development pathways, covering a wide range of demographic, economic and technological driving forces and resulting GHG emissions.

A1: The A1 storyline assumes a world of rapid economic growth, a global population that peaks in mid-century and speedy introduction of new and more efficient technologies. A1 is divided into three groups that describe alternative directions of technological change: fossil intensive (A1FI), non-fossil energy resources (A1T), and a balance across all sources (A1B).

B1: B1 describes a convergent world, with the same global population as A1 but with more rapid changes in economic structures toward a service and information economy

B2: B2 describes a world with intermediate population and economic growth, emphasizing local solutions to economic, social, and environmental sustainability.

A2: A2 describes a very heterogeneous world with high population growth, slow economic development and slow technological change.

## 3.2 Literature on Climate Change Impacts in the Brahmaputra Basin

Climate change is likely to lead to an intensification of the global hydrological cycle and to have a major impact on regional water resources (Arnell 1999). The IPCC Fourth Assessment Report mentions with high likelihood of an overall net negative impact on water availability and the health of freshwater ecosystems (Kundzewicz et al. 2007). Observed and projected increases in temperature, sea level rise and precipitation variability are the main causes for reported and projected impacts of climate change on water resources.

Among the river systems, the hydrological impact of climate change on Ganges-Brahmaputra Basin is expected to be particularly strong. There are three major reasons for this:

1. Influence of snow and ice melt on stream flow
2. Increased monsoon rain intensity
3. Increase in sea level rise, hampering drainage of rivers

Stream flow is strongly influenced by snow and ice melting in the upstream parts of the basin. The locations of glaciers in the Hindu-Kush-Himalayan region are shown in Figure 3.3. The glaciers contributing to the Brahmaputra River are mainly located on the eastern Himalaya ranges. As 60% of the basin area has an elevation of over 2,000m a.s.l, cryospheric processes are deemed important when considering potential impact of climate change on the basin hydrology. Immerzeel et al., (2010) estimated that snow and glacier melt contribution, compared to total runoff generated below 2,000m is about 27%. Projected rise in temperature will lead to increased glacial and snow melt, leading to retreat of glaciers. Frauenfelder and Kääb (2009) estimated that total glacier area has been decreasing by -7% to -13% per decade in the Upper Brahmaputra River basin (UBRB)[3] for the period from 1970/80 to 2000. Bolch et al., (2010) carried out detailed length measurements for five glaciers in the south-eastern centre of the Tibetan Plateau, which feeds into the Tsangpo-Brahmaputra River. Their study found that the glaciers in this area have been retreating at a rate of around 10 m/year for the period 1976 to 2009. Estimates for other glaciers are also provided in Bolch et al., (2012). The increased rates of snow and glacial melt are likely to increase summer flows in some river systems for a few decades, followed by a reduction in flow as the glaciers disappear and snowfall diminishes (Immerzeel 2008). This is particularly true for the dry season when water availability is crucial for the irrigation systems. Immerzeel et al., (2010) stated that the Brahmaputra is the most susceptible to reductions of flow, threatening the food security of an estimated 26 million people.

The Ganges-Brahmaputra basin is highly influenced by extreme monsoon rainfall and flooding (Mirza 2002; Warrick et al., 1996). If climate change results in variations in both the intensity and reliability of the monsoon, it will affect both high and low flows, leading not only to increased flooding but possibly also to increased variability of available water, both in space and time (Postel et al., 1996). The latter point refers to the fact that increased water flows during floods and wet seasons cannot be used during the low flow seasons unless large storage systems are in place (Oki and Kanae 2006).

Sea level rise is likely to result in increased coastal flooding and also in riverine flooding due to back-water effects of the Ganges-Brahmaputra basin along the delta (Agrawala et al., 2005).

A recent study by Gain et al., (2011) found that climate change is likely to lead to reduced frequency of extreme low flow conditions and also an increase in peak flows. Ghosh and Datta (2011) also found that the impact of climate change is likely to be greater compared to changes in land use/land cover in the basin. Another study by IWM and CCC (2008) found that the frequency of flood flows in the Brahmaputra River at Bahadurabad has already increased compared to earlier flow records. As a result, the modelling study found that with climate change, the frequency, extent and depths of floods would increase further in many parts of both Assam Plains and Bangladesh.

Past studies focused on one type of output or results from only a few models considered. However, this study provides a composite assessment of 22 GCM model outputs, for 3 scenarios and across various hydro-meteorological variables.

## 3.3 Development Projects

Compared to many other river basins, the Brahmaputra Basin is relatively underdeveloped. The total hydropower potential of the basin has been estimated to be about 40,550 MW (Megawatt)  (Phukan

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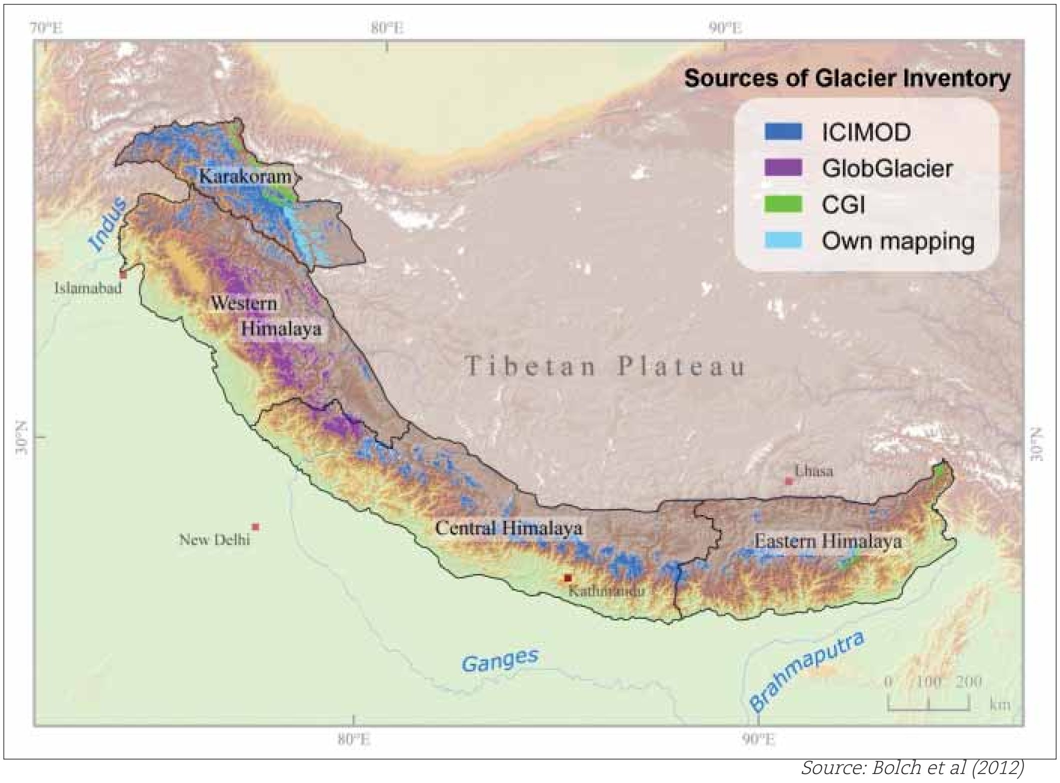
[3] This is part of the basin upstream of Guwahati (Assam, India), see Figure 2 2 for location of the town.

2004). In Tibet (China), a 510 MW run-of-the-river hydropower project has commenced on the main stem of the Tsangpo River in Zangmu (Yannan and Haining 2011).

The Government of India (Ministry of Power) has identified 226 potential sites for large multi-purpose dams on the rivers of northeast India, most of them being in the Brahmaputra basin. Over the next fifty years, around 99,256 MW hydropower is expected to be generated from the northeastern rivers of India (Brahmaputra Board, 2000). Several dam projects such as the Upper Subansiri (2,500 MW), Upper Siang (11,000 MW), Middle Siang (750 MW), Lower Siang (1,700 MW), Kameng (600 MW) and Ranganadi (450 MW) were reported to be at various stages of planning and development (Goswami and Das 2003). Mohile (2001) has identified potential development sites for the Brahmaputra Basin (see Table 3.1). By 2030, the total live storage can be around 32,000 MCM with installed capacity of about 29,000 MW. Subsequently, Central Electricity Authority projections (2001) identified 168 hydropower projects for a total capacity of 63,328 MW in the Northeast (Figure 3.4)

Figure 3.3

Location of Glaciers in the Hindu-Kush-Himalayan Region



*Source: Bolch et al (2012)*

Building of embankments in the Brahmaputra floodplains (in Assam and Bangladesh) has been another major structural intervention. These structural measures have been used so far as the main answer to tackling floods and river bank erosion. Out of a total of 15,675km of embankments built in India, Assam alone has around 5,027km (Goswami and Das 2003). In Bangladesh, the Brahmaputra River has a 220km long embankment on its right bank, which was built in the late 1960s and early 1970s (Halcrow et al 1992). The embankment has been breached in several locations and every year, erosion threatens different parts of this embankment. About 90km of the left bank also has embankments (World Bank 1990).

## Table 3.1

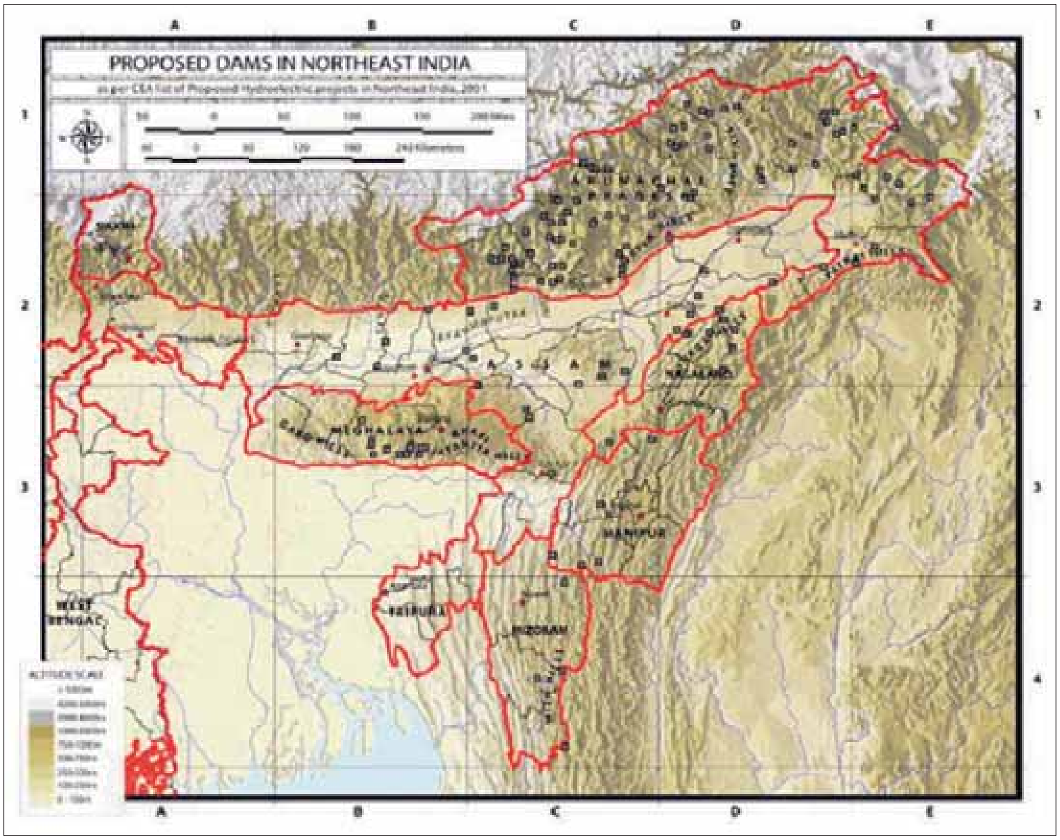
## Some Potential Storage Sites for Development

| Basin/sub-basin | Live storage (MCM) | Installed Capacity (MW) |
|---|---|---|
| **By 2010** | | |
| Subansiri at Gerukamukh | 640 | 600 |
| Bairabi | 1,780 | 75 |
| Jadukata | 720 | 450 |
| Siang (lower) | 800 | 2,000 |
| Noa-dihing | 130 | 75 |
| Kulsi | 690 | 36 |
| Someswari | 90 | 130 |
| Um-N-got | 30 | 710 |
| Total | 4,880 | 4,076 |
| **By 2020** | | |
| Subansiri (upstream reservoirs) | 6,020 | 6,700 |
| Lohit | 2,750 | 3,000 |
| Kameng | 1,070 | 1,100 |
| Kulsi | 690 | 36 |
| Total | 10,530 | 10,836 |

*Source: Adapted from Mohile (2001)*

**Figure 3.4**

**Central Electricity Authority projections (2001) identify 168 hydropower projects for a total capacity of 63,328 MW in the Northeast India**



*Source: Vagholikar and Das 2010*

# 4

# Data Collection and Analyses

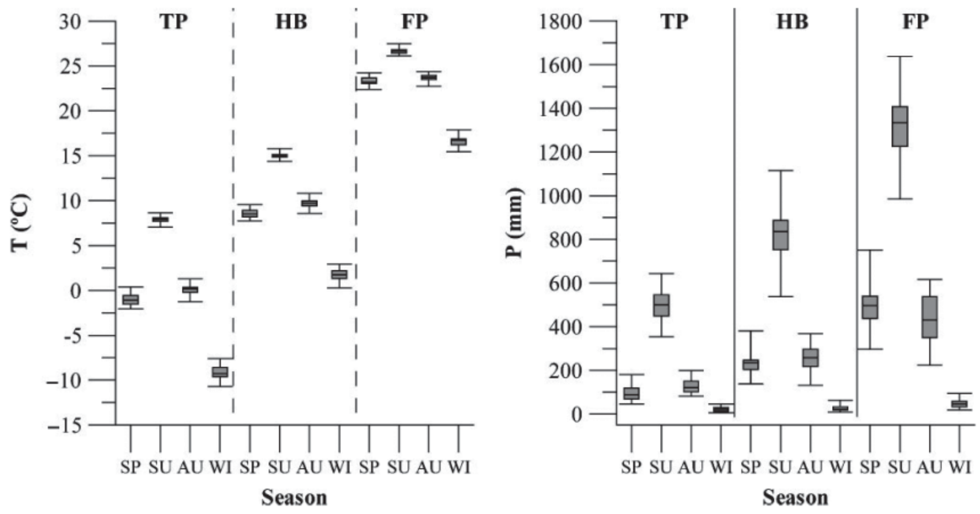
## 4.1 Climate

Immerzeel (2008) analyzed the seasonal climate normals from 1961 to 1990 for the TP, the HB and the FP in a boxwhisker plot (see Figure 4.1; see Figure 2.6 for location of the 3 zones). The plot shows the median, the upper and lower quartiles and the caps at the end of the box show the minimum and maximum. The TP is the coldest with average temperatures ranging from -10°C in winter to 7°C in summer. Winter temperatures in the HB fluctuate around 2°C, while summer temperatures reach values of approximately 15°C on average. The FP is the warmest of the three zones with winter temperatures around 17°C and summer temperatures on average as high as 27°C. For all zones, the seasonal temperature variation is largest in winter and smallest in summer. The annual rainfall is concentrated in the monsoon months June, July, August and September (JJAS) in all zones. The TP located in the rain shadow of the HB is the driest zone in the basin (734mm/year), while the FP is the wettest with an annual precipitation of 2,354mm. The HB has an average annual precipitation of 1,349mm.

The Brahmaputra basin, excluding the Tibetan portion, forms an integral part of the southeast Asian monsoon regime with a mean annual rainfall of 2,300mm.

Figure 4.1

**Seasonal Climate Normals (1961–1990) for Different Physiographic Zones**



SP = spring (Mar, Apr, May), SU = summer (Jun, Jul, Aug), AU = autumn (Sep, Oct, Nov), WI = winter (Dec, Jan, Feb), Physiographic Zones: TP = Tibetan Plateau, HB = Himalayan Belt, FP = Floodplain
Immerzeel (2008)

Distribution of rainfall over the basin varies from 1,200mm in parts of Nagaland to over 6,000mm on the southern slopes of the Himalaya. The Himalayas exercise a dominating influence on the prevailing weather of the basin due to their location in the path of the southwest monsoon. Rainfall in the Himalayan sector averages 500cm/year with the lower ranges receiving more. A gradual increase in rainfall from the valley bottom towards the lower ranges followed by a decrease towards the higher ranges is evident from the annual rainfall at Dibrugarh (2,850mm) in the far eastern part of Assam valley, Pasighat (5,070mm) in the foothills and Tuting (2,740mm) further up the Himalayas. Monsoon rains from June to September account for 60-70% of the annual rainfall in the basin, while the pre-monsoon season from March through May produces 20-25% of the annual rainfall. Snowfall is experienced in the Brahmaputra basin in areas with elevations of 1,500m and above. There are altogether 612 glaciers in the Brahmaputra basin, of which 450 are in the Teesta sub-basin of Sikkim while 162 are in the Kameng river (upper JiaBharali) sub-basin of Arunachal Pradesh.

## 4.2 Hydrology

The mean annual flows at various Indian locations of the Brahmaputra River are shown in Table 4.1. The mean annual flow exceeds 500,000 MCM at Pancharatna. As

**Table 4.1**

**Mean Annual Flows at Various Locations of the Brahmaputra River**

| Location | Mean Flow (MCM/yr) |
|---|---|
| Bechamara, Majuli | 278,447 |
| Bhurbandha, Bhurgaon | 365,550 |
| Pandu, Guwahati | 526,092 |
| Pancharatna, Goalpara | 509,435 |
| Bahadurabad, Bangladesh | 605,491 |

*Source: Brahmaputra Board (1995), Parua (2010)*

**Table 4.2**

**Monthly Break-up of Annual Flows (% of Annual Mean flow)**

| Month | Bechamara | Bhurbandha | Pandu | Pancharatna |
|---|---|---|---|---|
| January | 2.14 | 2.67 | 2.23 | 3.17 |
| February | 1.86 | 2.21 | 1.89 | 1.7 |
| March | 2.75 | 2.97 | 2.62 | 2.31 |
| April | 4.66 | 4.24 | 4.15 | 3.96 |
| May | 6.73 | 6.83 | 7.33 | 6.35 |
| June | 12.86 | 13.48 | 11.83 | 11.42 |
| July | 19.38 | 17.68 | 15.92 | 18.94 |
| August | 17.03 | 16.58 | 24.6 | 18.46 |
| September | 13.96 | 14.78 | 13.02 | 16.07 |
| October | 10.56 | 10.25 | 9.18 | 10.5 |
| November | 4.91 | 4.74 | 4.3 | 4.35 |
| December | 3.16 | 3.57 | 2.93 | 2.77 |

*Source: Brahmaputra Board (1995)*

**Table 4.3**

**Annual Flows at Various Exceedance Probabilities**

| Site | Flow (MCM/yr) at Different Exceedance probabilities | | |
|---|---|---|---|
| | 50% | 75% | 90% |
| Bechamara | 278,700 | 274,700 | 236,000 |
| Bhurbandha | 263,800 | 333,600 | 265,800 |
| Pandu | 525,600 | 446,500 | 398,400 |
| Pancharatna | 513,000 | 427,200 | 403,000 |

*Source: Brahmaputra Board (1995)*

Table 4.4

Important Tributaries of the Brahmaputra River

| Name | Bank | Chainage (km) | Tributary length (km) | Catchment area (sq. km) | Average annual yield (MCM) | Water yield ($m^3/s/$ sq.km) |
|---|---|---|---|---|---|---|
| BurhiDihing | Left | 877 | 360 | 8,730 | 11,906 | 0.043 |
| Dikhow | Left | 842 | 236 | 4,022 | 4,230 | 0.033 |
| Subansiri | Right | 762 | 375 | 28,200 | 52,705 | 0.059 |
| Dhansiri | Left | 757 | 352 | 10,305 | 6,785 | 0.021 |
| Jia Bharali | Right | 677 | NA | 14,738 | 28,844 | 0.062 |
| KopiliKalang | Left | 557 | 261 | 20,068 | 9,023 | 0.014 |
| Aie-Manas-Beki | Right | 429 | 228 | 41,350 | 2,925 | 0.002 |
| Sankosh | Right | 337 | 321 | 10,345 | 17,197 | 0.053 |
| Dudhkumar / Raidak | Right | 336 | 220 | 5,800 | 14,980 | 0.082 |
| Dharla | Right | 324 | 307 | n/a | n/a | n/a |
| Teesta | Right | 299 | 308 | 12,540 | 21,413 | 0.054 |
| Atrai-Gumani-Hurasagar | Right | 136 | n/a | n/a | n/a | n/a |
| Ganges confluence | Right | 105 | n/a | n/a | n/a | n/a |
| Megna confluence | Left | 0 | n/a | n/a | n/a | n/a |

***Sources:*** *Brahmaputra Board (1995), Hossain and Hosasin (2011), Mullick et al (2010), Jain et al (2007)*

shown in Table 4.2, majority of the mean annual flow (about 70%) tends to occur from June to end of October.

The median annual flow at Pancharatna is about 500,000 MCM and the 90% percentile dependable annual flow is around 400,000 MCM (see Table 4.3). This shows that there are significant surface water resources available in the Brahmaputra Basin.

In terms of water yield per unit discharge area, the Brahmaputra leads other major rivers, the rate for the catchment upstream of Pandu being 0.0306 $m^3/s/km^2$. Water yields of some of the tributaries of the Brahmaputra such as the Subansiri, Jia Bharali and Sankosh rivers are as high as 0.06, 0.06 and 0.05 $m^3/s/km^2$ respectively (see Table 4.4). High monsoon rainfall in the upper catchments and steep gradients are the major reasons for the high rates of unit discharge, which also contribute to generate the high sediment yield from the basin.

## 4.3 Water Demand

Mohile (2001) estimated gross and net water demand for the Brahmaputra Basin for 2050 (see Table 4.5). It is expected that irrigation will continue to be by far the highest water user (about 88%) in the basin. The growth in domestic and industrial demand is not considered to be significant up to the period 2050.

For the Bangladesh portion of the basin, water demand estimates from the National Water Management Plan (NWMP) are available for 2025 (WARPO 2001). The NWMP divides the country into eight hydrological regions, of which the North-Central (NC), and the Northwest (NW) falls in the Brahmaputra basin. Approximately 59% of the NC region and 80% of the NW region fall within the basin. Agriculture will remain the main water using sector in this part of the basin.

**Table 4.5**

**Gross and Net Water Demands for 2050 in Brahmaputra (India)**

| Sector | Gross demand (MCM)a | Consumption (%) | Net demand (MCM)a |
|---|---|---|---|
| Domestic water supply: | | | |
| Rural, domestic | 2,920 | --- | --- |
| Rural, livestock | 694 | --- | --- |
| Total rural | 3,614 | 50 | 1,807 |
| Urban | 1,533 | 30 | 459 |
| **Subtotal domestic (1)** | 5,147 | | 2,266 |
| **Industrial (2)** | 5,147 | 20 | 1,060 |
| Agricultural water supply: | --- | --- | --- |
| Surface water | 3,520 | 44 | 15,500 |
| Irrigation | --- | --- | --- |
| Groundwater | 16,900 | 50 | 8,500 |
| **Subtotal agriculture (3)** | 52,100 | --- | 24,300 |
| **Total (1+2+3)** | 62,394 | | 27,630 |

**Table 4.6**

**Water Demands in Bangladesh Portion for 2025**

| Sector | NW Region (MCM) | NC Region (MCM) | Total Demand (MCM) | % of Total Demand |
|---|---|---|---|---|
| Domestic and industrial water supply: | | | | |
| Cities | 35 | 311 | 346 | 2.8 |
| Other Urban areas | 142 | 58 | 199 | 1.6 |
| Rural | 274 | 124 | 397 | 3.2 |
| Environment | 117 | 27 | 145 | 1.2 |
| Fisheries | 522 | 118 | 640 | 5.2 |
| Forest | 439 | 257 | 697 | 5.7 |
| Agriculture: | | | | |
| Irrigable | 7,736 | 1,859 | 9,595 | 78.2 |
| Rainfed | 215 | 36 | 251 | 2.0 |
| **Total** | 9,481 | 2,789 | 12,270 | 100 |

# 5

# Climate Change Impact Analysis

## 5.1 Global Climate Change Models

Climate simulations performed with general circulation models (GCMs) are widely viewed as the principal scientific basis for developing policies to address potential future global climate change (Houghton et al., 2001).

Coupled ocean-atmospheric general circulation models are the tools to quantitatively simulate the climate system. Since the end of the 1980s, a group of scientists in the State Key Laboratory of Numerical Modelling for Atmospheric Sciences and Geophysical Fluid Dynamics (LASG), Institute of Atmospheric Physics (IAP), Chinese Academy of Sciences (CAS), have been working to develop a global OGCM and a global coupled ocean-atmosphere general circulation model (CGCM). More than twenty GCM results are available that are widely used for regional or global climate change impact assessment.

## 5.2 Observations of IPCC

IPCC-TAR (IPCC 2001) using the SRES emissions scenarios projected an increase in globally averaged surface temperature of 1.4°C to 5.8°C over the period 1990 to 2100. This is about two to ten times larger than the central value of observed warming over the 20th century. Temperature increases were projected to be greater than those in the Second Assessment Report (SAR), which were about 1.0°C to 3.5°C, based on six IS92 scenarios. The higher projected temperatures and the wider range are due primarily to lower projected sulfur dioxide ($SO^2$) emissions in the SRES scenarios relative to the IS92 scenarios. For the periods 1990 to 2025 and 1990 to 2050, the projected increases are 0.4°C to 1.1°C and 0.8°C to 2.6°C, respectively.

IPCC-TAR (IPCC 2001) projected global mean sea level to rise by 0.09 to 0.88 m between the years 1990 and 2100, for the full range of SRES scenarios, but with significant regional variations. This rise is due primarily to thermal expansion of the oceans and melting of glaciers and ice caps. For the periods 1990 to 2025 and 1990 to 2050, the projected rises are 0.03 to 0.14 m and 0.05 to 0.32 m, respectively.

Table 5.1

**IPCC 4th Assessment Report of Global Expected Range of Changes to Climate Parameters**

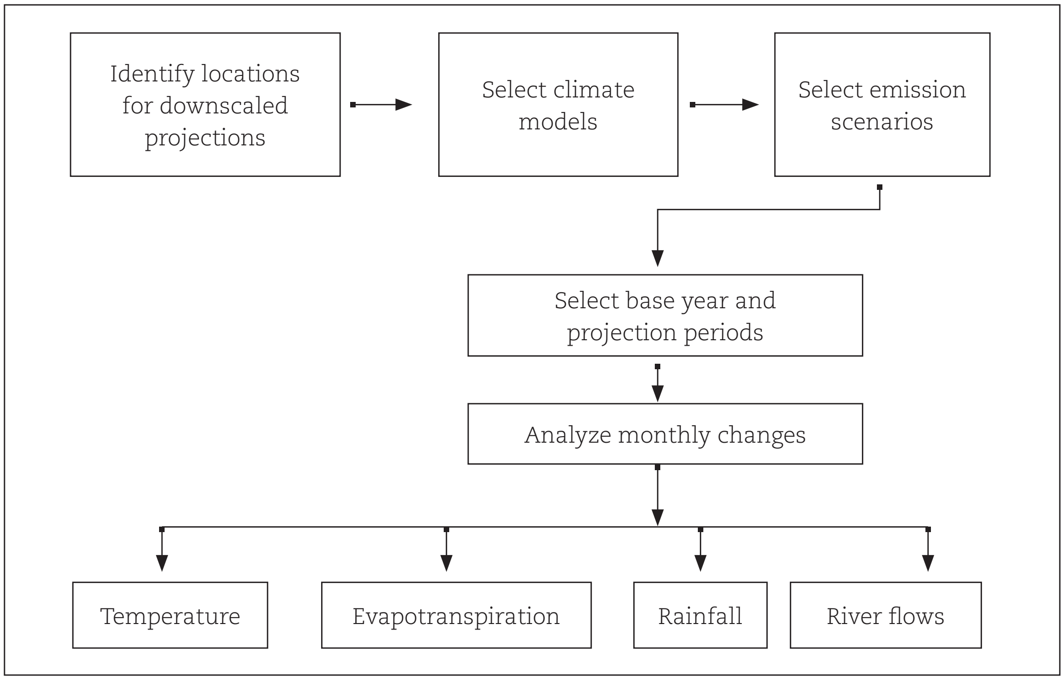
| Emission scenario | Temperature (°C at 2090-2099 relative to 1980-99) | | Sea level rise (m at 2090-2099 relative to 1980-99) |
|---|---|---|---|
| | Best estimate | Likely range | Model-based range excluding rapid dynamical changes in ice flow |
| Constant 2000 Conc. | 0.6 | 0.3 – 0.9 | Not available |
| B1 scenario | 1.8 | 1.1 – 2.9 | 0.18 – 0.38 |
| A1T scenario | 2.4 | 1.4 – 3.8 | 0.20 – 0.45 |
| B2 scenario | 2.4 | 1.4 – 3.8 | 0.20 – 0.43 |
| A1B scenario | 2.8 | 1.7 – 4.4 | 0.21 – 0.48 |
| A2 scenario | 3.4 | 2.0 – 5.4 | 0.23 – 0.51 |
| A1FI scenario | 4 | 2.4 – 6.4 | 0.26 – 0.59 |

The IPCC 4th Assessment Report (IPCC 2007) projected global average surface warming and sea level rise at the end of the year 2100 based on Atmosphere-Ocean Global Circulation Models (AOGCMs) are presented in Table 5.1.

As IPCC (2007) observed, the 4th assessment projections are different from the third because of better model resolutions and better representation of processes, and because of inclusion of some of the interventions made in post Kyoto Protocol.

**Figure 5.1**

**Climate Change Impact Analysis Methodology**



## 5.3 Analysis Methodology

This study has analyzed the impact of climate change on three climatic parameters (temperature, evapotranspiration and rainfall) and river flows. The basic analytical steps are shown in Figure 5.1. First, the locations of interests were identified. These were based on GIS analyses, which identified the centroids of catchments delineated for the (MIKE Basin) hydrologic model, which is discussed in more detail in Section 6. Then the climate models and emissions scenarios of interests were selected. After that the base year and projection periods for climate impact analysis were selected. Finally, the changes in temperature, evapotranspiration, rainfall and river flows (discharge) were analyzed.

Most of the required data have been collected from secondary sources. The impact of climatic change on temperature, evapotranspiration and rainfall have been analyzed month wise using Climate Change Tool of Danish Hydraulic Institute (DHI) for a total of 22 GCMs with 1 to 3 future emission scenarios (DHI 2011a). The tool is based on the best available data regarding future climate change scenarios. The tool calculates climatic parameters under future climate change condition using ‘delta change’ factors. These factors indicate how much a certain quantity (e.g. precipitation) will change over time. The climate change scenario functionality of the module modifies time series of precipitation, temperature and potential evapotranspiration according to the geographic location and the projection year. The change factors are a result of the climate models for various emission scenarios. The IPCC’s (Intergovernmental Panel on Climate Change) Fourth Assessment Report includes results of a number of Global Circulation Models (GCM) based on which predicted future changes for air temperature and precipitation are generated for a number of emission scenarios. Table 5.2 lists the GCM models and emission scenarios that are available in the Climate Change Tool.

**Table 5.2**

**Results of GCMs available in Climate Change tool of MIKE ZERO**

| SN | Model (GCM) | Acronym | Emission scenarios | Agency |
|---|---|---|---|---|
| 1 | BCCR:BCM2 | BCM2 | A1B, A2, B1 | Bjerknes Centre for Climate Research (BCCR), Univ. of Bergen, Norway |
| 2 | CCCMA:CGC M3_1 T-63 | CGMR | A1B | Canadian Centre for Climate Modelling and Analysis (CCCma) |
| 3 | CCCMA:CGC M3_1-T63 | CGHR | A1B, B1 | |
| 4 | CNRM:CM3 | CNCM3 | A1B, A2, B1 | Centre National de Recherches Meteorologiques, Meteo France, France |
| 5 | CONS:ECHO-G | ECHOG | A1B, A2, B1 | Meteorological Institute of the University of Bonn (Germany), Institute of KMA (Korea), and Model and Data Group. |
| 6 | CSIRO:MK3 | CSMK3 | A1B, A2, B1 | CSIRO, Australia |
| 7 | GFDL:CM2 | GFCM20 | A1B, A2, B1 | Geophysical Fluid Dynamics Laboratory,NOAA |
| 8 | GFDL:CM2_1 | GFCM21 | A1B, A2, B1 | |
| 9 | INM:CM3 | INCM3 | A1B, A2, B1 | Institute of Numerical Mathematics, Russian Academy of Science, Russia |
| 10 | IPSL:CM4 | IPCM4 | A1B, A2, B1 | Institut Pierre Simon Laplace (IPSL), France |
| 11 | LASG:FGOAL S-G1_0 | FGOALS | A1B, A2, B1 | LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences, P.R. China |
| 12 | MPIM:ECHAM 5 | MPEH5 | A1B, A2, B1 | Max Planck Institute for Meteorology, Germany |
| 13 | MRI:CGCM2_ 3_2 | MRCGCM | A1B, A2, B1 | Meteorological Research Institute, Japan Meteorological Agency, Japan |
| 14 | NASA:GISS-AOM | GIAOM | A1B, B1 | NASA Goddard Institute for Space Studies (NASA/GISS), USA |
| 15 | NASA:GISS-EH | GIEH | A1B, B1 | |
| 16 | NASA:GISS-ER | GIER | A1B, A2, B1 | |
| 17 | NCAR:PCM | NCPCM | A1B, A2, B1 | National Center for Atmospheric Research (NCAR), NSF (a primary sponsor), DOE (a primary sponsor), NASA, and NOAA |
| 18 | NIES:MIROC3 _2-HI | MIHR | A1B, A2, B1 | CCSR/NIES/FRCGC, Japan |
| 19 | NIES:MIROC3 _2-MED | MIMR | A1B, B1 | |
| 20 | UKMO:HADC M3 | HADCM3 | A1B, A2, B1 | Hadley Centre for Climate Prediction and Research, Met Office, United Kingdom |
| 21 | UKMO:HADG EM1 | HADGEM | A1B, A2, B1 | |
| 22 | NCAR:CCSM3 | NCCCSM | A1B, A2, B1 | National Center for Atmospheric Research (NCAR) |

*Source: DHI (2011a)*

For each emission scenario, month wise changes of parameters obtained from GCMs have been arranged in ascending order. Then month wise changes of parameters have been computed by averaging the values within 2nd and 3rd quartile of the series (obtained from all GCMs). Hydrological parameter i.e. river discharges, have been analyzed using the basin model of the Brahmaputra river.

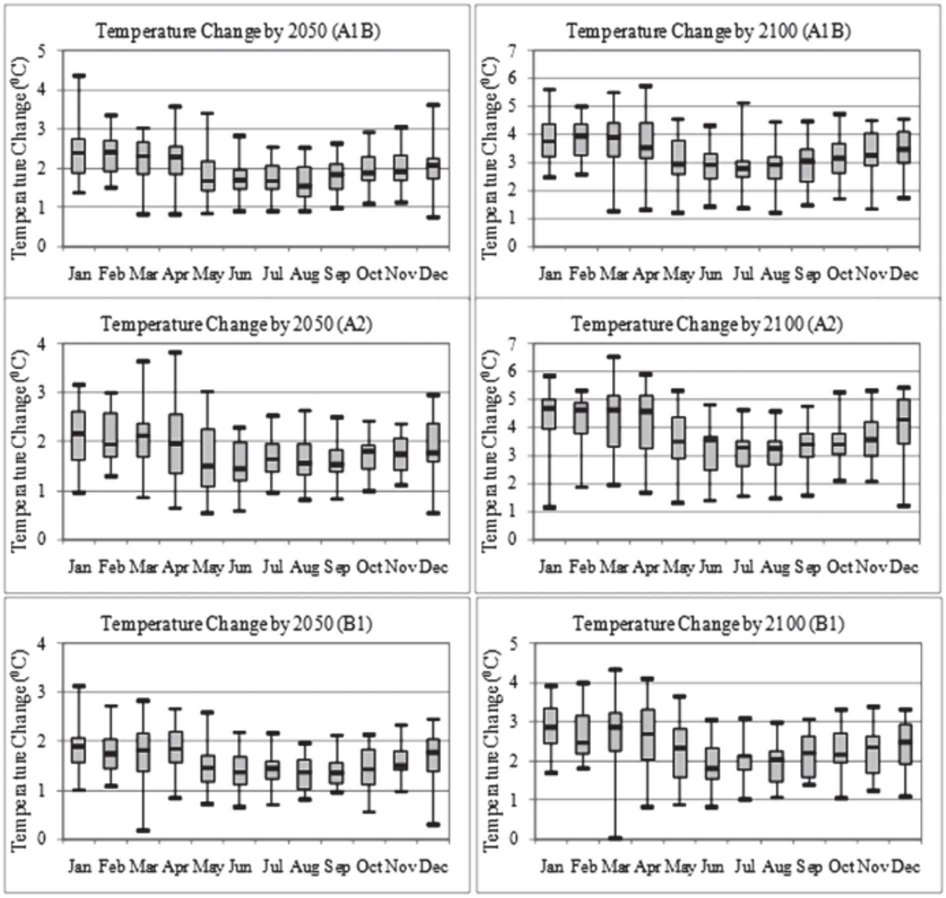
The basin model has been simulated for the period of 2008 to 2011 to generate the base hydrological feature of the basin. Month wise changes of river discharges (in 2050 and 2100) due to climate change have been determined by simulating the basin model using the base hydrological data modified with month wise changes of climatic parameters.

## 5.4 Temperature

Future monthly average temperature changes have been computed for 2050 and 2100 using future prediction results of 22 GCMs, each model comprises three future emission scenarios (A1B, A2, B1). All climate model results show tendency of gradual increase of temperature in the Brahmaputra basin. The increase of temperature ranges from 0$^0$C to 4.5$^0$C by 2050 and that from 0$^0$C to 6$^0$C by 2100 in different months (Figure 5.2). The average of increases of monthly temperature (Table 5.3) ranges from 1.3$^0$C to 2.4$^0$Cby 2050 and that from 2.0$^0$C to 4.5$^0$C by 2100. It is observed that increase of temperature is more in dry and winter months and less in monsoon months.

**Figure 5.2**

**Temperature Changes by 2050 and 2100 Due to Climate Change**



*Top, middle and bottom markers of the bar indicate maximum, median and minimum value, respectively. Wide part of the bar represents values ranging from 25 percent to 75 percent.*

**Table 5.3**

**Monthly Average Temperature Changes Due to Climate Change**

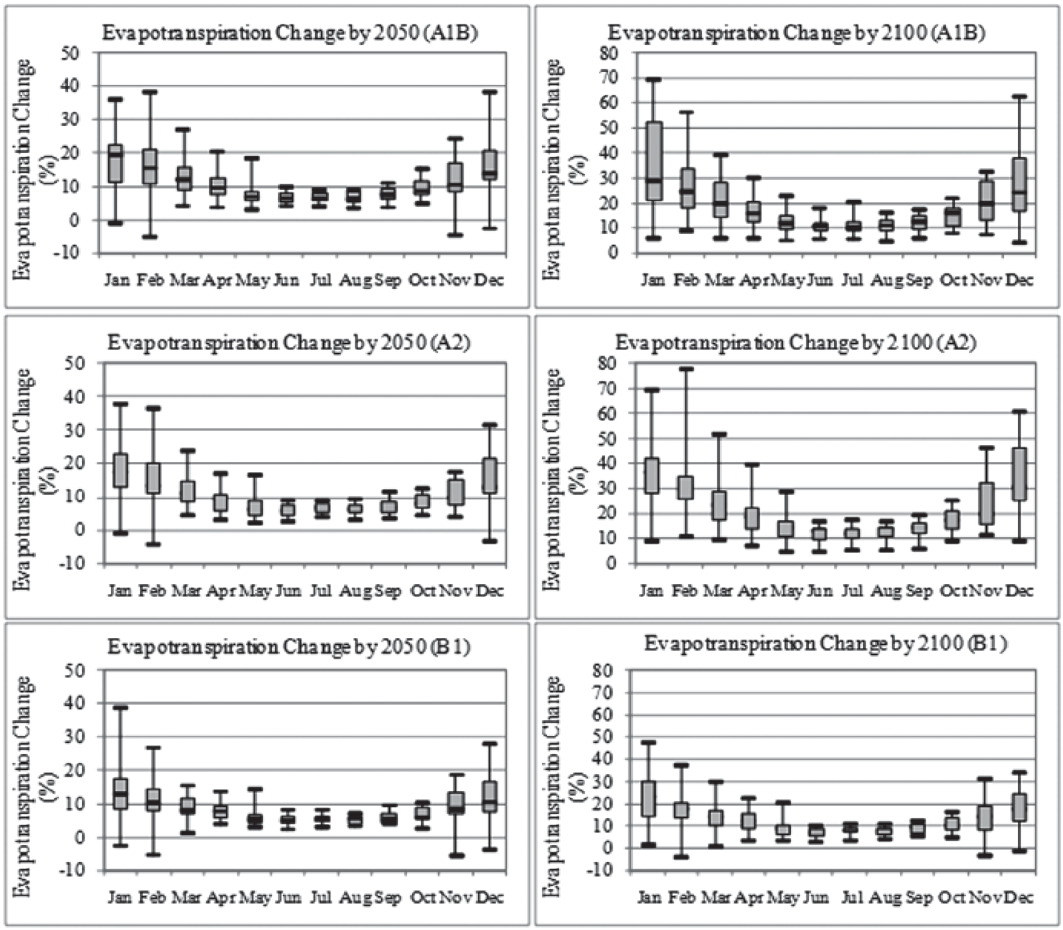
| Future Condition | Emission Scenario | Monthly Average Temperature Increase (0C) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 2050 relative to 2000 | A1B | 2.38 | 2.35 | 2.20 | 2.23 | 1.80 | 1.70 | 1.71 | 1.64 | 1.80 | 1.98 | 1.98 | 2.00 |
| | B1 | 1.89 | 1.77 | 1.70 | 1.80 | 1.45 | 1.38 | 1.43 | 1.34 | 1.45 | 1.40 | 1.56 | 1.60 |
| | A2 | 2.10 | 2.08 | 2.08 | 1.99 | 1.61 | 1.51 | 1.70 | 1.62 | 1.63 | 1.71 | 1.74 | 1.85 |
| 2100 relative to 2000 | A1B | 3.84 | 3.80 | 3.71 | 3.68 | 3.07 | 2.86 | 2.85 | 2.79 | 2.95 | 3.15 | 3.34 | 3.36 |
| | B1 | 2.82 | 2.65 | 2.58 | 2.65 | 2.21 | 1.86 | 2.02 | 1.95 | 2.15 | 2.25 | 2.27 | 2.44 |
| | A2 | 4.43 | 4.31 | 4.34 | 4.16 | 3.47 | 3.21 | 3.13 | 3.15 | 3.30 | 3.55 | 3.61 | 3.96 |

## 5.5 Evapotranspiration

Future monthly average evapotranspiration changes have been computed for 2050 and 2100 using predictions of 22 GCMs and three emission scenarios. All climate model results show increase of average evapotranspiration in the Brahmaputra basin. The increase of evapotranspiration ranges from 5% decrease to 40% increase by 2050 and that from 5% decrease to 80% increase by 2100 in different months (Figure 5.3). The average of increases of monthly evapotranspiration (Table 5.4) ranges from 5% to 18% by 2050 and that from 7% to 36% by 2100. Again it is observed that increase of evapotranspiration is significant in dry and winter months compared to monsoon months. Comparing the three emission scenarios, A1B and A2 have similar impacts, which are higher than impacts in B1.

**Figure 5.3**

**Evapotranspiration Changes by 2050 and 2100 Due to Climate Change**



*Top, middle and bottom markers of the bar indicate maximum, median and minimum value, respectively. Wide part of the bar represents values ranging from 25 percent to 75 percent.*

**Table 5.4**

**Monthly Average Evapotranspiration Changes due to Climate Change**

| Future Condition | Emission Scenario | Monthly Average Evapotranspiration Change (%) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 2050 relative to 2000 | A1B | 17 | 16 | 13 | 10 | 7 | 6 | 7 | 6 | 7 | 9 | 12 | 16 |
| | B1 | 15 | 11 | 9 | 8 | 6 | 5 | 5 | 5 | 6 | 7 | 9 | 12 |
| | A2 | 18 | 15 | 12 | 9 | 7 | 6 | 6 | 6 | 7 | 8 | 11 | 15 |
| 2100 relative to 2000 | A1B | 32 | 28 | 21 | 17 | 12 | 11 | 11 | 11 | 12 | 15 | 21 | 28 |
| | B1 | 23 | 17 | 14 | 12 | 9 | 7 | 8 | 7 | 9 | 11 | 14 | 19 |
| | | 36 | 33 | 25 | 19 | 14 | 12 | 12 | 12 | 14 | 17 | 23 | 34 |

## 5.6 Rainfall

Different climate model results comprising three future scenarios (A1B, A2, and B1) show both increasing and decreasing rainfall trends. Increase of rainfall under different months ranges from 0% to 300%, while decrease ranges from 2% to 70% by 2050. For the year 2100, increase of rainfall under different months ranges from 1% to 250% while decrease ranges from 1% to 90% (see Figure 5.4). The average change of rainfall under different months ranges from 14% decrease to 15% increase by 2050 (see Table 5.5). For the year 2100, the average change of rainfall under different months ranges from 28% decrease to 22% increase by 2100. In the A2 scenario, the change in rainfall by 2100 from 2050 is much more pronounced than for the other two emission scenarios.

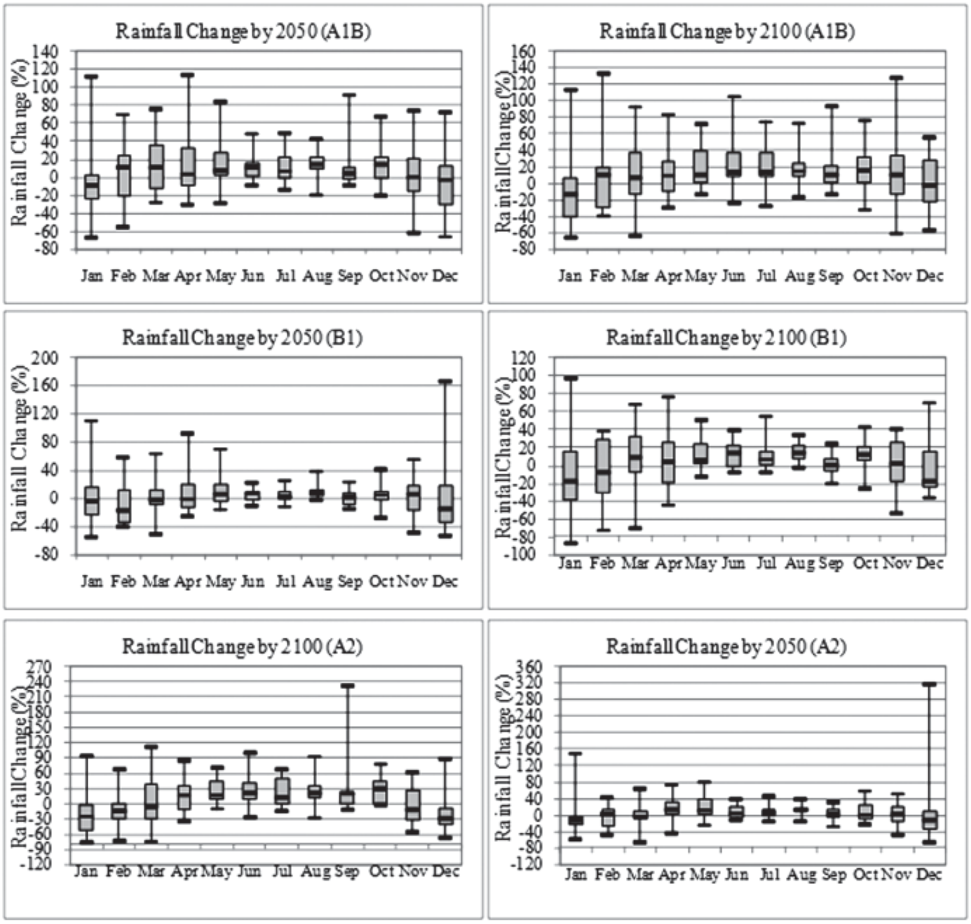
**Table 5.5**

**Monthly Average Rainfall Changes due to Climate Change**

| Future Condition | Emissions Scenario | Monthly Average Rainfall Change (%) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 2050 relative to 2000 | A1B | -11 | 8 | 10 | 8 | 11 | 10 | 8 | 14 | 4 | 12 | 2 | -7 |
| | B1 | -4 | -14 | -2 | -1 | 7 | 5 | 3 | 8 | 1 | 3 | 3 | -13 |
| | A2 | -13 | -5 | -2 | 15 | 15 | 5 | 5 | 12 | 3 | 5 | 3 | -14 |
| 2100 relative to 2000 | A1B | -16 | 1 | 9 | 9 | 16 | 18 | 15 | 15 | 10 | 14 | 6 | -4 |
| | B1 | -16 | -6 | 9 | 0 | 8 | 12 | 7 | 14 | 0 | 12 | 2 | -11 |
| | A2 | -28 | -16 | -4 | 14 | 18 | 22 | 15 | 20 | 15 | 22 | -6 | -27 |

**Figure 5.4**

**Rainfall Changes by 2050 and 2100 Due to Climate Change**



*Top, middle and bottom markers of the bar indicate maximum, median and minimum value, respectively. Wide part of the bar represents values ranging from 25 percent to 75 percent.*

# 6

# Model Update and Development

## 6.1 Model Objective and Selection

The modelling objective was to estimate the impact of climate change on river flows in the Brahmaputra Basin. For this purpose, a suitable hydrologic model that can simulate changes in river flows due to the changes in key climatic variables (as presented in the previous section) was required.

IWM developed the Ganges Brahmaputra Meghna (GBM) basin model for the Flood Forecasting and Warning Centre (FFWC), Bangladesh Water Development Board (BWDB) in 2005. This model comprises the catchments and reaches of three major rivers: the Ganges, the Brahmaputra, and the Meghna Rivers. After development, the model has been tested at IWM using several rainfall data sets (Nishat and Rahman 2009). The model was calibrated at outlet stations: Hardinge Bridge (of the Ganges River) and Bahadurabad (of the Brahmaputra River) inside Bangladesh. The performance of the model could not be tested within India due to non-availability of data. The model has been used in several studies in the last several years by IWM. The model is based on MIKE BASIN, the GIS based water resource modelling interface developed by DHI Water and Environment, Denmark. The model comprises 133 sub-catchments, out of which 79 in the Ganges basin, 47 in the Brahmaputra basin and the rest 7 in the Barak basin. Model areas under the Ganges, Brahmaputra and Barak basins are 979503 sq. km, 520663 sq. km. and 26567 sq. km, respectively. The model includes snow melt feature in the snow fed catchments of Hindukush Himalaya region. The Brahmaputra Basin part of the GBM basin model was therefore deemed suitable for this particular climate change impact study.

## 6.2 Input Data

This study used rainfall data, evapotranspiration data, temperature data, river discharge data, topographic data (land terrain) and results of Climate Change Models. Availability and sources of those data are described briefly below.

### 6.2.1 Rainfall Data

Daily rainfall data have been collected from IWM data base and several web sites for the period of 2007 to 2011, which comprise of both station data and grid data. Total number of stations where rainfall data could be made available is about 78. Rainfall data are not available for entire period at all stations; rather it varies from 1 to 5 years at different stations. Satellite estimated rainfall data published by TRMM have also been downloaded and processed for the period of 1998 to 2010.

### 6.2.2 Evapotranspiration Data

Monthly evaporation data at different stations in the Brahmaputra basin area within India and China (Tibet) have been collected from database of IWM, published books, publications and web sites. Total number of evaporation stations used in the model is five which are: Doimukh, Gangtok, Sillong, Dibrugarh and Thakurgaon. The first four of the five stations are located in India, where evaporation data have been collected (Mutreza 1990). The last station of the five is located in Bangladesh, where data have been collected from database of IWM.

### 6.2.3 Temperature Data

Daily high-low temperature data have been collected from IWM data base and web sites for the period of 2007 to 2011 at several important stations in the study area. Data from five stations have been used: Lhasa, Nyingchi, Zigaze, Dibrugarh and Gangtok in the Brahmaputra river basin area. Daily average temperatures have been calculated from daily high-low data and used in the model.

### 6.2.4 River discharge Data

Measured river discharge data have been collected from IWM data base, which are mostly measured at Bahadurabad and Serajganj stations of the Brahmaputra river for the period of 2007 to 2011.

### 6.2.5 Land Terrain Data

There are three types of land terrain data: GTOPO30, SRTM and ASTER of the basin area available in IWM data base, which is downloaded from web sites of USGS.

**GTOPO30 Land Terrain Data**

GTOPO30 land terrain data set was developed over a three year period through a collaborative effort led by staff at the U.S. Geological Survey's EROS Data Center (EDC), and completed in late 1996. It is a digital elevation model with a horizontal grid spacing of 30 arc seconds (approximately 1 kilometer near the equator), and covers the full extent of latitude from 90 degrees south to 90 degrees north, and the full extent of longitude from 180 degrees west to 180 degrees east. The horizontal coordinate system of the data set is decimal degrees of latitude and longitude referenced to WGS84. The vertical units represent elevation in meters above mean sea level. The data set is derived from several raster and vector sources of topographic information. It is divided into 33 no of tiles. The data has been downloaded from the website http://www1.gsi.go.jp/geowww/globalmap-gsi/gtopo30/gtopo30.html for the Brahmaputra basin, processed, developed by Digital Elevation Model (DEM) and preserved in GIS grid format.

**SRTM Land Terrain Data**

The Shuttle Radar Topography Mission (SRTM) obtained elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of Earth. SRTM consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission in February of 2000. SRTM is an international project spearheaded by the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA). Virtually all of the land surface between +/- 60 degrees latitude was mapped by SRTM. The data may be obtained through URL: http://dds.cr.usgs.gov/srtm/ where both version 1 and version 2 directories may be found.

The original SRTM data is provided in 1-degree digital elevation model (DEM) tiles from the USGS ftp server (ftp://e0srp01u.ecs.nasa.gov/srtm/version2/SRTM3/). The data is available continent by continent at 3-arc seconds (approximately 90m at the equator) resolution for the entire terrestrial surface. The data is projected in a Geographic (Lat/Long) projection, with the WGS84 horizontal datum and the EGM96 vertical datum. The data has been downloaded from website, processed into a grid DEM by adopting mosaic facilities of ARC GIS software. The grid DEM then has been projected under Universal Transverse Mercator (UTM) projection. SRTM data have been used only for some minor re-delineation of sub-catchment boundaries.

**ASTER G-DEM Land Terrain Data**

The ASTER elevation data is also another high resolution Satellite estimated data. Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM), in short ASTER G-DEM, is provided in 1-degree × 1-degree scene (equivalent to 3,600 km$^2$). It is available via electronic download from the Earth Remote Sensing Data Analysis Center (ERSDAC) of Japan (http://www.ersdac.or.jp/GDEM/E/). The data is projected in a Geographic (Lat/Long) projection, with the WGS84 horizontal datum and the EGM96 vertical datum. The data is available at 1-arc seconds (approximately 30m at the equator) resolution for the globe between 83° latitude. About 58 nos. of tiles have been downloaded, which are in the form of tiff file. The downloaded tiles then have been converted into a grid DEM by adopting mosaic, using ARC GIS 9.2 software. The grid DEM was projected under Universal Transverse Mercator (UTM) projection.

## 6.3 Model Setup

The river reaches and sub-catchments of the GBM model have been delineated based on the Satellite estimated land terrain data of SRTM. The GBM basin model comprises 133 sub-catchments, out of which, 79 in the Ganges basin, 47 in the Brahmaputra basin and the rest 7 in the Barak basin. Areas included in the model under the Ganges, Brahmaputra and Barak basins are 979503 sq. km, 520663 sq. km. and 26567 sq. km, respectively. The model includes snow melt feature in the snow fed catchments of Hindukush Himalaya region. However, the complex glacier melt phenomenon is not defined in the model. Lumped features of the water retention and control structures (reservoirs and dams) within

India are incorporated in the model based on information available in secondary sources. The extent, sub-catchments distribution and river system of the model in the Brahmaputra basin area is shown in Figure 6.1.

The Brahmaputra basin model is developed from the original GBM basin model. The sub-catchments of the model are listed in Table 6.1. The model uses a rainfall-runoff model (NAM) of the basin together with hydrological routing facilities available in MIKE BASIN. Further details of the NAM model can be found in DHI (2011b). Typical values used for the NAM model are provided in Table 6.2.

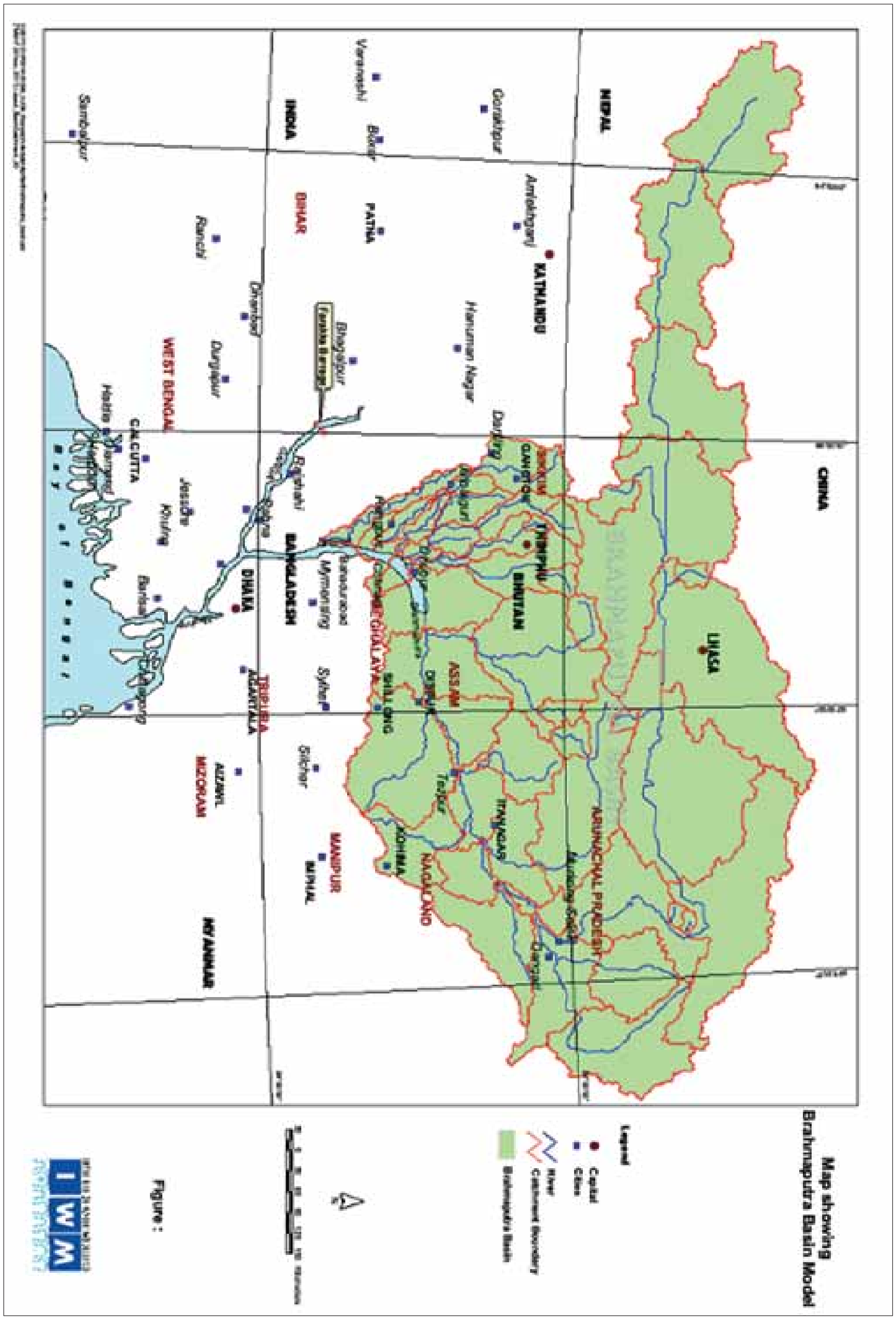


Figure 6.1

Extent of the Brahmaputra River Basin Model

**Table 6.1**

**Sub-catchments of the Brahmaputra river basin model**

| Name of Sub-catchments | Area (sq. km) | Name of Sub-catchments | Area (sq. km) |
|---|---|---|---|
| BRAHMAPUTRA1 | 24,233 | DHARALA2 | 2,155 |
| BRAHMAPUTRA2 | 23,543 | DIBANG | 11,238 |
| BRAHMAPUTRA3 | 23,957 | DUDKUMAR1 | 3,569 |
| BRAHMAPUTRA4 | 44,279 | DUDKUMAR1-GLACIER | 2,159 |
| BRAHMAPUTRA4-GLACIER | 2,859 | DUDKUMAR2 | 2,640 |
| BRAHMAPUTRA5 | 39,406 | DUDKUMAR3 | 1,150 |
| BRAHMAPUTRA5-GLACIER | 1,419 | KAMENG | 9,504 |
| BRAHMAPUTRA6 | 41,618 | KOPILI | 21,555 |
| BRAHMAPUTRA6-GLACIER | 1,010 | LOHIT | 19,056 |
| BRAHMAPUTRA7 | 32,004 | MANAS | 23,169 |
| BRAHMAPUTRA7-GLACIER1 | 560 | MANAS-GLACIER1 | 1,882 |
| BRAHMAPUTRA7-GLACIER2 | 667 | MANAS-GLACIER2 | 3,204 |
| BRAHMAPUTRA8 | 18,651 | SUBANSIRI1 | 23,927 |
| BRAHMAPUTRA9 | 14,200 | SUBANSIRI1-GLACIER | 2,559 |
| BRAHMAPUTRA10 | 3,148 | SUBANSIRI2 | 9,019 |
| BRAHMAPUTRA11 | 5,503 | SUNKOSH1 | 7,866 |
| BRAHMAPUTRA12 | 7,319 | SUNKOSH1-GLACIER | 1,826 |
| BRAHMAPUTRA13 | 8,133 | SUNKOSH2 | 3,828 |
| BRAHMAPUTRA14 | 13,934 | SUNKOSH2-GLACIER | 735 |
| BRAHMAPUTRA15 | 12,794 | SUNKOSH3 | 1,336 |
| BRAHMAPUTRA16 | 1,832 | TEESTA1 | 5,428 |
| BRAHMAPUTRA17 | 3,193 | TEESTA1-GLACIER | 2,953 |
| BURI-DIHING | 13,150 | TEESTA2 | 1,897 |
| DHANSIRI | 10,291 | TEESTA3 | 2,006 |
| DHARALA1 | 3,505 | TEESTA4 | 4,796 |

Along with the meteorological inputs, (rainfall, temperature and evaporation) the NAM needs a set of parameters for four different conceptual storage zones: the snow storage, the surface storage, the root zone storage and the ground water reservoir storage. The parameters and their used and typical values are given in Table 6.2

**Table 6.2**

**Typical NAM Model Parameters**

| Storage Zone | Nam Parameters | Value used | Default values | Typical values |
|---|---|---|---|---|
| Snow | Csnow | 2-4 | 4 | 2 - 4 |
| | T0 | 0 | 0 | 0 |
| Surface & Rootzone | Umax | 8-20 | 10 | 10 - 20 |
| | Lmax | 30-300 | 100 | 50 - 300 |
| | CQOF | 0.1-0.90 | 0.50 | 0 -1.0 |
| | CKIF | 200-1000 | 1000 | 500 - 1000 |
| | CK1,2 | 10-130 | 10 | 3 - 48 |
| | TOF | 0-0.99 | 0 | 0 - 0.70 |
| | TIF | 0-0.99 | 0 | |
| Groundwater | TG | 0-0.99 | 0 | 0 - 0.70 |
| | CKBF | 1000-4000 | 2000 | |
| | Carea | 1 | 1 | |
| | Sy | 0.1 | 0.1 | 0.01 - 0.30 |
| | GWLBF0 | 10 | 10 | |
| | GWLBF1 | 0 | 0 | |
| | Cqlow | 0-100 | 0 | |
| | Cklow | 1000-3000 | 10000 | |

**Notes:**

| | |
|---|---|
| Umax | Maximum water content in surface storage |
| Lmax | Maximum water content in root zone storage |
| CQOF | Overland flow runoff coefficient |
| CKIF | Time constant for interflow |
| CK1, 2 | Time constants for routing overland flow |
| TOF | Root zone threshold value for overland flow |
| TIF | Root zone threshold value for inter flow |
| CKBF | Time constant for routing base flow |
| Tg | Root zone threshold value for ground water recharge |
| Carea | Ratio of ground water catchment to topographical catchment area |
| Sy | Specific yield for the ground water storage |
| GWLBF0 | Maximum ground water depth causing base flow |
| GWLBF1 | Depth for unit capillary flux |
| Cqlow | Lower base flow. Recharge to lower reservoir |
| Cklow | Time constant for routing lower base flow |
| Csnow | Constant Degree-day coefficient, mm/day/$^0$C |
| T0 | Base Temperature snow/rain. |

Some of the key model assumptions are as follows:

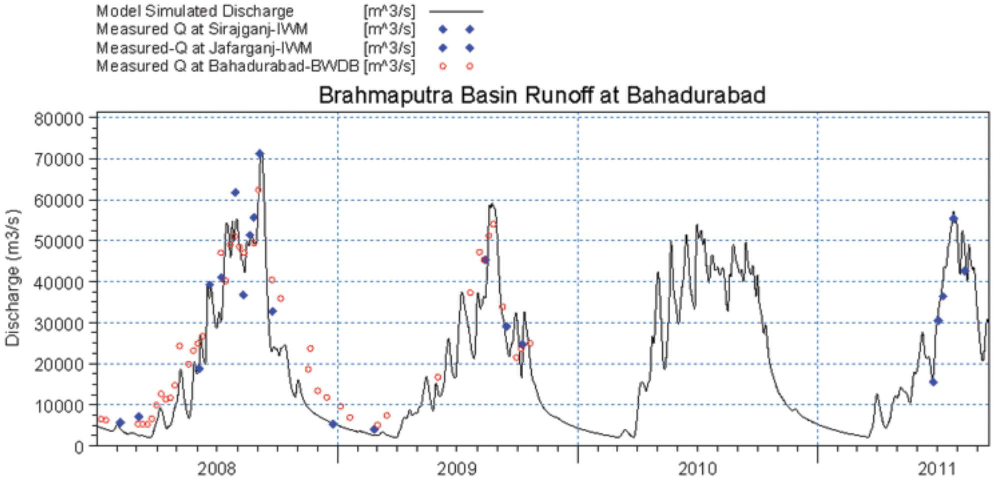
- Land use and land cover will not change dramatically in the future, i.e. catchment runoff coefficients will be similar
- Water losses from the basin (through evapotranspiration) will not be significantly different in the future
- There will be no major dams built in the future
- Water demands will not alter the hydrological regime
- Snow melt modeled using area-elevation relationship
- Glacier contribution to runoff is included in the snow-melt modelling procedures

## 6.4 Model Calibration and Validation

The model was calibrated and validated for the period 2008 to 2011. The comparison plots of model simulated and observed discharges at Bahadurabad have been shown in Figure 6.2 Daily flow records for places in the Indian portion of the basin were not available for calibration/validation. The results for Bahadurabad indicate that the model performance is sufficiently good for the modelling objective. The base simulation period (2008 to 2011) includes hydrologically average, wet and dry conditions.

**Figure 6.2**

**Comparison of Simulated and Measured Discharge at Bahadurabad**



The performance of the model has been checked at Bahadurabad against measured discharge using Nash Sutcliffe Co-efficient (E) (see Table 6 3). It is observed that the value of E varies from 0.75 to 0.89. This is deemed acceptable for the purposes of this study.

**Table 6.3**

**Performance of Brahmaputra basin Model**

| Year | Nash Sutcliffe Co-efficient (E) |
|---|---|
| 2008 | 0.75 |
| 2009 | 0.80 |
| 2010 | n/a |
| 2011 | 0.89 |

## 6.5 Model Scenarios

In order to assess the impacts of climate change on river flows, the following modelling scenarios were run:

- Base period (2008 to 2011)
- A1B (2008 to 2011 with changes in temperature, rainfall and evapotranspiration for 2050 and then for 2100 for the A1B climate change scenario)
- B1 (2008 to 2011 with changes in temperature, rainfall and evapotranspiration for 2050 and then for 2100 for the B1 climate change scenario)
- A2 (2008 to 2011 with changes in temperature, rainfall and evapotranspiration for 2050 and then for 2100 for the A2 climate change scenario)

# 7

# Results and Discussion

## 7.1 Average Monthly Flows

The flow of the Brahmaputra River has been simulated at Chilmari, Bangladesh for the base period and also for three climate change scenarios. This location was selected as it is close (less than 30km) to the international border. In the base period, 2009 had the lowest average flows and rainfall. As shown in Table 7.1, there is good correlation between changes in monthly basin rainfall and average flow at Chilmari. Where there is an increase in rainfall, in general, there is a corresponding increase in flow and vice versa. Comparing average monthly flows of 2010 with 2009 shows an increase of about 12% while there is  decreases in flow in three months (prior to onset of monsoon). The results show that large increase in monsoon flows tends to lead to an increase in the lean season (base) flows.

By 2050, the river flow changes by-1% to 15% in different months (Table 7.2), while the same analysis shows  river flow changes ranging from 5% to 20% in 2100. It is observed that change of monthly average flow due to climate change is more prominent in summer months (Mar, Apr, May) compared to wet (Jun, Jul, Aug, Sep) and winter (Dec, Jan, Feb) months. By 2050, A1B impacts tend to be highest compared to A2 followed by B1. In April and May of 2050, the A2 scenario flow changes are similar or higher than the A1B flow changes. This is driven by the higher increase in rainfall in the A2 scenario compared to the A1B scenario (see Table 5.5). As with the climate variables, the impacts are similar for A1B and A2 by 2100, which are higher than impacts in the B1 emissions scenario.

**Table 7.1**

**Change in Monthly Basin Rainfall and Simulated Average Flow at Chilmari from 2009**

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Rainfall** | | | | | | | | | | | | |
| 2009 (mm) | 8 | 15 | 38 | 89 | 175 | 220 | 251 | 376 | 123 | 122 | 6 | 4 |
| 2008 | 225% | 10% | 314% | 38% | 20% | 85% | 80% | 10% | 57% | -5% | 51% | -27% |
| 2010 | -98% | -6% | 323% | 160% | 126% | 125% | 43% | -19% | 184% | 9% | 461% | -89% |
| 2011 | 113% | 93% | 352% | 84% | 63% | 48% | 95% | -20% | 150% | -51% | n/a | n/a |
| **Flow** | | | | | | | | | | | | |
| 2009 (m3/s) | 3941 | 2882 | 2357 | 5466 | 11640 | 17766 | 30139 | 44747 | 27824 | 19552 | 8093 | 5136 |
| 2008 | 1% | 3% | 13% | 6% | 11% | 56% | 47% | 4% | 40% | -9% | 16% | 13% |
| 2010 | -12% | -16% | 24% | 240% | 167% | 123% | 48% | -10% | 45% | 12% | 18% | 20% |
| 2011 | 6% | 1% | 77% | 24% | 3% | 23% | 52% | -6% | 4% | 1% | n/a | n/a |

The increase in flow in winter months was not initially expected. Further analyses of the hydrographs from each of the catchments provided explanations for the overall increase in flows throughout the year. First of all, the large increase in monsoon flows (flood peaks) has also resulted in increases in the rising and recession limbs of the hydrograph. The increase in monsoon flows is not only driven by the increase in rainfall and snowmelt rates

**Table 7.2**

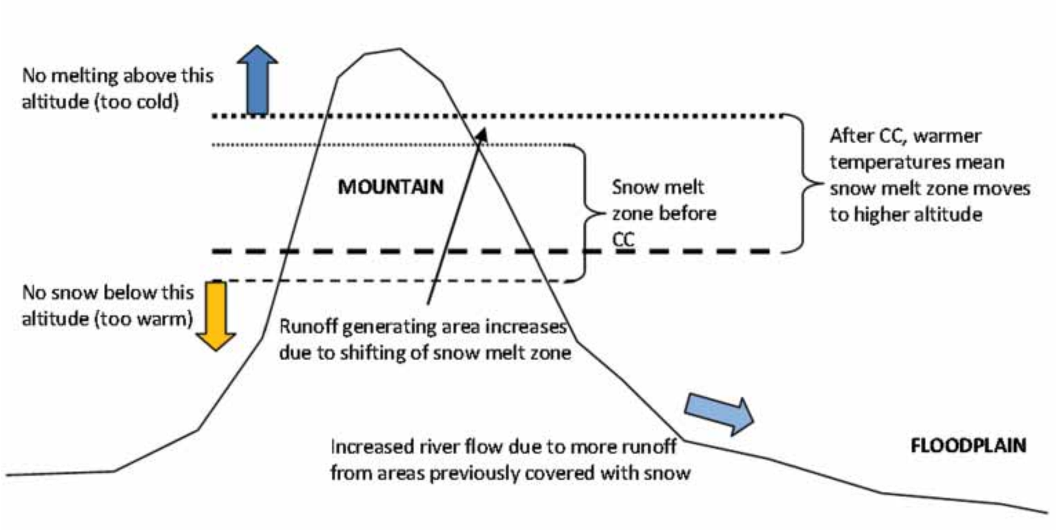
**Monthly Average River Flow Changes at Chilmari Due to Climate Change**

| Yr | Emission Scenario | Monthly Average River Flow Change (%) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 2008-11 | Base ($m^3$/s) | 3885 | 2803 | 3031 | 9154 | 16894 | 26718 | 41230 | 43360 | 34016 | 19727 | 9008 | 5692 |
| 2050 | A1B | 9 | 9 | 15 | 13 | 11 | 8 | 7 | 11 | 9 | 9 | 11 | 10 |
| | B1 | 4 | 3 | 0 | -1 | 4 | 3 | 1 | 5 | 3 | 3 | 4 | 4 |
| | A2 | 6 | 5 | 3 | 13 | 16 | 6 | 3 | 8 | 7 | 6 | 7 | 7 |
| 2100 | A1B | 14 | 13 | 16 | 12 | 13 | 13 | 12 | 13 | 12 | 13 | 15 | 14 |
| | B1 | 7 | 6 | 11 | 5 | 5 | 7 | 6 | 10 | 6 | 7 | 9 | 8 |
| | A2 | 17 | 15 | 7 | 9 | 15 | 16 | 13 | 17 | 17 | 19 | 20 | 18 |

but also by the increase in runoff generating areas in snowmelt catchments. As shown in Figure 7.1, the increase in temperature due to climate change results in the snowmelt zone shifting to higher altitudes. As a result, this exposed areas in mountains that previously would have remained frozen (or covered in snow) throughout the year now generates runoff during rain events.

**Figure 7.1**

**Effect of Increased Temperature on Runoff Generating Area in Mountain Regions**



## 7.2 Dependable Flows

As shown in Table 7.3, the 90% dependable flow is expected to increase by 1% to 11% by 2050 and by 7% to 14% by 2100. Unlike the other variables, the impacts are higher for A1B compared to A2, which in turn has higher impacts than in the B1 emissions scenario. Like the other variables, the 2100 impacts are higher than those estimated for 2050.

**Table 7.3**

**Change in Dependable Flows at Chilmari Due to Climate Change**

| Future Condition | Emission Scenario | Exceedance Probability | | | | |
|---|---|---|---|---|---|---|
| | | 50% | 80% | 90% | 95% | 99% |
| 2050 | A1B | 12 | 12 | 11 | 11 | 10 |
| | B1 | 3 | 3 | 1 | 3 | 1 |
| | A2 | 12 | 7 | 4 | 6 | 4 |
| 2100 | A1B | 14 | 15 | 14 | 15 | 12 |
| | B1 | 6 | 9 | 7 | 8 | 6 |
| | A2 | 15 | 14 | 13 | 16 | 12 |

## 7.3 Study Limitations

There were several limitations to this study:

- Water demands were not included in the model
- Future land use changes were considered to be limited
- It was assumed that there would not be any major dams built in the basin
- It was assumed that there would be no significant inter-basin transfers of water
- Tidal and hydrodynamic processes were not included in the basin model

Some of the above mentioned limitations have an effect on the model results at Chilmari. For example, if the water demands were included, the dependable flows would tend to decrease. Future land use changes, such as urbanization, would tend to increase runoff and lead to increase in river flows. On the other hand, further expansion of irrigation areas could lead to decrease in river flows due to higher evapotranspiration losses from the basin. If dams are built in the basin, some of the higher monsoon flows could be reduced and dry season flows increased. However, it is unlikely that inter-annual changes in the flow regime could be achieved, given the very large annual flow volume of the river. Transfer of water out of the basin will alter the flow in the river, especially during the dry season. Tidal and hydrodynamic processes are likely to affect the flows simulated at the end of the system, near the Bay of Bengal. In the dry season, the tidal signal would propagate upstream to the Padma River (after the confluence of the Ganges and Brahmaputra Rivers). In the monsoon season, backwater effects would also influence flows in the Padma River. Despite the above limitations, the potential impacts of climate change on the physical river system could still be researched.

The large variations in rainfall (seasonal and annually) highlight the need for regional climate models. It is expected that the hydrologic model will perform better with outputs from regional climate models. Therefore, there needs to be regional modelling efforts rather than downscaling of GCM models.

For many of the Indian catchments, remote sensing rainfall data has been relied upon. It is expected that using more station data will improve the performance of the hydrologic model. Therefore, more emphasis should be given on ground based measurements.

# 8

# Stakeholder Consultations

## 8.1 Initial Discussions and Project Formulation

A joint Project Advisory Committee (PAC) oversees implementation of the E4L Initiative and acts as a bridge for the dialogue process between government and civil society at the regional level. The PAC is comprised of National Advisory Committee (NAC) members from Bangladesh and India. Each committee comprises of eight members and included prominent professionals, legislators, diplomats, researchers and academics of high repute at the national, regional and international level. The Project Advisory Committee met for the first time on 7 February 2011 in Dhaka. Aban Marker Kabraji, Regional Director of IUCN Asia, Dr Q. K. Ahmed, Co-Chair of NAC Bangladesh, and Mr Ashok Jaitley, Co-Chair of NAC India, were nominated as Co-Chairs for the Project Advisory Committee. Institute of Water Modelling (IWM) and Indian Institute of Technology (IIT) Guwahati agreed to carry out the physical assessment part under separate contract with IUCN, Bangladesh.

## 8.2 Workshop on Approach and Methodologies

A consultation workshop was held in August 2011 in Nepal to discuss different focus themes and approaches, related to the various E4L joint research projects. In this 2-day event, members of joint research team also discussed in detail the important methodological issues pertaining to their respective projects. The consultation participants included experts in research, water infrastructures, climate science, hydrology, economics, fisheries, etc. This interdisciplinary mix offered important opportunities for cross-discipline discussions within and between the groups from different countries. IUCN has prepared a detailed report on the workshop (IUCN 2011).

**Figure 8.1**

**Photo of participants at Stakeholder Workshop in Nepal**

## 8.3 Dhaka Workshop

An E4L stakeholders' workshop was held in Dhaka on 24th November, 2011. The objectives of this day-long event were to:

- Present findings and results of the joint research by the teams
- Share knowledge and experiences on thematic research methodologies with multi-stakeholders
- Engage in an active dialogue between the experts on water resources management and transboundary initiatives in the region
- Establish a larger network of individuals and institutions in both the countries

This workshop was also covered by the national media in Bangladesh. For example, a press clipping is shown in Figure 8.2.

**Figure 8.2**

**Press Clipping of Dhaka Workshop from Bangladesh's Daily Star Newspaper**

# Hold more talks to solve Indo-Bangla problems

## Suggests joint research

STAFF CORRESPONDENT

A joint research of Bangladesh and India suggested holding dialogues, more research, sharing knowledge, capacity building and disseminating climate issues to solve problems between the two countries.

The suggestions came at a workshop on "Trans-boundary water resource knowledge sharing: presentation of joint research findings and initiatives" organised by International Union for Conservation of Nature (IUCN), a Netherlands-based organisation, at a city hotel yesterday.

"Ecosystem for life: a Bangladesh-India initiative", a platform of civil society members and researchers of Bangladesh and India under IUCN, carried out the research.

The platform is holding dialogues involving stakeholders to promote better understanding of the management of natural resources in the two countries.

The dialogues involve research on food security and safe drinking water productivity for poverty alleviation; climate change impacts and its adaptation methods and mitigating strategies; preserving navigability of rivers and integrated water resources management.

Besides, the dialogues emphasise on the link between economic development and environmental security and improving understanding of ecosystems and habitats.

Speakers at the workshop said climate change has serious impacts on four issues -- water, food, migration and disasters -- threatening the lives of around 655 million South Asians, especially those living in the Ganges-Brahmaputra and Meghna deltas.

*Climate change has serious impacts on four issues -- water, food, migration and disasters -- threatening the lives of around 655 million South Asians, especially those living in the Ganges-Brahmaputra and Meghna deltas*

Therefore, civil society members of the two countries need to hold dialogues to share knowledge for solving issues related to protection of these people and preservation of biodiversity, they said.

Addressing the workshop as the chief guest, State Minister for water resources, Mahbubur Rahman, said collective actions and mutual learning are needed to resolve the common issues and problems of the two countries.

Besides, the civil society, policymakers and visionary scientists of multiple disciplines would benefit from sharing of knowledge by the researchers in the two countries, he said.

Former adviser to a caretaker government, CM Shafi Sami, chaired the workshop.

The results from this joint research project were presented in this workshop to a diverse audience that included stakeholders from India, Bangladesh and other countries. There were representatives present from government and non-government agencies.

A summary of the discussions related to this joint research project are as follows:

- Dr. Mitra, Former Secretary and present advisor of Water Resources Ministry in Assam (India), appreciated the implementation of climate models for water resources management under changing climatic condition. He highlighted the glacier melting issue under climate change and the uncertainties of model predicted results. He also expressed the importance of climate change adaptability.
- Dr. Maminul Haque Sarker of CEGIS, provided positive feedback on the projection based outcomes for climate change in water resources system of Brahmaputra basin. He also highlighted the need to better understand water flow regime under uncertainty, higher rainfall intensities and flooding conditions.
- Dr. Niaz Ahmed Khan of IUCN commented on the simulation model results. He appreciated the manner

in which Climate change projections were successfully included in the hydrologic (basin) model. He also stated the importance of climate change related scientific research and expressed satisfaction that now there are some tangible results of its potential impacts on water resources.
- Mr. Shah-Newaz (member of this joint research team) also described some of the major outputs of a study on the Alakananda Basin, located in the lower Himalayan region.
- Prof. Dr. Chandan Mahanta (member of this joint research team) highlighted the challenging task of data collection and checking its accuracy. He also emphasized on the importance of robustness of models to predict possible impacts of climate change, which can lead to better adaptation decisions.

A more detailed description of the workshop consultations are provided in a separate IUCN report (IUCN 2012).

## 8.4 Project Team Meetings

Throughout the project, there have been several meetings amongst the joint research team. This included discussions in Dhaka and Guwahati that focussed on issues related to:

- Features and processes in different parts of the basin
- Modelling approach and assumptions
- Model results
- Report finalization

# 9

# Conclusions and Recommendations

## 9.1 Concluding Remarks

For the river Brahmaputra, being one of the largest international rivers, with a huge resource base and high hazard potential, only effective cooperation and coordination among the riparian countries can overcome the basin's problems and put the region in a development trajectory. This project has successfully demonstrated the potential of fruitful collaboration between researchers from India and Bangladesh in the field of water resources. Water resource planning is a complex issue entwined in the web of political red tapism; however, employing a rigorous scientific approach, with good quality data and using transparent, adaptive, and resilient mathematical models that integrate different data types, framework for a productive collaboration can be established.

Analyses of outputs from various GCM models suggest that climate change will lead to a gradual increase in temperatures and evapotranspiration rates throughout the basin. The impact on rainfall will be a decrease in winter rainfall but an increase in the monsoon season. Preliminary climate change simulation results suggest that there will be a net increase in flows of the Brahmaputra River in the next 50 to 100 years. The overall increase in flows throughout the year is driven by significant increase in monsoon flows arising from increased rainfall, higher snow melt rates and increase in run off generating areas (as snow melt zone shifts to higher latitudes due to climate change). The increase in flows by 2050 concurs with common understanding of climate change impacts in the Brahmaputra Basin. However, the continued increase in inflows by the year 2100 goes against the common understanding that reduction in glacier contributions over the long term would have a decreasing impact on flows. This highlights the large uncertainties associated with long term climate change impact estimates.

Generally A1B and A2 impacts are similar, which tend to be more severe than impacts in the B1 emission scenario. Also, 2100 impacts are projected to be more severe than impacts estimated for 2050.

## 9.2 Recommendations

### 9.2.1 Further Collaboration

Further initiatives should be taken to encourage collaborative research amongst individuals and institutes from India and Bangladesh. Wherever possible, research participants from other riparian countries should be involved. The pressing issue of Climate Change can be a driver for further transboundary cooperation.

### 9.2.2 Sharing Data and Analyses

An interesting area where more collaborative activities can be undertaken is in snowmelt research. Further data on snowmelt areas, rates, etc. need to be collected and analysed in order to better understand the underlying processes, which can then be used to improve hydrological and water resources models. We also recommend that further studies be undertaken with downscaled GCM projections, more in line with observations at local level.

### 9.2.3 Joint Modelling Studies

Further basin model simulations can be undertaken with climate change predictions from IITG and regional PRECIS model (CCC 2009) or DSSAT model. This will help better understand the uncertainties associated with climate change and potential impacts. Incorporating a broad range of climate change scenarios (and impacts) in modelling studies will help identify more robust adaptation measures. Another area for future work is to include water demand projections into the basin model. This will require population projections, future agricultural and irrigation needs, hydropower demands, possible land use changes, cumulative impact assessments of existing and proposed dams in the Brahmaputra Basin and so on. Such modelling applications will, apart from initiating informed debate over future course of action, will also help evaluate the scenario in a detailed manner and may help to identify the possible tradeoffs among quantifiable objectives so that further assessment, and analyses can be more informed and precise and would help planners and policy makers. Such works are already in progress both at IWM and IITG. A research project completed in 2013 at IITG on PRECIS and DSSAT modelling of climate change impact on rice has important implication to both Brahmaputra-Barak and Jamuna-Padma-Meghna floodplains. There is thus clear scope of future joint research that can benefit the unique ecosystems dependent livelihoods of the region.

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