Initial National Communication

under the United Nations Framework Convention on Climate Change (UNFCCC)

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ABBREVIATIONS

AD	:	After the Death
ADB	:	Asian Development Bank
ALGAS	:	Asia Least Cost Greenhouse Abatement Strategy
BARC	:	Bangladesh Agricultural Research Council
BaU	:	Business as Usual
BBS	:	Bangladesh Bureau of Statistics
BCM	:	Billion Cubic Meter
BEMP	:	Bangladesh Environment Management Project
BFD	:	Bangladesh Forestry Department
BFIDC	:	Bangladesh Forest Industries Development Corporation
BL	:	Boro Local
BMD	:	Bangladesh Meteorological Department
BNH	:	Bangladesh National Herbarium
BOGMC	:	Bangladesh Oil, Gas and Mineral Corporation
BPC	:	Bangladesh Petroleum Corporation
BWDB	:	Bangladesh Water Development Board
BWE	:	Back Water Effect
CAP	:	Coastal Afforestation Project
CC	:	Climate Change
CCS1	:	Climate Change Scenario-1
CCS2	:	Climate Change Scenario-2
CEP	:	Coastal Embankment Project
CERP	:	Coastal Embankment Rehabilitation Project
CFL	:	Compact Florescent Lamp
CH_4	:	Methane
CHT	:	Chittagong Hill Tracts
CIDA	:	Canadian International Development Agency
CNG	:	Compressed Natural Gas
CO	:	Carbon Mono Oxide
CO_2	:	Carbon-di Oxide
COP	:	Conference of Parties
CPP-II	:	Cyclone Protection Project
CSIRO	:	Commonwealth Scientific and Industrial Research Organization
DMB	:	Disaster Management Bureau
DMP	:	Disaster Management Policy
DOC	:	Degradable Organic Compound
DOE	:	Department of Environment
ECA	:	Environment Conservation Act
ECR	:	Environment Conservation Rules
EEZ	:	Exclusive Economic Zone
EGIS	:	Environmental Geographical Information System
EIA	:	Environment Impact Assessment
EMS	:	Environment management System
ESCAP	:	Educational, Scientific and Cultural Organization in Asia and the Pacific
FAO	:	Food and Agriculture Organization
FAP	:	Flood Action Plan
FCDI	:	Flood Control, Drainage and Irrigation
FD	:	Forestry Department

FFWC	:	Flood Forecasting Warning Center
FMP	:	Forestry Master Plan
FPCO	:	Flood Plan Coordination Organization
GBM	:	Ganges, Brahmaputra and Meghna
GCM	:	General Circulation Models
GDP	:	Gross Domestic Productions
GEF	:	Global Environment Facility
GFDL	:	Geophysical Fluid Dynamic Laboratory
GgC	:	Giga Gram Carbon
GHG	:	Green House Gas
GIS	:	Geographical Information System
GLOF	:	Glacier Lake Outburst Floods
GOB	:	Government of Bangladesh
Ha	:	Hectare
HP	:	Horse Power
HYV	:	High Yielding Variety
ICZM	:	Integrated Coastal Zone Management
IMDMCC	:	Inter Ministerial Disaster Management Coordination Committee
INC	:	Initial National Communication
IPCC	:	Intergovernmental Panel for Climate Change
IUCN	:	International Union for Conservation of Nature
IWTA	:	Inland Water Transport Authority
JBO	:	Jute Bleaching Oil
JCE	:	Joint Committee of Experts
JRC	:	Joint River Commission
KWH	:	Kilo Watt Hours
L	:	Local
LDO	:	Light Diesel Oil
LPG	:	Liquid Petroleum Gas
LT	:	Local Transplanted (paddy)
MDMR	:	Ministry of Disaster Management and Rehabilitation
MES	:	Meghna Estuary Study
Mha	:	Million Hectare
MOEF	:	Ministry of Environment and Forestry
MP	:	Murate of Phosphate
MPO	:	Master Plan Organization
MSL	:	Mean Sea Level
MSW	:	Municipal Solid Waster
MSWL	:	Mean Sea Water Level
MSY	:	Maximum Sustainable Yield
MT	:	Metric Ton
MV	:	Mega Volt
MW	:	Mega Watt
N	:	Nitrogen
N_2O	:	Nitrous Oxide
NA	:	Not Available
Na_2CO_3	:	Sodium Carbonate
NCA	:	Non Crop Agriculture
NCS	:	National Conservation Strategy
NDMAC	:	National Disaster Management Advisory Committee
NE	:	North East

NEMAP	:	National Environmental Management Action Plan
NGL	:	Natural Gas Liquid
NGO	:	Non Government Organization
NMDC	:	National Disaster Management Council
NMHC	:	Non Methane Hydro Carbon
NMVOC	:	Non Methane Volatile Organic Compounds
NO_2	:	Nitrogen Oxides
NPV	:	Net Present Value
NW	:	North West
NWMP	:	National Water Management Plan
NWP	:	National Water Policy
O&M	:	Operation and Maintenance
OIC	:	Organization of Islamic Countries
PET	:	Potential Evapo-transpiration
PgC	:	Peta Gram Carbon
ppmv	:	Parts per million volume
RF	:	Reserve Forest
SBM	:	Sundarbans Bio-diversity Management
SBP	:	Sundarbans Bio-diversity Program
SEMP	:	Sustainable Environment Management Project
SL	:	Sea Level
SLR	:	Sea Level Rise
SMRC	:	SAARC Meteorological Research Center
SOI	:	Southern Oscillation Index
SPARRSO	:	Space Research and Remote Sensing Organization
SST	:	Sea Surface Temperature
SWD	:	Solid Waste Disposal
SWMC	:	Surface Water Modeling Center
TC	:	Ton Carbon
TCF	:	Trillion Cubic Feet
Tg	:	Tera Gram
TJ	:	Tera Joule
TOR	:	Terms of Reference
TSP	:	Triple Super Phosphate
UKTR	:	United Kingdom Meteorological Office Transient Model
UNDP	:	United Nations Development Program
UNEP	:	United Nations Environment Program
UNFCCC	:	United Nations Framework Convention on Climate Change
USCSP	:	United States Country Studies Program
USF	:	Unclassified State Forest
V&A	:	Vulnerability and Adaptation
VOC	:	Volatile Organic Compounds
WARPO	:	Water Resources Planning Organization
WB	:	World Bank
WBS	:	World Bank Study
WHO	:	World Health Organization
WMO	:	World Meteorological Organization

FOREWORD

I am pleased to know that the Ministry of Environment and Forest has completed its Initial National Communication to the United Nations Framework Convention on Climate Change (UNFCCC). This Initial National Communication has been prepared through the Enabling Activities Programme, funded by Global Environment Facility (GEF) and the Government of United States of America. Implementing agency had been the United Nations Environment Programme (UNEP). This Initial National Communication of Bangladesh comprises the National Circumstances, Greenhouse Gas Inventory (1994), Vulnerability and Adaptation, Mitigation and Climate Change Response Strategies.

We are aware that Bangladesh, being a low-lying deltaic country, would be adversely affected by global warming and concomitant sea level rises. According to IPCC Third Assessment Report, a 45 cm sea level rise will inundate about 10.9% of the total landmass of Bangladesh, which is about 15,668 sq. km. including 15 percent or 750 sq. km. of the landmass of Sundarban, the largest single-stretch mangrove forest of the world. 5% or 5.5 million people of the country will be under direct threat. A 100 cm sea level rise will affect the country with even more catastrophic magnitude.

The present environment-friendly government has been undertaking various steps towards sustainable development through conservation of the environment and pollution control. Implementation of agreements, both at regional and international levels, including the United Nations Framework Convention on Climate Change (UNFCCC) and Kyoto Protocol, have been among such steps. Bangladesh, as a Non-Annex 1 Party to the UNFCCC, is ready to cooperate with the international community and regional partners in addressing climate change issues in accordance with the principle of common but differentiated responsibilities.

This Initial National Communication of Bangladesh will serve as a basis for concrete future actions. I am optimistic that it will pave the way to adapting to climate change impacts in a more sustainable and consolidated way in our country.

Finally, I would like to express my sincere thanks to the consultant team, members of the Technical Working Committee, concerned Ministries, Departments, Institutions and other individuals for successfully carrying out the task.

Shajahan Siraj
Minister
Ministry of Environment and Forest

PREFACE

I am happy to Learn that the Initial National Communication in response to United Nations Framework Convention on Climate Change has been finalized. Extensive research has been carried out in Bangladesh since the mid-nineties on the impacts of climate change Phenomena and means to adapt to the changed situations as well as mitigation measures of the adverse consequences. The study concerning this Initial National Communication had been in continuation of those research findings with the entire exercise funded by Global Environment Facility (GEF) and United States Government through the United Nations Environment Programme (UNEP).

National Circumstances, Greenhouse Gas Inventory, Vulnerability and Adaptation, Mitigation and Climate Change Response Stategies-the chapters comprising the Initial National Communication-take due consideration of the peculiarity of Bangladesh in respect of her geographic location, topography, river system, population, socio-economic system, etc.

Through making this Initial National Communication, the present environment-friendly government has once again proved its sincerity toward fulfilling its commitment to the nation as well as to the global community.

I like to extend my heartiest thanks to all those who contributed their intellect, labour and sweat in making this endeavour a success.

(Jafrul Islam Chowdhury)
Minister of State
Ministry of Environment and Forest

ACKNOWLEDGEMENT

I acknowledge with gratitude the valuable financial assistance provided by the Global Environment Facility (GEF) and the Government of United States of America through the United Nations Environment Programme (UNEP) as implementing agency toward the preparation of this Initial National Communication on Climate Change.

This Initial National Communication to the United Nations Framework Convention on Climate Change (UNFCCC) has been the outcome of sincere and devoted efforts of a number of organizations and individuals who collectively contributed to the preparation of this Communication. The process has certainly enabled the country to understand the various impacts of Climate Change and the means of combating its menace and the harmful consequences.

My thanks are due to the concerned Ministries, Departments and Organizations and also to the members of the Technical Working Committee, the Consultant Team and the officers of the Department of Environment who have put-in relentless efforts and provided valuable inputs toward finalization of this National Communication.

Sabihuddin Ahmed
Secretary
Ministry of Environment and Forest

EXECUTIVE SUMMARY

Bangladesh as a signatory to the United Nations Framework Convention on Climate Change (UNFCCC) and pursuant to Article 4.1 and 12.1 of UNFCCC, is committed to submit to the Conference of Parties (COP) National Communication comprising the status of GHG emission, climate change and vulnerability, adaptation and related matters.

This Initial National Communication includes the National Circumstances; Greenhouse Gas Inventory (for 1994), Vulnerability and Adaptation, Mitigation and Climate Change Response Strategies.

National Circumstances

Bangladesh, with an area of about 147,570 sq. km, is located in the tropics between $20^0 34'$ and 26°38' north latitudes and $88^0 01'$ and $92^0 41'$ east longitudes in South Asia and is bounded by India on the west, the north and the northeast and Myanmar on the southeast. In the south, she has a long coastline along the Bay of Bengal. Except the hilly regions in the northeast and the southeast and some areas of highlands in the north and northwestern part, the country consists of low and flat land.

Bangladesh has a sub-tropical monsoon climate. Average annual temperature varies from 19^0c to 29^0c while average annual rainfall ranges from 1429 to 4338 mm. About 80% of the total rainfall occurs during the monsoon (June-September).

Bangladesh population according to the census of 2001 had been 123.1 million with an annual growth rate (over 1991 – 2001) of 1.47%. The population density is 834 persons per km^2. Over 76% of the country's population lives in the rural areas. Urbanization, however, is rapid particularly due to an increasing trend of rural-urban migration. The 1995-96 Labor Force Survey estimated the total civilian labor force of the country at 56.0 million, of which 34.7 million had been male and 21.3 million had been female.

The education system in Bangladesh comprises three sub-systems, i.e. General Education, Technical and Vocational Education and Higher Education. At present, 30 Govt. and Non-Govt. universities provide higher education. Both the public and private sectors provide healthcare. The public sector provides preventive, curative and rehabilitative health care and the private sector mainly provides curative care. There are 1289 hospitals (including rural health complex), 30869 registered physicians and 43143 hospital beds in the country. Ninety five percent of in-patient care is provided by the public sector.

The Country has a fair deposit of natural gas. Other mineral resources include coal, limestone, ceramic clay and glass sand. Natural gas is used for power generation, industrial, domestic and other purposes.. The total installed generation capacity for electricity was 3685 MW during 1999-2000.

Bangladesh is predominantly an agricultural country. Thirty two percent of the GDP originates in agriculture while 68.5% of the labour force is employed by the sector. Rice is the major crop. Other major crops include wheat, jute, sugarcane, tobacco, tea, oilseeds, pulses and potatoes.

Industries account for only about 11.5% of the GDP. Readymade garments are the most important export industry. Other major industries include jute, textile, paper and newsprint, sugar, cement, chemicals, fertilizers and leather. The industrial sector accounts for of the country.

The principal export items of Bangladesh are ready-made garments, raw jute, jute products, tea, fish, hides and skins and newsprint. The principal import items are food grains, oilseeds, various industrial products including machineries, industrial raw materials and petroleum products.

Bangladesh is rich is fish resource both in its diversity and in terms of output. Fisheries habitat includes the numerous rivers, small and large water bodies and wetlands and the estuaries. Culture fishery is widely practiced in the country.

The forests cover about 17% of the land area of the country. The main forest type is the mangrove including the Sundarbans along the southwestern coast. The biodiversity in the mangroves still remains to be totally mapped . Other forest types include those in the hilly areas and Sal forests in the north and central Bangladesh.

Bangladesh has about 230 rivers with a total length of about 24,140 km. Among them, 54 rivers including the major rivers such as the Ganges, the Brahmaputra and the Meghna (GBM) originate in India. The GBM river system is one of the largest river networks in the world. The river network of Bangladesh drains out about 132 million hectare-meter of water and carry about 2.4 billion tons of sediment annually to the Bay of Bengal. Rivers of Bangladesh carry water from a collective catchments area of about 1.75 million km^2, only about 7 percent of which is in Bangladesh area. Wetlands or marshes belong to topographically depressed areas known as haors, baors and beels with negligible flows. These wetlands occupy about 1236 km^2 or 0.9% of Bangladesh area.

Available recharge of ground water in Bangladesh is about 21100 km^3. Both surface and ground water are extensively used for agriculture, fisheries, navigation, livestock, industries, hydropower generation, households, businesses and recreation. Water bodies and wetlands act as habitats for numerous aquatic and amphibian species. Thus, availability of water, or lack of it, has profound effects on the economy and the ecology of Bangladesh.

Floods affect about 80% of land in Bangladesh. Four types of flooding occur in Bangladesh.

- Flash floods caused by overflow of hilly rivers of eastern and northern Bangladesh (In April – May and September – November).
- Rain floods caused by drainage congestion and heavy rains.
- Monsoon floods in the floodplains of major rivers (during August - September).
- Coastal floods due to storm surges.

As will be detailed in the main text, each type of flood may be more frequent due to climate change.

The coastline of Bangladesh is about 710 km long. The coastal zone covers about 23% of the area. Much of the coastal area lies within the delta of the GBM river system and has been formed by their sedimentary deposits. The coastal region is marked by a vast network of river systems and deltaic tidal channels, and ever dynamic estuary and interaction of vast volumes of fresh water that are discharged by the major river systems, and a saline waterfront penetrating inland from the sea. In addition to the coastal plains, there are a number of offshore islands subject to strong wind and tidal interactions throughout the year. These islands are inhabited by a large number of people.

Greenhouse Gases Inventory

Greenhouse gases comprising Carbon Dioxide, Oxides of Nitrogen and Methane are found naturally in the atmosphere in trace quantities. Their accelerated generation as a result of anthropogenic activities contributes significantly to global warming. The main areas of green house gas generation are energy, industrial process, agriculture, land-use change and forestry and waste sectors. The national GHG inventory for the year 1994 is given below:

GHG EMISSION (GIGA GRAM) IN 1994			
Greenhouse gas Source and Sink Categories	CO_2	CH_4	N_2O
Total (Net) National Emission	24297.63	1190.85	14.38
1. All Energy	**15178.25**	**0.63**	**0.06**
Fuel combustion			
Energy and transformation industries	5750.98		X
Industry	3708.03		
Transport	2538.12		
Residential	2013.55		
Commercial-institutional	176.25		
Other (Agriculture/forestry/fishing, Non CO_2 from fuel combustion)	991.32	0.54	0.06
Biomass burnt for energy*	58624.63		
Fugitive Fuel Emission			
Oil and natural gas systems		0.09	
Coal mining		X	
2. Industrial Processes	**1281.48**		X
3. Agriculture		1127.73	14.32
Rice Cultivation		662.23	
Enteric Fermentation		416.58	
Savanna Burning		X	
Others (Manure management and field burning of agriculture residues)		48.92	14.32
4. Land Use Change and Forestry	**7837.97**		
Changes in Forest and other woody bio-mass stock	7837.97		
Forest and Grassland Conversion **	X		
Abandonment of Managed Lands **	X		
5. Other Sources (Waste)	X	**62.49**	X

* *Traditional biomass such as crop residues burnt for energy are not included in the national total.*

** *Abandonment of managed land and grassland conversion of land use change and forestry sectors are not considered because appropriate data were not available.*

x *Not estimated.*

In Bangladesh, CO_2 emission has been the largest due to the energy sector (62.74%) followed by land-use changes and forestry sector (32.26%) and industrial process (5.27%). CH_4 emission from agriculture sector is about 1128 Gg contributing about 95% of total methane emission of the country. Due to application of synthetic fertilizer, agriculture sector emits N_2O also. Emission of N_2O from this sector is 14.32 Gg. Insignificant amount of CH4 and NO_2 are emitted from energy sector also.

Vulnerability and Adaptation to Climate Change

Global warming is expected to lead to higher atmospheric temperatures, high intensity rainfall, increased natural disasters (floods and cyclone storm surges),more frequent and prolonged droughts and a sea level rise along the coast in Bangladesh. These anticipated changes would create significant threat to the different sectors of the national economy, human activity and health. While most sectors will be affected due to combinations of the several physical phenomena, some of these will be impacted more by one type of initial causes than others. A summary of these sectors and the main cause of the effects on those sectors are provided below.

POTENTIAL IMPACTS	
Physical impacts of climate change	**Consequent physical/societal/sectoral and other impacts**
Sea level rise	• *Inundation of low-lying coastal settlements, coastal wetlands and mangrove forests.* • *Increased coastal morphological dynamics (erosion and accretion)* • *Water logging and drainage congestion in coastal areas* • *Backwater effect and prolonged flooding in the main land areas* • *Salt water intrusion (increasing salinity in ground and surface water, and corresponding impacts on soil salinity)* • *Coastal resources and economic development activities (agriculture, fisheries, industry etc.)* • *Coast protective infrastructures (embankment and other structures)* • *Near-shore infrastructure-land based infrastructure and land reclamation* • *Tourism*
Temperature rise	• *Agriculture output* • *Human health* • *Transport infrastructure* • *Energy consumption*
Droughts	• *Water supply (surface and ground water)* • *Forest resources* • *Agricultural output* • *Human health* • *Power generation* • *Transport infrastructure*
High intensity rainfall	• *Floods* • *Soil erosion and land degradation* • *Agricultural output* • *Human health* • *Transport Infrastructure* • *Other economic development sectors*
Increased natural disasters (floods and storm surges)	• *Damage to human life and property* • *Erosion and sedimentation* • *Human health* • *Economic development sectors (agriculture, livestock, fisheries etc.)* • *Transport, FCDI and protective infrastructures.*

Adaptation measures are required to address the potential adverse impacts of climate change. A few adaptive measures have already been taken in some sectors for promoting improved environmental management or other purposes in Bangladesh. But targeted interventions to combat the potential adverse impacts of climate change are still to be decided and put in place.

Mitigation Options for Climate Change

Bangladesh, compared to other countries, emit relatively very little of the GHGs due to anthropogenic factors. Yet, there are mitigation measures, which she can take to serve well her other development goals. Particularly, energy production and use in Bangladesh is wasteful and inefficient. A more efficient energy system saves her resources and at the same time lowers GHG emission.

The generation of power, and use of energy for industrial, residential and transport purposes are the main areas of focus for mitigation. Improved energy using devices and more efficient processes for generation of power constitutes the major thrust for energy conservation.

GHG abatement action programs that are being implemented / proposed in Bangladesh include the following:

- Establishment of 8800 MW gas-based power generation capacities by the year 2005 for Gas Based Efficient Power Generation and conversion of open cycle to combined cycle power plant
- Dissemination of improved cooking stoves in rural areas of Bangladesh to replace 1 million traditional cooking stoves by improved ones.
- Phasing out of two-stroke engines with four-stroke engines for three wheelers to replace about 14311 retiring two-stroke engines with four-stroke engines in auto-rickshaws
- Conversion of 17000 petrol driven cars into CNG-driven cars
- Solar electricity with Photo-voltaic (PV) system to disseminate PV electricity in about 100,000 rural households.
- Replacement of Incandescent bulbs with Compact Fluorescent Lamps to replace at least 50% of all incandescent bulbs with CFLs by the year 2020
- Improvement in brick manufacturing efficiency by changing wood-fuel based kiln to natural gas-fired kiln. Such changes may lower emission of 54421 tones of CO_2 per year.
- More energy efficient cold storage processes.
- Promotion of Environmental Management System (EMS) in industries.
- Bio-methanation from landfills.

Climate Change Response Strategy

Bangladesh is among the countries of the world that are most vulnerable to climate change. The weak economy and widespread poverty will exacerbate the problem. Government of Bangladesh has given due attention to understanding the problems related to causes of climate change, its impacts and resulting vulnerability and adoption of appropriate coping mechanisms to reduce such vulnerability. It has undertaken the following steps, which directly or indirectly serve as response to climate change in addition to their role in environment protection, nature conservation, disaster management and sustainable development.

Existing Institutions, Links, Strategies and Actions

The Ministry of the Environment and Forest of the Government of Bangladesh (GOB) with the Department of Environment (DOE) under the ministry is the key institution as a coordinating agency to address the issues of environmental concern and thus deals with the climate change issues nationally and internationally in addition to its other functions. Bangladesh is a member of WMO and IPCC and a signatory to UNFCCC and the Kyoto Protocol. She actively takes part in the various conferences of parties. She is thus committed to the global effort to mitigate climate change and adapt to it. The present National Communication of Bangladesh on Climate Change to UNFCCC reflects the commitment and provides a summary view of the national situation at the moment.

Government of Bangladesh along with a number of public and non-government research organisations has completed a number of studies on impact of and vulnerability to climate change and adaptation strategies. Though not a major emitter of GHGs, Bangladesh has also studied possible mitigation measures as a guide towards global effort at mitigation. These studies include.

- Bangladesh Country Study on Climate Change.
- Asia Least Cost Greenhouse Abatement Strategy (ALGAS).
- Climate Change in Asia: Bangladesh.
- Preparation of background report for Initial National Communication to the UNFCCC.
- Institutional Strengthening for the Phase-out of Ozone Depleting Substances.
- Vulnerability and Adaptation to Climate Change.
- Conversion to CFC-free Technology in the Manufacture of Aerosol Products.
- Coastal and Wetland Biodiversity Project.

These projects are referred to as the first generation of impacts, vulnerability, and adaptation studies.

Besides, there are a number of on-going activities which have certain interface with climate change issues. These include institutional strengthening for the phase-out of Ozone Depleting Substances in Bangladesh; Air Quality Monitoring Project; and the phasing out of two-stroke three wheelers and their substitution with CNG driven ones.

Policies and Measures

Several major policies and plans having direct or indirect implications for climate change impacts and vulnerability that have been formulated to-date include: the National Environment Policy, National Conservation Strategy, National Environmental Management Action Plan, Forestry Policy and Forestry Master Plan, National Energy Policy, the National Disaster Management Policy and National Water Policy. There is a need for revising some of these policies to attune them more directly to take account of activities related to climate change and its impact. While strengthening the existing policies and preparing new ones, it is important to bear in mind the need for: (a) building up relevant databases (b) providing market-based incentives/disincentives, (c) cost-effectiveness, (d) adoption of an integrated approach, (e) promoting stakeholder collaboration, (f) increasing the awareness of climate change. (g) consider the integration of adaptation strategies in the national development / environmental plans and strategies for sustainable development to reduce poverty and (h) harmonization with other global agreements with emphasis on Biodiversity, Combat Desertification and Montreal Protocol. Adaptation policy will be directed at important sectors of the national economy such as agriculture, forestry, water resources, energy resources, and the transportation infrastructure. Adaptation and the development process is likely to include different measures, such the provision of saline resistant crops, reducing the associated adverse impacts due to increase in salinity, provision of additional water supplies in drought prone area, drought tolerant crops, the storage of emergency food supplies and development of early warning systems. The ultimate aim of such policies should be to increase the resilience to adverse impacts of climate change and consequent vulnerability such as food insecurity as well as expanding communities range of coping strategies.

National Capacity Building

The national capacity building is an important aspect for climate change research, formulation of mitigation, adaptation and response policy, strategy, programmes and projects. For this purpose, intensive training on a continuous and regular basis is to be provided to the policy makers and planners on the climate change issues, mitigation, impacts and adaptations. A major lacuna that needs to be filled up is the institutional capacity to respond and negotiate on a continuing basis to and on the various proposals in the relevant international for a.

Institutionalization

At present the climate change studies in Bangladesh are being dealt by the Department of Environment (DOE) of the Ministry of Environment and Forest. For intensification of the climate change impacts and response actions in Bangladesh it is necessary to make provision of an institutional arrangement with requisite number of trained manpower to facilitate the climate change related activities.

Such an institution may be established under the umbrella of DOE with the adequate facilities of research and power and authority of policy formulation. The institution will disseminate the information on climate change impacts, maintain international links and explore extending all sorts of collaboration and cooperation to the planners and policymakers and all other departments related with environment, water resources, disasters, ecology, forestry and fisheries, agriculture, authorities related with disaster management and coastal zone development.

It will develop National Climate Change Policies and advise other institutions to introduce climate change concerns into their respective policies, plans and acts such as National Water Policy (NWP), National Water Management Plan (NWMP), National Energy Policy, National Environment Management Action Plan (NEMAP), Environment Conservation Rules, Environment Conservation Acts and Disaster Management Policy.

Awareness Generation

A number of mass awareness programs related to environmental management are on-going in the country. There is also one on climate change. The programme needs further strengthening. The campaign may be directed towards the efficient use of energy, afforestation, the policy of Clean Development Mechanism (CDM), reducing the use of wood fuels, limiting the use of CFC in the aerosols and cooling devices, encourage greater use of renewable energy and the like. The government and the NGOs may collaborate in such awareness campaigns.

Recommended research studies and development projects

Proper societal intervention to mitigate climate change, adapt to its impacts and reduce vulnerability necessitates the preparation of appropriate policies, plans, programmes and projects. While there are certain such activities are on-going, these are still fragmented and rather adhoc. There are two basic reasons for such a state affairs, viz., lack of appropriate knowledge and adequate resources (including institutional capacity) and technology. At the same time, this is also true that there are activities, which while climate friendly, would be in Bangladesh's interest to be taken up without waiting for generation of knowledge (through studies).

To assess the climate change impacts and vulnerability in Bangladesh, to formulate and implement the adaptation policies, and contribute effectively towards the global efforts at mitigation, specific mechanisms and action plans need to be prepared locally. It is necessary to undertake studies to address these and the related issues in the most appropriate and realistic manner. These studies and projects may include the following:

- Strengthening the GHG monitoring system in Bangladesh
- Detailed study on GHG mitigation mechanisms and policy options
- Research on climate change impacts, vulnerability and adaptation
- Research on the improvement of the design criteria and development of the suitable technology adaptive to the changed scenarios due to climate change
- Strengthening of the disaster monitoring and warning system
- Integrated coastal zone development project in respect of climate change
- Study of climate change impacts on agriculture and crop production
- Water management improvement projects considering probable climate change impacts
- Study of the impact of climate change on existing sewerage and drainage systems and urban water supply schemes
- Study on impact of climate change on existing flood control, irrigation and drainage project
- Study on ecosystem management, bio-diversity and wild life conservation and protection
- Study of the changes of agro-ecological zone, droughts and floods in Bangladesh at the changed scenario
- Climate change impact modeling for the coastal zone
- Study of tropical cyclones using numerical models
- Strengthening of the coastal environmental monitoring system

Such studies and activities will help in formulation of projects for mitigation and adaptation. However the resource requirements are likely to be large while many technological and policy barriers to change may occur. Resource inflow commensurate with the extent of vulnerability and the effort at mitigation should be ensured for such plans and programmes to be implemented properly. The resources may be from various sources, both existing ones and those that are being created as part of the Kyoto Protocol initiatives and follow-ups. Furthermore, such resource flows must be complemented with appropriate and effective technology transfer.

1 INTRODUCTION

1.1 Introduction

The People's Republic of Bangladesh has signed the United Nations Convention on Climate Change (UNFCCC) in 1992 and ratified it in 1994. It has ratified the Kyoto Protocol on 22 October 2001.

Bangladesh as a Non-Annex-1 country party to the UNFCCC has to prepare a National Communication to the Conference of the Parties (COP) in accordance with article-4, paragraph-3 of the Convention. The Initial National Communication has been prepared in response to this obligation.

The COP adopted the guidelines for the communications of Non-Annex-1 countries in July 1996. In accordance with the article-12 of the UNFCCC, detailed guidelines for the preparation of communications were presented in the document FCCC/CP/1996/L.12, to parties not included in Annex-1. These guidelines have been followed in the preparation of the communication.

Bangladesh's contribution to the emission of greenhouse gases is negligible. Nonetheless the adverse impacts of the anticipated changes arising out of global warming are significant. Due to climate change the most affected areas of the country are: Fresh water resources, coastal regions, agriculture, fisheries, ecosystem and bio-diversity and human health. Moreover climate change will increase magnitude, intensity and frequency of natural disasters like cyclonic storm surges, floods and droughts in Bangladesh.

Since the Decision 10/CP.2 requires non-Annex-1 Parties to use 1994 as base year, this report (Initial National Communication) incorporates the updated (1994) inventory of greenhouses gases in Bangladesh and the potential measures to abate the increase and, the national action plan to address the climate change.

This communication presents, in several chapters, the National Circumstances; Greenhouse Gas Inventory, Vulnerability and Adaptation, Mitigation, Climate Change Response Strategies and Conclusions.

2 NATIONAL CIRCUMSTANCES

2.1 Historical Background

The territory constituting Bangladesh was under the Muslim rule for over five and a half centuries from 1201 to 1757 AD. It went under the British rule after the defeat of the last sovereign ruler, Nawab Sirajuddowla, at the Battle of Plassey on the fateful day of 23 June 1757. The British ruled over the entire Indian sub-continent including this territory for nearly 190 years from 1757 to 1947. During that period Bangladesh was a part of the British Indian provinces of Bengal and Assam. With the termination of the British rule in August 1947, the sub-continent was partitioned into India and Pakistan. Bangladesh was then a part of Pakistan and was known as East Pakistan. It remained so for about 24 years from 14 August 1947 to 25 March 1971. It appeared on the world map as an independent and sovereign state on 16 December 1971 following the victory at the War of Liberation from 26 March to 16 December 1971.

2.2 Geography of Bangladesh

Bangladesh is located in the tropics between $20^0$34' and $26^0$38' north latitudes and $88^0$01' and $92^0$41' east longitudes in South Asia. The country is bounded by India on the west, the north and the northeast and Myanmar (Burma) on the southeast. In the south, Bangladesh has a long coastline along the Bay of Bengal. The area of the country is about 147,570 sq.km. Except the hilly regions in the northeast and the southeast, some areas of high lands in the north and northwestern part, the country consists of low, flat and fertile land.

Bangladesh has about 230 rivers with a total length of about 24,140 km. Among them 54 rivers originate in India including the major rivers such as the Ganges, the Brahmaputra (Jamuna) and the Meghna (GBM). These three rivers form one of the largest river networks in the world. Three minor rivers have their origin in Myanmar (Burma). Bangladesh is classified into the following four physiographic regions (Figure 2.1):

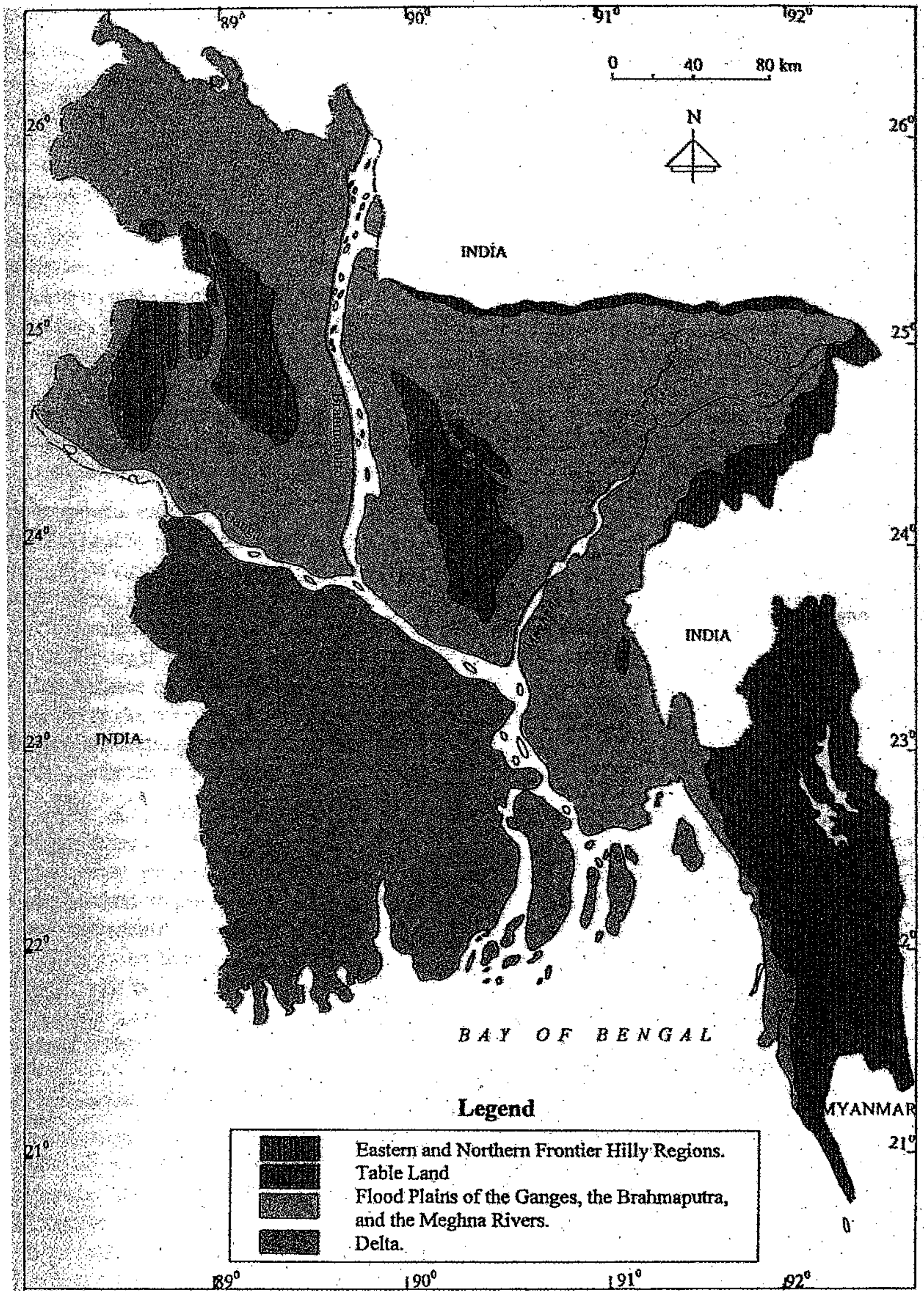
- Eastern and Northern Frontier Hilly Regions
- Great Table Land
- Flood plains of the Ganges, the Brahmaputra and the Meghna (GBM) river systems.
- Delta

With hundreds of rivers flowing in the country, Bangladesh is divided into 30 agro-ecological sub-regions on the basis of physical features and drainage systems (BBS,1999 "Bangladesh Compendium of Environment Statistics, 1997).

The river network of Bangladesh flashes out approximately 132 million hector-meter of water per year, which includes 25 million hector meter of local rainwater plus 107 million hector meter of water flowing into Bangladesh from India. The river systems in Bangladesh carry about 2.4 billion tons of sediment annually to the Bay of Bengal (MPO, 1991).

The ground slopes of the country generally extend from the north to the south and the elevation ranges from 60 m above mean sea level (MSL) at the northern boundary to 1 m in the coastal area in the south. Flood plains of the major rivers occupy 80 percent of the country, hills about 12 percent and uplifted blocks (terraces) about 8 percent of the country. Flood plains are generally smooth relief comprising broad and narrow ridges and depressions.

Figure 2.1: Physiographic Divisions of Bangladesh



Source: Khan 1991

Information regarding the National Circumstances reference to 1994 is given in Table 2.1.

Table 2.1: National circumstances

Criteria	1994
Population (million)	116.00
Relevant areas (km^2)	147570.00
GDP (US $ million)	25776.00
GDP per capita (US $)	219.00
Estimated share of the informal sector in the economy in GDP (percentage)	N/A
Sectoral share in GDP %	
Industry and Services	9.85
Power, Gas, Water and Sanitary Sources	1.99
Transport, Storage and Communication	12.54
Trade Services	8.36
Home Services	9.44
Public Administration and Defence	5.34
Banking and Insurance	2.09
Professional and Miscellaneous Sources	14.82
Construction	5.86
Mining and querying	0.02
Agriculture in GDP	29.69
Land area used for agricultural purposes (km^2)	33413.00
Urban population as percentage of total population	18.00
Livestock population (million)	52.26
Forest area (km^2)	8460.00
Population in absolute poverty (%)	47.50
Life expectancy at birth (years)	58.00
Literacy rate (7 years and over) (%)	32.40

2.3 Climate

Bangladesh enjoys generally a sub-tropical monsoon climate. There are four prominent seasons in a year namely; winter (December - February), pre-monsoon (March – May) monsoon (June – September) and post monsoon (October – November). Winter, which is quite pleasant begins in December and ends in February. In winter there is not usually much fluctuation in temperature which ranges from a minimum of 7.22^{0}C – 12.77^{0}C (45^{0}F – 55^{0}F) to a maximum of 23.88^{0}C – 31.11^{0}C (75^{0}F – 85^{0}F). The maximum temperature recorded in pre-monsoon months is 36.66^{0}C (98^{0}F) although in some places it occasionally rises up to 40.55^{0}C (105^{0}F) or more. Monsoon starts in June and stays up to first week of October. During monsoon, surface wind blows from the southwest direction and carries lot of moisture from the Bay of Bengal and the north Indian Ocean and causes rainfall in Bangladesh and the adjoining areas, occasionally leading to disastrous floods. Average annual temperature ranges from 19^{0}C to 29^{0}C. The average annual rainfall varies from 1429 to 4338 mm. About 80% of the total rainfall of the country occurs during monsoon. The maximum rainfall is recorded in the coastal areas of Chittagong (in the south-east) and northern part of Sylhet district (in the north-east of Bangladesh), while the minimum is observed in the western and northern parts of the country. The annual rainfall pattern of Bangladesh has been shown in Figure-2.2.

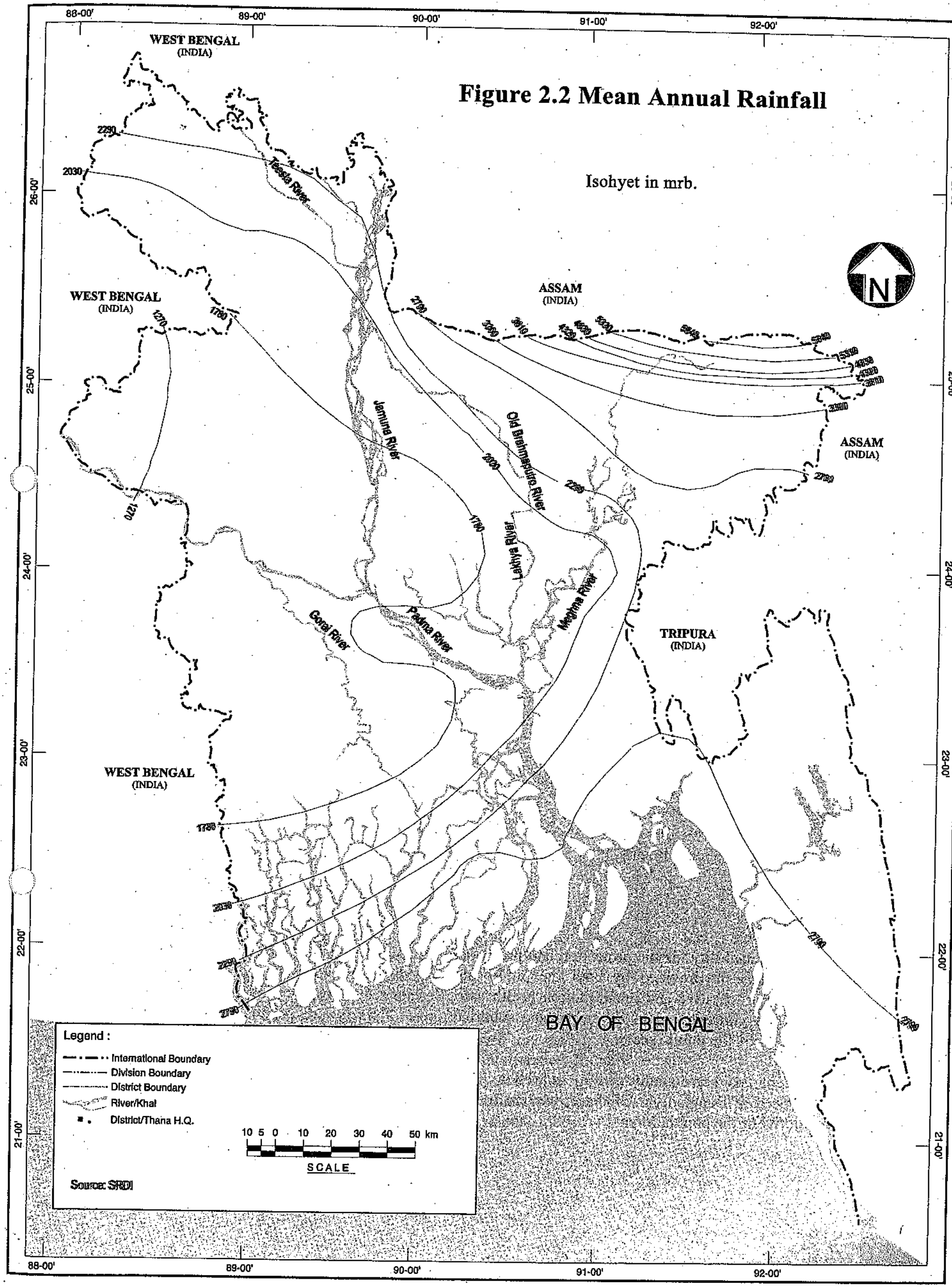


Figure 2.2 Mean Annual Rainfall
Isohyet in mrb.
WEST BENGAL
(INDIA)
ASSAM
(INDIA)
TRIPURA
(INDIA)
BAY OF BENGAL
Teesta River
Jamuna River
Old Brahmaputra River
Lakhya River
Meghna River
Padma River
Gorai River
Legend :
International Boundary
Division Boundary
District Boundary
River/Khal
District/Thana H.Q.
10 5 0 10 20 30 40 50 km
SCALE
Source: SRDI
88-00'
89-00'
90-00'
91-00'
92-00'
21-00'
22-00'
23-00'
24-00'
25-00'
26-00'

2.4 Population

As per 2001 census the population of Bangladesh was 123.1 million and annual growth rate (1991-2001) is 1.47%. Average population density of Bangladesh is 834/km^2 and over 76% of the country's population lives in the rural areas. Sex ratio: 104 (males per 100 females). Life expectancy by birth for both male and female is 61 years (source: BBS, 2002).

2.5 Labour Forces

According to 1995-96 Labor Force Survey (LFS), the total Civilian Labor Force of the country was estimated at 56.0 million of which 34.7 million are male and 21.3 million are female while it was 51.2 million for both the sexes, 31.1 million for male and 20.1 million for female in 1990-91 (LFS). In extended definition the activities like care of poultry & livestock, processing, husking, preservation of food etc. are considered as economic activities which are usually performed by females in an out of the agriculturally based household in rural areas.

2.6 Education

The education system of Bangladesh comprises three sub-systems: general education, higher education and technical and vocational education.

Educational Institutions and enrollments (1999) of Bangladesh are presented below:

Govt. Universities	:	11
Non-Govt. Universities	:	19
Govt. Medical Colleges	:	13
Non-Govt. Medical Colleges	:	11
Engineering Colleges	:	4
General Colleges	:	2288
Polytechnic Institutes	:	20
Secondary Schools	:	14070
Primary Schools	:	65610
Primary School enrollment	:	19.6 million
Secondary School enrollment	:	6.6 million
College enrollment	:	1.62 million
Govt. University enrollment	:	226 thousand

Source: BBS, 2002

2.7 Health

The responsibility for the protection and promotion of public health lies with the Ministry of Health. Health care is provided by both the public and private initiatives. The public sector provides preventive, curative and rehabilitation health care. Private sector mainly provides curative care and is largely concentrated in the urban and suburban areas. Ninety five percent of in-patient care is provided by the public sector.

Western and homeopathy system as well as indigenous systems such as ayurvedic and Unani are practiced in Bangladesh. Of these, western medicine is the main sector catering to the needs of the majority of the population.

Health care facilities of Bangladesh (1999) are shown below:

- Hospitals (including rural health complex)	:	1289
- Hospital Beds	:	43143
- Persons per hospital bed	:	2966
- Registered Physicians	:	30869
- Persons per physician	:	4147
- Households per physician	:	821

Source: BBS, 2002.

2.8 Administrative Setup

Bangladesh is governed by a Parliamentary form of government. The Prime Minister is the chief executive of the country and is selected by the president from the majority party leader. The Prime Minister has a council of ministers who assist him/her in the discharge of his/her duties. For the convenience of administration the country is divided into six administrative divisions, each placed under a Divisional Commissioner. Each division is further sub-divided into districts. After the administrative re-organization carried out in 1984 the country has been divided into 64 districts. A Deputy Commissioner who is assisted by other officials heads the administration of each district.

District is divided in a number of upazilas headed by Upazila Nirbahi Officers. Currently there are 460 upazilas, in Bangladesh.

2.9 Law Making

The constitution provides for a unicameral legislature, which is called as the Jatiya Sangsad. It consists of 300 members directly elected by adult franchise. Jatiya Sangsad is the national parliament and is vested with all powers under the constitution to make laws for the country.

2.10 Judiciary

The highest judiciary in the country is the Supreme Court headed by the Chief Justice. The Supreme Court comprises the Appellate Division and the High Court Division. There are both criminal and civil courts at district head quarters to try criminal and civil cases. Special court or tribunals such as labour courts, family courts are in existence for adjudication of relevant disputes. For metropolitan areas of Dhaka, Chittagong, Rajshahi and Khulna, Metropolitan Magistracy has been setup. Moreover, Environment Courts are in operation under Environment Court Act, 2000 to ensure speedy disposal of environmental suits.

2.11 Local Government

Local government in urban and rural areas is entrusted to bodies elected by the people. Such bodies in the urban areas are called Municipalities or Pourashavas and, in rural areas, these are called Union Parishads (Union Councils). There are also Zila Parishad and Upazila Parishad at the Zila and Upazila levels respectively.

2.12 International Relations

The foreign policy of Bangladesh is based on the principles of sovereign equality, territorial integrity, peaceful co-existence and non-interference in each others internal affairs. Bangladesh strictly adheres to the policy of non-alignment. In foreign relations Bangladesh has been playing an increasingly positive role in various international forums upholding the cause of oppressed people, renunciation of force, policy of non-alignment and settlement of all issues through peaceful negotiations, etc.

At the initiative of Bangladesh and after prolonged fruitful discussions between concerned governments, a 7 member South Asian Association for Regional Co-operation (SAARC) with India, Bangladesh, Nepal, Bhutan, Pakistan, Sri Lanka and Maldives having a population of about 1,000 million was formally launched in Dhaka in a summit meeting of heads of state and government held in December 1985.

Bangladesh has also developed fraternal relations with the Muslim countries on the basis of Islamic solidarity. She is a member of the Organization of Islamic Conference (OIC) and its various affiliated organs.

Bangladesh is a member of the United Nations and its various specialized bodies and agencies. She is also a member of the Commonwealth of Nations. She recognizes and maintains diplomatic missions abroad in 49 countries while there are 46 foreign diplomatic missions resident in the country and 56 non-resident foreign missions.

2.13 Flora and Fauna

Bangladesh is endowed with rich and diverse genetic resources of flora and fauna because of its bio-climatic environment and its location at the complex interface of the Himalayan and the Southeast Asian bio-geographic region. It has about 5000 species of flowering plants (Angiosperms) and 1500 species of fauna. But the biodiversity was remarkably more a century ago. At present, 129 species, including 37 mammals, 21 reptiles, 69 birds and 2 amphibians are on the IUCN Red List of endangered species. A further 308 species are listed by IUCN as rare or doubtful. Thus, nearly 50 percent of all the wildlife species in the country are rare of threatened. Some 27 plant species are listed as threatened or endangered.

The total forest area covers about 17% of the land area. The country produces timber, bamboo and cane. Bamboos grow in almost all areas but quality timber grows mostly in the valleys. Among the timber sal, gamari, chaplish, telsu, jarul, teaks, garjan, chandon and sundri are important. Sundri trees are grown in the Sundarbans (Details appear in Chapter-4) located in the southwestern part of the country bordering the Bay of Bengal. Plantation of rubber in the hilly regions of the country has recently been undertaken and extraction of rubber has already started.

Varieties of wild animals are found in the forest areas. Sundarban is the home of the world famous 'Royal Bengal Tigers' and Cheetahs. Of other animals elephants, bears, deer, monkeys, boars, leopards, and crocodiles are worth mentioning. A few hundred species and sub-species of birds are found in the country. Some of them are of seasonal and migratory types.

2.14 Agriculture and Main Crops

Agriculture is the main occupation of the people employing 68.5% of the labour force. This sector directly contributes around 32% to the gross domestic products. Bangladesh has got one of the most fertile lands but due to paucity of capital and lack of knowledge of new inputs and techniques its yield per hectre is one of the lowest in the world. Rice, wheat, jute, sugarcane, tobacco, oilseeds, pulses and potatoes are the principal crops. Various kinds of vegetables and spices are produced. The country produces about 51 million kg of tea per year, a sizeable quantity of which is exported to foreign markets after meeting the internal demand. Bangladesh produces about 1057 thousands M. Ton of superior quality jute annually and 16% of the export earning come from raw jute and jute manufactures. Among the fruits and nuts grown in Bangladesh bananas, papayas, pineapples, mangoes, jackfruits, guavas, plums and coconuts are important. Except coconuts, bananas and papayas, which are grown and available throughout the year, others are seasonal.

Bangladesh is marginally deficit in food grains. All out efforts are being made by the Government and the people to increase the production of food grains and diversity of agricultural output.

2.15 Fish Resources

Bangladesh is rich in fish resources. In the innumerable rivers, canals, tanks and other low lying and depressed areas and paddy fields that remain under water for about 6 months in a year and cover nearly 5 million hectares, tropical fish of hundreds of varieties are abound. Rice and fish constitute an average Bangladeshi's principal diet. Hilsa, lobsters and shrimps are some of the fish, which are exported to foreign countries. With the Bay of Bengal in the south the country enjoys geographic advantage for marine fishing. The shrimp sector has been contributing significantly to the national GDP by earning over US$ 300 million a year in foreign currency.

2.16 Mineral Resources and Energy

Bangladesh has a few proven mineral resources. The country has vast deposit of natural gas. So far, 20 gas fields have been discovered from which natural gas is available for power-generation, industrial and other uses. Fertilizer factories in operation including the petro-chemical complexes and those to be setup are and will be using sizeable quantity of natural gas. About one percent of the gas reserve is being consumed annually at present.

Coal deposits have been found and efforts are under way to exploit them with international assistance. Electricity is produced by both thermal and hydroelectric processes. The total generation of electricity amounted to 12,882 million KWH (kilowatt hours) in 1997-98. The solitary hydroelectric project having capacity of producing 230MW electricity is located at Kaptai in the Chittagong Hill Tracts in the southeast. Limestone, the basic raw materials for the production of cement, has been found in some places and they are being used for cement production and more cement factories are being setup for their utilization. Other minerals found include hard rock, lignite, silica sand, white clay, etc. There is possibility of oil deposit in the country and efforts are being made for its exploration. Salt is not mined but manufactured on small scale at several thousand evaporation sites in the coastal areas of Chittagong and Cox's Bazar.

Extensive radioactive sand deposits have been found all along the beaches in the southeast coastal belt. A survey estimates the reserve to be of the order of 0.5 million tons of sand containing a significant amount of usable heavy minerals.

2.17 Industries

Although Bangladesh is predominantly an agricultural country, a significant number of small, medium and large scale industries based on both indigenous and imported raw materials have been setup. Among them jute and cotton textile, paper and newsprint, sugar, cement, chemicals, fertilizers and tanneries are important. Other notable industries are engineering and ship building, iron and steel including re-rolling mills, oil refinery, paints, colours and vanishes; electric cables and wires, electric lamps, fluorescent tube lights, other electrical goods and accessories, matches, cigarettes, etc. Among the cottage industries, handlooms, carpet making, copier, bamboo and cane products, earthenware, brass and bell metal products, bidi and cheroots small tools and implements, ornaments, etc. are exported. The industrial sector contributing about 11.5% of the GDP is dominated by the jute processing followed by cotton textiles, cigarettes and garment industry.

2.18 Communication System

The country has all the three modes of transport; land, water and air. It has about 2,706 km of railroad, 17,554 km of paved road and roughly 5,968 km of parental and seasonal waterways. Water transport is an important sector and it has been in practice for long time. In fact, rivers are the lifelines of the nation, which provide the cheapest means of transport, water for agricultural operation and ensure supply of fish for her people. Steps have been taken to put more mechanized vessels into service and modernize the existing country boats.

The country is connected by air with a number of international cities by the Bangladesh Biman (the national airline of Bangladesh called Biman), and a number of foreign airlines. Biman also connects the capital city Dhaka with other major cities/towns in the country. The country has two seaports located at Chittagong and Mongla and good number of river ports and terminals.

The country has a network of Radio and Television broadcasting. One national channel and a few private channels operate in the country. Telecommunication lines have also been established with major cities of the world through the earth satellite ground stations in the country. IT sector has been given great priority in Bangladesh.

2.19 Socio-Economy

Bangladesh's socio-economic environment is characterized by high population density, widespread poverty and predominantly rural settlement with a majority of households dependent mainly on agriculture, fisheries and other forms of primary production. Presently about 79 % of the country's 123 million people are rural. Land-ownership is highly skewed and about 50% of rural households are functionally landless. Unemployment, poverty and malnutrition are widely prevalent. Rural population densities are also high (> 1000/km^2 in some parts of the country) and rural to urban migration rates are accelerating. Main socio-economic characteristics of Bangladesh are presented below:

Table 2.2: Socio-economic Characteristics of Bangladesh

Total Population	123.1 million (2001)
Annual growth rate of population	1.47% (1991-2001)
Infant Mortality (Rate per 1000 Life Birth)	67 (1996)
Life Expectancy at birth by sex	61 (2001)
Crude Birth (Rate per 1000 population)	19.9 (1998)
Crude Death (Rate per 1000 population)	4.8 (1998)
Civilian Labor Force (1998)	60.3 (2000)
Per capita Net cultivated land	0.5 (1996)
Landless percentage	10.18 (1996)
Small Farmer percentage	52.85 (1996)
Medium Farmer percentage	11.65 (1996)
Large Farmer percentage	1.67 (1996)

Table 2-3: Production and Income

i)	GDP at current prices (Billion US$)	45.60 (2000)
ii)	Agricultural Growth Rate (%)	5.04 (2001)
iii)	Domestic Savings (in million US$)	33.50 (2001)
iv)	National Savings (in million US$)	0.42 (2001)
v)	Per capita Income (in US$)	363.00 (2000)

Source: BBS, 2002

2.20 Hydrology

Bangladesh is a land of water. Annually, the country receives between 1000 to 5000 mm of rain in various regions. The surface water system of the country is dominated mainly by the three major river systems, the Ganges – Padma, the Brahmputra – Jamuna and the Meghna river (GBM) Systems. These river systems covers about 7 percent of the surface of the country and discharge about 142000 cumec in to the Bay of Bengal during the peak discharge. Rivers of Bangladesh carry water from a collective catchments area of GBM about 1.7 million square kilometers, only 8 percent of which are in Bangladesh. Figure-2.3 presents the river network of Bangladesh. The intricate network of over 200 large and small rivers discharge about 175 billion m^3 of water (80% dependable flow) to the sea. Most of the rainfall occurs in monsoon season.

2.20.1 Hydrological Aspects

The hydrological aspects of the rivers in the region are governed by the annual reversal of the wind system i.e. the monsoon. The northeastern monsoon occurs in the winter with the presence of a high-pressure zone in the Asian Highlands near the Gobi Desert. Therefore, the region receives relatively moisture free continental winds. During the summer a low-pressure zone develops in Central Asia near the Thar Desert generating onrush of moisture –laden winds from the Arabian Sea and the Bay of Bengal. The result of such a wind system is manifested in a distinct seasonal distribution of rainfall. A light rainfall of about 25 mm occurs in January –February. During March–May, pre-monsoon thunderstorms known as Nor'Westers occur with a rainfall of about 90 mm in the northwest to about 420 mm in the northeast. The southwest monsoon occurs during the June – September period with heavy rains. The surface and subsurface runoff generated by such rainfall distribution governs the hydrology of the rivers.

One important hydrological aspect of the Bangladesh rivers is that the rise and fall of the river stages are very weakly dependent on the local rainfall. This is because, as pointed out earlier, 92% of the catchments lie outside the territorial boundary of Bangladesh. In addition, the seasonality of the Bangladesh rivers can be best described by defining a seasonality index. This was attempted by Khan and Barua (1995) for the Ganges River. For surface water elevation the seasonality index (mean monthly / mean annual) varies from 0.7 in April to 1.5 in August. The same for discharge is 0.1 in April to 3.5 in August. This can be compared with the Jamuna river where the surface water elevation seasonality index varies from 0.8 in February to 1.2 in July and the same for discharge varies from 0.2 to 2.4. The authors also indicated non-linearity in the stage – discharge and discharge – sediment transport relations.

2.20.2 Chars and Floodplains (Inland Rivers)

Having a low relief with a gentle slope of about $0.3x10^{-5}$ the greater part of Bangladesh forms the floodplains of its numerous rivers, Brammer (1971) divided the whole Bangladesh area into three basic physiographic zones, namely the hill areas, the terrace areas and the floodplains. Floodplains occupy 80% of the total Bangladesh area (FAO, 1988). Physiographically, floodplains in Bangladesh can be divided into three distinct zones.

Active floodplain comprising natural levee and chars

When a river spills over its banks during flood, relatively coarser fractions of sediments are deposited through splays and over bank flooding along a strip of land along the bank. This strip is known as a natural levee, which is topographically higher than the rest of the floodplain. The vegetated chars or islands within the rivers also belong to this group. Deposition in natural levees is characterized both by lateral accretion (mostly coarse fraction) and vertical accretion (mostly fine fraction in thin layers). The elevation of natural levees generally conforms to a flood level having a 2 to 5 years return period (Volker, 1981). The geological map of Bangladesh shows these areas characterized by alluvial sand and silt deposits (Alam et al., 1990). Natural levees vary in width between one-half and four times the channel width, and in elevation vary from a few decimeters to as much as 8m depending on river size and caliber of sediment load (Allen, 1970). The down slope gradient of levees is a few to many times the slope of the adjacent channel. Natural levees are usually cut in different places by sizable channels, called crevasses, which serve to route floodwater from the main channel on to the flood plain.

The active floodplains of Bangladesh rivers are the most dynamic regions with high bank-erosion rates and channel migration.

Seasonally drained floodplains or back swamps

These are topographically lower areas which work as storage basins with low flows both in transverse and longitudinal directions. Mostly fine sediments are deposited in these areas through vertical accretion. These areas are mostly characterized by alluvial silt and clay deposits (Alam et al., 1990). The back swamps are at least a few decimeters lower than the natural levees (Volker, 1981)

Wetlands or marshes

Wetlands or marshes belong to topographically depressed areas known as haors, boars and beels with negligible flows. According to SPARRSO (1985), the total wetlands in Bangladesh are about 1,236 km^2 or 0.9% of Bangladesh area, 60% of which is located in the northeastern region. These areas are mostly characterized by paludal deposits (marsh clay and peat). Wetlands in proximal locations to the sources of sediments may also have fan-type deposits locally.

2.20.3 Ground Water

Ground water is an important resource of Bangladesh and extensively used for both domestic and agricultural needs. There is a fairly extensive aquifer at a very shallow depth of 6-15 meter below ground level. A deeper aquifer at about 60-120 meter has also been identified in many parts of the country, which is used for irrigation purposes. Availability of ground water is a function of technology used to extract it.

Table 2.4: National Water Plan groundwater balance (Mm^3)

Resource Potential	Whole Country
Available recharge	21088
Present agricultural use	8806
Domestic and industrial reserve upto 2010	3191
Surplus to agriculture	1026
Future use potential	9447
Unbalanced volume Future use upto 2010	1382
DSSTW	2430
DTW	6071
Total	8501
Balance Beyond 2010	946

Source: MPO 1991.

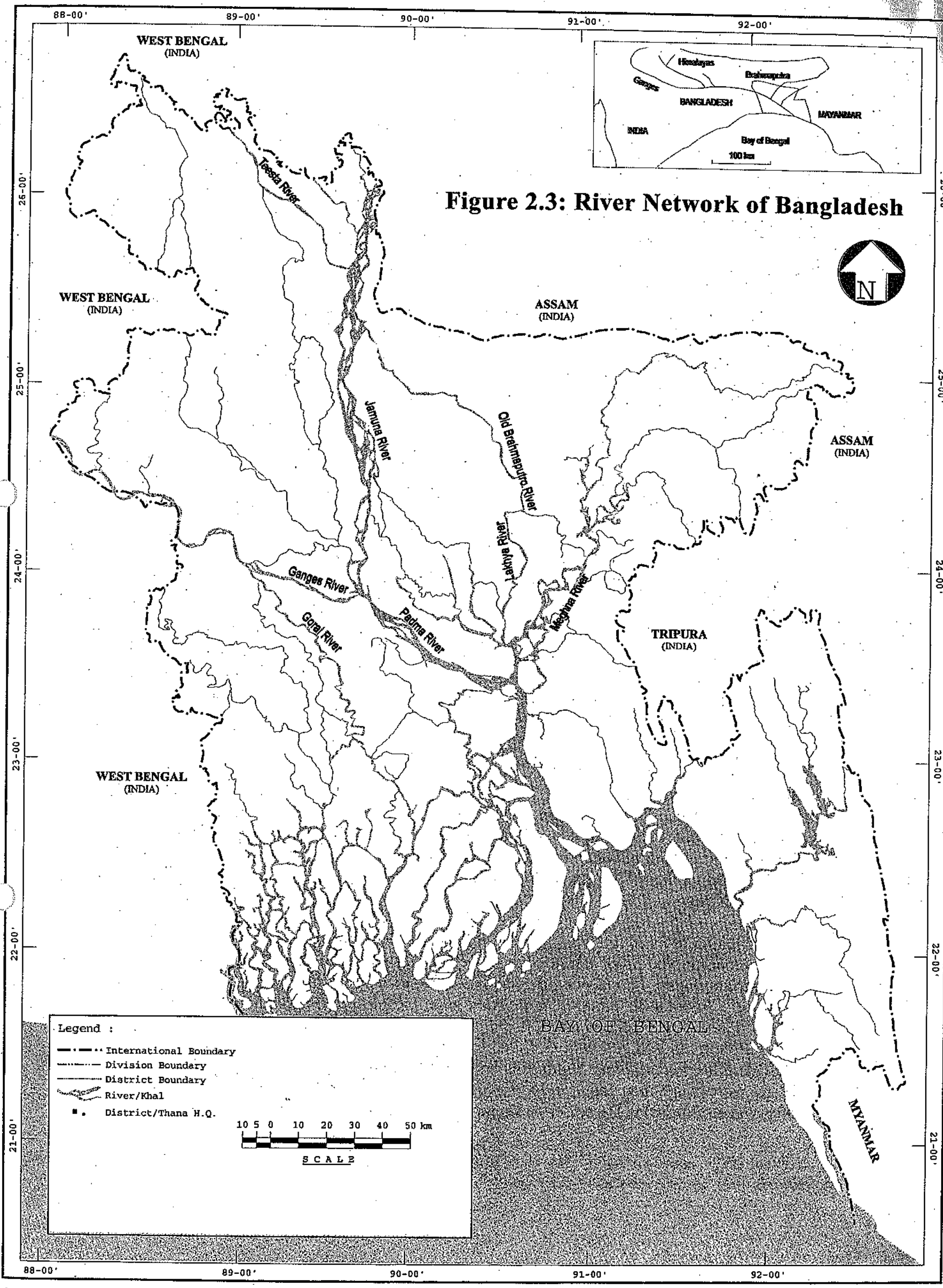


Figure 2.3: River Network of Bangladesh

Source: FAP-24

2.20.4 Water Use

Water is an essential commodity for life. It is used in households, agriculture, livestocks, fisheries, businesses, industries, navigation, hydropower generation, recreation, etc. Wetlands and water bodies act as habitats for numerous aquatic and amphibian species. Thus, availability of water, or lack of it has profound effects on the economy and the ecology of Bangladesh.

Agricultural use

Bangladesh, being an agricultural country, depends heavily on both surface water and groundwater for land preparation and irrigation. Agriculture contributes about 32% of the GDP and 70% of the export while sustaining about 74% of male labor force and 48% of female labor force. Agricultural water use constitutes about 85% of total consumptive water use. Due to continued emphasis on obtaining self-sufficiency in food grain by the Government of Bangladesh, agriculture sector will remain as the major water user in near future.

Fisheries

Fisheries industry represent only 8% of agricultural GDP, but it fully employs 1.5 million rural people and provide partial employment to another 11 million. Fisheries contributed 10% of the total export earnings in 1994-95 period (WB, 1997). Rivers, lakes, haors, baors, beels and household ponds produce about 600,000 metric tons of fish annually that make up nearly 80% of the total animal protein consumed in the country. In the wet season, inundated flood plains serve as breeding ground and nursery for fish.

The Ganga-Jamuna deltaic plain encompasses an area of 2.5 million hectares of coastal tidal land. The length of the coastline is approximately 710 km. Much of this area is ideal for brackish aquaculture and tropical shrimp culture. (Rahman, 1994). As a result, a large shrimp culture industry has developed in the coastal area. Traditional open sea fishing and drying on land is also a common practice along the coastline.

Navigation

Bangladesh has an intricate network of khal, beel, hoar, baor and river, which is used as navigational channels year round. In the monsoon, water level in many parts of the country rises 6m or more and waterways become very wide spread. According to Inland Water Transport Authority (IWTA, 1999), the total length of waterways in rainy season exceeds 8000 km. At the end of dry season, this length shrinks to about 4800 km. But for country boats the total length in the rainy season extends to about 24,000 km.

Due to siltation of many rivers and improved road network, transport via waterways is decreasing all over the country. The major inland ports that carry substantial amount of freight and passengers are Dhaka, Narayanganj, Chandpur, Barisal, Khulna, Potuakhali, Narsingdi, Bhairab Bazaar and Azmiriganj. Some of the ports – Dhaka, Narayanganj, Chandpur, Baghabari and Azmiriganj may be developed as container ports in future.

Bangladesh has two seaports: Chittagong and Mongla. Chittagong has been used as an international port for more than a thousand years. Mongla port, which is located 48 km south of Khulna on Passur River, was established in December 1950 and since then, it has grown rapidly.

Hydropower

Due to unfavorable topographical conditions, Bangladesh has only one hydropower plant at Kaptai of 230 MW capacity. Total hydropower potential of Bangladesh is reported to be 1500 GWh per year. This is made up of 1000 GWh at Kaptai, 300 GWh at Matamuhuri and 200 GWh at Sangu.

It is interesting to note that per capita power consumption in Bangladesh is approximately 90 KWh/year whereas the same in developed countries is more than 8000 KWh/year. This shows the very low level of development in Bangladesh.

2.20.5 Floods

Floods affect about 80% of land in Bangladesh. Four types of flooding occur in Bangladesh.

- Flash floods caused by overflowing of hilly rivers of eastern and northern Bangladesh (In April – May and in September – November).
- Rain floods caused by drainage congestion and heavy rains.
- Monsoon floods in the flood plains of major rivers (during June - September).
- Coastal floods due to storm surges.

Pattern of flood cycle in Bangladesh is shown below

Severity of flood	Return Period
Normal Flood	2.25 years
Moderate Flood	4 years
Severe Flood	7 years
Catastrophic Flood	40-50 years

The following factors have been identified as being responsible for flood in Bangladesh:

- Heavy and incessant rainfall in the upper catchments of the cross – boundary rivers as well as inside the country.
- Heavy snowmelt in Himalayas
- Topographically about half of the country is situated below 7.60 meter above mean sea level (MSL). Floodwater spills from the rivers and accumulates on these low-lying areas.
- Bangladesh and surrounding catchments areas lie in the heavy monsoon rainfall area that leads a concentrated large discharge in the rivers. As a result, this channel is frequently overloaded and spills over the banks and cause flood in the plain.
- There have been significant changes in the behavior of off-takes of the main rivers – distributaries of the Ganges – Padma and the Brahmaputra after the Assam earthquake of 1950, which caused the Brahmaputra River to become heavily silted. Due to blockage at confluence and off-take of distributaries, there has been a concentration of water in the main river system.
- Simultaneous high discharge of the upland streams and high tides in the estuaries, low topography of the country and river bed siltation all contribute to the over bank spilling of the rivers.
- More than 80% of the annual precipitation occurs during the monsoon. This localized heavy rainfall and runoff coincide with the high discharge in rivers resulting in drainage congestion.

Locally concentrated rainfall of more than 300 mm in 2 – 6 hours leads to severe flash / local floods.

- Springtide of the Bay of Bengal retards drainage of floodwater into the sea and locally increases monsoon flooding. A rise of MSL at times during the monsoon period due to effect of monsoon winds also adversely affect the drainage and rises the flood level along the coastal belt.
- High water level of the main rivers slows down the flow from the tributaries. In particular, the flow of the Dharla and the Teesta being backed up by the Brahmaputra and mutual backing up by the Ganges and the Jamuna affect the drainage of the Hurasagar. This increases the flood intensity in the adjoining areas. The backing up the drainage of the Sylhet – Mymensingh haors through the Meghna due to high water prevailing in the lower Meghna at Chandpur is a well-known phenomenon.
- A series of monsoon depression passing over Rajshahi, Pabna, Bogra and the Sylhet – Mymensingh haor area. These areas become inundated with the monsoon activities and remain water logged until November. Generally, the Brahmaputra records its peak flood during the month of June – July and the Ganges in the August – September, while the Meghna remains high from May to September. Some years it may happen that these rivers reach peak-flood level simultaneously and aggravate the flood situation in the country.
- Flooding in the coastal areas due to spring high tide (May – November), tidal and cyclonic storm surges.

Statistics on Flooding

Many parts of the Asia during monsoon frequently suffer from severe floods. Some part of India and Bangladesh experiences floods almost every year with considerable damage. Flood statistics for Bangladesh are available since 1954 and are summarized in Table-2.5 as follows:

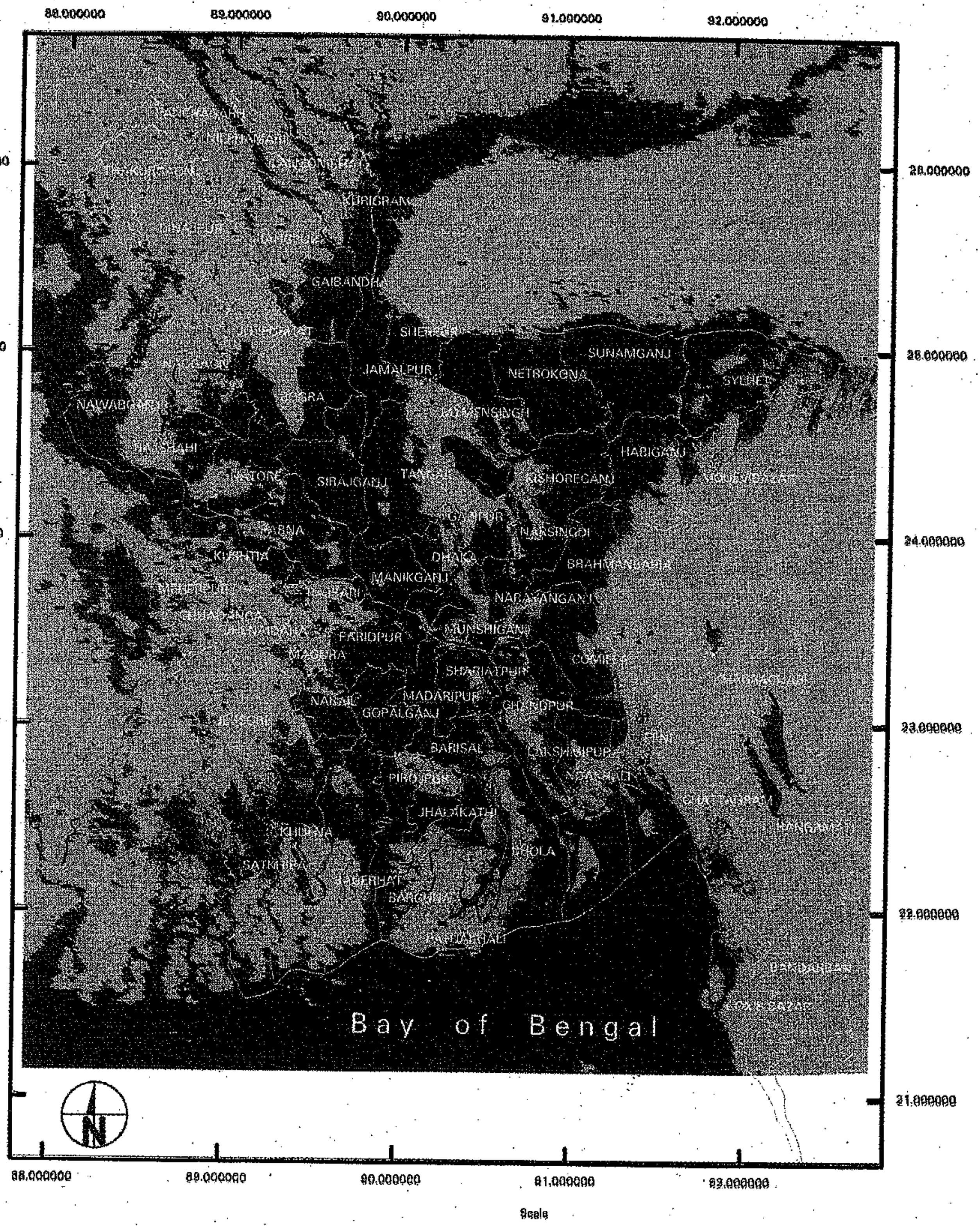
Table 2.5: Year-wise Flood Affected Area and Country Percentage in Bangladesh

Year	Flood affected area		Year	Flood affected area		Year	Flood affected area	
	Sq. Km	%		Sq. Km	%		Sq. Km.	%
1954	36,800	25	1973	29,800	20	1991	28,600	19
1955	50,500	34	1974	52,600	36	1992	2,000	1.4
1956	35,400	24	1975	16,600	11	1993	28,742	20
1960	28,400	19	1976	28,300	19	1994	419	0.2
1961	28,800	20	1977	12,500	8	1995	32,000	22
1962	37,200	25	1978	10,800	7	1996	35,800	24
1963	43,100	29	1980	33,000	22	1998	1,00,250	68
1964	31,000	21	1982	3,140	2	*1999*	*32,000*	*22*
1965	28,400	19	1983	11,100	7.5	*2000*	*35,700*	*24*
1966	33,400	23	1984	28,200	19	*2001*	*4,000*	*2.8*
1967	25,700	17	1985	11,400	8			
1968	37,200	25	1986	6,600	4			
1969	41,400	28	1987	57,300	39			
1970	42,400	29	1988	89,970	61			
1971	36,300	25	1989	6,100	4			
1972	20,800	14	1990	3,500	2.4			

The floods of 1954, 1955, 1974, 1987, 1988 all caused enormous damages to properties and considerable loss of life. The consecutive floods of 1987 and 1988 caused heavy damage. Again during 1998 Bangladesh experienced most devastating and prolonged flood in the history and caused serious disruption on the economy of the country. Areas of Bangladesh was flooded in 1998 is shown in Figure-2.4.

Figure 2.4: Area Affected by Flood 1998

Based on RADARSAT and GMS-5 Data series (Source: SPARRSO)



Scale

100 0 100 Kilometers

Legend:

- Flood Affected Areas
- Areas not Affected by Floods

The 1998 flood inundated about 100,000 km^2 affecting 68% of the country and seriously impacting the livelihoods of 30 million people. Overall damage was estimated at two to three billion U.S. dollars. Final estimates showed that 51 districts and 307 upazilas were inundated, about 1400 people were killed, 1.77 million houses were damaged, and 23,45,8713 people became homeless. The 1998 floods lasted for over 10 weeks (MDMR/UNDP, 2000). The origin and wide-ranging impacts of the 1998 flood, which began in July and ended in September, are summarized below. The magnitude and duration of the 1998 flood can be explained in large part by the simultaneous realization of the impacts from three factors:

- Heavy rainfall/snowmelt in India and Nepal (which increased the flow in the rivers entering Bangladesh.)
- Increased July rainfall within critical river basins in Bangladesh (Ganges, Brahmaputra, Meghna, Southeastern Basin).
- Tidal surges in the Bay of Bengal.

The first and second factors help explain the magnitude of the 1998 flood. In this respect, it is worth noting the extent to which the 1998 July rainfall totals within some of Bangladesh's critical river basins exceeded the typical July average. The third factor, tidal surge levels in the Bay of Bengal, with back water effects, reduced the Bay's capacity to receive the floodwaters. This, in part, contributed to the duration of the flooding.

2.21 Coastal Zone of Bangladesh

The coastline of Bangladesh is about 710 km long. The coastal zone covers about 23 % i.e. 2.85 mha of the area of Bangladesh and in habituate by 24 million people. The majority of the coastal area lies within the delta of the Ganges – Brahmaputrea – Meghna (GBM) river system and has been formed by sedimentary deposits in recent geologic time.

The coastline of Bangladesh can be divided into three zones – the West, the Central and the East (Figure-2.5). Each zone contains distinct coastal landforms and specific geological, physical and biological characteristics (Barua, 1991). The west and the central coasts are part of the Ganges - Brahmaputra – Meghna delta system, whereas the east coast is non-deltaic.

The coastal region is marked by a vast network of river systems and deltaic tidal channels, and ever dynamic estuary, interaction of huge quantities of fresh water that are discharged by the major river systems, and a saline water front penetrating inland from the sea. In addition to the coastal plains, there are a number of offshore islands those are subject to strong wind and tidal interactions throughout the year and are inhabited by a large number of people.

Coastal plains are mainly used for crop agriculture, brackish water shrimp culture and for grazing of livestock. Regular or periodic inundation and saline water intrusion has been a problem for agricultural activities in the coastal area. Since the seventeenth century, construction of small embankments or dikes has been a common practice in this country. In the 1960s, a series of dykes were built under the coastal embankment project. The main purpose of the project was to protect coastal agricultural land from flooding and intrusion of saline water during high tide, and thereby to increase cultivable areas in the coastal region as well as yields in the already cultivated areas.

Since most of coastal plains in the central zone and offshore Islands are within 0.8 to 4 meters from the mean sea level, it was previously thought that a significant part of the coastal areas (as high as 18% of the country) would be completely inundated by rising sea waters (Huq et al., 1995; Houghton et al., 1996). Such a speculation was made based on two major approximations: (a) the coastal plains are not protected and (b) the seawater front will follow the contour line. In reality, however, it is found that most of the coastal plains in the central regions are protected.

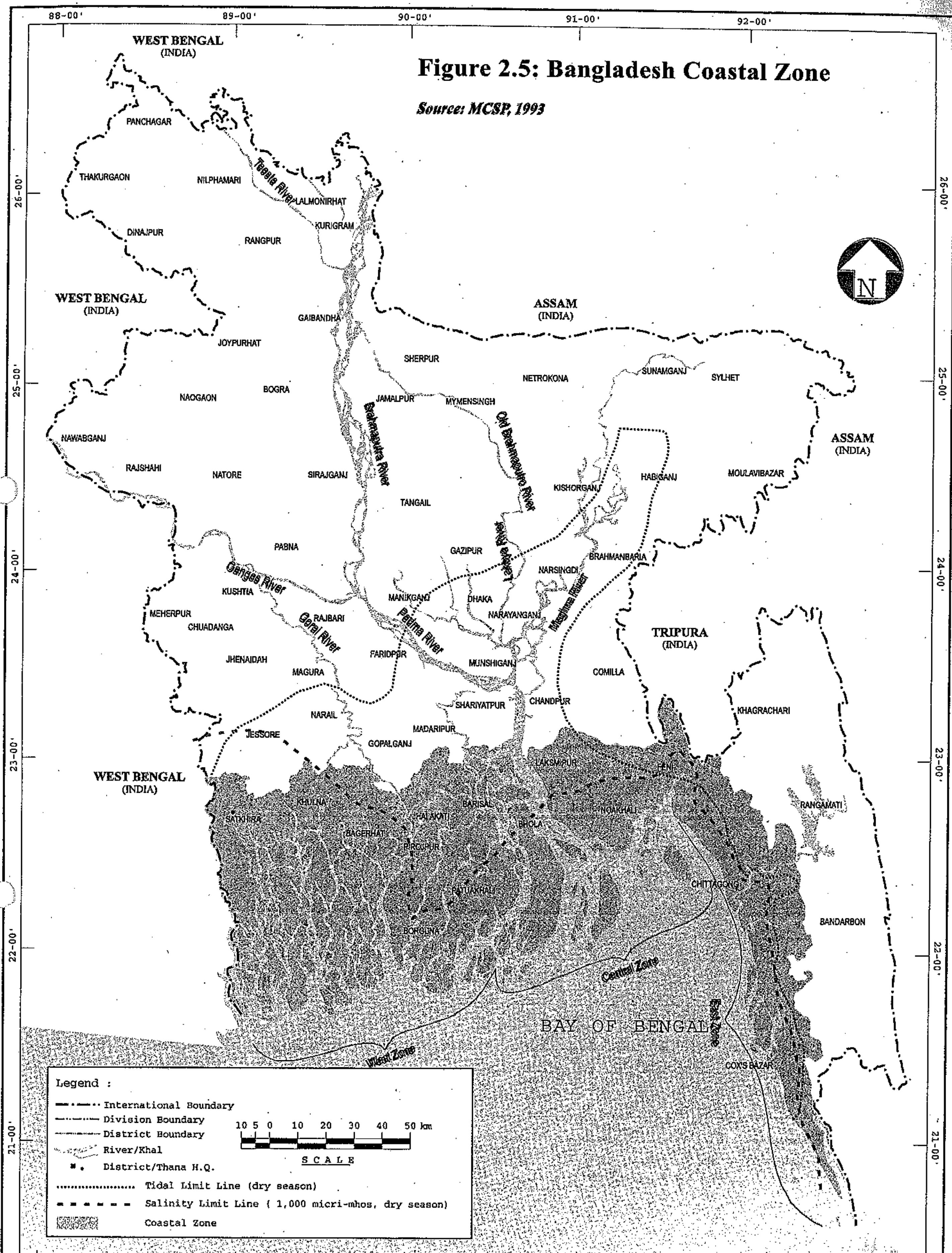


Figure 2.5: Bangladesh Coastal Zone

Source: MCSP, 1993

Drainage congestion has become serious threat in the coastal zone. Due to the siltation and the poor maintenance of the drainage channel network in many parts of the coastal zone, drainage congestion is already a grave problem *(EGIS, 1998)*, and the problem is increasing day by day. Unlike the densely populated seafront area, the Sundarbans is not protected and is heavily influenced by tidal effects.

2.21.1 Tides and Waves

High astronomical tides, storm surges and strong wind waves are the characteristics of the coastal area of Bangladesh. Seasonal variation of tide occurs due to upland flood discharge, wind and storm surges in the ocean. Tidal wave of the oceans while propagating through the surrounding rivers is deformed. Tides in estuarine channels are driven by changing water levels at the ocean boundary. During winter months when river flows are low, tidal effects extend deep inside the country. The extensive shallow area in the Meghna river estuary causes some refraction and distortion of the tidal wave. Also some reflection of the tidal wave occurs contributing in an increase of the tidal wave. The mean tidal range at the mouth of the Meghna estuary is about 4-6m.

Waves approach the shore; they undergo deformation due to reflection, refraction, shoaling and breaking. The slope of near-shore seabed is very small along the coast of Bangladesh and the seabed contours are nearly parallel to the coast. Therefore, the effect of reflection and refraction upon the wave height is small compared to that of shoaling and breaking. The shoaling and breaking mainly depend on the slope of seabed and water depth. Wave breaking will always occur at the near shore water depths. There are standard procedures for estimating the near shore wave heights from offshore significant wave heights. Near shore significant wave heights corresponding to the 20 years offshore significant wave height of 8.8 m and a corresponding significant wave period of 12.5 sec. has been given in the report of Cyclone Protection Project-II (1992). The offshore significant wave heights and near shore significant wave heights are presented in Tables-2.6 & 2.7 respectively

Table 2.6: Offshore Significant Wave height and Wave periods

Return Period (Years)	2.5	5	10	20	50	100
Offshore Significant Wave Height, H_S(m)	6.9	7.6	8.2	8.8	9.6	10.2
Offshore Significant Wave Period, T_S(sec)	11.1	11.7	12.2	12.5	13.1	13.6

Table 2.7: Near Shore Significant Wave heights (m) from Offshore Wave Statistics

Depth	Bed Slope				
(m)	0.001	0.002	0.005	0.01	0.02
10	6.04	6.06	6.13	6.26	6.52
9	5.52	5.54	5.60	5.72	5.96
8	5.00	5.02	5.07	5.17	5.39
7	4.47	4.49	4.54	4.63	4.83
6	3.95	3.97	4.01	4.09	4.26
5	3.43	3.44	3.48	3.55	3.69
4	2.91	2.92	2.95	3.00	3.13
3	2.39	2.39	2.42	2.46	2.56
2	1.86	1.87	1.89	1.92	2.00

Offshore Wave Statistics H_S=8.8 m, T_S = 12.5 sec., Duration = 12 hrs. during May to September, Return period = 20 years.
(Source: Cyclone Protection Project-II, 1992)

The wave-heights in front of the coastal embankments will be of the order of magnitude as shown in table below depending of the water depth defined as height of still water level above average ground level.

Water Depth (m)	1.0	2.0	3.0	4.0	5.0	6.0
Near Shore Significant Wave Height (m)	0.8	1.50	2.10	2.70	3.3	3.6
Near Shore Significant Wave Period (s)	7	8	8.5	9	9	9

2.21.2 Cyclones and Storm Surges

In Bangladesh, cyclones have two peaks in a year: during April and May (pre-monsoon), and between October and November (post monsoon). Cyclone of May 19, 1997 is shown in Figure-2.6. A storm surge during a cyclone inundates coastal areas and offshore islands, which causes most of the loss of life and property. Information on storm surge height is very scarce in Bangladesh. Available literature provides a range of 1.5 to 9.0 meter high storm surges during various severe cyclones (Haider et al., 1991). However, a SMRC report shows the surge height for 1876 cyclone was 13.6 m at Bakerganj and the surge height for 1970 cyclone was 10m (Karmakar, 1998). Locations of these surge heights are not known. Therefore, it is difficult to compare maximum wind speed and corresponding surge heights. Displacement of water surface during a cyclonic storm surge also depends on the height of tide.

Tide is a periodic phenomenon with a period of about 12 hrs 25 min. while cyclonic storm surge is an occasional phenomenon. The storm surge wave moves along with the tide and the displacement of water surface is due to combined action of tide and storm surge. The resultant displacement depends on the phase difference between peak surge and peak tide. In the Bay of Bengal, the displacement of water surface is largest when the cyclone storm reaches the coast at the time of spring tide. The interaction between storm surge and tide is non-linear.

The displacement of water surface during a cyclonic storm surge also depends on tide. The displacement of water surface is largest when the cyclonic storm surge reaches the coast during the time of spring tides. Such coincidence occurred during cyclones of November 12, 1970, December 10, 1981 and April 29, 1991.

The cyclonic storm surge is a gradually varied unsteady flow. The amplitude of cyclonic storm surge wave amplifies during its progression towards the coast of Bangladesh due to long and shallow continental shelf. The height of the surge at a point depends on the origin, track, forward speed and strength of the wind field associated with each particular cyclone event. Because of the large length of the cyclonic storm surge wave, movement of a huge mass of water accompanies it. When a cyclonic storm surge reaches the coast, the surge water floods the adjacent area.

Local waves can form over the surface of cyclonic storm surge wave and of tidal wave due to blowing wind. The height of wind, generated waves riding on top of the surge wave at the time of a severe cyclone may be large. As a rule of thumb, height of wind waves in shallow coastal water could be ½ to ¾ of the surge height (Jelenianski, 1989). The wind waves rapidly attenuate across inland terrain flooded by the surge (Jelenianski, 1989). Another important factor is the path of cyclones. Due to its geographic location, cyclones hitting the Khulna region in the South West have comparatively lower storm surges than those hitting the Meghna estuary. Table-2.8 shows the list of cyclones and number of affected people from these cyclones.

Table 2.8: Major Cyclones in Bangladesh

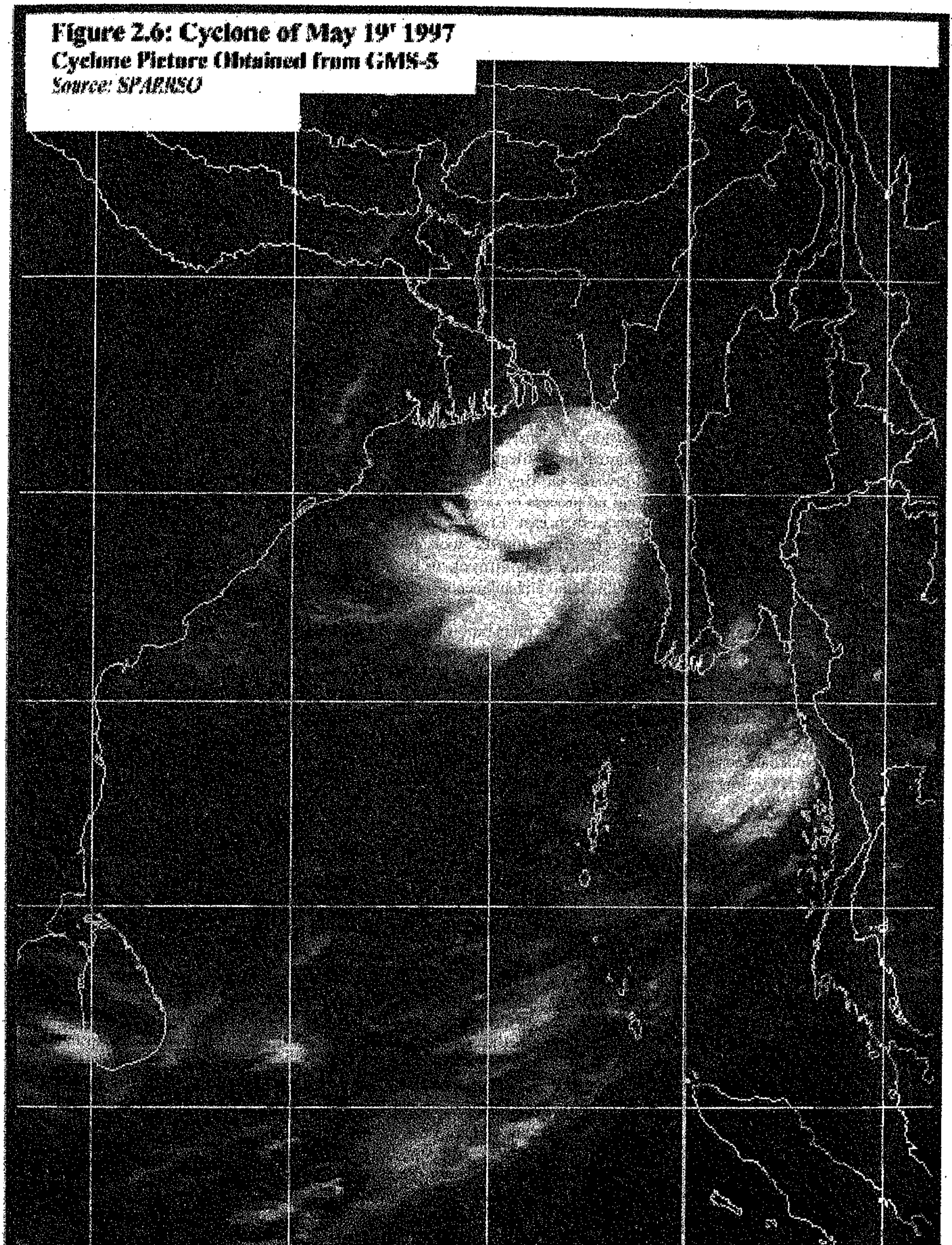
Year	Losses	Location	Other Information
1584	Deaths: 200,000	Bakerganj	
June 1822	Deaths:100,000;Animal losses 100,000	Barisal	
May 1869	Deaths:250, Huge property losses	Khulna	
October 1872	NA	Cox's Bazar	
November 1876	Deaths: 200,000	Bakerganj	3-10m high tide
October 1895	NA	Bagerhat/Sunderban	
October 1897	Deaths: 175,000	Kutubdia Is Chittagong	
May 1898	NA	Teknaf	
November 1901	NA	Sunderban	
October 1909	NA	Chittagong	
December 1909	NA	Cox's Bazar	
April 1911	NA	Teknaf	
1912	Deaths 40,000		
May 1917	NA	Sunderban	
September 1919	Deaths 40,000	Barisal	
May 1926	NA	Cox's Bazar	
May 1941	Deaths 7,500	Barisal/Noakhali	4m high tide
May 1948	NA	Chittagong/Noakhali	
November 1950	NA	Patuakhali	
October 1958		Noakhali/nearby Islands	
May 1960		Sunderban	3.2m high tide
October 1960 1st	Deaths 3,000	Noakhali/Islands	5.1m high tide
			200km/hr speed
October 1960 2nd	Deaths 8,149	Noakhali/Islands	6.6 high tide
May 1961	Deaths 11,468	Noakhali	3m high tide
May 1961 (2nd)	Deaths 10,466	Chittagong, Cox's Bazar	6-8m high tide
October 1962	NA	Feni	
May 1963	Deaths 11,520	Chittagong, Noakhali	8.1m high tide
June 1963	NA	Jessore	3.1m high tide
October 1963	NA	Teknaf	
May 1965	Deaths 11,270	Barisal/Noakhali	
May 1965(2nd)	Deaths 12,000	Chittagong	7.6m high tide
December 1965	Deaths 873	Cox's Bazar	8.8m high tide
October 1967	NA	Cox's Bazar	7.6m high tide
May 1970	NA	Cox's Bazar	5m high tide
October 1970	Deaths 300	Chandpur	4.7m high tide
November 1970	Deaths 275,000	Coastal districts	9m high tide
September 1971	NA	Chandpur	5m high tide
December 1973	Deaths 83	Patuakhali/Islands	4.5m high tide
August 1974	NA	Khulna	6.7m high tide
November 1975	NA	Barisal/Noakhali	3.1m high tide
November 1983	300 fishermen unaccounted	Chittagong, Cox's Bazar	
May 1985	Deaths 11,069, Property losses: 9400 homes	Chittaogng, Cox's Bazar Islands	4.3m high tide
November 1988	Deaths 5704; Unaccounted persons 6000; Animal Deaths 65,000, Tiger deaths 9.	Khulna and adjacent Islands	4.4m high tide
October 1990	Deaths 150 (fishermen)	Barisal	
April 1991	Deaths 150,000; Animal Deaths 70,000.	Chittagong-Cox's Bazar	4-8m high tide.

Source: Warrick, RA; Bhuiya, AH; Mitchell, WM; Murty, TS; and Rasheed KBS, (1994)

2.21.3 Coastal Morphology of Bangladesh

As stated earlier Bangladesh is drained by a large networks of rivers centering one of the largest river systems in the world: the Ganges, the Brahmaputra and the Meghna (GBM). The GBM carries about 2.4 billion tons of sediments per year (Colenan, 1968) into the Bay of Bengal. These sediments interact with dynamic processes in the Bay leading to accretion in one place and erosion in the other.

Figure 2.6: Cyclone of May 19' 1997
Cyclone Picture Obtained from GMS-5
Source: SPARRSO



According to Ali (1991) the salient and major features of coastal morphology of Bangladesh are:

- Low coastal bottom topography.
- Low coastal land topography.
- A large network of rivers, canals and streams.
- A huge discharge of river water heavily laden with sediments.
- A deep submarine canyon called Swatch of No Ground apparently controlling to a great extent the flow dynamics.
- A funnel shaped Bay converging northward and meeting the Bangladesh coast.
- High wind and tidal wave actions.
- Frequently occurring tropical cyclones and storm surges.
- A vast tract of mangrove forests influencing the flow dynamics.
- A large continental shelf particularly near the Meghna estuary.

From the analysis of the historical maps of the 16th century up to that of satellite imagery of the 20th century, the Ganges – Brahmaputra – Meghna delta was found maturing gradually from west to east. The delta did not extend towards the Bay in this period except in the Tetulia – Shahbazpur – Hatiya Channels. Gradually silting up process of the distributaries of the Ganges contributed to the gradual maturing of the delta from west to east. Erosion and accretion were found prominent in the coastal area when major changes of river courses took place either by natural phenomena, such as geological activities of subsidence or upliftment, or by human interference, such as cross-dam over the Meghna channel in Noakhali and embankments and sluices of the Coastal Embankment Project.

During the last 200 years, (i.e. since preparation of Rennell's map) the delta development activities remained confined in Noakhali, Bhola and Patuakhali districts around the Meghna, Shahbazpur and Tetulia channels. Major accretions took place along the Noakhali coast, south of Bhola and Hatiya islands. Major erosion took place along the eastern coast of Bhola, northern side of Hatiya and northern and western side of Sandwip. During this period the Bhola Island has extended 60 kms towards south. Hatiya has shifted 45 kms to south having adopted new shape and location and Noakhali coastline has shifted 17 km towards south in Char Jabbar area. The growth and decay of Sandwip was observed in the same location.

Erosions and accretions between the period 1972-91 shown in the Table-2.9 and Figure-2.7 can be interpreted as follows. Major stable accretions are taking place in Patuakhali – Bhola districts coastal fronts. The past rate of net accretion in this region was found to be 12 sq km per year. Erosion at the rate of 3 sq km per year and accretion at the rate of 15 sq km per year took place in the last 20 years. Islands in this region may grow by silting up of small channels. The past trend of erosion and accretion may continue to follow for the next 25 years.

Both erosion and accretion occurred in the Meghna estuary region were found to be prominent. The past rates of erosion and accretion per year were detected as 20 sq km and 28 sq km respectively resulting to net accretion rate of 8 sq km per year. This past trend of erosion and accretion may continue for the next 25 years but the net accretion may be a bit less. Major threat of erosion in the next 25 years may be in the region of northern part of Bhola, Lakshmipur coastline, north and northeastern parts of Hatiya, north and western parts of Sandwip. Slow accretion may take place in the southern part of Hatiya and Noakhali mainland. Erosion and accretion in the Feni coastal belt is expected to be insignificant.

Erosions and accretions all along the coast from Feni River to Shahapuri island is found to be not significant. This non-deltaic coastline is found stable.

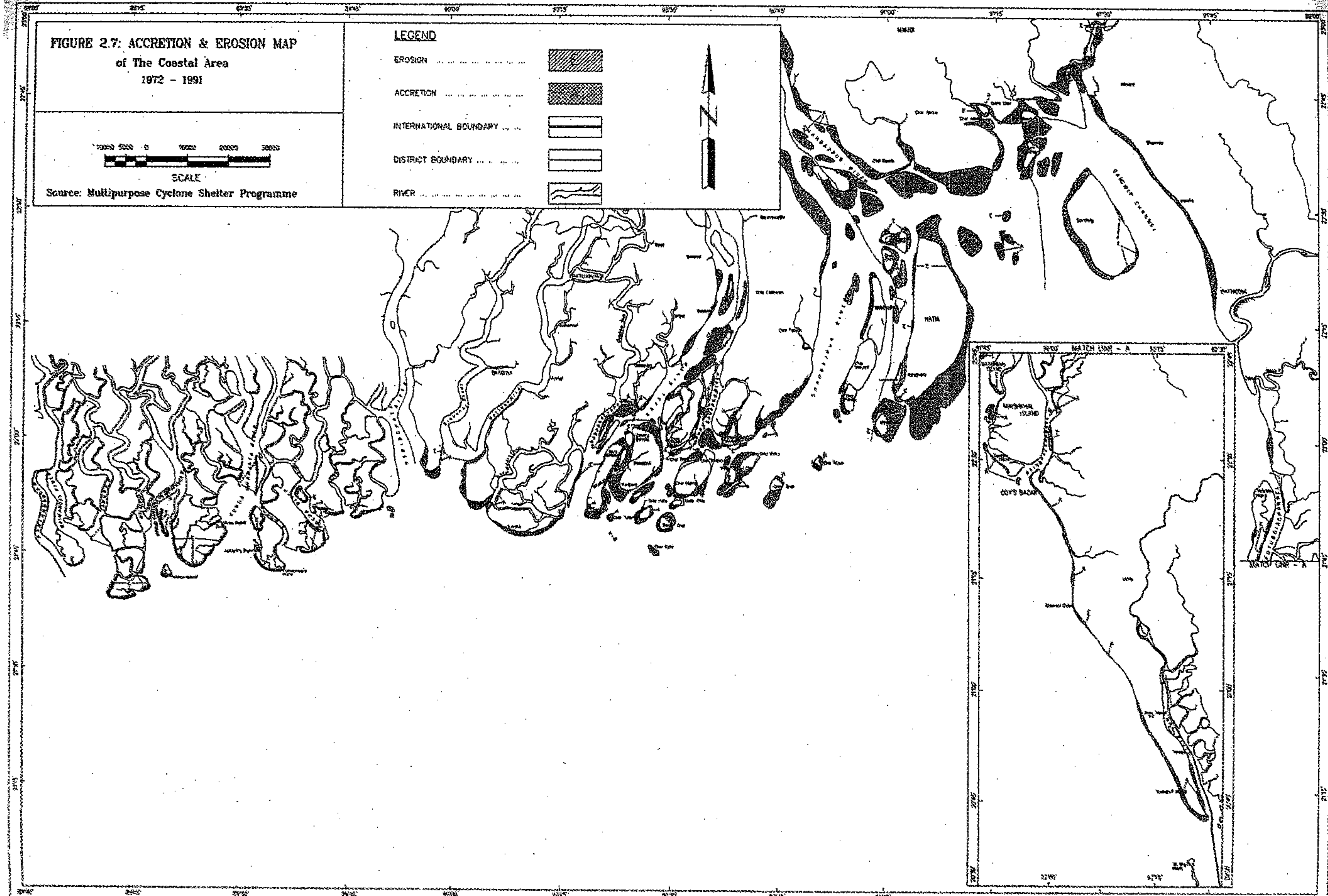


FIGURE 2.7: ACCRETION & EROSION MAP
of The Coastal Area
1972 - 1991
SCALE
Source: Multipurpose Cyclone Shelter Programme
LEGEND
EROSION
ACCRETION
INTERNATIONAL BOUNDARY
DISTRICT BOUNDARY
RIVER
N
HATIA
MATCH LINE - A
COX'S BAZAR

Coastal afforestation activities have helped the stabilization of the accreted areas and accelerated the rate of sedimentation. But the impact of afforestation in retarding the process of erosion needs to be studied more thoroughly.

Islands formed in the Hatiya channel area may not be assured for their stability and longevity. This is a trough area. Sandwip Island may be reduced gradually in the next 25 years.

Table 2.9: Erosion and Accretion in the Coastal Area Between 1972-91

Area	Boundaries in Spherical Coordinates	Erosion in Sqkm	Accretion in Sqkm
Sundarbans	Lat.N^{O}21^{O}30'-22^{O}10' Long. E^{O}89^{O}00'-90^{O}00'	74.73	14.45
Bhola area	Lat.N^{O}21^{O}45'-22^{O}30' Long. E^{O}89^{O}45'-91^{O}00'	69.63	329.49
Noakhali – Chittagong area	Lat.N^{O}21^{O}45'-23^{O}00' Long. E^{O}90^{O}45'-92^{O}00'	494.39	587.04
Cox's Bazar area	Lat.N^{O}20^{O}30'-22^{O}00' Long. E^{O}91^{O}30'-92^{O}30'	33.43	8.88

A time series of geo-referenced satellite images from the period 1973 to 1998 were used by the Meghna Estuary Study (MES) Project to examine and assess the erosion and accretion in the Meghna Estuary area. The Project attempted to assess the long-term changes in the coastal morphology by comparing historical maps with satellite imageries. The MES predicted accretion and erosion in the Meghna Estuary within 2025 is shown in Figure-2.8.

2.21.4 Mangrove Forest

Mangrove ecosystems of Bangladesh are located in the Sundarbans, the South-West parts of the country bordering India and in Chittagong, Noakhali, Cox's Bazar and Patuakhali coastal areas and in newly accreted char lands in south of Bhola Island (Char Kukri – mukri), South of Hatia Island (Nizum Dhwip), Char Gazaria, Char Yunys, char Bhata, Boyer char, Urir char, Moheshkhali etc. Area covered under Mangrove forest of Bangladesh is shown in Figure-2.9.

Sundarbans is known as the single largest stretch of productive mangrove forest in the world. It occupies an area of about one million ha in South West Bangladesh and South Eastern part of the state of West Bengal of India (between 88^{0}85'to 89^{0}55'E and 21^{0}30' to 22^{0}40'N). About 62% of this forest is within the territory of Bangladesh. One third of this forest area consists of water bodies in the form of rivers, channels and tidal creeks. The forest is highly influenced by tidal interactions. Sundarbans hosts the Royal Bengal Tiger and the forest has been endowed with a number of commercially important mangrove species such as Sundri, Gewa, Goran and Keora.

In general, dicotydonous tree species are represented by 22 families and 30 genus, while Rhizophoraceae is represented by all the 4 known genera and at least 6 species. The shrubs are represented by 12 species belonging to 11 genus under 7 families. Eleven different species of climbers belonging to 6 families have so far been identified in the Sundarbans. In addition to the plants, there is epiphytic parasitic flora found in the forest. Orchids of 13 species and ferns of 7 species are found in the Sundarbans.

Mangroves have a strong interrelationship with tidal and river flows. The mangrove trees slow down these flows allowing sediment to drop out of suspension, building up the mud flats and supplying nutrients to support mangrove growth.

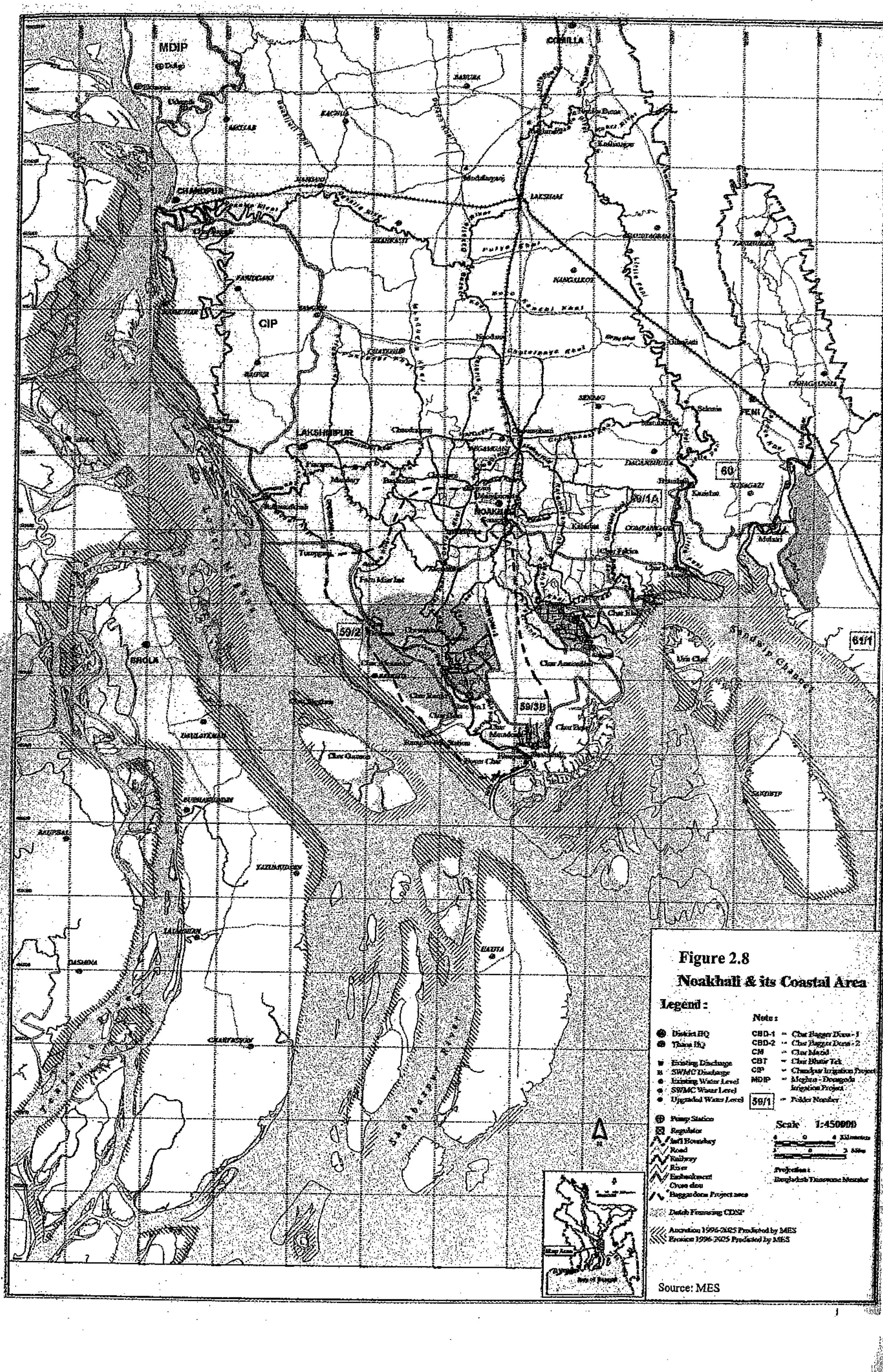


Figure 2.8
Noakhali & its Coastal Area

Source: MES

Mangrove species are specially adapted to survive in saline waters. Different species thrive in different salinities through their own specialized adaptations to ensure growth and reproduction. The salinity distribution and degree of water logging within the forest determines the overall ecological zonation of the sundarban into fresh water, moderately salt-water and salt-water zone. Differences in salinity within zones produce variations in local species. Ecological zonation and characteristic species of the Sundarban mangrove forest is presented in Table-2.10.

Table 2.10: Ecological zonation, characteristic species and main economic uses of the Sundarban mangrove forest

Zonation	Area (km^2)	% of forest area	Bangla -deshi Name	Latin Name	Main economic uses
Fresh water zone	1,124	28%	Sundri	Heritiera fomes	Timber, fuel wood
Moderately salt-water Zone	1,823	46%	Gawa	Excoecaria agallocha	Pulpwood, matchwood baling board
Salt water zone	1,008	25%	Goran	Ceripos decandra	Fuel wood

Source: ESCAP, 1987, after Chaffey, et al., 1985

The Sundarban has been systematically managed since 1887, when a system of forestry and fishery permits was established. Since then the forest has been a considerable source of revenue and at present contributes about 2% to the GDP of the country and about half a million people are involved in the commercial exploitation of timber fuel wood, fish, honey, beeswax etc. of the forest (ESCAP, 1987). The indirect benefit of the forest is a result of the protection it gives to the breeding of shrimp and shrimp larvae, thereby protecting the marine, brackish and freshwater coastal fishing industries. The forest also provides protection for large areas of Khulna, Shatkhira and Bagerhat districts including Khulna City and Mongla port from cyclonic storm surges.

Presently, the Sundarban is in a state of decline, attributed to the combination of the effects of reduction in freshwater flow, heightened silt deposition and non-sustainable forestry management. Depletion of this mangrove forest will bring serious implications for the coastal economy as well as large area of south western zone of Bangladesh will be exposed to the direct on salt and risk from tidal and cyclonic storm surges.

Besides, the Forestry Department (FD) commenced the natural mangrove forest coastal afforestation program in 1966. According to the RIMS wing of FD, 109000 ha of coastal plantations have been raised in the early nineties of the last century. By a Government notification dated 13th August 1976 a total area of about 500000 ha accreted lands arising out of the sea or confluence of big rivers falling in the coastal districts of Noakhali, Barisal, Chittagong and Patuakhali was transferred by the Ministry of Land to the Ministry of Forest as reserve forest for 10 years for the purpose of coastal afforestation. The main objective of coastal afforestation was stated to be conservation and stabilization of newly accreted char-land and soil for making the same suitable for cultivation.

The Forestry Department (FD) thereafter started planting trees in the said reserve forest area under an internationally funded Coastal Afforestation Project (CAP). Keora is the dominant species of coastal plantations followed by Bean. Almost 80% of the area was planted with Keora, followed by Bean of about 15% of the planted area. Remaining 5% area was planted with Gewa, Kankra, Golpata, Babla etc.

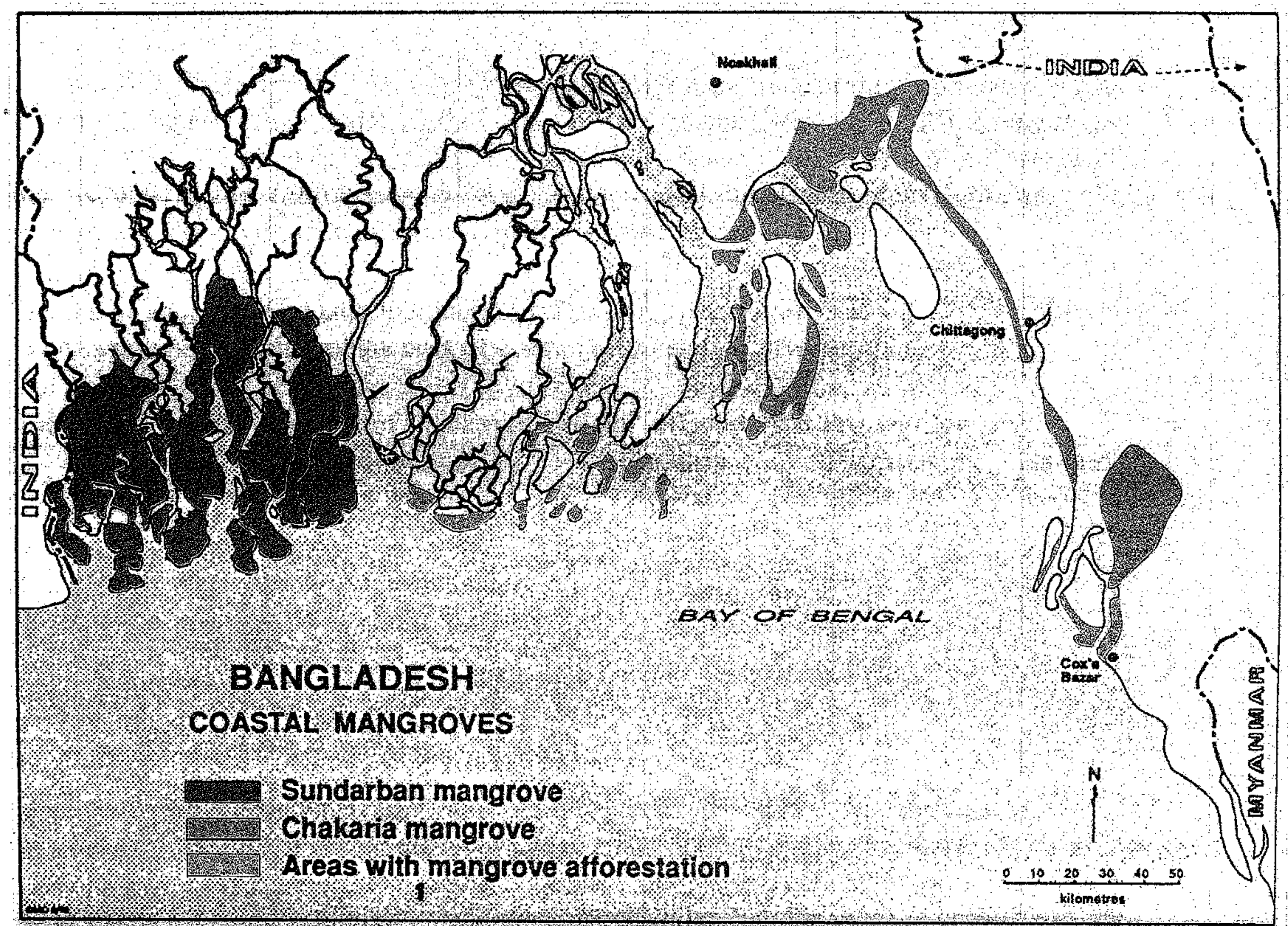


Figure 2.9: Coastal Mangrove of Bangladesh

Source: ESCAP. 1987

2.21.5 Water Logging and Drainage Congestion

Drainage is the main concern for water management in the coastal regions. After the construction of several thousands kilometers of coastal embankments for different polders in sixties and early seventies under the Costal Embankment Project (CEP) greatly reduced the tidal prism and volume of tide water entering and leaving the coastal area during the tide cycles. This resulted in gradual siltation of the drainage channels of the coastal belt and drainage congestion began to affect in the polders of the greater Khulna, Barisal and Noakhali districts.

Due to inadequate maintenance a large number of CEP polders could not serve the desired purpose properly. Maintenance budgets have been too small to keep the infrastructures of the polders in good condition and operative. Problems of water logging and reduction of agriculture production have been occurred in different polders in the west and central coastal zones due to outfall channel siltation of drainage sluices, breach / public cut of embankment and saline water intrusion into the polders.

In some areas interpolder channel siltation has seriously reduced the long-term sustainability of the polders and channel siltation has also created problems for river transport, especially for Mongla port, Khulna City and other riverine ports and cities of the area. In a large part of coastal zone of Bangladesh drainage congestion have become more serious threat than higher flood risks and the problem is deteriorating day by day.

Flood Action Plan Studies (FAP-4 and FAP-5) concluded for future human interventions to maintain the channels so as to maintain agricultural production from the polders on a sustainable basis.

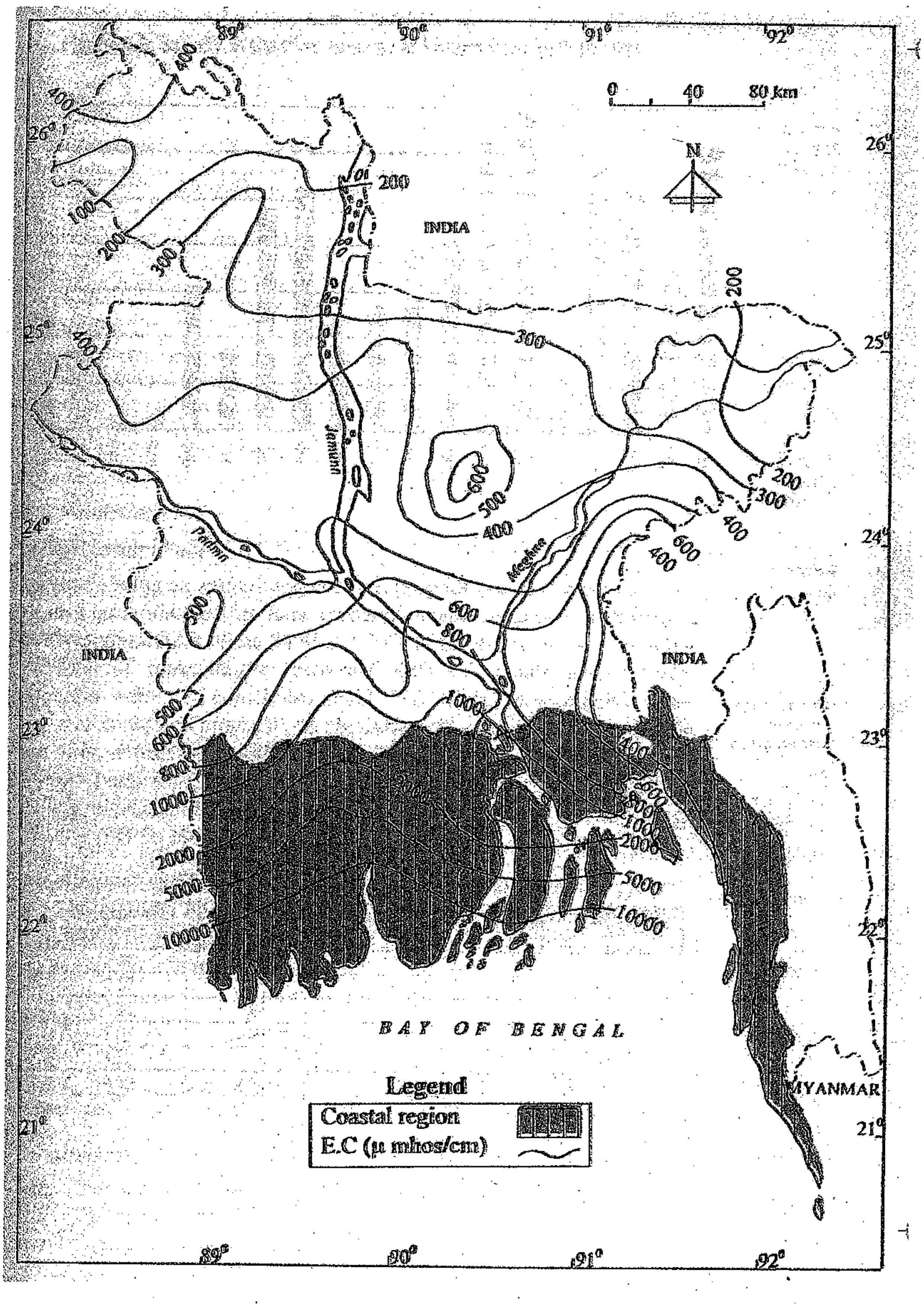
2.22 Soil Salinity

The effect of saline water intrusion is highly seasonal in Bangladesh. Saline water intrusion is minimum as the salinity front in estuarine and floodplains greatly push back during the monsoon (June – September) when the rivers discharge about 80 percent of the annual fresh water flow. The majority of coastal soils are non-saline in the rainy season. From December onwards due to the reduction of fresh water flows allow increasing levels of estuarine salt-water penetration inland. Saline waters penetrate up to 130 km inland in the lower Meghna and up to 290 km up the Passur River in the South West of the country (Nishat, 1988). Maximum Salinity levels occur during March-April.

Withdrawal and diversion of water from the Ganges at Farakka during the dry season reduced drastically the fresh water flow. Lower river flow from upstream increasing the pushing effect of saline water from the sea is the main cause of increasing salinization in the south-west deltaic regions of Bangladesh. In Khulna and Patuakhali districts 60-70 percent of arable land is affected by salinity in the dry period. While about 15 percent of the arable land of Barisal, Noakhali and Chittagong districts are saline. Figure-2.10 presents the Salinity in ground water table of Bangladesh.

Groundwater is crucial for agriculture, drinking water and industrial use. Main source of potable water is ground water in the coastal zone because of high surface water salinity. There are both shallow and deep aquifers beneath the coast, separated by thick clay layers (Nishat, 1988). Shallow aquifer salinity levels and depths are extremely variable within short distances. In contrast, the deep aquifer is regionally continuous and its salinity levels relatively uniform. The saline/freshwater boundary of the deep aquifer is close to the coast, except in the far west where the boundary is 120-160 km inland.

Figure 2.10: Salinity in Ground Water Table



3 GHG INVENTORY

3.1 Introduction

One of the key elements of the National Communication is the preparation of inventory of the Greenhouse gases (GHG) sources and sinks. For preparing the inventory of GHG, the activity data were collected from secondary sources, including public and other organizations.

The main anthropogenic sources of GHG emissions are Energy, Industrial processes, Agriculture, Land use changes & Forestry and Waste sector. According to Decision 10/CP.2 of UNFCCC, the emission inventory is to be provided for the gases Carbon Dioxide (CO_2), Methane (CH_4) and Nitrogen Oxide (N_2O) in the fulfillment of the commitments under the convention.

The first Emission Inventory was produced under the US Country Study Program (USCSP) based on Intergovernmental Panel on Climate Change (IPCC) methodology considering 1990 as the base year. Later on Asia Least Cost Greenhouse Gas Abatement Strategy (ALGAS) study was carried out in 1998 considering 1990 as the base year. In the present study GHG inventory has been carried out for a base year 1994. This study followed "Sectoral Approach" of revised IPCC guideline 1996.

3.2 Energy Sector

Energy supply in Bangladesh is mainly based on five primary sources, namely petroleum products, natural gas, coal, hydroelectricity and biomass. As fossil fuels are combusted, the carbon stored in the fuels is emitted as carbon dioxide and smaller amounts of other gases, including CH_4 and Non Methane Volatile Organic Compounds (NMVOC). The other gases are emitted as a byproduct of incomplete fuel combustion. The amount of carbon in the fuel varies significantly by fuel type. As biomass energy is the key player in the arena of energy supply/usage in rural area, the CO_2 emission from the burning of the crop residues consumption is assumed to be balanced by re-growth.

Petroleum fuel

Bangladesh imports crude oil and refined petroleum products. In 1994, the quantity of crude oil import amounted to about 1.2 million metric ton. There was little export of Naphtha and Furnace Oil. At the same year, about 16,000 metric tons of condensates (NGL) and local crude oil were produced in the country. *(Ref. BBS 1998).*

Natural gas

Total Production of natural gas was 6338 million cubic meter in 1994 of which 41% used in electricity generation, 9% in industry, 33% in fertilizer production, 7% in domestic uses and only 1.25% used in the commercial purpose (Ref. BBS 1998).

Coal

Bangladesh is dependent on imported coal, which is mostly used in the brick burning as well as in the industry and commercial sectors. Total consumption of coal was 59000 metric ton in 1994 of which 80% of the coal was used in the brickfield. *(Ref. BBS 1998)* Recently use of imported coal is reducing due to increasing fuel-switching to natural gas.

Renewable Energy

Hydro-electricity

Total hydropower potential in Bangladesh is reported at 1500 GWH per annum, in which Kaptai Hydropower plant generate (1000 GWH), Matamuhuri (300 GWH) and Sangu (200 GWH). Total generation of hydro-electricity was 846 GWH in 1994. *(BBS 1998).*

Others

Due to the abundant solar radiation, it is possible to convert it into the energy. The yearly potential solar energy of Bangladesh is estimated to be 25,610 million metric ton of coal equivalents. Biogas generation from cow dung, human excreta, and poultry dropping through anaerobic decomposition is a prospective field of renewable energy in Bangladesh and contribute a considerable amount of energy. Wind and wave energy is another possibility. *(BCAS 1999).*

Methodology of Greenhouse gases inventory in Energy Sector

TIER 1 method for Sectoral Approach of the IPCC guideline for national greenhouse gas inventories (*IPCC 1996*) is followed for the CO_2 emission with respect to fuel types and use of country's specific lower heat values (H_0) of fuel. The methodology, specific to this component, is summarized below in 6 steps:

- Step 1: Collection of sectoral fuel consumption data
- Step 2: Converting to a common energy units (TJ)
- Step 3: Multiplying by carbon emission factors to compute the carbon content (GgC)
- Step 4: Calculating Carbon stored and net carbon emission by subtracting carbon stored from carbon content
- Step 5: Correcting for carbon un-oxidized
- Step 6: Converting to carbon dioxide emissions

Data used

Data were collected mostly from secondary sources. Data for Petroleum fuel consumption has been collected from Bangladesh Petroleum Corporation (BPC), natural gas consumption from Bangladesh Oil, Gas and Mineral Corporation and coal from Bangladesh Bureau of Statistics. Collected data have been critically reviewed before analysis.

Carbon Emission Factors

Once fuel consumption data are provided in Gg for the relevant sectors and/or technology types, these consumption estimates can be multiplied by the appropriate carbon emission factors to determine potential carbon emissions in kilograms (kg). Carbon emission factor for different types of fuels is taken from IPCC guidelines 1996. (Annex A; Table A-1).

Carbon Stored

The adjustments for stored carbon (deductions of Gg CO_2 stored) have been made to the appropriate sector for which emissions are estimated. In most cases, these adjustments are made to emission estimates from the industrial sector and have been taken from the IPCC guideline 1996. Some default factors have been changed with expert judgment considering local condition of Bangladesh. For example, IPCC guideline suggested that for natural gas the value of stored carbon fraction should be counted 0.33 for manufacturing and construction industry only. In the ALGAS study, specific fraction of 0.5 was used and thereby in this study done the same for fertilizer production.

For LPG default factor has been depicted from Inventory of GHG emission & sinks. Fraction of Carbon stored has been shown in Annex A; Table-A.2.

Adjustments for Carbon Unoxidized

The amount of carbon that may remain un-oxidized from combustion activities can vary for many reasons, including type of fuel consumed, type of combustion technology, age of the equipment, and operation and maintenance practices, among other factors. It is possible to specify the assumptions for oxidized carbon by application, which is presented in Annex A; Table-A.3. The total energy consumption in physical unit is shown in Table 3.1.

Table 3.1 Total Energy Consumption in Physical Unit for 1994

Fuel Type	Consumption (Mt)-1994
Diesel	952055
Octane	24971
Light Diesel Oil	10905
JBO	19478
Furnace Oil	213228
Lubs/Grease	36456
Bitumen	75356
JP/1	90344
SBP/MTT	3628
Petrol	128518
Kerosene	391651
LPG	12549
Coal	59000
Natural gas*	5800

** Unit of Natural Gas is Million Cubic Meter*

Results

The sector wise distribution of consumption of natural gas, coal and petroleum products has been shown in Table 3.2.

Table-3.2: Sector wise consumption of natural gas, coal & petroleum products in1994 (TJ)

Fuel type	Energy Industries	Manufacturing industries & construction	Transport				Residential	Agriculture/ Forestry/ Fishing	Commercial/ Institutional
			Road	Rail	Navigation	Dom. Aviation			
Gasoline	0.14	7.09	5480.08	0.38					
LPG							535.84		
Kerosene	579.44	14.82		39.24	2.86		16087.14		
Diesel	4070.21	1236.46	17105.96	1704.93	3480.90			13054.24	
L.D. O	92.06	37.92		0.90	334.81				
JBO		831.71							
Fur. Oil	4173.37	2886.95		21.78	1669.90			352.79	
Lubs/Gr	23.66	264.31	570.56	52.99	42.14			195.22	
Jet petrol						3857.60			
Octane		0.20	1064.34			1.71			
Gasoline	0.14	7.09	5480.08	0.38					
Bitumen		67.94	3149.77						
SBP/MT		154.92							
Coal		1593							280.80
Nat. Gas	91079.81	93491.25					15447.90		2691.1

Source: BBS 1998, BPC 1995

Energy Industries

The amount of carbon varies by fuel type. Most of the Power stations in Bangladesh depend on natural gas as well as petroleum products except one hydropower plant situated at Kaptai. The fuel consumption for Energy Industries is given in Table-3.2. The CO_2 emission from this sector was 5750 Gg in 1994.

Manufacturing Industries and Construction

Fuel combustion in the manufacturing and construction industries contributes GHG emissions. These are manufacture of iron and steel as well as casting of iron and steel, manufacture of basic ferrous and non-ferrous metals, manufacture of basic chemicals, fertilizers and nitrogen compounds, pulp, paper, pharmaceuticals, food processing, beverage and tobacco and other chemical products. The fuel consumption for Manufacturing Industries and Construction is given in Table-3.2. The CO_2 emission from this sector was 3708 Gg in 1994.

Transport

The transport sector of Bangladesh comprises both domestic transport and international transport. Each of these sectors could be further subdivided into passenger transport and freight transport. The domestic passenger transport consists of individual transport such as cars, vans, light duty vehicles and motorcycles, while public transport comprises mainly buses and railways. Domestic freight movement depends mainly on road, rail and coastal shipping. The road freight transport fleet consists of trucks. International transport comprises both air and sea transport. Air transport handles nearly all of the passenger transport and a relatively small amount of freight. Sea transport on the other hand handles the bulk of the freight dealing with imports and exports. GHG emissions from mobile sources consist of the gaseous product of engine fuel combustion and evaporation and leaks from vehicles. The fuel consumptions in the transport sector are shown in Table 3.2 for domestic aviation, road transportation, railways and navigation. The CO_2 emission from this sector was 2537 Gg in 1994.

Domestic Aviation

Both public and private sector/organizations operate the local air transport, which includes both passenger, and freight transport. Octane and jet petrol is the main fuel for both passenger and freight transport. The CO_2 emission from this sector was 273 Gg in 1994.

Road Transportation

Total length of road in Bangladesh was 11662 km (approximately) of Bitumen surfaced road in 1994. Around only 20% comprise new imported vehicle and 80% imported reconditioned vehicle are active in the road. Diesel and petrol are the main fuels used for road transport in Bangladesh. Cars, vans and pick-up mainly consume petrol and buses and trucks consume diesel. The CO_2 emission from this sector was 1724 Gg in 1994.

Railways

Total length of railways tract in Bangladesh is 2706km including Broad and Meter gauge and most of it is limited to single line with meter gauge. The total length of meter gauge line is 1822 km and broad gauge line is 884 km (BBS, 1998). Diesel is the major fuel type used and a small amount of coal is also used for steam railways. The CO_2 emission from this sector was 131 Gg in 1994.

Navigation

Chittagong Port is the main marine port for navigation in Bangladesh and it handles most of international marine transport. Another port at Mongla also handles some coastal shipping, fishing boats and international marine transport. Ferry, steamer, launch and boat are also used for transport of passenger and goods inside the country. Diesel and fuel oil are the main fuel used in the navigation purposes. The CO_2 emission from this sector was 409 Gg in 1994.

International Bunkers

International Bunkers consists of International Marine Bunkers and International Aviation Bunkers. It should be noted that emissions of international bunkers are excluded from national totals and are reported for international purpose only (IPCC, 1996). In Bangladesh context both these data are not available.

Residential Sector

Natural gas is used everywhere with a big amount in the urban areas. Fuel wood and agricultural wastes are the traditional sources of energy used by the domestic sector of Bangladesh. These fuels, which are used as energy sources for cooking in many households, are derived from forests, tree crops, home gardens, scrubs and wasteland. However, with the introduction of LPG, it has become a popular fuel for cooking mainly in urban area where natural gas is not available. Today, the entirety of the LPG consumed is used for household cooking. Kerosene is another fuel used for lighting amongst rural households. Small quantities of kerosene and electricity are also used for cooking. Fuel consumption values in the residential sector are shown in Table-3.2. The CO_2 emission from this sector was 2013 Gg in 1994.

Agriculture/Forestry/Fishing Sector

Rice is the major food crop grown in Bangladesh. In addition to rice other seasonal crops like sugar, jute, tea, pulse, oil, spices, cereal, vegetable, etc. are also grown in Bangladesh. For irrigation, cultivation and harvesting purpose fuel is heavily used in this sector due to modernization of technology. The fuel consumption for Agriculture Sector is given in Table-3.2. The CO_2 emission from this sector was 991 Gg in 1994.

Commercial/Institutional Sector

The commercial sector consists of commercial organizations such as shops, markets, banks and hotels. Although natural gas is the main energy source in the commercial sector, coal and small quantities of biomass are also used. The fuel consumption for Commercial/Institutional Sector is shown in Table-3.2. The CO_2 emission from this sector was 176 Gg in 1994.

Biomass Burned for Energy

The major traditional fuel used in rural Bangladesh is comprising of cow dung, Jute stick, rice straw, rice hulls, bagasse, firewood, twigs, leaves and other wastes. As already mentioned, the largest share of traditional fuels burnt in Bangladesh that stay in equilibrium with regeneration and hence has not been considered for CO_2 emissions and used for reference only. The CO_2 emission from this sector was 58624 Gg in 1994.

Non-CO_2 from Fuel Combustion by Source Categories

Due to incomplete combustion of fossil fuel, non-CO_2 gases such as, methane, Nitrous oxide, Oxides of nitrogen, Non-methane volatile organic compounds are emitted into the atmosphere. For non-CO_2 gases, estimated emissions by applying emission factors to fuel statistics, which are organized by the sector. In reality, emissions of three gases depend on the fuel type used, combustion technology, operating conditions, control technology, and on maintenance and age of the equipment. Emissions of CH_4 and N_2O gases were estimated by using emission factors to fuel statistics from IPCC reference manual 1996, which have been shown in Annex A; Table-A.4 and Table-A.5. CH_4 emission from this source was 0.54 Gg and N_2O emission was 0.06Gg in 1994.

Fugitive emissions from fuel

Oil and Gas Activities

CH_4 is emitted from oil and natural gas production, transportation, refining, storage and leakage. Though the emission is primarily CH_4, some smaller quantities of other photo chemically important gases are also emitted. In this study, we have calculated only CH_4 emission by using the default emission factors of IPCC guidelines 1996.The default emission factors have been depicted in the Annex A; Table-A.6. CH_4 emission from this source was 0.086 Gg in 1994.

Summary of GHG emission in Energy Sector

The result of the CO_2 emission in energy sector as obtained from the calculation based on the secondary data has been shown in Table-3.3. From the table it can be seen that the energy industries contribute the highest proportion of the CO_2 emission in energy sector and Manufacturing industries and construction, Transport, Residential, Agriculture and Commercial sectors are also contribute subsequently. The contribution of CH_4 and N_2O emission from this sector is insignificant.

Table-3.3: GHGs Emission in 1994 in Energy Sector (Gg)

Sources and Sinks				CO_2 Emission	CH_4 Emission	N_2O Emission
ENERGY						
A	**Fuel Combustion Activities**					
	A1	**CO_2 Emission by main source categories**				
		a	Energy Industries	5750.98		
		b	Manufacturing Industries and Construction	3708.03		
		c	Transport	2538.12		
		d	Residential	2013.55		
		e	Agricultural/Forestry/Fishing	991.32		
		f	Commercial/Institutional	176.25		
		g	Traditional Biomass burn for Energy *	58624.63		
	A2	**Non-CO_2 from Fuel Combustion**			0.54	0.06
	A3	**Fugitive emissions from fuel**				
		a	Oil and Gas Activities		0.09	
TOTAL				15178.26	0.63	0.06

* *Traditional biomass burn for energy are not included in the national total.*

3.3 Industrial Processes Sector

Greenhouse gases emissions are produced from a variety of industrial activities, which are not related to energy. The main emission sources are industrial production processes, which chemically or physically transform materials. During the industrial processes many different greenhouse gases including CO_2, CH_4, N_2O may be released.

Methodology

The general methodology employed to estimate emissions associated with each industrial process involves the product of activity level data, e.g. amount of material produced or consumed, and an associated emission factor per unit of production.

Data Used

All the data on the Industrial production have been collected from Bangladesh Chemical Industries Corporation, Bangladesh Bureau of Statistics 1998 and Chatak Cement Co. Ltd. The collected data are presented in the Table-3.4. The default emission factors have been used from the IPCC guidelines 1996.

Results

In Bangladesh, the industrial processes produce CO_2 during the production of ammonia, iron and steel, limestone, dolomite, clinker and soda ash. The production data of these products the respective emission factors and estimated CO_2 emission have been shown in Table 3.4. The CO_2 emission from the industrial process sector is 1281.5 Gg.

It is found that the contribution is much small in the Industrial process compared to energy sector. The highest contribution in Industrial processes comes from ammonia production (1000.71Gg). Contribution of GHG from iron and steel, limestone, clinker, soda ash and dolomite production comes subsequently.

Table-3.4: GHGs Emission in 1994 in Industrial Processes Sector (Gg)

Sources and Sinks		Production (Mt)	Carbon Emission factors	CO_2 Emissions
	INDUSTRIAL PROCESSES			
A	**Mineral Products**			
a	Clinker Production	105818	0.5071	53.66
b	Limestone Production	145040	440	63.82
c	Dolomite Production	1188	477	0.57
d	Soda Ash Production and Use	6376	415	2.65
B	**Chemical Industry**			
a	Ammonia Production	667138	1.5	1000.71
C	**Metal Production**			
a	Iron and Steel Production	100041	1.6	160.07
TOTAL		1281.46		1281.46

Source: BBS(1998), IPCC (1996)

3.4 Agriculture Sector

Agricultural activities contribute directly to emission of greenhouse gases through a variety of processes. This part presents emission estimates for 4 types of agricultural activities: (1) livestock - Enteric Fermentation and Manure Management, (2) Rice cultivation – Flooded Rice Fields, (3) Field burning of agriculture residues and (4) Agricultural Soils. Methane (CH_4) is the most significant GHG emitted by agricultural activities. In addition to methane, agricultural residues are the sources of nitrous oxide (N_2O), carbon monoxide (CO) and nitrogen oxides (NOx).

Rice Cultivation

Cultivable land in Bangladesh amounts to approximately 8.50 million ha (67.5% of the total land area) of which 37% is single cropped. 50% double cropped, 13% triple-cropped. Due to double or triple cropping, the total cropped area amounts to about 13.0 million ha with a cropping intensity of 176%; since 1986-87, there has been a gradual increase in the cropping intensity from 150% to nearly 176% (GOB, 1996). At present, there are close to 15 million households in rural areas. Due to the population explosion, per capita land holding has been steadily declining as plots fragment in a continuing process cutting average farm size from 1.4 ha in the 1970s to 0.9 ha in the 1980s. That means that every person working in agriculture has only on average 0.06 ha of cropland.

In Bangladesh three major types of fertilizer: Urea, TSP and MP are used for rice production. About 90% of the gross cultivated area in Bangladesh is under rice cultivation grown in three seasons. The three crop growing seasons (Table-3.5) are identified as follows:

Table-3.5: Crop Growing Season

Season	Duration	Selected Crops
Kharif 1 or Pre-kharif	February-June	BL Aus,HYV Aus, BL Aman
Kharif 2 (full monsoon)	July-October	LT Aman, HYV Aman
Rabi (winter)	November-February	L Boro, HYV Boro, Wheat, Potato, Oilseeds etc.

note: *i) Applicable for the entire country.*
ii) BL: Broadcast Local, HYV: High Yielding Variety

Anaerobic decomposition of organic material in flooded rice fields produces Methane. However, not all of the methane that is produced is released into the atmosphere. As much as aerobic methanotrophic bacteria in the soils oxidize 60-90 percent of the produced methane.

Rationale for CH_4 emission rate adjustment from Flooded rice field:

- *Inundation due to monsoon/tidal flooding and irrigation varies with land type, soil texture and with space. Generally speaking, flooding during different paddy growing seasons is as follows:*
  Aus - 1-4 cm
  Aman - 4-6 cm (in northwest)
  8-10 cm (east)
  20-25 cm (south)
  Boro - 2-4 cm (by irrigation)
- *In case of Boro, flooding lasts for only few hours on the days of applying irrigation and in most cases alternate wetting and drying practice is followed.*
- *Upland rice fields are not flooded, and therefore are not subject to produce methane.*

- *In case of deep water, broadcast Aman (B. Aman) height of water column creates enormous pressure within the ecosystem resulting meager or no emission of CH_4.*
- *Local Aus is mostly grown under rain fed situation and there is virtually no inundation and as such no CH_4 emission.*
- *HYV Aus in the eastern region (coverage is more than 75% of the total) is almost rain fed as well. In the northwest it is mostly with intermittent irrigation. Flooding thus is insignificant in respect of submerges, depth and duration.*
- *In around of 50% of the total irrigated areas, soil is of medium to light textured type. Efficiency of irrigation is thus low resulting meager possibility of standing water or inundation situation. This means CH_4 emission is lower than expected.*
- *Recent development of HYV rice, which is suitable for late transplanting, has been widely accepted and cultivation of those varieties now covers over 30% of the total Aman Area. Thus the period of inundation and CH_4 emission is low.*
- *Organic matter contents of over 70% of Bangladesh soil is bellow critical level (1.5%). Decomposition of organic matter is thus slow. These situations though unfavorable for soil health but are favorable in respect of CH_4 emission. Massive infrastructure development like roads, embankment etc. has created hindrance age in water flow and thus water level in the so-called low lands has lowered much compared to earlier years. This reality is against the general assumption of CH_4 emission from lowlands.*
- *In Bangladesh, croplands are intensively used round the years and there is hardly any practice of organic amendment or even organic recycling through green manures crops. Even the plant residues, are taken out or fed to cattle/burned as fuel. As such, this correction is not applicable in our case.*
- *With about 41 percent of the net-cropped area under irrigation, crop production in Bangladesh is predominantly monsoon dependent or carried out under rain fed conditions. Of the total rain fed area about 3 million ha is estimated to be prone to severe drought. The entire Barind and Madhupur Tracts constituting about 12 percent of the total arable area are characterized by shallow land profiles having low moisture holding capacity and heavy sub-surface clay. Crop production in these areas and all the four Gangetic flood plains is mainly dependent on rainfall and on the inundation from the Ganges River and tributaries. For the entire Ganges belt including the Barind and Madhupur Tracts however no crop cultivation or rain fed farming practices specially suited to the prevailing soil and agro-climate conditions have been developed yet (Mahtab and Karim, 1991).*

Methodology

Based on the rationale, described necessary adjustment in defining water management regime seasonally integrated emission factor scaling factor and emission of CH_4 has been done and used for calculation of CH_4 emission from flooded rice. Keeping USCSP, ALGAS findings in mind, the country's circumstances were evaluated and based on rationale framed and following IPCC guidelines, appropriate adjustment made to fit country context. Agricultural cycle, input use and their management etc. all were taken into account and scientific judgment made to get the country specific values. For example, IPCC default value of scaling factor for continuous flooded is 1 and, here also the same value used. But, as, in our case, irrigation is "alternate wetting and dry" – a value of 0.3 for multiple aeration which is in between continuous flooded default value of 1 and multiple aeration default value of 0.2 of IPCC guideline has been assigned.

Emissions of methane from the rice fields were estimated from the annual harvested area under different water regime multiplied by the factors. It is well assumed that about 95% of all irrigated areas are intermittently flooded and the remaining irrigated areas are continuously flooded (ALGAS, 1998). For the deep-water rice variety (non-irrigated broadcast local aman), it is assumed that is 50% of the areas, the water column is less than 100 cm deep and in the rest, 50% about 300 cm or more. We readjusted the default values because of he uniqueness of the situation, since; emission is inversely proportional to height of water column. The remaining rice cultivated areas are considered as drought prone. Because of intensive use of land, multiple aerations is predominant in rice cropping and the single aeration is virtually assent. Scaling factor for rice cultivation have been taken from the IPCC guideline and readjusted. The default seasonally integrated emission (SIE) factor for various types of rice cropping is taken from the IPCC guideline, 10 (5-15) as the basis and then re-fixed for the reasons stated earlier. In this study SIE factor 10 used for water depth less then 100 cm, and 5 for water depth greater then 100 cm and 15 was used for the remaining.

Data Used

Area of rice production for the year 1994 (BBS 1998) is presented in Table-3.6. For Bangladesh, no emission factors for rice is available, as no in-situ measurement done as yet. As a result, the emission parameters (scaling factors for methane emission and seasonally integrated emission factor) have been re-fixed with country's context and through expert judgement. In deciding the scaling factor for methane emission and seasonally integrated emission IPCC guidelines along with country's context and expert judgment were used. Since, in Bangladesh there is virtually no organic amendment, this factor is considered to be 1. The re-fixed emission factors have been given in Table-3.7.

Table-3.6: Cropping type and area in 1994

(Area in '000' ha)

Year/ Crop Type	L Aus	HYV Aus	BL Aman	L Aman	HYV Aman	L Boro	HYV Boro	Total
1994	1248.20	401.20	907.10	2606.10	2330.00	245.60	2337.20	10073 .50

Source: BBS 1998

The emission is then estimated using the formulae:

$$E = H_A \times S_f \times C_f \times SIE_f$$

Where, H_A - *Harvested area*
S_f - *Scaling factor*
C_f - *Correction factor*
SIE_f - *Seasonally integrated emission factor*

Emissions in Rice Cultivation

The result of the estimation of CH_4 emission from this sector is presented in Table-3.7. The results of the analysis show that CH_4 emission due to rice cultivation was 662.23 Gg in 1994. Much of it is due to intermittently flooded and rain-fed (flood and drought prone) rice cultivation contributing about 108.70 Gg and 488.66 Gg respectively for 1994. Remaining gas is emitted from irrigated continuously and deep-water rice fields.

Table 3.7: Harvested Areas and adjusted IPCC default factors

Water management regime			Harvested areas (H_A) '000 ha	Scaling Factor (S_i)	Correction Factor for Organic Amendment (C_i)	Seasonally Integrated Emission Factor (SIE_i) (g/m²)	Total Methane Emission/Gg
Irrigated	Continuous Flooded		100.735	1.0	1	15	15.11
	Single Aeration:			-	-	-	-
	Intermittently Flooded:	Multiple Aeration	2415.620	0.3	1	15	108.70
Rain fed	Flood Prone		1511.020	1.0	1	15	226.65
	Drought Prone		3493.490	0.4	1	15	262.01
Deep water	Water depth 50-100cm		452.300	0.8	1	10	36.18
	>100 cm		452.300	0.6	1	5	13.57
Total							662.23

Notes: Scaling factors and seasonally integrated emission factors are not measured for our case. Rationale cited used for readjustment of default factors provided by IPCC and used for calculation of CH_4 emission.

Livestock

Enteric Fermentation

Methane is produced from enteric fermentation in herbivores as a by-product of the digestive process by which carbohydrates are broken down by microorganism into simple molecules for absorption into the blood stream. Both ruminant animals (e.g., cattle, sheep) and non-ruminant animals (e.g., pigs, horses) produce methane although ruminants are the largest source. The amount of methane production by an individual animal depends upon the type, age and body weight and on the amount and type of feed it consumes.

Bangladesh Context: Rationale in Fixing Enteric Fermentation

Since no country specific data is available, hence the IPCC guidelines 1996, especially the default figures for Asia/Indian sub-continent was taken into account. Further, professionals in this line were consulted and knowledgeable judgment made in fixing the rationale for emission criteria for livestock's Enteric Fermentation and manure management. Body weight of the animal, feed consumption, digestibility and milking are the prime factors influencing emission. For example, in our case the improved dairy cattle has a body weight of 300-450 kg only against the Indian's (which is almost double). Milk production is only 200-350 kg compared to the Indians 900 kg. As such, we assigned 30, while the IPCC guidelines give a value of 46 for Indian sub-content.

Rationales are:

- *Improved breeds are insignificant in number compared to local breeds.*
- *In Bangladesh, both dairy & non-dairy female cattle & buffaloes are used both for milking & draft power. Consumption of feed is also very low.*
- *Average body weight of cattle & buffaloes are also low compared to even the Indian sub-continent. In case of cattle, weight is 200-250 kg for local breeds and 300 – 450 kg for improved breeds.*
- *Milk production, because of low body weight & feed consumption ranges between 200-350 kg which is even only 1/4th that of the Indian subcontinent. (Ref: IPCC guidelines 1996).*
- *Feed digestibility of bovines ranges between 40-50% .*

Based on the rationale, the country's emission factors has been re-fixed & used in our calculation that is presented in the Table-3.8. As obvious, for each type of animal, the emission factor varied and as such, different values by types were first obtained in order to reach the country estimate.

Table-3.8: Livestock population, methane emission factors for enteric fermentation

Livestock type	Population (Million)	Methane Emission factor for Enteric Fermentation (kg/head/yr)	Total Emission (Gg)
Local Dairy Cattle	3.70	15	54.90
Improved Dairy Cattle	0.44	30	14.70
Local Non Dairy Cattle	17.00	12	201.96
Improved Non Dairy Cattle	2.06	20	40.80
Buffalo	0.78	25	18.75
Sheep	1.04	3	3.0
Goat	29.75	3	82.47
Local Poultry	103.32	Not estimated	-
Improved Poultry	25.83	Not estimated	-
Total			**416.58**

Manure Management

When animal manure decomposes in an anaerobic environment, decomposition of the organic material in the manure produces methane. These conditions often occur when a large number of animals are managed in a confined area, which however, is not the case in Bangladesh, since, our dairy farms are small in number and also number of animal heads are not to large.

Bangladesh Context: Rationale in Fixing Manure Management

Since no country specific data is available, consultation of the IPCC guidelines 1996, especially the default figures for Asia/Indian sub-continent was taken into account. Further, professionals in this line were consulted and knowledgeable judgment made in re-fixing the rationale for emission criteria for livestock's enteric fermentation.

Rationales are:

- *Climatically, Bangladesh can be termed as a sub-tropical to tropical humid country. Mean annual temperature varies between 11-29°C during winter and 21-34°C in summer. The temperature has certain bearing on the decomposition of manure and thus on the emissions of CH_4.*
- *Average body weight of cattle & buffaloes are also low. In case of cattle, weight is 200-250 kg for local breeds and 300 – 450 kg for improved breeds.*
- *Feed digestibility of bovines ranges between 40-50%.*
- *Local cattle produces 10-15 kg excreta per day while improved ones leaves 15-20 kg excreta. Total gas production is 1.3 cft / kg excreta of which CH_4 is only 30-50%. The value is little higher for buffalo and 15-20% less for sheep & goats.*
- *In Bangladesh, only 15-20% poultry, birds are of improved breeds whose excreta is collected and subjected to CH_4 emission. However, as optimum production of CH_4 occurs at 37°C and*

below 10°C as such emission of CH_4 from the improved breeds is negligible. Local poultry birds which comprises 80% of the total birds population leaves on scavenging and are not confined in a particular place. As such the excreta, is scattered, exposed to sunlight, gets dried and thus scope for fermentation and subsequent CH_4 emission is too negligible.

Based on the rationale, the country's emission factors has been adjusted and used in our calculation this is presented in the Table-3.9

Table-3.9: Livestock population, methane emission factors for manure management

Livestock type	Population (Million)	Methane Emissions factor for Manure Management (kg/head/yr)	Total emission (Gg)
Local Dairy Cattle	3.70	2.000	7.32
Improved Dairy Cattle	0.44	3.000	1.47
Local Non Dairy Cattle	17.00	1.500	25.25
Improved Non Dairy Cattle	2.06	2.000	4.08
Buffalo	0.78	3.500	2.63
Sheep	1.04	0.100	0.10
Goat	29.75	0.100	2.75
Local Poultry	103.32	0.003	0.29
Improved Poultry	25.83	0.015	0.36
Total			44.24

***Source:** Livestock population of 1994 obtained from the Department of Livestock Services.*

Methodology

Although the methodological issues are very complex, a simplified methodology has been used as per IPCC guidelines for national GHG inventories: workbook *(IPCC 1996)*. Emissions are calculated by applying an emission factor to the number of animals, of each livestock type in the country to produce a total for enteric fermentation. Keeping in mind the IPCC default values and considering the rationale specifically body weight, digestibility. excreta release and temperature regime etc. readjustment were done. The same basic methodology was used to estimate emissions from manure management. Simple multiplication of populations by emission factors produces emission estimates as shown below.

$$\text{Emission} = N_A \times E_f$$

Where, N_A = Number of Animal
E_f = Emission factor

E_f for enteric fermentation and manure management has been given in Table-3.8 and Table-3.9.

Data Used

All the data on the livestock were collected from the Department of Livestock Services. The emission factor per animal head in Bangladesh would be much lower than the world/Asia/Indian Sub-Continent because of the rationales stated above. For example, excreta produced by the bovines are almost one third to that of the Indian sub-continent because of the reasons stated earlier. Further, in most cases excreta are left in the field; which is subjected get dried. As such emission is much lower.

Summary Results of Livestock

The results of the above analysis have been given in Table-3.8 and Table 3.9 CH_4 emission from Livestock sub-sector in Bangladesh is 460.82 Gg of which contribution due to enteric fermentation is 416.58 Gg and manure management 44.24 Gg.

N_2O Emission from Animal Production

Regarding N_2O emission through animal waste management systems, none of the factors provided by IPCC guideline 1996 is applicable in Bangladesh context. No solid storage and dry lots or liquids system and daily spread are practiced. Vary few anaerobic lagoons are in existence and their volume is insignificant to bring into N_2O emission estimates. Considering the reasons stated above, estimation of this sub-module is not made.

Burning of Crop Residues

Large quantities of crop residues are produced from farming systems. Burning of crop residues in the fields was earlier common agricultural practice but since mid 1980's because of rural energy crisis and scarcity of fodder this has drastically been reduced. Further in Bangladesh some crop residues are used for making the thatched house in rural areas. Field burning of crop residues is not treated as a net source of CO_2 because it is assumed that carbon released to the atmosphere is reabsorbed during the next growing seasons. However, crop residue burning though not significant source of emissions of CH_4, CO, N_2O & NO_x in Bangladesh context, calculation is done based on field experience.

Methodology

In the first step, the annual production data of major crops are collected and then multiplied by the residue to crop ratio to get the total amount of residue. The quantity of residue was then multiplied by the dry matter fraction to estimate the quantity of dry residue. Using the IPCC guidelines, through step-by-step by appropriate factors multiplication eventually, the amount of emissions from burning of agriculture residue is obtained from the Table-3.10.

Data Used

Annual crop production statistics of the crops were obtained from the Handbook of Agricultural Statistics *(BBS, 2001)*. In determining crop specific data on ratio of residue to crop production, dry matter fraction of residue burnt, fraction oxidized and Carbon and Nitrogen contents of residue, emission rating etc. revised IPCC guidelines were the basis; while to fit into the country's context and Inventory of US Greenhouse Gas Emission and sinks guide line, opinion of the experts in this line (Ref. Table 3.10) were used to re-adjust the values. This has been explained in the rational.

- *Paddy grown in Bangladesh is mostly dwarf in nature and negligible portion are left in the field as residue.*
- *Yield of wheat, maize, pulses, oilseeds, etc. are low in Bangladesh. Yield of sugarcane is almost half compared to countries like Mauritius. Much of the crop residue of maize, sugarcane, and jute are taken back for domestic purposes.*
- *Because of the reasons stated in 1 and 2, dry matter fraction has been taken, average of IPCC values.*
- *Fraction oxidized value provided in IPCC guideline was followed.*

Based on the yield of crop, temperature regime etc. of the case carbon fraction and N:C were fore re-adjustment re-fixed taking into account the values provided in the IPCC and guidelines. The values of emission ration provided in the IPCC were used in the calculated.

Table-3.10: Selected Crop Residue Statistics

Crops	1994 Production (Gg)	Residue to crop ratio	Dry matter fraction	Fraction burned in fields	Fraction oxidized	Carbon fraction of residue	Nitrogen carbon ratio		Emission ratio	Total emission
Rice	18041.600	1.0	0.83	0.10	0.9	0.4144	0.0140			
Wheat	1131.000	1.0	0.83	0.05	0.9	0.4853	0.0040	CH_4	0.005	4.67
Barley	6.200	1.1	0.82	0.02	0.9	0.4567	0.0060			
Maize	3.000	1.2	0.40	0.10	0.9	0.4709	0.0081	N_2O	0.007	0.0931
Sugarcane	7110.700	0.8	0.85	0.05	0.9	0.4695	0.0030			
Pulses	530.100	1.0	0.65	0.02	0.9	0.4500	0.0230			
Potatoes	1865.000	0.5	0.50	0.05	0.9	0.4226	0.0110			
Jute	799.488	1.5	0.50	0.02	0.9	0.4226	0.0110			
Oilseeds	480.000	1.5	0.70	0.02	0.9	0.4226	0.0110			

Source: BBS 1998

Emission from Field Burning of Crop Residue

The results of the analysis have been given in the Table-3.10. Though the major crop in Bangladesh is rice, estimation of non-CO_2 gas emission has been done for field burning of all major crops. The estimated amount of CH_4 and N_2O released due to field burning of biomass was about 701.31 Gg of carbon and 8.462 Gg Nitrogen in 1994. The emission of CH_4 and N_2O from field burning of Agriculture residues in 1994 was 4.675Gg and 0.0931 Gg respectively.

Agricultural Soils

Nitrous oxide is produced naturally in soils through the microbial processes of de-nitrification and nitrification. A number of anthropogenic activities add nitrogen to soils; thereby increasing the amount of nitrogen available for nitrification and de-nitrification and ultimately the amount of N_2O is emitted. N_2O is calculated as 45% of the total fertilizer consumption. Various agricultural soil management practices contribute to greenhouse gas emissions. The use of synthetic fertilizers and organic manures add nitrogen to soils, thereby increasing natural emissions of nitrous oxide. Total consumption of Synthetic fertilizer (urea and Di Ammonium Phosphate as these two emit N_2O) has been taken from the Handbook of Agricultural Statistical BBS, 2001. The emission factor has been shown in Table-3.11. For direct emission a emission factor of 0.0125 and for Soil a emission factor of 5 were taken, followed the IPCC guideline 1996. Area of cultivated organic soils is virtually absent and knowledgeable assumption made though.

Table-3.11: Fertilizer consumption and emission factors

Type of N input to soil	Consumption of fertilizer (m. ton)	Emission factor for direct emission	Area of cultivated Organic soils (ha)	Emission Factor for direct soil	Total Emission (Gg)
		Emission (kg N_2O-N/kg N)		Emission (kg N_2O-N/ha/yr)	
Synthetic fertilizer	1607630	0.0125	2000	5	14.23

Source: IPCC 1996, BBS 1998

Emission from Agricultural Soils

The result of emission from the agricultural soil has been given in Table 3.11. In 1994, total direct emissions of N_2O from this source were 14.23 Gg. Total emission from agriculture sector may also be find in the Table 3-12.

Table-3.12: GHGs Emission in 1994-in Agriculture Sector (Gg)

Sources and Sinks			CH_4 Emissions	N_2O Emissions
AGRICULTURE				
A	Livestock			
	a	Enteric Fermentation	416.58	
	b	Manure Management	44.24	
B	Rice Cultivation		662.23	
C	Field Burning of Agricultural Residues		4.68	0.09
D	Agricultural Soils			14.23
TOTAL			1129.08	14.32

3.5 Land Use Change and Forestry Sector

The forest area comprises about 17% of the total area of Bangladesh. Of this Forest Department manages about 10% and off-forest land covered by trees is about 7 percent.

There are three major forest types of natural vegetation in Bangladesh. These are semi-evergreen forests occurring on the eastern hills (Hill forest), deciduous sal (*Shorea robusta*) forests on the central and northwestern terraces and the mangroves littoral forests facing the Bay of the Bengal. Additionally, there are human raised village forests all over the country covering an area of 1.87%, but highly productive. Besides, fresh water swamp forest occurs in low-lying areas of Sylhet and also in depression within semi-evergreen forests. Forestry Master Plan (FMP, 1992), has given details about the status of forest resources in Bangladesh.

Forests are complex ecosystems with several interrelated components, each of which acts as a carbon storage pool, including.

- Trees (i.e., living trees, standing dead trees, roots, stems, branches and foliage)
- Soil
- The forest floor (i.e., woody debris and tree litter) and
- Under story vegetation (i.e., shrubs and bushes).

As a result of biological processes and anthropogenic activities, carbon is continuously cycled through these ecosystem components, as well as between the forest ecosystem and the atmosphere. For example, the growth of trees results in the uptake of carbon from the atmosphere and storage in living trees.

Estimation of GHG Emissions

The calculations of emission from Land-use change & Forestry focus upon mainly three activities, which are sources or sinks of carbon dioxide. The most important land-use changes & management practices that result in CO_2 emissions & uptake are:

- Changes in forest & other woody biomass stocks
- Forest & grassland conversion
- Abandonment of managed lands

In the present study we have used only changes in forest & other woody biomass stocks sub-sector. Data on forest clearing, on and off site burning, biomass decay and abandonment of forestland were not available. Carbon uptake by soil data was also not available. Due to the non-availability of data the sub-sectors (Forest & grassland conversion and abandonment of managed lands) have not been considered in this study. IPCC default values for annual growth of different forest categories have been applied with some adjustment made through expert judgment considering Bangladesh condition. It must be pointed out that there are inherently large uncertainties associated with these calculations (IPCC 1996).

Changes in Forest and Other Woody Biomass Stocks

Methodology

To calculate the carton uptake, the following expression is used.

Carbon uptake = AF x AG x CFD

Where,

AF	=	Area of forest
AG	=	Annual growth
CFD	=	Carbon faction of dry matter.

Data Used

The Forestry Master Plan *(FMP, 1992)* has provided the forest area of 1991 according to forest types (Table 3.13). The GHG estimation is carried out for the year 1994 for which there is no countrywide data on forest area. The year-wise afforestation data from 1992 to 1994 were added with and the deforestation data were subtracted from the forest area of 1991 to obtain the area for 1994. The year-wise afforested areas from 1992-1994 may be seen in Table 3.14. The deforestation has mainly been occurring over the Hill forest and the rate of deforestation is 8000 ha per year. The denuded and encroached forests were not considered for emission estimation. The shrubs were also not considered for the estimation, as those do not have woody biomass. The water area in the mangrove forests has also been excluded.

The information of annual growth as provided by IPCC guidelines and suited for the Bangladesh conditions were used in to estimate the CO_2 uptake. Some adjustments of annual growth were made based on plant density. The weighted average growth rates for each forest types have also been shown in Table 3.15.

To calculate carbon released, the following expression has been used.

Carbon Released = CH x BCR x CFD

Where,

CH	=	Commercial harvest
BCR	=	Biomass conversation/ expansion ratio
CFD	=	Carbon fraction of dry matter

Table-3.13: The Forest Area (ha) and annual growth (Tones/ha/yr) of Bangladesh by Type for 1991

Forest type	Natural Forest medium to good density	Natural forest poor density	Scattered Trees and Denuded	Mainly bamboo	Plantation Including Failed Plantation	Jhum and Encroach-Ment	Unproductive Including Blanks	Parks and sanctuary	Water/ Swamp/ Agri.	Other including USF	Total
Hill forest	85816 (6.8)	52359 (3.4)	57593 (1)	71196 (15)	197714 -50% (8)	70793 (0)	11779 (0)	64237 (6.8)	31980 (0)	718652 (1)	1361670
Sal forest	0 (0)	27531 (3.4)	23461 (1)	0 (0)	19875 -10% (14.5)	26684 (0)	6224 (0)	13510 (6.8)	0 (0)	0 (0)	117282
Mangrove forest	374899 (6.8)	0 (0)	0 (0)	0 (0)	112966 -10% (14.5)	0 (0)	0 (0)	32426 (6.8)	170000 (0)	67820 (1)	758111
Total											2241793

Source: Forestry Master Plan 1992.
Note: The figure shown in parenthesis indicates the growth rate. Figures shown as % indicates failed plantation

Table 3.14: Year wise Area of Afforestration from 1992 to 1994 (Acre)

Year	Hill Forest	Sal Forest	Mangrove Forest
1992	8965	8418	8810
1993	13895	12479	10887
1994	20690	14564	12328

1 acre=0.4047 ha
Source: Bangladesh Forest Department (BFD) has provided Data

Table-3.15: Estimated Forest area and annual growth for the year 1994).

Forest	Area of forest (Kha)	Annual Growth Rate (t dm/ha)
Mangrove forest	589.74	7.91
Hill forest	1141.79	4.17
Sal forest	99.91	7.26
Village forest	270	8

The consumption of round wood, fuel wood and bamboo are given in FMP 1992. Commercial harvest like round wood and fuel wood are given in thousand cubic meters. The data for bamboo is given as number of trees. The data of round wood belongs to 1991, and those of fuel wood and bamboo are the projected data of 1993.The per capita consumption was then computed and the consumptions were adjusted for 1994 based on population. Estimated commercial harvest has been given in Table-3.16. For bamboo, to convert the number of bamboo into the thousand cubic meter a bamboo is assumed to have an average height of 5.5 meters, outer and inner diameter are 10 cm and 6.3 cm. Average volume becomes 0.02766 m^3 (USCSP 1996).

The biomass conversation ratio is 0.5 tdm/m^3 and Carbon fraction of dry matter is 0.5 according to IPCC default values. The carbon released has been calculated using the above formula.

The net annual carbon released is obtained by subtraction of carbon uptake from carbon release. If the figure is positive then this counts as a removal of CO_2, and if the figure is negative, it counts as an emission. Finally, the net carbon emission/uptake is expressed as CO_2.

Table-3.16: Estimated commercial harvest for the year 1994.

Harvest Categories	Commercial Harvest (000 m³ round wood)
Round wood	4771.53
Fuel wood	8426.53
Bamboo	19975.36

GHG emission in Land use change and Forestry Sector

The results of the GHG inventory in this sector have been given in Table-3.17. In 1994, total carbon uptake was 6155.73 Gg and carbon released was 8293.36 Gg. From here it can be seen that there is a net Carbon emission of 2137.62 Gg, which is equivalent to 7837.97 Gg of CO_2 emissions.

Table 3.17: Emission from Changes in Forest and other Woody Biomass Stocks

Carbon Source/Sink	Gg
Total carbon uptake	6155.73
Total carbon released	8293.36
Net carbon released	2137.63
Net CO_2 Released	**7837.97**

3.6 Waste Sector

Waste is generated mainly as domestic and industrial activities. Domestic waste also known as municipal waste includes any waste generated domestically. These wastes are disposed from their point of origin.

Solid Waste Disposal on Land

Anaerobic decomposition of organic material in landfills such as, household garbage, garden waste, food waste, kitchen waste and paper waste, market waste can result in emissions of methane, carbon dioxide, and other greenhouse and photo-chemically important gases. This decomposition process is a natural mechanism through which, methane-producing bacteria convert the fermentation products into organic materials and biomass consisting of approximately 50 percent carbon dioxide and 50 percent methane by volume. The percentage carbon dioxide in the biogas released from a landfill may be smaller because some CO_2 dissolves in landfill water.

Municipal and Industrial Waste Water Disposal

Methane emission from wastewater stream with high contents of organic material including domestic, commercial and industrial wastewater can emit significant amount of methane in absence of Oxygen. Since most of the wastewaters are discharged into the canal and river hence methane emission from this river stream is nil or little due to presence of oxygen. Hence methane emission from all types of wastewater is ignored. Most of the industrial plant and cities domestic sewage are disposed to septic tank, which is connected with soak pit. But the statistics and data are not available for calculation of methane emission.

Data Used

The actual solid waste generation cannot be determined since no proper records have been maintained. Data on municipal solid waste (MSW) generation and percentage of MSW disposed to SWDs are collected from Dhaka City Corporation only and other three City corporations Khulna, Chittagong, and Rajshahi data are not available. However generation of waste estimated on the basis of the population in these four City Corporations.

Methodology

To calculate methane emission the following expression is used.

Methane Generation = A x B x C x D x E x F

Where,

A	=	MSW disposed to SWDSs
B	=	Methane correction factor
C	=	Fraction of DOC in MSW
D	=	Fraction of DOC which actually degrades
E	=	Fraction of C as methane
F	=	Conversion ratio from C to methane

Here, multiplying population of four City Corporations and generation of waste 0.5 kg per person per day calculate solid waste generation. Methane correction factor of 0.4 have used. Fraction of DOC in MSW used is 0.09, fraction of DOC actually degrade used is 0.77, fraction of C as methane used is 0.5 and the value of conversion ratio from C to methane used is 1.33. Default factors of methane from waste sector are shown in Table 3.18. And finally on the basis of the above and using IPCC guideline total net annual methane emission has been calculated.

Daily production of Municipal Solid Waste (MSW) are determined based on survey and estimation of municipal solid waste expressed as kg MSW / person / day. Based on the estimate made the daily MSW generation is 0.5 kg per person.

Table 3.18: Disposal of waste (Gg) and CH_4 Emissions in Waste Sector (Gg)

Methane Correction factor	Fraction of DOC in MSW	Fraction of DOC which actually degrades	Fraction of C as Methane	Total Annual MSW Disposed To SWDSs [Gg MSW]
0.40	0.09	0.77	0.50	3381.696

GHG emission in Waste Sector

The results of the Methane emission from the waste sector have been given in Table-3.18. In 1994 the estimated methane emissions from landfills was 62.49 Gg. At present methane is not recovered from Municipal Land Fill Site for use as an energy source.

Summary result of the National GHG inventory reference to 1994

The national GHG inventory for the year 1994 is given in Table 3.19. From the table it is seen that in Bangladesh energy sector is the largest contributor of CO_2 emission 15178.25 Gg (62.47%) followed by land use changes and forestry sector 7837.97 Gg (32.26%) and industrial process 1281.48 Gg (5.27%). CH_4 emission from agriculture sector is about 1128 Gg contributing about 95% of total methane emission of the country. Methane emission from municipal solid waste in waste sector is 62.49 Gg and emission of N_2O from the agriculture sector due to use of fertilizer is 14.32 Gg. Some insignificant amount of CH_4 and NO_2 are also emitted from energy sector.

Table-3.19: Summery of GHGs Emission in 1994 (Gg)

Greenhouse gas Source and Sink Categories	CO_2	CH_4	N_2O
Total (Net) National Emission	24297.63	1190.85	14.38
1. All Energy	**15178.25**	**0.63**	**0.06**
Fuel combustion			
Energy and transformation industries	5750.98		X
Industry	3708.03		
Transport	2538.12		
Residential	2013.55		
Commercial-institutional	176.25		
Other (Agriculture/forestry/fishing, Non CO_2 from fuel combustion)	991.32	0.54	0.06
Biomass burnt for energy*	58624.63		
Fugitive Fuel Emission			
Oil and natural gas systems		0.09	
Coal mining		X	
2. Industrial Processes	**1281.48**		**X**
3. Agriculture		**1127.73**	**14.32**
Rice Cultivation		662.23	
Enteric Fermentation		416.58	
Savanna Burning		X	
Others (Manure management and field burning of agriculture residues)		48.92	14.32
4. Land Use Change and Forestry	**7837.97**		
Changes in Forest and other woody bio-mass stock	7837.97		
Forest and Grassland Conversion **	X		
Abandonment of Managed Lands **	X		
5. Other Sources (Waste)	X	**62.49**	X

* *Traditional biomass such as crop residues burnt for energy are not included in the national total.*

** *Abandonment of managed land and grassland conversion of land use change and forestry sectors are not considered because appropriate data were not available.*

x *Not estimated.*

4 VULNERABILITY AND ADAPTATION TO CLIMATE CHANGE

4.1 Introduction

The low-lying topography, funnel shaped Bay of Bengal to the south exposing the land to the fury of cyclones and storm surges, seasonal flooding, widespread poverty, large population base and dependence of people at large on primary economic activities have made Bangladesh vulnerable to climate change. Vulnerability and Adaptation (V&A) Assessment for Bangladesh have been performed through the following stages :

i) *Generation/Selection of climate change scenarios for Bangladesh*
ii) *Impact assessment on the basis of climate change scenarios*
iii) *Identification of the adaptation measures*

Sectors covered in the assessment are as under :

- *Three major river basins: Ganges, Brahmaputra and Meghna.*
- *Freshwater resources.*
- *Coastal zone, coastal resources and coral reefs*
- *Agriculture and food security*
- *Forests, bio-diversity and ecosystems*
- *Fisheries and marine resources*
- *Human health*
- *Socio-economic impact.*

Although other relevant sectors issues not specifically covered but important to Bangladesh context are: ecosystem management, transportation infrastructure, de-stabilization of marine resources, cross boundary issues, adaptive capacity and implications of adaptation strategies for equity and for social justice.

4.2 Climate Change Scenarios and Probable Other Changes in Bangladesh by 2030 and 2050

4.2.1 Climate Change Scenarios

The climate change scenarios and potential effects of climate change on Bangladesh during period up to 2050 are presented in Table 4.1. Most development projects of Bangladesh have a planning horizon of 30 years or less, while a few have a planning horizon of 50 years or slightly more. The climate change impact studies in this communication have been mainly based on the climate change scenarios developed for 2030 and 2050 as reported by a study carried out by the World Bank in 2000.

Table 4.1: Climate change scenarios for Bangladesh by 2030 and 2050

Year	Sea Level Rise (cm)	Temperature Increase (°C)	Precipitation Fluctuation Compared to 1990 (%)	Changes in Evaporation
2030	30	+0.7 in monsoon +1.3 in winter	-3 in winter +11 in monsoon	+0.9 in winter +15.8 in monsoon
2050	50	+1.1 in monsoon +1.8 in winter	-37 in winter +28 in monsoon	0 in winter 16.7 in monsoon

Source: World Bank 2000

According to the above scenarios, the magnitude of these changes in climate may appear to be very small. But, if added to existing climatic events (such as floods, droughts, and cyclones), these could substantially increase the magnitude of these events and decrease their return period. For example, a

10 percent increase in precipitation may increase runoff depth by one-fifth and the probability of an extreme wet year by 700 percent. Thus, within the planning horizon for development activities, it is quite possible that there could be a significant increase in the intensity and frequency of extreme climate events in Bangladesh *(WB 2000)*.

4.2.2 Sea Level Rise and Subsidence

Sea level rise will have disastrous consequences for Bangladesh. The people living in coastal villages and islands of Bangladesh form about 20 percent of the country's population are among the most vulnerable to sea level rise. The possible physical effects from sea level rise pose such threats to Bangladesh as damages to coastal infrastructure that could reach as much as 12 percent of GDP by the year 2010; increased incidence of disease; degradation of ecosystem; changes in cropping patterns and other agricultural activities, which could result in drop rice production by as much as 10 percent. It is estimated that due to the predicted rise in sea levels, the 65 percent of the population who are currently vulnerable to floods, may increase to more than 90 percent with about 5 million people being severely affected by the inundation.

Geologically, Bangladesh is located in an active sedimentary basin known as the Bengal Basin. The Eastern Himalayan Rivers (for example, the Ganges, the Brahmaputra and the Meghna) carry a large amount of sediments, a substantial part of which is deposited each year on the riverbeds and on the floodplains.

It is believed that a part of the sediment load is also deposited on the shallow continental shelf of the basin. In addition, the basin is undergoing subsidence that may be attributed to the following two major factors: one is related to the isocratic adjustment of the crust (sediment load and rise of Himalayas); the other is related to de-watering and compaction of shale and mud of Proto-Bengal Fan (Alam, 1989). However, there is not enough evidence in favour of the latter factor. Tectonic subsidence usually occurs over a large extent of area, in a uniform manner and at a very slow rate. These areas are generally bound by active faults or hinge zones. Although the entire Bengal Basin is subsiding slowly, more rapid subsidence has been taking place in the Bengal Foredeep, particularly in the Sylhet Trough, Faridpur Trough and Hatiya Trough.

In the context of Bangladesh, hence, sea level rise would result in, among other impacts,

- Inundation of low-lying coastal areas
- Retreat of shoreline
- Intrusion of saline water further inland and into ground water
- Increase of wave height
- Uncertainly in existing distribution pattern of aquatic and marine resource.

The study by Khan et. al. (1999) has shown that the mean tidal level at Hiron Point in the west coast of Bangladesh has been rising at the rate 4 mm/per year during the last two decades (1977-1998). The rise of mean tidal levels at the Meghna estuary (Char Chenga) and at Cox's Bazar are 6.0 and 7.8 mm per year respectively. This rise may be due to thermal expansion of the sea, geological subsidence and other reasons like intensification of monsoon winds and higher runoff from the landside. This shows that the relative sea level rise in Bangladesh coast is highly prominent, however, since the data length is short, it might not reflect the exact nature of the long-term change of mean sea level. It may be mentioned here that the average sea level rise for Indian coast (continuous with Bangladesh coast) has been reported as 2.5 mm/year since the 1950s (climate change in India 2001, http://www.ccasia.teri.res.in/country /india/india.htm).

According to the IPCC (2001, Technical Summary of the Working Group-II Report) with no adaptation a 45-cm rise in mean sea level will lead to a potential loss of 15,668 km^2 area (10.9%) of the country exposing about 5.5 million people (5%) of the country, assuming no adaptation. A 100 cm rise could cause loss of 29,846 km^2 (20.7%) of land exposing 14.8 million (13.5%) people of Bangladesh under the same a assumption.

4.2.3 Cyclones and Storm Surges

Tropical cyclones accompanied by storm surges are one of the major disasters in Bangladesh. These cyclones form in the Bay of Bengal, which is situated to the south of the country and is a favorable breeding ground of tropical cyclones. They hit the littoral countries namely, Bangladesh, India, Sri Lanka and Myanmar. Bangladesh is the worst sufferer of all cyclonic casualties in the world.

A country-wise break up shows that Bangladesh is hit by about 0.93% (~1%) of the world total of tropical cyclones, India by 3.34%, Myanmar by 0.51%, Sri Lanka by 0.22% and 0.50% die in the Bay of Bengal without hitting any country (Ali 1996, 1999).

Apparently it would seem that Bangladesh is not a high-risk cyclone-prone area. The situation is however otherwise. If the world's tropical cyclones due to each of which death tolls were in excess of 5000 are considered, it is found that about 53% human deaths of the world total due to cyclones occurred in Bangladesh. This shows the gravity of the situation. It has been found that major cyclone disasters are still continuing in Bangladesh. In Bangladesh, storm surge heights in excess of 10m are not uncommon. For example, in 1876, the great Backerganj cyclone had a surge height of 13.6 m and in 1970 the height was 10m. Storm surges once generated are modified, mostly amplified by a number of factors. Some of these factors are:

- Shallowness of water in the northern Bay of Bengal in the Bangladesh coast
- Convergence of the Bay of Bengal towards Bangladesh in the north
- High astronomical tides
- Presence of islands
- Presence of large number of inlets and channels in the coast area

The Meghna estuarial region is the area where most of the surge amplifications occur. The country's low and flat terrain in easily flooded by amplified surge waters, thus converting the coastal area into a vast sea. The dependence of cyclone formation and intensification on Sea Surface Temperature (SST) has led to the speculation that any rise in SST due to climate change is likely to be accompanied by an increase in cyclone frequency and cyclone intensity, which in turn will affect the storm surges generated by cyclones. Using SST data for the Bay of Bengal for the period 1951 to 1987, Joseph (unpublished) has shown that SST has been increasing in the Bay of Bengal since 1951. Singh et. el. (2000) have also shown that both SST and the intensity of Bay of Bengal cyclones in May and November have been increasing.

Ali (1999, 2000) has reported that the frequency of striking or land-falling cyclones is likely to increase at an increased SST in the Bay of Bengal. During 1877-1997, about 366 cyclones forming in the Bay of Bengal did not strike any littoral country (Bangladesh, India, Sri Lanka and Myanmar); they died in the Bay of Bengal. The percentage of such cyclones is about 25. If there were higher sea surface temperatures in the Bay of Bengal, these so-called dead (or non-land falling) cyclones could have further developed and struck the littoral countries, thereby increasing the frequency of land-falling cyclones and thus causing more casualties and damages. The frequency of striking cyclones would have increased by 32%. It may, therefore, be said that climate change is very likely to increase the frequency or number of land-falling cyclones by a big percentage even if the actual frequency of cyclones in the Bay does not increase. An analysis by Choudhury (2002) has shown that though the frequency of tropical cyclones in the Bay of Bengal is not changing much, the number of intense tropical cyclones hitting Bangladesh have increased in the recent years.

There is an apparent observation that number of more intense cyclones in the Bay of Bengal is on the rise. It is almost certain that an increase in SST will be accompanied by a corresponding increase in cyclone intensity (wind speed). An increase in SST is likely to cause greater convective instability, leading to an increase in the wind speed of a cyclone. A modeling study using variable SST has shown that the tropical cyclone intensifies more rapidly and acquires higher intensity at a warmer SST (Quadir, 2000 unpublished report). As noted by Ali and Ahmad (1992), SLR may also cause an increase in the destructive effect of cyclones in Bangladesh. The SLR will force the shoreline to retreat. As a result, everything else remaining unchanged, the path distance of the cyclone will increase and the cyclone will have more time in the sea to acquire energy to increase its intensity.

The SLR may change the circulation pattern in the Bay leading to changes in the SST distribution pattern. Any change in SST distribution may affect the place of actual formation, cyclone intensity, cyclone tracks, etc. The SLR may also cause changes in the pressure distribution (one way is through redistribution of SST as mentioned above) and hence a change in cyclone activity and storm surges (Ali and Ahmad 1992). An increase in cyclone frequency due to climate change will expose the coastal area of Bangladesh to more frequent flooding due to storm surges. An increase in cyclone intensity would increase the storm surge heights, which will increase the depth, extent and duration of flooding.

The stress exerted by wind on water underneath is proportional to the square of the wind velocity. Thus an increase in SST due to climate change will lead to higher storm surges. Using a numerical model for storm surges for the north Bay of Bengal and covering the coast of Bangladesh, Ali (1996) developed a few storm surge scenarios under two different temperature increases (2^0C and 4^0C) and 2 SLRS (0.3m and 1.0m rise). The 1991 cyclone that caused a death toll of about 138,000 people was used as a model case. The maximum wind speed was 225 km/hr. The results correspond to a grid point near Chittagong, the largest seaport of Bangladesh in the northeast corner of the Bay of Bengal. With no sea level rise, surge height increases by 21% and 49% respectively for SST rise of 2^0C and 4^0C respectively, with respect to the present. Surge height is inversely proportional water depth. Thus apparently, SLR will cause a decrease in surge height. But, SLR will simultaneously, inundate the present land area which will then become shallow water area due to SLR, and surge height will increase in the newly inundated shallow water area. The convergence of the Bay will also increase through SLR, thus making the surge height to amplify further. A corresponding increase in inland penetration of surges will increase by 13% and 31% respectively.

A preliminary investigation Ali (2000) shows that tidal ranges will increase due to SLR and compound the interaction between storm surges and tides and hence increase the vulnerability of the country. In an earlier experiment, Flather and Khandaker (1987) found that an increase in sea level increases the tidal amplitudes in northeast Bay and a decrease in the northwest Bay.

4.2.4 Cross Boundary River Flows

It is apprehended that climate change induced alterations in temperature would affect the timing and rate of snow melt in the upper Himalayan reaches. As a result, the hydrological aspects of the Eastern Himalayan Rivers and the Ganges – Brahmaputra – Meghna (GBM) river basins could change significantly. GBM river system would begin to swell early, while increased precipitation in monsoon would generate additional volumes of runoff. With only 7 percent of GBM catchment area, Bangladesh receives over 90 percent of the water discharged through the GBM river systems, and already suffers from repeated floods. Problems concerning drainage congestion will aggravate further with increasing volumes of water coming through the cross boundary rivers during the monsoon.

During the winter period, however, flows in the GBM rivers might decrease because of lower rainfall and higher surface evaporation. Developments and climate change induced moisture stress in the upstream areas of the river basin will result in an increase of the rate of water withdrawal for agriculture, domestic and industrial activities. This might lead to even lesser availability of water flow in the cross-boundary rivers in Bangladesh during the winter months.

There are 57 cross-boundary rivers in Bangladesh, 54 are shared with India and 3 are shared with Myanmar. Bangladesh is the common lower riparian for all these cross-boundary rivers. In December 1996, the governments of Bangladesh and India came to an agreement on sharing the low Ganges flows. Discussions on sharing of cross-boundary river flows need to include contingencies for changes in runoff, and demand due to climate change.

4.2.5 El Nino and La Nina

Although no direct correlation has been found between the Southern Oscillation and consequent temperature anomaly in the oceanic systems and the extreme weather events in Bangladesh, some studies report that the El Nino Southern Oscillation (ENSO) events influenced the record-breaking floods of 1987, 1988 and 1998 (Choudhury, 1998). The rapid transformation of La Nina from El Nino phase in early monsoon in 1998 is said to have influenced high rates of precipitation over the entire GBM catchments basin. As a result, after a prolonged dry season, the wettest monsoon came along with extremely high levels of precipitation eventually resulting in the deluge of the century. Such global events could therefore intensify some of the extreme climate change related weather events even further.

4.3 Vulnerability and Adaptation Assessment of Three Major River Basins: Ganges, Brahmaputra and Meghna (GBM)

4.3.1 Background

The Ganges-Brahmaputra-Meghna (GBM) river basin covers an area of about 1.75 million square kms and is home to over 558 million people of Bangladesh, in part or all of 16 Indian states, Nepal and Bhutan and in the Tibet region of China which lies to the north of the eastern and central Himalayas. The three rivers constitute an interconnected system with an annual discharge of 1350 billion cubic meters (BCM) of water. Additionally, the annually replenishable groundwater resource of the GBM basin is estimated to be around 231 BCM. The GBM basin is shown in Figure-4.1.

Though second only to the Amazon in drainage area and volume of discharge, the GBM system ranks first by far in most other respects. Everything about it is monumental: tremendous agro-climatic diversity: a highly fertile, arable area of 79 mln ha, a 2.6 billion ton silt load, an enormous delta with its apex just below Farakka in India, some 110,000 MW of identified hydro-power potential, a vast navigable water way rich and varied forest resources including the largest mangrove forest anywhere and a treasure-house of bio-diversity an abundance of fish resources and a still burgeoning populations, already far larger than that of Europe or North America.
The salient details of the GBM basin are set out in Table-4.2.

Table 4.2: GBM basin: Salient Details

Country/Basin Parameters	Bangladesh	India	Nepal	Bhutan	Tibet (China)	GBM Total
Ganges						
Drainage Area (1000 km^2)	46	861	140	-	33	1,080
Arable Area (M. ha)	3.0	60.2	2.6	-	Neg	65.8
Population (Million)	34	370	22	-	1	427
Brahmaputra						
Drainage Area (1000 km^2)	47	195	-	45	293	580
Arable Area (M. ha)	3.6	5.5	-	0.2	Neg	9.3
Population (Million)	47	31	-	2	2	82
Meghna						
Drainage Area (1000 km^2)	36	49	-	-	-	85
Arable Area (M. ha)	2.5	1.5	-	-	-	4.0
Population (Million)	42	7	-	-	-	49
Ganges-Brahmaputra-Meghna						
Drainage Area (1000 km^2)	129	1,105	140	45	326	1,745
Arable Area (M. ha)	9.1	67.2	2.6	0.2	Neg	79.1
Population (Million)	123	408	22	2	3	558

Neg = Negligible
Source: Mahbub ul Haq, 1999

The average annual flow in the GBM basin is estimated at around 1350 billion cubic meters (BCM). The Ganges accounts for about 500 BCM, the Brahmaputra for 700 BCM and the Meghna 150 BCM. The combined runoff at the tributaries of the Ganges as they cross into India is assessed at around 225 BCM, the remaining runoff in the river being largely added in India. The average flow in the Brahmaputra system contributed by Tibet (China) and India is around 630 BCM; the balance comes from Bhutan and Bangladesh. The groundwater potential of India has been assessed as 171 BCM in the Ganges sub-system and 26 BCM in the Brahmaputra sub-system. The South Asian regional vision document estimates the economically exploitable groundwater in Nepal as 13 BCM. Similar estimates for Bangladesh put the annual recharge at 21 BCM. Whatever be the exact figures, the total surface and ground water resources of the region are adequate to meet all reasonable needs *(Ahmad et al. 2001)*.

4.3.2 Vulnerability

The impact of climate change due to global warming on the water resources of GBM region could be very significant. General Circulation Models have revealed that mean annual rainfall in the northeastern part of the South Asian Subcontinent would increase with higher temperatures. The "best-estimate" scenarios for 2030 are that monsoon rainfall where would increase by 10 to 15 percent. It is believed that increased evaporation (resulting from higher temperatures), in combination with regional changes in precipitation characteristics (e.g., total amount, spatial and seasonal variability, and frequency of extremes), has the potential to affect mean runoff, frequency, and intensity of floods and drought, soil moisture, and surface and ground water availability in GBM region.

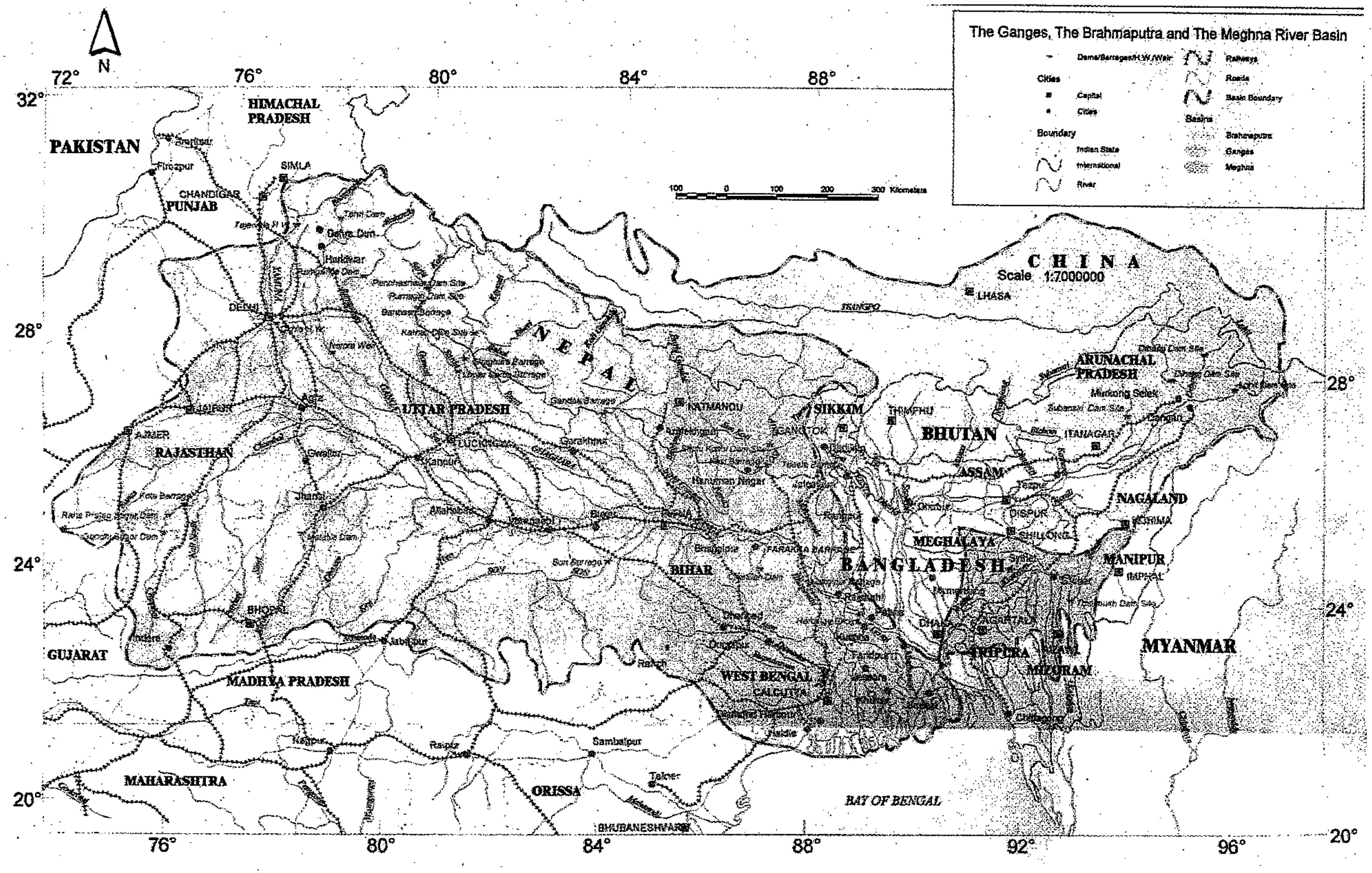
Climate change related increases in temperatures could also increase the rate of snowmelt in the Himalayas and reduce the amount of snowfall if winter is shortened. In the event of climate change altering the rainfall pattern in the Himalayas, the impacts could be felt in the downstream countries, i.e., India (northern part) and Bangladesh. The impact of any change in the length of the monsoon also would be significant. If the monsoon is shortened, soil moisture deficits in some areas might get worse, while prolonged monsoons might cause frequent flooding and increases inundation depths. By and large, any change in the availability of water resources as a consequence of climate change could have a substantial effect on agriculture, fishery, navigation, industrial and domestic water supply, salinity control, and reservoir storage and operation. Besides, the anticipated sea level rise in the Bay of Bengal would further compound the problem in Bangladesh through coastal submergence and enhanced drainage congestion in the floodplain.

4.3.2.1 Floods, Riverbank Erosion and Sedimentation in GBM Basin

The GBM countries are severely handicapped by recurrent floods, which cause loss of lives and damage to property, and infrastructure. It is the poor who occupy the more flood prone areas and constitute the bulk of the victims. The general flooding pattern is similar in Bangladesh, India and Nepal and is characterized by some 80 percent of annual rainfall occurring in four months of monsoon, often concentrated in heavy spells of several days. In Nepal, the runoff generated by heavy precipitation cannot quickly drain out, often because of the high stage of the outfall river. Flooding in hill valleys occurs due to sudden cloudbursts, which are localized in nature, but may be heavy for several days. In the higher mountains, floods induced by glaciers, i.e. Glacier Lake Outburst Floods (GLOF), are also experienced. The Nepalese terrain region is prone to flash floods, which also produce spillover effects in northern India.

Floods have become an annual feature in the GBM plains of India. Of the total estimated flood prone area in India, about 68 percent lies in the GBM states, mostly in Assam, West Bengal, Bihar,

Figure 4.2:



Source: ***Water Asia SWMC***

and Uttar Pradesh. The Ganges in northern India, which receives waters from its northern tributaries originating in the Himalayas, has high flood damage potential, especially in Uttar Pradesh and Bihar. Likewise, the Brahmaputra and the Barak (headwaters of the Meghna) drain regions of very heavy rainfall, and produce floods from over bank spilling and drainage congestion in northeastern India.

Bangladesh, being the lowest riparian, bears the brunt of flooding in the GBM region. Even in a normal year, up to 26 percent of the country is flooded, and up to about 80 percent of the land area is considered flood prone. Flooding in Bangladesh is caused by a combination of factors like flash floods from neighboring hills, inflow of water from upstream catchments, over bank spilling of rivers from in-country rainfall, and drainage congestion. The conditions could be disastrous if flood-peaks in all the three rivers synchronize.

A natural corollary of flooding is riverbank erosion, especially in the Brahmaputra system. Large seasonal variations in river flows and the gradual loss of channel depth cause banks to erode and river courses to change. Wave action during the high stage further accelerates the process. Riverbank erosion is manifested in channel shifting, the creation of new channels during floods, bank slumping due to undercutting, and local scour from turbulence caused by obstruction. Riverbank erosion is responsible for the destruction of fertile agricultural lands, homesteads, and sometimes, entire clusters of villages, making people environmental refugees.

The GBM rivers convey an enormous amount of sediment load from the mountains to the plains, which compound the adverse effects of floods. The Kosi and some tributaries of the Brahmaputra are particularly notable in this regard. Bangladesh is the outlet for all the major rivers and receives 2.4 billion tones of sediment load. Most of this sediment load passes through the country to the Bay of Bengal, but a part of it is deposited on the floodplain during over bank spilling. This process gradually changes the valley geometry and floodplain topography, often reducing the water conveyance capacity and navigability of the drainage channels.

4.3.3 Adaptation

4.3.3.1 Flood Management

In order to mitigate the impact of floods and minimize the damages, Bangladesh had undertaken certain measures – mostly physical in nature – during the last four decades. These in-country structural measures for flood management include (a) construction of embankments, (b) channel and drainage improvement, and (c) river training. The construction of upstream storage reservoirs (outside Bangladesh) is technically and economically feasible provided there are suitable reservoir-regulation arrangements. Such storage reservoirs for only flood moderation purposes may not be economically justified; but such projects may become strongly justified if they are planned and constructed as multipurpose reservoirs to provide additional benefits such as hydropower generation and irrigation and dry season flow augmentation. Potential reservoir sites do exist in the GBM region; their exploration and construction of reservoirs at appropriate sites should form part of a long-term regional flood management vision.

Embankment construction has been a major activity as part of the comprehensive water resources development and management strategy. Embankments of a total length of more than 8,300 km have been constructed since 1959, many of which have periodically failed primarily due to operation and maintenance problems. The tying up of embankments on common rivers along the borders of Bangladesh and India will ensure coordinated flood mitigation approaches between the two countries.

Among the non-structural options adopted within Bangladesh are flood proofing measures (to avoid the loss of human life and minimize disruption of normal activities) floodplain zoning (to avoid vulnerable and unwise use of the floodplain) and training & awareness build. The principal non-structural flood management approach that has a great potential for regional cooperation is flood forecasting and warning. When an advance warning about the intensity of an approaching disaster is available, preventative and protective measures can be undertaken to save life and property. As the lowest riparian, Bangladesh has much to gain from a collaborative arrangement within the region if it ensures that Bangladesh receives real time data concerning flood forecasting and warning.

The Flood Forecasting and Warning Center (FFWC) established in 1972 under the Bangladesh Water Development Board (BWDB) has since undergone a series of restructuring and upgrading, both organizational and technical, to meet the existing and emerging challenges. After the devastating flood of 1988, the Government of Bangladesh took the initiative to modernize the operation of the FFWC. Further improvement in the warning system is planned in response to climate change under Comprehensive Disaster Management Programme (CDMP) of the Ministry of Disaster Management and Relief. The present flood forecasting and warning system in operation is composed of four main elements, which are:

- *real-time rainfall and water level data collection;*
- *meteorological forecasting*
- *flood forecasting and*
- *flood warning dissemination*

At present, there exists bilateral cooperation between Bangladesh and India for transmission of flood related data. Cooperation with India needs to be strengthened further and cooperation with other countries like Nepal and Bhutan also needs to be established to acquire more data for improvement of flood forecasting and warning capability in Bangladesh. Existing arrangements for data availability in Bangladesh from stations in India do not provide a lead-time of more than 24-30 hours for the central part of the country, while it does not exceed even four hours for some areas near the border. Currently, actual and forecast data are transmitted to the FFWC in Dhaka from five stations in India, viz., Farakka on the Ganges, Dhubri and Goalpara on the Brahmaputra, Domohani on the Teesta, and Silchar on the Barak-Meghna. Besides, point-to-point communication of flood time data through wireless has been established for the flashy rivers; Teesta, Kushiyara, Manu and Gumti. These stations operate during pre-monsoon and monsoon periods, i.e., from 1 April to 15 October. The Bangladesh Meteorological Department receive rainfall data from seven stations in India, viz, Goalpara, Dhubri, Tura, Coochbehar, Siliguri, Jalaiguri and Agartala. Data transmission from India starts whenever the water level and rainfall are at the warning stage, i.e. when the water level reaches one meter below danger level and rainfall exceeds 50 mm.

Since 93 percent of the total GBM catchments area lies outside Bangladesh, flood forecasting and warning would be an incomplete and inadequate exercise without meaningful cooperation among all co-riparian. Increased lead-time to make more reliable forecasts can be achieved through the following arrangements:

- *Three-hourly real-time and daily forecast level data transmission between May and October, irrespective of the warning stage:*
- *Real-time and forecast data transmission from further upstream stations such as Monghyr, Patna and Allahabad on the Ganges; Guwahati, Tejpur, and Dibrugarh on the Brahmaputra; and Teesta Bazar, Gajaldoba, and Jalpaigri on the Teesta; and*
- *Joint calibration of hydrodynamic simulation models by Bangladesh and India for increased accuracy of lead-time and forecasts.*

These arrangements were part of the suggestions made in the flood studies undertaken by Bangladesh bilaterally with India, Nepal, and Bhutan between 1988 and 1990.

A review of the current status of development of flood forecasting methods in Bangladesh and India shows that both countries are using similar technologies for data observation and/or transmission. They use similar methods for processing data concerning flood forecasts, mostly based upon statistical correlation between base stations and forecasting stations. Automatic water level recorders have been installed at a number of sites in the Ganges Basin, both in Bangladesh and India. Many of the hydrological stations in both the countries have facilities for the observation of other parameters such as rainfall, humidity, temperature etc., which are usually taken into consideration in mathematical models used for flood forecasting.

Further improvement in model development for effective flood forecasting in Bangladesh is possible if data exchange arrangement with India is reached in respect of the following.

- *River cross-section data of upstream stretches on the Ganges, the Brahmaputra, the Meghna/Barak and the Teesta;*
- *Three-hourly water levels and daily forecast for several upstream stations on the four above mentioned rivers;*
- *Daily discharge data at these stations and at the outfalls of Kosi, Gandak, and Ghagra;*
- *Daily rainfall data of several upstream stations in all the four systems the Ganges, the Brahmaputra the Meghna/Barak, and the Teesta; and*
- *Water level discharge and rainfall data from representative stations along medium and flashy rivers in the northwest, north, and east of the country.*

Such exhaustive data sharing with India, Nepal, and Bhutan will enable Bangladesh to develop a dynamic river-routing model for its river systems, and this could generate a state-of-the-art flood-forecasting scenario to benefit the flood-prone population of the GBM region.

4.3.3.2 Dry Season Flow Augmentation

The GBM river systems experience wide seasonal variability of water flows and volumes. The dry season flows, particularly of the Ganges, are inadequate to meet the combined needs of Bangladesh and India. As early as in 1974, the Prime Ministers of the two countries had recognized the need for augmentation of the dry season Ganges flows. Augmentation could be achieved in two ways: (a) by inversion of surplus water from one river system to another; or (b) through the creation of surface water storage facilities for use within the system and / or for diversion to the neighboring systems. Also, some positive results can be achieved through demand arrangement, focusing on conservation and recycling, for example. All three options could form parts of the long-term vision of water management.

The Ganges Water Sharing Treaty of 1996 between Bangladesh and India recognized the need for augmenting the dry season flows of the Ganges, urging the two governments "to cooperate with each other in finding a solution to the long-term problem of augmenting the flows of the Ganges during the dry season." The northern tributaries of the Ganges contribute substantially to the flows of the Ganges obtaining in the lean season in the lower region. A major option for significant flow augmentation in the Ganges river system – which can benefit Nepal, India and Bangladesh – would be to construct large storages on the tributaries originating in Nepal. The terrains of the northern and middle belts of Nepal offer excellent sites for storage reservoirs.

Studies in Nepal have identified 28 potential reservoir sites, nine of which are classified as large, each having large storage capacity of over three billion cubic meters. From the Bangladesh perspective, the storage project in Nepal that has the maximum potential for augmenting the flows at Farakka is the Sapta Kosi High Dam Project. This potential reservoir envisages a live storage of about nine billion cubic meters, and the stored water behind the High Dam could augment the lean season Ganges flows and benefit both India and Bangladesh. It must be repeated here that storage reservoirs in the Himalayas would have to be multipurpose in order to be economically justifiable.

4.3.3.3 Sharing of Common Rivers

Three large interacting river systems stretching over several countries would necessarily contain issues or problems relating to the sharing of transboundary water flow among the upper, middle, and lower riparian. In GBM region, Bangladesh is the lowest riparian with 54 rivers entering the country from India. Since Bangladesh receives the residual flow after upstream utilization, shortage of flow in the dry season has always been the critical issue in water sharing negotiations with India. Of the 54 common rivers, sharing arrangement has been agreed upon only in the case of the Ganges. The Ganges Water Sharing Treaty of 1996 states in Article IX that both Bangladesh and India should endeavor to "agree to conclude water sharing Treaties/Agreements with regard to other common rivers".

Following the 1996 Treaty, the Indo-Bangladesh Joint Rivers Commission (JRC) agreed to set up a Joint Committee of Experts (JCE) to work out arrangements for long-term/permanent sharing of the waters of common rivers between the two countries in phases. There exists, therefore, a favorable climate for negotiating arrangements for sharing of all common or transboundary rivers between Bangladesh and India.

It was agreed by the JCE to examine and negotiate the sharing issues in phases. In the first phase, seven medium sized rivers are being considered, viz. Teesta, Dharla, and Dudhkumar in the northwest, and Manu, Khowai, Gumti, and Muhuri in the east. However, the JCE accorded priority to the sharing of the Teesta river – especially because both countries have constructed barrages on this river, and since both of these are based on the natural flows of the river, and the dry season flows are inadequate for the combined needs of the two countries. Some progress on the sharing issue has been achieved. Meanwhile the tying up of the embankments along the Teesta right bank at the border has been completed.

Although protracted sharing negotiations in the past had often ended in a quagmire, the expectation now – following the 1996 Treaty – is that there will be equitable sharing of the lean season flows of not only the Teesta, but also of other common rivers. Since the Teesta, by itself, has insufficient flows to meet the requirements of the two projects (one on each side of the border), it may be useful to examine seriously the option for Teesta augmentation as well as coordination in the operation of the two barrages. Parallel with the sharing issue the co-riparian should also agree on an arrangement whereby all the countries are kept informed of any intervention in the international rivers so that there is a transparent and trusted partnership among all. This will also facilitate a continuous assessment of cooperative activities, thereby helping shape more constructive future trade-offs for strengthened regional cooperation.

4.4 Fresh Water Resources

4.4.1 Background

Water plays vital roles in agricultural, forestry, fisheries and livestock production in Bangladesh. It also plays significant roles in settlement, domestic water supply and communications and indirectly in sanitation and health. Any change in water resources caused by climate changes could have additional impacts on agricultural, fisheries, forestry and livestock production as well as domestic and industrial water uses and water communications.

Availability of fresh water in Bangladesh is highly seasonal. Based on rainfall patterns, about 75 percent of the annual rainfall occurs during the monsoon (June-September). Annual rainfall ranges from 1,400 mm in the western Rajshahi region to over 5,000 mm in the northeastern Sylhet region (Task Force, 1991). In the post-monsoon (October-November) and winter period (December – February) only 10 percent of the annual rainfall is available, making agriculture highly dependent on remaining soil moisture and irrigation from surface and groundwater. In the subsequent pre-monsoon period (March – May), on an average, there is 15 percent of the annual amount of rainfall. Rainfall is extremely unreliable in this period.

The water ecosystem of Bangladesh comprises the tributaries and distributaries of three major river systems: the Ganges, the Brahmaputra, and the Meghna and numerous perennial and seasonal wetlands like haors, baors and beels. All the three major river systems originate outside the country. In fact, out of some 230 rivers in the country, 57 are trans-boundary rivers – 54 coming from India and 3 from Myanmar.

Seasonality is reflected in river discharges as well. Approximately 85 percent of the mean dry season stream flow is found in the GBM rivers. Smaller regional rivers carry the remaining 15 percent. In terms of water availability, March is the critical month in Bangladesh. The Brahmaputra accounts for 67 percent of the flow measured within the country, whereas the share of the Ganges is only 13 percent. The Meghna discharge contributes only 2 percent of the total measured discharge in Bangladesh during the month of March. It is estimated that the ratio between the discharges of the dry and monsoon for the Ganges River is 1:6 (Mirza and Dixit, 1997). Maximum discharges in the Ganges, Brahmaputra and Padma during 1973-1998 are shown in Figure-4.2.

4.4.2 Vulnerability

Climatic factors, both natural and anthropogenic, which change the water availability through their impacts on such primary physical effects as floods, droughts and salinity intrusion, are:

- *precipitation and evaporation;*
- *upstream (cross-border) river flows; and*
- *sea level rise, which results in higher flood levels; rise in river bed levels; and salt water intrusion.*

Most climate change models (GCMs) estimated increased annual precipitation over Bangladesh. Increases were more pronounced particularly during monsoon period. GCMs models also estimated changes of peak discharges of the main rivers due to climate change.

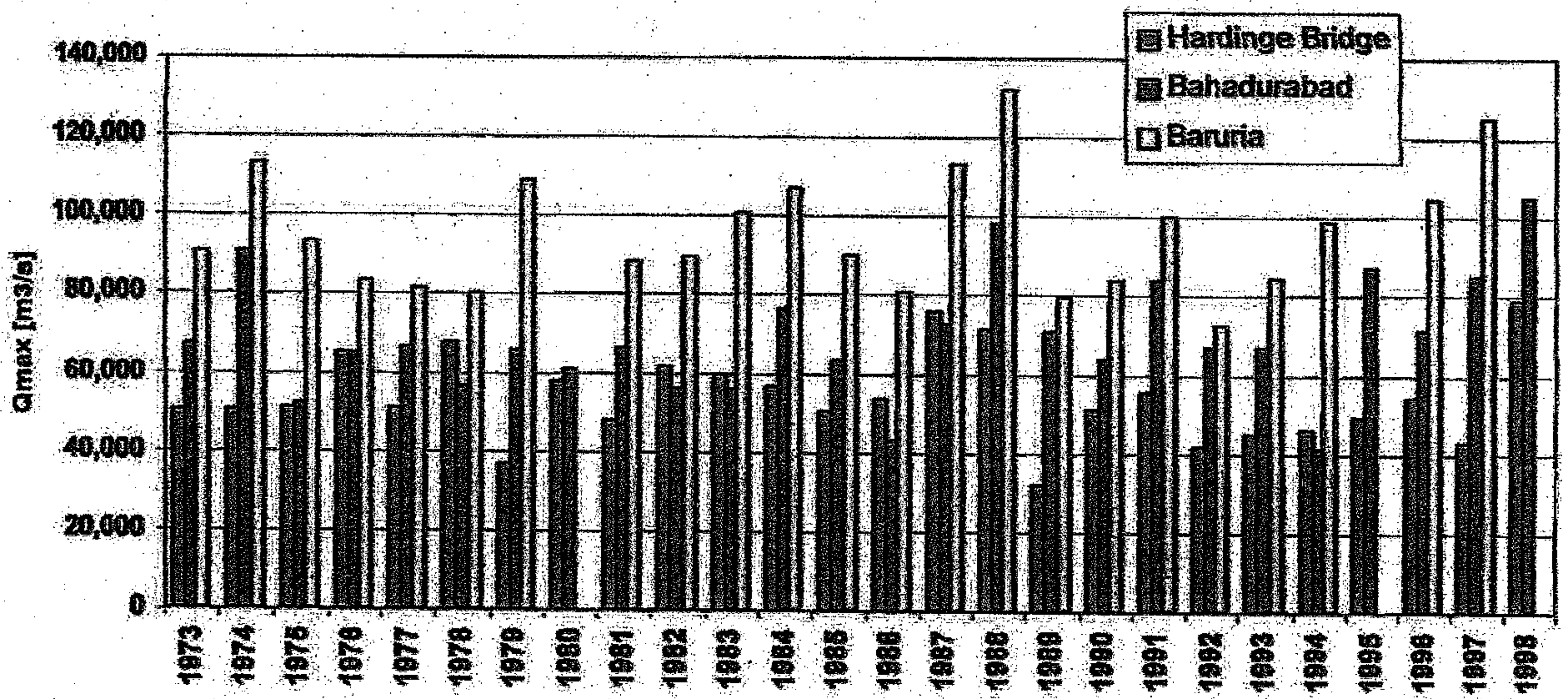
Changes in peak discharge were calculated for 2020 and 2050 using 4GCMs (WB, 2000). Results for 2020 are provided in Table-4.4. The greatest changes occur with the GFDL and UKTR GCMs, and relatively smaller changes are found with the CSIR09 and LLNL GCMs. Results are provided for climate sensitivities of 1.5, 2.5, and 4.5^{O}C, and correspond with the precipitation changes. Changes in peak discharge are relatively higher between 2020 and 2050, than between 1990 and 2020 Table-4.5.

Table 4.4: Peak Discharge (m^3/s) for the Mean and 20-Year Floods for the Ganges, Brahmaputra and Meghna Rivers.

Flood Changes in Bangladesh for 2020

	Mean			20-year		
	Ganges	Brahmaputra	Meghna	Ganges	Brahmaputra	Meghna
Reference year 1994						
	51,050	67,200	14,080	66,354	89,025	19,016
2020						
UKTR						
1.5	52,398	67,385	14,469	67,702	89,210	19,405
2.5	52,976	67,465	14,636	68,280	89,289	19,572
4.5	53,795	67,577	14,873	69,099	89,.401	19,809
GFDL						
1.5	51,655	67,240	14,467	66,969	89,065	19,403
2.5	51,929	67,257	14,633	67,233	89,082	19,569
4.5	52,303	67,282	14,867	67,607	89,106	19,803

Figure 4.3: **Maximum Discharge in Jamuna, Ganges and Padma**



Source: SWMC, 2001

	Mean			20-year		
	Ganges	Brahmaputra	Meghna	Ganges	Brahmaputra	Meghna
CSIR09						
1.5	51,994	66,871	14,232	67,298	88,696	19,168
2.5	52,399	66,730	14,297	67,703	88,555	19,233
4.5	52,972	66,531	14,389	68,276	88,355	19,326
LLNL						
1.5	51,321	66,946	14,343	66,625	88,812	19,279
2.5	51,437	66,837	14,455	66,741	88,721	19,392
4.5	51,602	66,683	14,615	66,906	88,592	19,551

Table 4.5: Range of Change in Peak Discharge (m^3/s) for Both Mean And 20-Year Flood Events, 2020 and 2050

River	1990 to 2020	2020 to 2050
Ganges	+271 to +2,745	+252 to 3708
Brahmaputra	-669 to +377	-904 to +509
Meghna	+152 to + 793	+ 141 to +1,071

Potential evapo-transpiration (PET) is the largest determinant in the water requirement for crops. Brammer et al, (1996) provided possible increases in PET in five meteorological stations in Bangladesh. The results indicate 4 mm, 3 mm and 2 mm increases in PET in the Ganges, Brahmaputra and Meghna basins; respectively in the month of March for a 1.1 degree Celsius rise in monthly mean temperature. On average, the GCM results show similar or slightly higher changes in mean annual temperature.

Sea level rise will affect river water and riverbed levels, and will increase saline intrusion as well. Backwater effects, induced by higher sea levels, occur over the whole year. Back Water Effect (BWE) may be defined as raising or stagnation of water inside a river due to conditions at the mouth of a river. Causes of BWE are: tides, storm surges, monsoon winds and sea level rise. This eventually will lead to higher bed levels in the main rivers, which in turn will lead to higher water levels. One modeling study shows that a 50 cm instantaneous increase in sea level in the Bay of Bengal may raise the bed level of the lower Padma river by 22 cm over a period of 100 years (Halcrow 1992). It is expected that a rise in sea level would have significant impacts on the morphological behavior of the major rivers in Bangladesh (BCAS/RA/Approtech, 1994).

Flooding

Analysis of past floods suggests that about 26 percent of the country is subject to annual flooding and an additional 42 percent is at risk of floods with varied intensity (Ahmed and Mirza, 1999). According to government sources, the 1998 flood inundated about 100,000 km^2. In contrast, the 1987 flood had inundated about 57,000 km^2 and the 1988 flood inundated 89,000 km^2. The 1998 flood affected 68% of the country, and seriously impacted the livelihoods of 30 million people. Overall damage was estimated at two to three billion US dollars. Final estimates showed that 51 districts (out of a total of 64) and 307 Upazilas were inundated, about 1400 people were killed, 1.77 million houses were damaged, and 23,458,713 Bangladeshis became homeless. While the 1987 and 1988 floods inundated three-quarters of the country, and killed more people, they receded after three weeks. The 1998 floods lasted for over 10 weeks (MDMR/UNDP 2000).

A 10 percent increase in monsoon precipitation in Bangladesh could increase runoff depth by 18 to 22 percent, resulting in a sevenfold increase in the probability of an extremely wet year (Qureshi and Hobbie, 1994). Since it is provided that monsoon precipitation will increase by 11 and 28 percent (Table 4.1) by 2030 and 2050, surface runoff will increase by 20-45 percent, respectively (Ahmed and Alam, 1998). Alam et al, (1998) reported that, by the year 2030, an additional 14.3 percent of the country would become extremely vulnerable to floods, while the already flood-vulnerable areas will face higher levels of flooding. It is also reported that, even if the banks of the major rivers are embanked, more non-flooded areas will undergo flooding by the year 2075. Mirza and Dixit (1997) estimated that a 2°C warming combined with a 10 percent increase in precipitation would increase runoff in the GBM rivers by 19, 13 and 11 percent respectively. Increased depth of flooding will be pronounced in the lowlands and depressions in the Faridpur, Southwest Dhaka, Rajshahi-Pabna, Comilla and Sylhet – Mymensingh greater districts and more areas are likely to be flooded by the year 2030, even after completion of about 60 percent of the flood protection schemes considered under the Flood Action Plan (Alam et al., 1998).

Changes in Flooded Area and Land Inundation Classes

There were two important outputs from the flood calculation in BDCLIM, the change in total flooded area and the change in land inundation classes. Land use in Bangladesh corresponding to flood inundation classes is presented in Table-4.6. Changes in total flooded area, and area of each of the land inundation classes were calculated for both the mean and the 20-year flood. Results are provided for the mean flood only Table-4.7. For comparison the 1990, 20-year mean values are also presented in the Table.

Table 4.6: Flood Inundation Classes and Crop Suitability in Bangladesh

Land Type of Inundation Class	Range of Inundation Depth	Crop Suitability
Medium Highland (FO)	0 cm and 30 cm	Land suited to HYV T. aman in wet reason, wheat and HYV boro in rabi season
Medium Highland-(F1)	30 cm to 90 cm	Land suited to local varieties aus and T. aman wet season, wheat and HYV boro in rabi season
Medium Lowland (F2)	90 cm to 180 cm	Land suited to B aman in wet season and wheat and HYV boro in rabi season
Lowland and Bottomland (F3 and F4)	Greater than 180 cm	Land suited to B aman in wet season and HYV boro in rabi season, LV boro in bottomland (F4)

Source: Brammer et al. (1996)

Table 4.7: Changes in Area of Flood Inundation Classes and Total Flooded Area

	Area (km²)				
	FO	F1	F2	F3	Total
1990					
Mean	6,170.40	16,042.30	20,568.60	24,327.60	67,108.80
20 year	3,598.80	12,012.60	27,130.80	48,069.00	90,811.20
2020 – INCREASE IN AREA RELATIVE TO 1990 MEAN					
CSIOR09					
1.5	8,477.40	727.20	844.80	1,1159.80	11,209.20
2.5	8,636.40	1,350.60	1,249.20	1,740.60	12,976.80
4.5	7,323.60	2,562.60	1,777.20	2,581.20	14,244.60
LLNL					
1.5	8,831.40	748.80	894.80	1,164.00	11,209.20
2.5	8,977.20	1,404.60	1,312.20	1,736.40	13,430.40
4.5	7,486.20	2,738.40	1,877.40	2,571.00	14,673.00
GFDL					
1.5	10,530.00	762.60	1,056.60	1,461.60	13,810.80
2.5	10,411.20	1,572.00	1,507.20	2,175.00	15,665.40
4.5	8,251.80	3,283.80	2,149.80	3,229.80	16,915.20
UKTR					
1.5	10,907.40	727.20	1,084.2	1,555.20	14,274.00
2.5	10,660.80	1,584.00	1,555.20	2,304.60	16,104.40
4.5	8,391.00	3,371.40	2,207.40	3,423.60	17,393.40

Source: WB, 2000

By 2020, most of the scenarios indicate that the total area flooded approaches the amount of area flooded under the current 20-year flood event. However, there are differences in the depth of flooding (and thus the flood inundation classes). Most of the 2020 increases in flooded area are in the shallowly flooded land (F0). The higher rainfall GCMs (GFDL and UKTR) coupled with a climate sensitivity of 4.5°C show a proportionately higher increase in the more deeply flooded land. However, the area of deeply flooded land under these two high scenarios is still much smaller than the area of deeply flooded land for the current 20 year flood event.

Drainage Congestion and Sedimentation

SLR would exacerbate flooding and backwater effect will also increase the extent of flooding, as it would limit the river runoff discharge. This effect was observed in the floods of 1998 (Ahmed and Mirza, 1998). Backwater effect will also increase the extent of flooding. Moreover, due to prolonged discharge of floodwaters, the rate of sedimentation will increase. As a result, both the riverbed and the bed of the adjacent floodplains will rise leading to further drainage congestion, and possibly more intense flooding in the following years. Such a cyclic course of events would intensify flood problem in the already flood prone areas of the country.

Major sources of the sediments carried by the region's rivers are in the upstream areas in India, China, Nepal and Bhutan. Sediments generally originate in the mountainous areas. In recent years, increased deforestation in the mountains has exposed topsoil, and eventually might have increased the sediment load in the rivers. Increased rainfall runoff in the vast GBM region, comprising a total catchments area of 1.41 Mkm^2, also contributes to enhanced sediment flows along the GBM river systems. This is likely to increase the rate of bed level rise in the channels and the floodplains. Moreover, instead of fertile silt, if infertile sand or coarse sediments are deposited with flooding of the Brahmaputra, it will severely reduce productivity of the topsoil. Climate change induced higher sedimentation rates will, therefore, have serious social and economic implications for the future.

Low River Flows

Lower precipitation in combination with higher evaporation will lead to increased withdrawal of surface water. Low flow conditions of the rivers will be subsequently accentuated. This will also reduce the cross-boundary river flows, and the availability of fresh water for irrigation, livestock and people. Moreover, reduced cross-boundary river flows will also negatively impact upon riverine communication system.

Droughts

Bangladesh will also be at higher risk from droughts. Between 1949 and 1991, droughts occurred in Bangladesh 19 times Mirza and Paul, 1992). Very severe droughts hit the country in 1951, 1961, 1975, 1979, 1981, 1982, 1984, and 1989. Past droughts have typically affected about 47 percent area of the country and 53 percent of the population (Task Force, 1991). A geographical distribution of drought prone areas under climate change scenarios shows that the western parts of the country will be at greater risk of droughts, during both the Kharif (January – May) and pre-Kharif (June – October) seasons. It is found that, under a moderate climate change scenario, Aus production would decline by 27 percent while wheat production would be reduced to 61 percent (Karim et al., 1998). Under a severe climate change scenario (with 60 percent moisture stress), yield of Boro might reduce by 55-62 percent. Moisture stress might force farmers to reduce the area for Boro cultivation.

In case of a severe drought, forced by a change of temperature by +2°C and a reduction in precipitation by 10 percent, runoff in the Ganges, Brahmaputra, and Meghna rivers would be reduced by 32, 25 and 17 percent respectively (Mirza and Dixit, 1997). This would limit surface irrigation potential in the drought-vulnerable areas, and challenge food self-sufficiency programs of the country.

River Erosion and Accretion

Rivers in Bangladesh are morphologically highly dynamic. The main rivers are braided, and form islands or chars in between the braiding channels. These chars, of which many are inhabited, "move with the flows" and are extremely sensitive to changes in the river conditions. Erosion processes are highly unpredictable, and not compensated by accretion. These processes also have dramatic consequences in the lives of people living in those areas. A four year study concluded in 1991 reported that: out of the 462 administrative units in the country, 100 were subject to some form of riverbank erosion, of which 35 were serious, and affected about 1 million people on a yearly basis (REIS, 1991).

A study by EGIS (1997), analyzing remote sensing images from 1973 to 1996 of the 240 km long Brahmaputra-Jamuna River between the Indian border, and the confluence with the Ganges concluded that the river has been widening at an average rate of about 130 m per year. This corresponded to a loss of about 70,000 ha in 23 years, while only 11,000 ha had been accreted. The same EGIS study concluded that the observed erosion during the flood years 1987 and 1988 was 8,000 ha per year against an average of 3,000 ha per year during the mentioned 23 year period – this gives some indication of how sensitive these processes are. Changes in the river flows and sediment transport due to multi-dimensional impacts of climate change are expected to increase the dynamics of these rivers even more. While the consequences are highly uncertain, they give rise to major concern especially given the related loss of land and property.

Demand for Fresh Water

In Bangladesh, the largest demand for both surface and groundwater is to support irrigation in the dry months. However, in setting priorities for allocating water during critical periods, the national water policy gives this sector a relatively low priority and sets the following order: domestic and municipal uses, non-consumptive uses (e.g., navigation, fisheries and wild life), sustenance of the river regime, and other consumptive and non-consumptive uses including irrigation, industry, environment, salinity management, and recreation (WARPO, 1999).

By 2018, demand for irrigation may reach 58.6 percent of the total supply. Demand for other sectors is estimated to reach 40.7 percent for navigation, salinity, and fisheries, and 0.7 percent for domestic and industrial use (MPO, 1991).

Water Balance

Changes in water supply and demand caused by climate change will be overlaid on top of changing water use due to growths in both population and income. Currently Bangladesh withdraws 22,500 million m^3 of water (WRI, 1998). According to the MPO (1991), the total requirement for water consumption in 2020 will be 24,370 million m^3 and supply will be 23,490 million m^3. Thus, there would be a shortage of 880 million m^3. Agriculture is estimated to constitute 58.6 percent of demand; navigation, salinity and fisheries 40.7 percent, and municipal and industrial demand will be only 0.7 percent. It is also estimated that on a yearly basis, about 77 percent of water supply comes from surface water sources.

Under climate change availability of surface water during monsoon will increase, whereas the winter water availability will decrease, and more water will be required for irrigation in winter. Irrigation will be more dependent on groundwater withdrawal. Under that condition, it would be quite difficult to control salinity intrusion, to keep navigational routes functional, and to ensure environmental and ecological harmony in various places – especially in the Ganges, Atrai and Teesta dependent areas of the country. In stream flow decrease will largely affect the river ecosystem.

4.4.3 Adaptation

The adaptation suggested here might help Bangladesh to reduce the risk of climate change impacts on fresh water resources. Moreover, many of these adaptations have significant benefits even if climate change does not materialize or occurs in a slower rate than currently predicted or anticipated. The suggested adaptation measures for fresh water resources examine areas of reduced fresh water availability, drainage congestion, increased morphological dynamics, and increased flooding. The measures are discussed in the light of the WB Report (2000) ,

Adaptations to Reduced Fresh Water Availability

Physical Adaptation

Possibilities for physical adaptations to reduced fresh water availability refer to increasing surface water availability through additional inflows from upstream, increasing drainage capacity of infrastructure, and increase of storage of water in the area itself. Increasing drainage capacity of infrastructure is an important incremental future action. Increase of inflow, e.g., by diversion of rivers is in itself effective but seems not so feasible because of the conflicts with upstream users even within the country. One-way of storage would be through rainwater harvesting, excavation of ponds etc., which could be a promising alternative.

Institutional Adaptation

Institutional adaptation includes reducing water demand, and participatory management of infrastructure. For example: groundwater extraction, which is basically uncontrolled, could be bettered regulated and monitored; or farmers could be trained to increase water use efficiency through farm practices. Again, market concepts could be introduced (by having consumers pay for water use, or allowing trading of water rights) which may help ensure that water goes to the most efficient applications. Another important and promising institutional mechanism to increase the flexibility to adapting to climate changes is proper participatory arrangements for operation and maintenance of water resources infrastructure.

Adaptation to Drainage Congestions

Physical Adaptation

Physical adaptation to drainage congestion include restoration of channels, flushing capacity enhancement, enhance drainage capacity of infrastructure in roads, controlled sedimentation and landfills, and pumped drainage.

Institutional adaptation

It includes improved design criteria for openings in drainage blocking structures, and community involvement in the operation and maintenance of the water resources infrastructures.

Adaptations to Dynamic Morphological Changes

Physical Adaptation

Physical adaptations to increased morphological dynamics (erosion & accretion) may include river training and bank protection, and dredging of navigation channels, which suffer from increased sedimentation. River training and bank protection have long been practiced in Bangladesh in particular on a local scale. More recently, efforts are being made on a national level to harness the main rivers (e.g., the Right Bank Protection of the river Jamuna). On the dredging of navigation channels, the study on the morphological dynamics of the Jamuna River (GIS, 1997) showed a continuous increase in river width, which is partly compensated by a decrease in river depth. Dredging activities could be intensified, but they have low feasibility, and medium priority.

Institutional Adaptation

Institutional adaptation includes improved monitoring and forecasting of changes, relocation of victims of erosion, and navigation management and information dissemination. Monitoring and forecasting morphological changes become more and more important to prepare for anticipatory measures to protect the increasingly important infrastructure such as the Jamuna bridge, Bhairab bridge, Meghna bridge etc. Knowledge and experience to analyze the morphological behavior of the rivers in Bangladesh are growing though still inadequate for proper management. Other institutional arrangements include programs to relocate the victims of erosion. An institutional and regulatory framework is necessary to relocate the victims in government owned Khas lands, which may be supplemented by NGO-driven micro-credit programs to facilitate income generation activities in those areas. Navigation would greatly benefit from proper and real time information about the navigability of rivers during the dry season and demarcation of navigation channels.

Adaptations to Increased Flooding

Physical Adaptation

It includes full flood protection embankments, controlled flooding, and elevated land as flood refuge, and flood refuge areas. Full flood protection embankments are widely practiced in Bangladesh in areas where full flood control is economically needed and justified. Although effective, their feasibility is medium because of the O&M requirements. Controlled flooding in combination with compartmentalization has been practiced under the FAP Project (FAP20), and deserves more attention. In terms of feasibility, controlled flooding scores low. Landfills (elevated land) and flood refuge areas focus directly on the affected people and assets rather than on limiting or managing the excess floodwater. In response to the need for increased dredging operations in Bangladesh, introduction of larger scale landfill or flood shelter operations could be considered. Most of the pucca schools and the elevated roadsides are considered now as flood refuge areas. These measures are quite effective and feasible.

Institutional Adaptation

Improved flood warning and forecasting, setting limit to developments in high-risk areas, awareness brief up and evacuation of vulnerable people and valuables are some possible institutionally adaptation measures. Flood warning should not only predict water levels in rivers, but should also give an estimate of inundation depth and duration of floods, which is much more useful to farmers. Improved forecasts need to be combined with proper dissemination mechanisms and techniques. Improved damage assessment techniques would then support efficient and effective relief measures. Involving local community in maintaining flood protection embankments should be a priority both as physical and institutional adaptation.

4.5 Coastal Zone and Coastal Resources

4.5.1 Coastal Zone of Bangladesh

The landmass of Bangladesh is connected to the Indian Ocean through a 710 km long coastline. The coastal region is marked by a vast network of river systems, and ever dynamic estuaries, interaction of huge quantities of fresh water that are discharged by the river systems with saline water and a saline waterfront – penetrating inland from the sea. In addition to the coastal plains, there are a number of small islands that are subject to strong wind and tidal interactions throughout the year, and are inhabited by a large number of people. As described earlier the coastal areas are highly prone to cyclone induced storm surges.

The coastal area of Bangladesh has three distinct regions: The eastern, western and central. The eastern coastline extends from the Feni river to Badar Mokam, the southern tip of the mainland. This part is more or less unbroken, characterized by flat beaches comprising of clay and sand. Karnaphuli, Matamuhuri, Sangu and Naf rivers discharge fresh water through the plains. In the western coastal areas of Bangladesh, the Sundarbans, a large patch of naturally occurring mangrove forest is located. The Sundarbans stretches further west into the southeastern part of the state of West Bengal in India. It occupies a total area of about one million hectares, about 62 percent of which is situated within Bangladesh.

The central region of the coastline is situated between the eastern and western coastal areas. Most of the combined flow of the GBM system is discharged through this low-lying area. The lower Meghna river is highly influenced by tidal interactions and consequential backwater effect. Heavy sediment inputs from the rivers result in a morphologically dynamic coastal zone. Cyclones and storm surges bring about the most catastrophic damages here.

The 1991 census recorded the size of the population of the coastal districts as approximately 24 million (BBS, 1991) whereas in 1901, the population of the coastal districts was only 7.2 million. Coastal districts have a population density of 959 inh/km^2, compared to the national average of 861 inh/km^2 (Mirza, 1998).

4.5.2 Coastal Resources

Geological Resources

In recent years, coastal area of Bangladesh has received international attention due to high potential for the exploration of in-shore and offshore natural gas. In the southeastern Sangu Valley, a large natural gas field has been discovered and subsequently put into commercial operation in 1998. Offshore drilling is also underway to explore untapped fossil fuel resources found in the coast. This has opened up new possibilities for installation of gas-based power plants in the Bhola Island and in Begerhat, which would promote export promotion zones, and rapid industrialization. Natural gas is well recognized to be cleaner than other greenhouse gas emitting fossil fuels such as coal. Besides natural gas, commercially important minerals such as monazite, limonite, rutile, zircon and cesium have been found in the sandy beaches along Cox's Bazar. These resources are yet to be exploited for commercial use.

Land Resources

For the local inhabitants, the flat plains in the coastal area are the most important resource that supports crop production, livestock rearing, salt manufacturing from the sea water, shrimp culture activities, ship breaking harbor activities and different types chemical and other industries.

Coastal plains are mainly used for crop agriculture and for grazing of livestock. However salt tolerant crop varieties are almost absent and traditional agriculture with local varieties and specific management are being practiced. Effort needs to be undertaken to intensify coastal Agriculture and alleviate land productivity. Regular or periodic inundation and saline water intrusion has been a problem for agricultural activities in the coastal area. In the 1960s, the government undertook an organized program to build a series of dykes under the coastal embankment project to protect coastal agricultural land from flooding and intrusion of saline water during high tide, and thereby to increase cultivable areas in the coastal region as well as yields in the already cultivated areas (GOB, 1992). Sluices were provided to facilitate drainage from the empoldered land. Faulty management however, has reduced the performances of the sluice gates, thus causing water logging within the polders.

Recent practice of shrimp culture inside the embankments, despite its adverse environmental and ecological effects and serious social problems, has been boosting the national economy. Major shrimp culture activities are centered at Satkhira, Khulna and Begerhat districts in the western zone and Chokoria, Cox's Bazar and Moheskhali Upazilas under the Cox's Bazar district. Salt producing pans and relevant industries are located primarily in the Cox's Bazar district.

Water Resources

Coastal areas are endowed with both fresh and brackish water resources. During monsoon, there is abundant fresh water, whereas during the winter, water becomes a scarce resource. Due to reduced flows in the rivers in winter, the surface water systems suffer from saline water intrusion, making the resource unsuitable for agricultural, domestic and industrial purposes. The groundwater aquifers in the coastal districts are under growing stress of salinization resulting from over-extraction. Sea level rise and low river flows would substantially contribute to that stress. Winter agriculture in the coastal areas is dependent on ground water. Rural water supply almost entirely depends on fresh water source.

Coastal water resources not only support agriculture and industrial activities but also provide extensively used navigational routes. There are two seaports in Bangladesh: Chittagong and Mongla. They support most of the international trade of Bangladesh, and might provide a good headway for Nepal and Bhutan's international trade in the future (especially if Bangladesh is connected to the proposed Trans-Asian road network).

Beaches

The beach along the southeastern coastal areas is continuous and flat. Although it stretches along the shore, there are only a few patches of sandy beaches, the rest are muddy. There is another important sandy beach in Kuakata in the central coastal area. Production of salt and shutkee (dried fish) is done in the beach areas. A long sandy beach runs from Cox's Bazar to Badar Mokam. Most of these sandy beaches offer good tourism opportunities. However, at present the beaches have rudimentary facilities to attract foreign visitors.

Mangrove Forests

The coastal region houses several mangrove ecosystems. Mangroves are available in the form of natural forests (Sundarban) and planted (in Barisal, Noakhali, Chittagong and Cox's Bazar Coastal area) forests together covering about 50% of the forest area of Bangladesh. These mangroves forests are transitional zones between fresh and marine waters, and are rich in marine and terrestrial flora and fauna.

UNESCO has declared part of the Sundarbans as a World Heritage Site. It is known as the single largest stretch of productive mangrove forest in the world and is inhabited by one of the most elegant creatures of nature, the Royal Bengal Tiger (Panthera tigris tigries). The dimensions and richness of bio-diversity in the Sundarbans is also proven by the availability of 3,033 MT of fish, 375 MT of mud crab, 3.600 MT of oyster shells and 35 MT of gastropod shells, which are obtained from the forest every year (Chantarasri, 1994). In addition, about 1.500 million tiger prawn fries are collected per year from the forest and its adjacent areas. The forest contains a total of 10.6 Mm^3 standing tree volume, 64 percent of which is occupied by the most commercially important species sundry (H. Fomes). The most important non-wood forest product is Nypa fruiticans. The Sundarbans provides livelihood and employment to wood cutters, fishermen, honey and wax collectors, shell collectors, timber traders and workers, workers of fish drying industries, etc. Overall, it estimated that the forest ecosystem provides employment for a total of 0.5 to 0.6 million people in Bangladesh.

Fisheries

Although the Exclusive Economic Zone (EEZ) of Bangladesh covers an area of 70,000 km^2 effective fishing areas for marine fish and shrimp have been estimated at about 10,000 km^2 and 5,000 km^2 respectively. Total annual marine fisheries catch is estimated at 0.23 million ton, which is around 28 percent of all fish produced per year (BBS, 1997).

Coral Reefs

Bangladesh has a tiny island at the tip of its southeastern reach, known as Narikel Zinzira, (or St. Martin's island) where coral colonies are located. Existing environmental conditions around the coral island are poor due to several reasons including: frequent spillage of bulge waters from sea vessels, increasing turbidity of coastal waters because of deforestation followed by land erosions in the hilly reaches of Chittagong Hill Tracts, and exploitation of corals by local traders. Without immediate and adequate conservation activities, the already endangered ecosystems of the coral island are likely to suffer further degradation.

4.5.3 Vulnerability

Coastal resources highly vulnerable to climate change include land and water resources, as well as the mangroves forests. More specifically these would be:

- *changes in water levels and induced inundation and water logging;*
- *increased salinity in ground and surface water, and corresponding impacts on soil salinity and agriculture.*
- *increased coastal morphological dynamics (erosion and accretion).*
- *cyclones and storm surges.*
- *Spatio-temporal variation in salinity may change the habitat of existing marine resources.*

Water Levels, Inundation and Water Logging

Any rise in the sea level will propagate upstream into the river system. In Bangladesh, this backwater effect will be more pronounced because of the morphologically dynamic rivers, which will adapt their bed levels in a relatively short time period (Huq et. al., 1996). This whole process will lead to decreased river gradients, increased flood risks and increased drainage congestion.

Since most of coastal plains are within 3 to 5 meters from the mean sea level, it was previously thought that a significant part of the coastal areas (as high as 18 percent of the country) would be completely inundated by rising seawaters (Huq et al., 1995; Houghton et. al., 1996). Such a speculation was made based on two major approximations; (a) the coastal plains are not protected and (b) the seawater front will follow the contour line. In reality, however, it is found that most of the plains in the coastal region is protected.

About 6000 km embankments have been constructed along the coastlines, banks of rivers and tidal estuaries to form polders. At present there are 108 polders, sub-polders in the greater Khulna, Barisal, Patuakhali, Noakhali and Chittagong districts in the coastal zone of Bangladesh. Several thousand drainage sluices are provided to remove accumulated rainfall run-off from the polders to the sea or adjacent rivers by gravity flow during low tide. Automatic flap gates are provided with the sluices to prevent saline water intrusion inside the polder during high tides. The existing coastal polders are shown in Figure 4.3.

Existing embankments provide protection against flooding from high tides but are not designed to prevent inundation by severe surges (GOB, 1992). In addition to the protection against regular inundations and saltwater intrusion, the embankments can reduce the tidal forces. This has an adverse effect on the drainage conditions (siltation due to reduced tidal volumes) and the ecosystems (water logging and stagnant waters). These negative effects have already been visible in parts of the coastal area such as Khulna, Barisal, Patuakhali and Noakhali regions.

Drainage congestion may become an even more serious threat than higher flood risks. Due to the siltation and the poor maintenance of the drainage channel network in many parts of the coastal zone, drainage congestion is already a grave problem (EGIS, 1998), and the problem is expected to increase considerably.

Proper emphasis should be given to the fact that protection measures against inundation by embankments interrupt with the natural processes of land sedimentation and delta formation. This implies that subsidence and sea level rise will not be compensated by sedimentation and the risks of inundation and drainage congestion will be even greater in the future. These amplifying effects are particularly alarming and indicate that quite a different approach may be required to face the problems especially in the seaward parts of Bangladesh.

Unlike the densely populated seafront area, the Sundarbans is not protected and is heavily influenced by tidal effects. A rise in sea level will tend to inundate the mudflats of the forest and reduce the land area of the forest. According to IPCC (2001 working Group-II report), a 0.5^{0}C rise in mean temperature and a 10 cm rise in sea level could lead to inundation of 15% (approximate 750 km^2) of Sundarbans. A 45 cm rise in sea level, corresponding to a 2^{0}C rise in temperature, is required to introduce changes in the low saline zone of the Sundarbans. The forest floor, however, may be experiencing a natural uplift at a rate similar to the anticipated rate of sea level change. Whether natural uplift is strong enough to counterbalance sea level rise is very uncertain. It is emphasized here that research on the vulnerability aspects of the Sundarbans should be more extensively pursued.

Saline Water Intrusion

The effect of saline water intrusion is highly seasonal in Bangladesh. Saline intrusion reaches its minimum during the monsoon (June – October) when the GBM rivers discharge about 80 percent of the annual fresh water flow. In winter months the saline front begins to penetrate inland and the extent of affected areas rise sharply from 10 percent of the country in the monsoon to over 40 percent in winter. Climate change would increase saline intrusion through several means, which are as follows:

- *directly pushing inland the saline-fresh waterfront in the rivers through higher sea levels;*
- *lower river flows from upstream, increasing the pushing effect from the sea;*
- *upward pressure on the saline/fresh water interface in the groundwater aquifers (every cm of sea level rise will result in a thirty-fold rise of the interface because of the hydrostatic pressure balance);*
- *percolation from the increased saline surface waters into the ground water system;*

- *increasing evaporation rate in winter, leading to enhanced capillary action and subsequent salinization of coastal soils; and*
- *increasing storm surges which carry sea water.*

All these effects would have significant adverse impacts on the coastal areas. Climate change induced extreme weather events especially low flow conditions in winter will accentuate the saline intrusion in the coastal areas (Habibullah et al., 1998).

Coastal Erosion/Accretion

The morphological dynamism of deltaic Bangladesh is manifested in the coastal zone. The coastal areas have been experiencing natural erosion and accretion. Although current literature suggests that coastal land is in the process of slow accretion at the approximate rate of 8 km^2/year during the past 210 years (Allison, 1998, Martin and Hart, 1997), much of this may be attributed to cross dams that have been built to reclaim land from the shallow continental shelves. Nevertheless, due to climate change induced alterations in thermal energy at the ocean-terrestrial interface and the expected changes in the inflow of riverine sediments, the dynamics of coastal morphology appears to be highly uncertain. Furthermore, new embankments for reclaiming additional land would affect the morphological dynamics of the coast. Details of coastal morphology are presented in Chapter-2.

Cyclones and Storm surges

From time immemorial, cyclones have been striking the delta causing extensive damages to the lives and properties of millions of people in the coastal districts of Bangladesh. In 1876, about 200,000 people were reportedly killed in Barisal by a cyclone. Another cyclone that hit in 1822 killed more than 70,000 people in Barisal and 95 percent population of the Hatiya Island. Considering the much lesser population during those times, the numbers of deaths give an indication to the severity of the cyclones. A cyclone in November 1970 hit the southern districts of Bangladesh forcing a 9 m high storm surge and killing approximately 300,000 people (Haider et al., 1991). The cyclone of 1991 caused 138,000 lives. In more recent years, however, numbers of deaths caused by the cyclones with severe intensity have declined due to the growing successful institutional arrangements for disaster management and the fact that there are now over 2000 cyclone shelters spread along the coast which are being utilized during the cyclones.

In addition, the occurrence of cyclones and storm surges reduce the economic potential and employment opportunities in the coastal area. Storm surges are associated with cyclones when high-speed winds interact with shallow waters in the seafront and produce several meters high waves. Such waves may overtop the protective embankments and inundate coastal lands with tremendous destructive power. Throughout history, the tidal bores have wrecked the coastal areas, causing deaths of millions of people, livestock and wildlife, destroying standing crops and vegetation; washing away saltpans and shrimp ponds; and demolishing infrastructure. Climate change is expected to increase the intensity of cyclones and the penetration of storm surges further inland, causing higher damages.

4.5.4 Adaptation

Key risks to coastal resources are:

- *Drainage congestion*
- *Salinization of land and water resources*
- *Increased morphological dynamics*
- *More intense natural disasters in the coastal zones.*

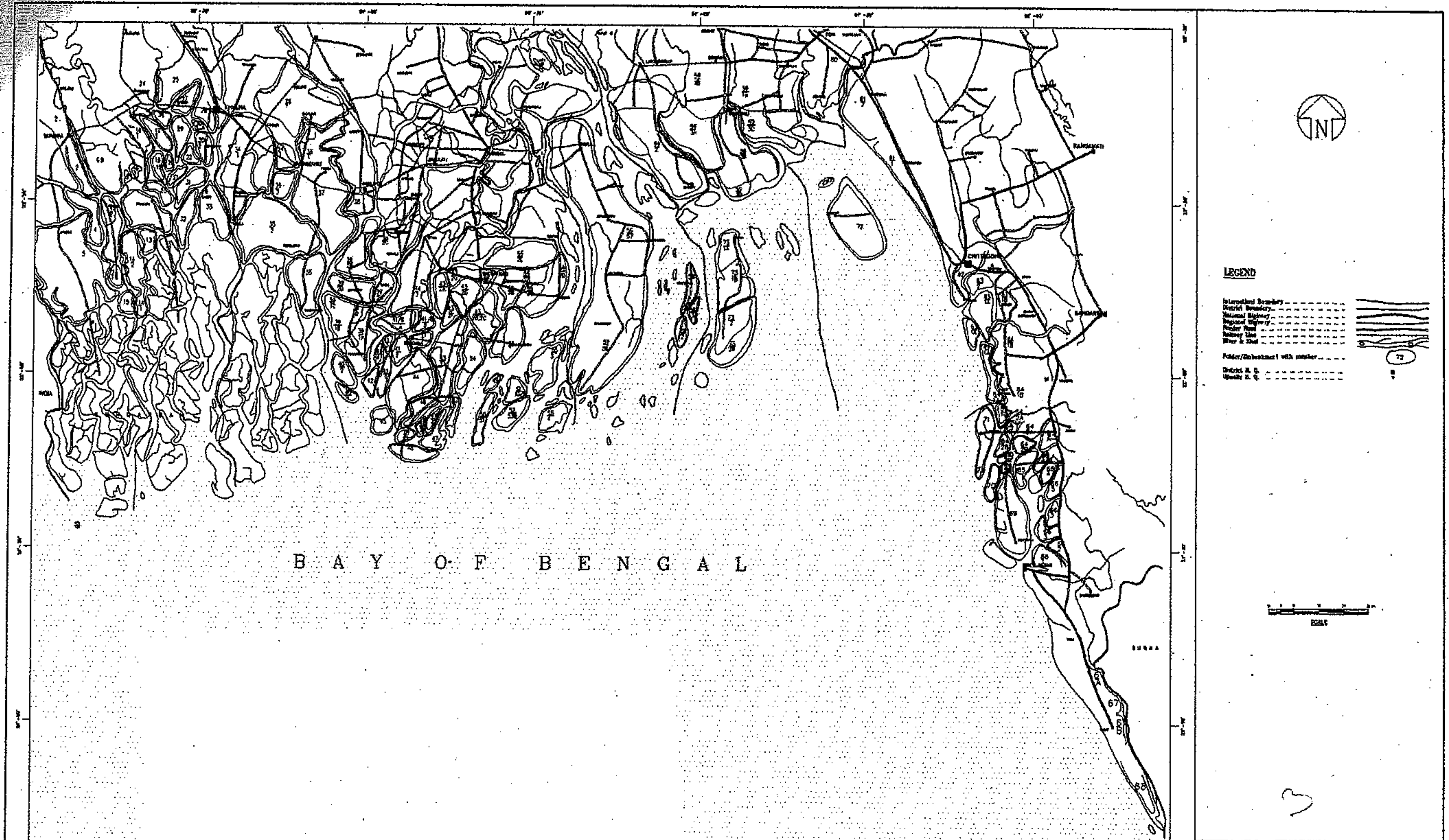


Figure 4.4: Existing Coastal Polders

Source: MCSP

Adaptations to Drainage Congestion

Physical Adaptation

Physical adaptation requires mainly two steps: (i) bringing water from the land into the main drainage system; and (ii) drainage of water to the sea. Step (i) presently is done under gravity, mostly though regulators, which open during low tides. When higher water levels impede this process, pumping remains the main option. Step (ii) requires a well-maintained drainage network, and improvement of drainage system. Increasing the drainage capacity of existing infrastructure, maintaining the out fall channels of hydraulic structures and providing new drainage structures in the locations where sedimentation process is less. Tidal basin is an alternative physical intervention to solve the drainage problem. Tidal basins stand out as a preferred option from an environmental and maintenance perspective (since tidal basins would substantially reduce the maintenance dredging and bring sediments to the beel area). The tidal basin in Khulna-Jessore Drainage Rehabilitation Project proves that this is a feasible approach in southwest Bangladesh. Pumped drainage seems a last and expensive resort especially when the outside water levels become too high for drainage under gravity.

Institutional Adaptation

Institutional measures include guidelines to incorporate climate change in long term planning. Establishing proper O&M arrangements for the maintenance of drainage channels and infrastructure could be an effective approach. Establishment of water management associations, support of local water management including involvement of local institutions and development of appropriate design criteria for drainage infrastructure are other adaptation options that can be pursued.

Adaptation to Salinity Problem

Physical Adaptation

Specific physical adaptations for the salinity problem should focus on increasing surface water flows from upstream, resuscitation of river networks, construction of cross dams/embankments, increasing local storage capacity of fresh surface or groundwater, and establishment of desalinization plants and equipment.

Institutional Adaptation

Institutional adaptations for salinity include maintenance and operation of sluices and regulators, groundwater management, land use practice, extension services, and water saving techniques. The first two are management options. Improving maintenance and operation of sluices and other regulators to hold water in areas that are under increased stress from salinization is high in priority. In Bangladesh, there still remains a tendency to consider water as a common property. Groundwater management and regulator operations should therefore incorporate and make use of the difference between the dry and wet seasons in Bangladesh.

Providing incentives to change agricultural practices so that agricultural demand for fresh water goes down can influence land use practice. Therefore, a cohesive approach is necessary with an intensification of extension services to promote changes in land-use and farm management techniques. For example, there could be a door-to-door service in providing access to, and information of weather extremity tolerant crops to the farmers and change of cropping pattern in the coastal zone.

Adaptation to Increased Morphological Dynamics

Physical Adaptation

Physical adaptations to the threat of increased erosion would include provision of mangrove greenbelts, cross dams and/or river training works. Mangrove greenbelts in the foreshore areas and along the coastal embankments, and cross dams at the same time enhance accretion. River training works, e.g., through bank protection or strong-holds are confined to the estuarine river branches. All these measures are effective. Cross dams and river training works and their long-term maintenance are basically costly. The high effectiveness and feasibility of mangrove greenbelts are well acknowledged. GOB has undertaken social afforestation program to restore the ecological balance and to mitigate environmental hazards in the coastal areas. Presently this is found very effective and community participation in this program is very high.

Institutional Adaptation

Institutional adaptations would aim at protecting the wetlands & mangroves and land use arrangements (including land tenure laws) & policies. The value of growing mangrove greenbelts is closely related to the effectiveness, feasibility and sustainability of protecting mangroves in existing forest areas (through a combination of enforcement of existing legal provisions, and awareness raising among the coastal population). Protection of wetlands is assessed in a similar way, and wetlands can serve as a buffer against coastal storms and erosion. Another promising approach may be found through community-based adaptation where the community decides on how to share the limited common resources.

Although loss of land and the accretion of new lands are common phenomena in Bangladesh, at present, taking accreted land into culture for either forestry or agriculture falls under the jurisdiction of different ministries. The loss of land, and relocation of displaced people needs to be addressed seriously (Freestone et al.1996). The mangrove belts could be managed in a much more flexible way. Reform of land tenure laws and policies, would give a sustainable adaptation base to climate change.

Adaptation to More Intense Natural Disasters in the Coastal Zones

Physical Adaptation

It includes construction of new infrastructure such as cyclone shelters, coastal embankments and raised platforms, improved road communication networks, and improved warning systems and mangrove greenbelts. In addition to cyclone shelters for people, adequate provisions would be made for livestock, food grains and other perishable items. In the past, cyclone shelters for coastal cyclones have helped mitigate risks from cyclones. The size and adequacy of the shelters should be re-examined in the light of increased number of people at risk and the increased cyclone intensity as well. In recent years, over two thousand multipurpose cyclone shelters have been built in the coastal zones. Cyclone shelters are the safe heavens for the people during storm surges and for other period these are used as schools and health/community centers. For livestock's and other perishable items raised platforms (Land fill above the flood levels) of adequate numbers should be built, that can also be used on a multipurpose basis as play grounds, village markets etc.

Embankments need to be maintained on a regular basis. Actual maintenance of the existing coastal embankments is insufficient; a sizeable proportion of the existing coastal embankments is in bad condition, and is already being breached. Therefore maintenance of embankments is very essential.

approximately coincide with the three meteorological seasons: Kharif I (pre—monsoon), Kharif II (monsoon) and Rabi (winter or dry). Aus, âman and boro are the three rice grown respectively in these three cropping seasons. The area and production of major cereals is given in Table 4.8.

Table 4.8: Crop statistics of major cereals for the fiscal year 1999-2000

Crop	Area (Thousand ha)	Average yield (Mt)	Current production (Thousand ton)
HYV Aus	439.27	1.82	798
HYV Aman	2764.94	2.26	3246
HYN Boro	3426.32	3.11	10.671
Other Rice	4082.43	1.31	5352
Rice Total	10.712.96	2.15	23.067
Wheat	832.80	2.21	1840
Major Cereal Total	75.15	.071	53.2

Source: BBS, 2001

Note: Average yields are national averages expressed as rough rice.

The crop calendar is presented in relation to temporal distribution of rainfall and temperature in Figure-4.4. Aman is the leading rice crop, occupying about 56 percent of the total area under rice, followed by boro (27 percent), and Aus (17 percent). A notable aspect of the pattern of growth in crop agriculture during the past two decades has been the increasing area covered by dry season HYV boro rice – a trend that is likely to continue.

Over the last one and a half decade, average farm size has declined and per capita cultivated area has come down from 0.10 ha in mid 1980s to only 0.06 ha in late 1990s. Farmers, generally speaking, are resource poor. Continuous utilization of land without proper replenishment; land degradation and decline in soil fertility has caused lowering of land productivity. Further due to population growth and related demand and different types of disasters, nearly 1% of the cultivable land is lost every year (appx. 220 ha loss/day). In spite of all these adversities, for the stride of survival and feeding the increasing population, transformation in the agricultural practice is remarkable. At present, over 62% of the land is covered by high yielding varieties, contributing towards higher yield. The introduction of HYV rice and the expansion of irrigation have both contributed to increased food production over the past two decades. The present production of food grain (rice and wheat) is over 25 million MT and thus Bangladesh are in the level of self-sufficiency. Retention of self-sufficiency is however, a big task or challenge because of risk factors in agriculture and the predicted change in climate. With Climate Change, the food security will be further threatened.

Essentially, a major strategy to increase/sustain food grain production will be through the expansion of irrigation coverage in terms of installed capacity, improvement in capacity utilization, and increase in cropping intensity. Irrigation, therefore, is expected to contribute heavily to a surge in water demand in the next 25 years. Of the total irrigable land in the country (7.6 million hectares), little over 4.0 million hectares were irrigated in 1996/97. Based on the 1991 National Water Plan estimates of irrigation expansion, the irrigated area would reach its maximum potential by 2025. The main source of irrigation water in the recent years has been the groundwater (68.5 percent in 1996/97). This is a risky over dependence, and as such a balanced conjunctive use of surface and ground water should be encouraged. This option would be pragmatic in view of the arsenic problem in groundwater. With the change in climate and sea level rise, situation would be different; for which preparation in advance is necessary.

4.6.2 Vulnerability

Climate change induced vulnerability is related mainly to biophysical, climatic and socio-economic situation of the population. In order to derive adaptation mechanism, factors contributing towards vulnerability are to be understood. These are briefly described. The socio-economic implications of climate change have been covered in a separate section of this chapter.

Climatic

Temperature, rainfall, solar radiation, prolonged drought and less cool winter period are the prime factors to influence agriculture due to climate change. Higher temperature and water stress due to heat would result in decline in vegetation and agricultural production.

Biophysical

Submergence and drainage congestion and inundation by saline seawater as a consequence of climate change will cause further degradation of land quality. Soil fertility will decline because of the change in physical and chemical characteristics and accumulation of salts on the surface. As regards irrigation water, over supply and under supply of surface water in different seasons and greater contamination of ground water by arsenic and other heavy metals because of over extraction owing to higher crop water demand with climate change, would result in disruption of ground water use for irrigation purposes. Due to climate change, coastal ecosystem and bio-diversity including the presently suitable germplasm will also suffer.

Rise in temperature: Both summer and winter temperature will rise. In summer, temperature rise will induce higher evapo-transpiration, resulting in more water demand by the plants. On the other hand, with temperature rise, there will be scarcity of surface and ground water. Performance of irrigation equipment will be less. As such, cropland will suffer from water stress resulting loss in crop yield as well as crop and forestry spices. With the rise in winter temperature and due to reduction in the cool water periods, many of the areas now suitable for production of different crops like wheat, will turn unsuitable or the yield will be reduced greatly.

Variation in Rainfall: Climate change will result in increasing summer rainfall by 11% and decreasing winter rainfall by 3% by the year 2030 (Table 4.1). By the year 2050, sea level rise will be 50 cm, summer rainfall will increase by 28% and winter rainfall will fall 37%. Low-flow conditions in the rivers are often observed in the winter months (lean period) when surface water irrigation becomes severely constrained. Under such conditions the farmers usually react to ensure irrigation by exploiting groundwater resources. Low-flow conditions cause economic hardship to the poor farmers. The situation is particularly observed in the upland areas in the northwest (Barind Tract) and in the lower Ganges floodplains. This phenomenon will be more serious under climate change situation.

In summer, increasing rainfall will result in greater surface water flow and thus flooding. Due to flooding, agricultural production loss will be more pronounced; as the flood of 1998 resulted in a loss of over 50% of the standing crops. River erosion and sedimentation of the floodplains because of more runoff will devour more agricultural land and make much of them less productive. During winter, water demand will be more, and the present tendency of irrigation expansion will continue. Whereas precipitation will be less, recharge of ground water will suffer. This phenomenon will further aggravate the risk in cultivation in winter resulting in loss in production. Due to fall in rainfall, surface water flow will be less, resulting greater backward thrust of seawater towards inland. Much of the presently suitable agricultural land will be turned unfertile or less productive.

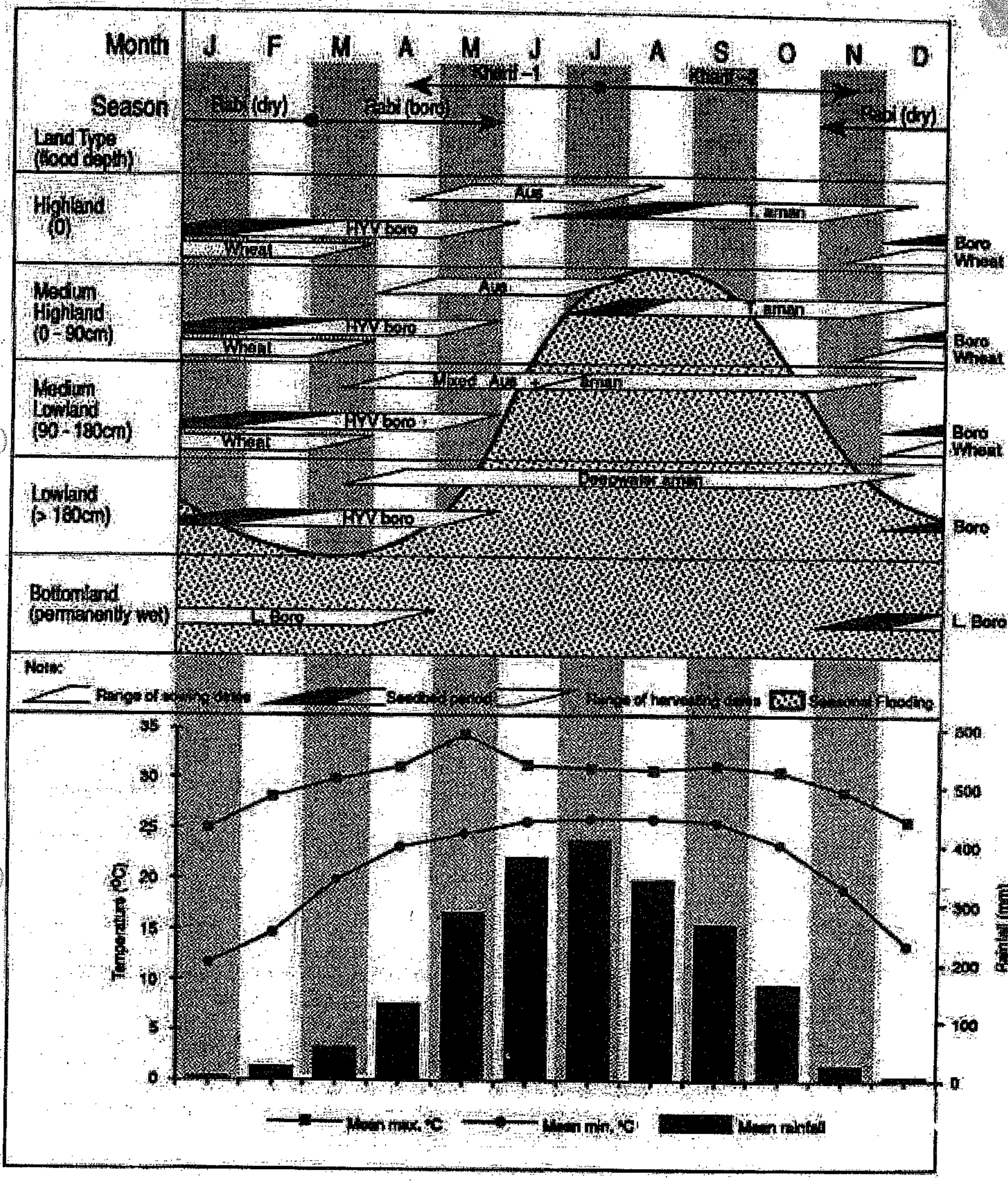


Figure 4.5: Crop Calendar in Relation to Seasonal Flooding, Rainfall and Temperature

Sea level rise: Due to sea level rise, as predicted by IPCC, 7-16% of the land area of the coastal area of Bangladesh will go under water, resulting displacement of huge population, loss of land, forest and fisheries and other resources. Much of the grazing lands now available or remains seasonally fallow in the coastal belt will be lost, depriving the livestock population from the natural feed. Loss of production in crop, fishery and livestock in the coastal zone will create pressure for compensation in the form of more intensive cultivation and exploitation of resources from the remaining non-inundated part of the country. This will have adverse effect on the soil fertility and agricultural land productivity of the country.

Intrusion of Saline water: Climate change and sea level rise will facilitate more cyclone and storm surges resulting in higher salinity in the coastal zone. Further, pressure of the seawater towards inland will induce greater and extended salinity towards inland of the country. Rise in temperature and absence of land cover will further aggravate the situation, as there will be higher capillary rise of saline ground water in the surface.

Forestry, fisheries and crop will suffer much as the present productive lands will be unproductive and forestry spices including the mangrove forest in Sundarbans will be seriously affected. Shrimp firms and many presently grown crop varieties will either be damaged or will seriously decline productivity.

Water Logging and Drainage Congestion

Bangladesh serves as the natural drainage for nearly 1.66 million-km^2 catchments area, of which nearly 92.5% is out of the country's territory. Because of the sea level rise, backwater thrust will create hindrance in the drainage of surface water flow. The F3 (180-300 cm, seasonal flooding) and F4 (more than 300 cm, seasonal flooding) land and other perennial water bodies will be under water for longer time. Climate change induced drainage congestion will compel to switch over from crop agriculture to non-crop agriculture like fisheries. Water quality will suffer degradation, affecting the water for human and livestock consumption as well as irrigation. Much of the productive land will either remain unused or will have to be operated with low productivity unless new crop varieties suitable to sustain in the changed ecosystem are developed.

Tropical cyclone and storm surges

Due to climate change and sea level rise, the quantum and the frequency of tropical cyclone will increase. This will give rise to intrusion of sea water much towards the inland and thus increasing soil salinities, contamination of ground water with salt and loss is suitability of present crop varieties now grown in the coastal region. Without salt tolerant new crop varieties, much of the coastal cropland will remain barren affecting the total agriculture production and food security. This part has also been covered under coastal resources.

Impact on crop Agriculture

From the previous descriptions, it is clear that the climate change will seriously affect the total agriculture production in general, and the crop agriculture in particular. Understanding of the country's climate as well as the regional integration climate for its obvious relationship needs to be known. Biophysical components and the dynamics of impact of climate change have much to do towards agricultural production mechanism and output from this sector. With the rise in CO_2 level, positive fertilization effect will occur but with the rise in temperature the yield will be suppressed. The interaction of CO_2 and temperature thus has to be synchronized with the choice of crop cultivars in order to derive the desired benefit. By that way, the climate change induced impacts can be turned into advantages rather than a problem.

Attempts have been made to clarify the vulnerability of climate change and its impact on agriculture in terms of the yield sensitivity through crop model studies and also in terms of degradation of agro environment. The results of the sensitivity study with GCM, using CERES – rice and CERES wheat, under various climate change scenarios have been shown in Tables-4.9, 4.10 and 4.11. Aggregated rice and wheat yield shows positive fertilization effects with CO_2 rise; which however did not sustain and lowered with the rise in temperature.

Table 4.9: Aggregated HYV Rice and Wheat Production of Bangladesh under Different Climate Change Scenarios

Treatment	HYV Aus (000t)	Percent Change	HYV Aman (000t)	Percent Change	HYV Boro (000t)	Percent Change	Wheat (000t)	Percent Change
Baseline (1999-2000)	798	0	3246	0	10671	0	1840	0
330ppmv CO_2 + 2°C	646.38	-19	2824	-13	10244	-4	1159.2	-37
580ppmv CO_2 + 0°C	1045.38	31	4058	25	13125	23	2539.2	38
580ppmv CO_2 + 4°C	750.12	-6	3278	1	12378	16	1104	-40
660ppmv CO_2 + 4°C	829.92	4	3538	9	13125	23	1269.6	-31

Source: USCSP 1998

Note: Gives the total country picture in respect of rice production by season and changes with climate change.

Table 4.10: Change in Rice Yields under Different Climate Change Scenarios (%)

reatmen	Coastal region			Central region			North-east region			North-west region		
	Aus	Aman	Boro	Aus	Aman	Boro	Aus	Aman	Boro	Aus	Aman	Boro
330ppmv CO_2 + 2°C	-19	-24	-8	-17	-12	-1	-16	-13	-9	-18	-11	-3
580ppmv CO_2 + 0°C	32	31	23	29	24	23	29	24	22	30	24	24
580ppmv CO_2 + 4°C	-5	-10	13	0	5	17	-3	2	8	-9	2	18
660ppmv CO_2 + 4°C	5	-1	20	9	12	24	6	9	14	1	10	25

Source: Karim et al. 1998

Table 4.11: Fluctuation in Wheat yield under Different Climate Change Scenarios (kg/ha)

Treatment	North-west region	Central region
330ppmv CO_2 + 2°C	2002	2340
330ppmv CO_2 + 4°C	944	1357
580ppmv CO_2 + 2°C	3204	3436
580ppmv CO_2 + 4°C	1850	2340
660ppmv CO_2 + 2°C	3545	3730
660ppmv CO_2 + 4°C	2153	2629

Source: USCSP 1998

Flood: Bangladesh being highly vulnerable to climatic events, floods and droughts of different intensities occur, especially in the drier NE and NW regions of the country. The droughts are due to deficit in rainfall, and floods occur, due to rainfall of high intensity in the catchments areas.

The rice crop is most affected by flood. The growth of the plant is hindered by the flood due to excessive moisture at the root zones, resulting in an overall decline in production of the crop. Transplanted Aman paddy does not grow well under submerged conditions of over 90 cm water depth. Such a relationship with water depth (or moisture availability), however, is variety specific. In Bangladesh about 1.0 Mha of cropland is highly and nearly 5.0 Mha is moderately flood prone. Usually, the flooding depth varies from 30 to over 300 cm. The extent of the unprecedented flood of 1998 inundated two-thirds of the country. The estimated loss of food grain well exceeded 3.5 Mt. The flash floods often damage the boro rice. The increase of rainfall with the change in climate in the future would produce even more severe floods of different nature causing greater severe damage to rice crops and others.

Drought: Agricultural drought (phonological) refers to a condition when the moisture availability at the root zone is less than adequate. Aman cultivation suffers from periodic drought conditions during Kharif II season. Similar conditions are often observed in early pre-Kharif period; affecting Boro and in Rabi season, wheat cultivation in the northeast and central-east regions of the country. Dry season drought affects the production of wheat, potato, mustard and Aus Paddy (Karim et. al., 1990) Drought-related vulnerability and its impact may be counteracted either by supplementary irrigation for the Kharif or ensured irrigation for the Rabi and pre-Kharif crops. Drought normally affects about 2.3 Mha of cropland during April to September (Kharif season) and 1.2 Mha in the dry season (October to March). Drought during Kharif severely affects the transplanted Aman rice incurring annual production loss by about 1.5 Mt of rice. With the change in climate, significant change in the present drought classes has been observed through model output and is shown in Table-4.12.

Table 4.12: Change in area under different drought classes due to climate change scenario in dry winter and pre monsoon (Area in km^2)

Drought Classes	Climate Change Scenarios (CCS)				
	Existing	CCS-1	%	CCS2	%
Very severe	3638.69	8636.12	(+137.34)	12219.64	(+235.82)
Severe	8580.95	10873.53	(+26.71)	15302.72	(+78.33)
Moderate	32846.70	30380.51	(-7.50)	25465.26	(-22.47)
Less Moderate	14571.20	9747.17	(-33.10)	19814.20	(+35.98)
Slight	43524.10	43524.10	(+0.00)	30359.82	(-30.24)

Source: ***Karim and Iqbal, 1997. Journal of Remote Sensing and Environment, Volume I***
Figures within parentheses indicate % increase (+) or decrease (-) in area over existing.

Salinity: The vast coastal croplands suffer from salinity related problems in the winter months. This is particularly common in nearly 1.0 Mha of the present salt affected soil in the coast. Because of cyclone and storm surges, high spring tide inundation and capillary actions salt accumulate at the surface and root zones. As a result, a large area in the coastal districts is virtually unsuitable for a number of crops, while the production of other crops is less due to salt injury. About 0.13 MT food grain is lost at present annually due to adverse impact of soil salinity. Climate change effect will be severe in the coastal region. Preliminary investigation reveals that the area of salinity has extended up to 3.05 mha covering the districts of Chandpur, Magura etc. Thus, due to extension of saline area and salt affect, crop loss will be higher. Loss in Aus paddy without and with climate change is given in Table-4.13.

Table 4.13: Loss of Aus Production due to enhanced salinity

Without Climate Change	Production loss (Mt)
Total B Aus Loss (ha)	39710.33
Loss of HYV Aus at early growth stage	25907.58
Total loss in Aus production	66617.91
Climate Change Scenario CCS1 (in 2030)	
Total B Aus Loss (ha)	46139.51
Loss of HYV Aus at early growth stage	29631.02
Total loss in Aus production	75770.53
Climate Change Scenario CCS2 (in 2050)	
Total B Aus Loss (ha)	53,478.80
Loss of HYV Aus at early growth stage	40,179.35
Total loss in Aus production	93658.15

Source: USCSP 1998 and organizational assessment.

4.6.3 Adaptation

Adaptation to climate change is primarily a function of a country's or individual's resource base and capability to respond. In addition, technological know-how, education and information system, infrastructure, and their maintenance, and management capabilities will be a part of the adaptation strategy. Agricultural research capability especially application of genetic engineering to develop heat, salt and water logged tolerant varieties of cultivars will be effective to adapt to climate change. Besides, agronomic management like, crop adjustment, selection and cultivation of low water demanding crop, conservation of moisture etc. will be useful to minimize the impact and thus to lessen the loss in yield. A study on drought and its effect with climate change, in relation to crop loss has been made using universally accepted models. The study with three levels of adaptation (Table-4.14) indicates the possibility of reduction in climate change impact and its adaptation to our situation. As can be seen with high adaptation, the loss in HYV Aus yield could be brought down from 20.7% to 6% only under CCS1.

Table 4.14: Percentage reduction in production of major crops from the existing level under two climate change scenarios over three levels of adaptation practices

Crops	CCS-1			CCS-2		
	HA	MA	LA	HA	MA	LA
HYV Aus	6.0	10	20.7	11.0	20	38.9
HYV T. Aus	2.0	8	15.2	5.0	18	36.2
HYV Boro	2.5	4	10.6	4.5	10	21.2
Wheat	15.0	25	54.4	2.5	40	68.6
Potato	8.0	10	53.9	20.0	30	68.8

Source: Journal of Remote Sensing and Environment, V-1, 1997, Dhaka.

Note: CCS1 = 2^0C rise + 330 ppmv CO_2
CCS2 = 4^0C rise + 660 ppmv CO_2
HA = *High adaptation: Improved technology and its wider adaptation;*
MA = *Moderate adaptation: Fames will be responsive and will adjust with the change;*
LA = *Low adaptation: Business as usual.*

In the context of Bangladesh, the following realities and the action programs to adapt to climate change deserves priority attention.

- Presently, available global circulation models do not reflect the situation at the region or country specific level. Country or regional data have to be fed to run models or develop regional models in order to understand more precisely the problems and its impact to develop adaptation strategy.

- In agriculture, traditional knowledge has great significance and implications on the coping mechanism. Thus, research investigation and generation of improved technology should have to take into account the knowledge base on the traditional practices of the people. Mitigation of the climate change impact can thus be lessened to a great extent.

- Agricultural research on the crop sector will require a drastic reorganization in terms of research programming and solving upcoming problems. To adjust with the change in climatic situation, heat tolerant crop cultivars, plants of high water submerge characteristics and crop to stand on high salinity have to be evolved. In addition, crop establishment and management practices like use of raised beds, hydro phonics, seedling and cropping in floating vegetative beds, improved irrigation efficiencies, etc. need to be developed. The national agricultural research system shall have to act accordingly.

- Land consolidation, especially newly accreted lands and crop agriculture in those areas needs to be scientifically developed. The process of acquiring new land through accretion should be given priority. This will assist in minimizing the loss of land in one area and the resettlement of the replaced people in another area.
- Agricultural research and extension service including the services of the NGO's needs to be strengthened and oriented towards addressing adaptation to climate change.
- Government policy towards the affected people to be more on settlement and employment generation. Specialized credit service and measures like, crop insurance, need to get priority importance.

Physical Adaptations

The performance of agriculture sector much depends on the land quality and availability of fresh water. Both these resources are going to be affected by climate change. It is suggested (World Bank, 2000) that, the physical adaptation to reduce flood and drought impacts will be more improved irrigation, conjunctive use of ground and surface water irrigation, crop diversification and fertilizer manure management. Flood impact can be reduced through selection of appropriate crop and cultivars and by adjustment of timing of crop establishment. It is pertinent to mention here that, agriculture has to be seen covering both crop and non-crop sector. Presently the Aus and Aman rice are at high risk of floods tides and storm surges. In the future scenarios of climate change, the monsoon rainfall would substantially increase over Bangladesh and in its catchments areas. This will increase the risk of very severe floods and cause the damage to Aman crops. To compensate the crop losses likely to be caused by floods induced by climate change, the safe period winter rice should be cultivated more intensively using the modern variety of crops (HYV/hybrids etc). As there is wide detection of arsenic in ground water much needs to be done on surface water irrigation.

For drought mitigation, improving irrigation efficiency would help reduce water stress. Present day cropping and irrigation practices are water intensive. Induction of legume crop and changes in fertilization techniques (application of granular or briquette urea) at field moisture condition will result in significant reduction in water consumption. For water use efficiency and conservation of soil moisture, reduction of conveyance loss, correct irrigation scheduling and amount of water use can prove to be rewarding.

Crop diversification is essential, both for food and nutritional security and maintaining land productivity. In case of climate change, transformation and switch over to crops and varieties with low water demand could be the correct strategy. To release more lands for high value crops, diversify cropping and to adapt with the climate change, greater use of hybrid / modern cereal varieties, including upcoming super rice would be effective. Through conjunctive use of water and using other water saving techniques need to be followed.

Coastal salinity will be greater by extent and volume. Use of raised beds, (Sarjon cropping) locally proven salt resistant crop cultivars and change in irrigation technique could be useful. In this respect, the issue of non-keeping of the land fallow, in order to prevent capillary rise of salt water from below the surface and appropriate tillage need not be over emphasized.

Institutional Adaptations

To adapt to climate change, institutional measures has much to do in minimizing the agricultural loss in production. This has also been stressed in a study on the subject (World Bank, 2000). Adaptations, as it relates to institutions may be furnished as under:

Adaptation to increased depth and duration of flooding would be severe in the agricultural sector under climate change situation. This will further be complicated by drainage congestion. Both structural and non-structural measures (in limited cases) would be necessary to adapt to this situation. Development of fast growing and less inundation sensitive crop varieties would be necessary and should be a part of the institutional adaptation. For dissemination of the developed varieties and their wider adoption, greater research-extension and NGO linkage will be necessary.

Drought effect is severe and will be more with climate change. Development of drought tolerant crop varieties and low water demanding crop cultivars should be a priority research agenda of the national agricultural research system. Development and field validation of the varieties developed should be followed by follow up training and trial and demonstration programs by the extension agencies to disseminate and ensure extensive use at the grass root level.

Salinity problem will be extensive and will take a great toll of the country's agricultural production. With climate change, soil, surface water and ground water salinity will be a challenge for the agricultural sector. Besides selection, screening and development of appropriate salt tolerant different crop cultivars, institutional adoption should also embrace management technology of the sea-surface ecosystem, land and soil management and crop-irrigation technique. Use of raised beds; rainwater harvesting, vegetation coverage of the lands etc. have to be considered all together. Research and extension afford for the purpose will be essential.

Fertilizer and manure application has relationship with emission of GHG, conservation of soil moisture and water use efficiency. Research information in respect of type, timing and amount of fertilizer use, needs and research investigation in the context of climate change situation. Appropriate cropping pattern technique with the inclusion of green moisture and leguminous crops and use of eco-friendly inoculums to lessen amount of fertilizer use, should also be the part of the institutional adaptation.

Under climate change situation fresh water for irrigation will be scarce while the demand of water will be more for cropping. To adapt to the situation, the national agricultural research system shall have to devise and disseminate information on appropriate soil-crop-irrigation water management technique without sacrificing crop yield. In this respect, the question of using arsenic contaminated ground water for crop production, its long-term effect on the crop quality and yield along with its effect on the food chain shall have to be considered.

Much of the cropland in the coastal region remains fallow during dry winter due to the absence of appropriate tillage device. Absence of the vegetation cover aggravates the soil salinity level through capillary rise of salt water from the ground. This reduces the total yield and thus creates pressure on the food production and employment situation. National agricultural research system shall have to evolve technique for low-cost tillage of land, timing, tillage equipment and various other techniques to adapt to the situation.

Coastal agriculture under climate change environment will require specialized extension service for crop and non-crop agricultural productivity. Extensive training of the field workers, their retention in those areas and measures for one stop extension service should be a part of the institutional adaptation. Under the climate change environment, cropping will be more stressed and, as such, matching with the dynamics of climate change will be a challenging task. The aspects of climate change and its effect on agriculture thus has to be in-built within the institutional framework. Broad institutional guidelines on research and development in agriculture for adaptation to climate change should be the major responsibility of the research system.

The climate change will seriously affect the resource base of the poor farmers. To assist the users in adopting improved technologies to mitigate climate change effect, soft term credit facility and its timely disbursement has to be a major component of the institutional adaptation.

4.7 Forests and Biodiversity

4.7.1 Forest

Forestry contributes to a great extent to the economic and ecological stability of Bangladesh. According to a recent estimate, total forestlands including plantations, gardens and homesteads cover about 2,600,000 hectares in Bangladesh, which is 17.87 per cent of the land surface of the country.

Forestlands

- 2,600,000 hectares (ca. 18% of total land surface) forestland, including village forests and tea gardens
- 670,000 hectares evergreen forest
- 123,000 hectares deciduous forest
- 601,700 hectares natural and 130,000 hectares coastal and forested mangrove forest
- 270,000 hectares village forest
- 40,000 hectares social forest
- 70,000 hectares tea garden

Source: Department of Forest, Bangladesh, 1995.

Most of the forests of Bangladesh are located in the greater districts of Chittagong; Chittagong Hill Tracts (CHT), Sylhet, Khulna, Dhaka, Mymensingh and Tangail. The moist deciduous forests are found in Dhaka, Mymensingh, Rangpur, Dinajpur and Rajshahi districts. In the coastal areas, plantations have been established on the newly accreted char land.

Types of Forests in Bangladesh

1. **Hill Forest**
   Reserved Forest
   Unclassified State Forest
2. **Plain-land Forest**
   Deciduous Forest
   Village Forest
3. **Mangrove Forest**
   Sundarban Natural Forest
   Coastal Afforestation
4. **Social Forest**
5. **Tea Garden**

Throughout the country the forestlands are largely devoid of adequate natural cover, except negligible forest pockets. To conserve plants and other bio-diversity, the GOB has declared a number of protected areas throughout the country. However, a vast majority of land designated as forests is without tree cover. Under the management of the Forest Department, the three main types of forests are hill forest, plain-land forest and mangrove forest.

Hill Forest

The total area of hill forest is 670,000 hectares, which is 4.54 per cent of total land area of the country. The hill forests have been broadly classified as tropical wet-evergreen forest and tropical semi-evergreen forest. Under hill forests the following types of forests are found:

- Reserved Forests (RF)
- Unclassified State Forests (USF)

The Reserved Forests are managed by the Forest Department who collect revenue from them. Rest of the hill forest comes under Unclassified State Forests.

Most of the hill forests in Bangladesh are characterized as mixed evergreen forests. In such forests, the tropical evergreen plant communities are mixed with tropical deciduous trees, in association with diverse herbs, shrubs and bamboo jungles. Forests in greater Chittagong Hill Tracts, Chittagong and in Sylhet and Mymensingh districts fall under this category. Usually canopies of different evergreen trees are formed, having three distinct heights and gallery sequences. Among the dominant trees are Garjan (*Dipterocarpus turbinatus*), Uriam (*Bouea oppositifolia*), Civit (*Swintonia floribunda*), Telsur (*Hopea odorata*), Chandul (*Tetrameles nudiflora*), Boilam (*Anisoptera scaphula*), Jarul (*Lagestroemia speciosa*), Dhaki jaam (*Syzgum grande*) and Chaplaish (*Artocarpus chaplasha*).

Hill forests in the eastern districts of Chittagong, Cox's Bazar, Sylhet and CHT region are tropical evergreen or semi-evergreen forests. The most important commercial timber species of the CHT are Jarul, Gamari (*Gmelina arborea*), Garjan, Chaplaish, Toon (*Cedrella microcarpa*), Koroi (*Albizia procera*), Civit, Champa (*Michelia champaca*), Shimul (*Salmalia insignis*) and Chandul.

Apart from evergreen and deciduous forest vegetation, bamboo and savannah type of forests areas are of immense economic and environmental value. Bamboo grows among various types of forests in CHT and Sylhet. The bamboo is used as a raw material to make pulp for paper mills. It is also used for house construction and supports many cottage industries. Forests of the savannah type are those where there are practically no trees and the areas are covered by Sun grass. A very large tree portion of the Unclassified State Forests consists of this type of forest. The natural look and character of the CHT forest has been changed due to human intervention through plantation activities. Rubber plantations undertaken by the Bangladesh Forest Industries Development Corporation (BFIDC) have not proven to be environmentally or economically successful. They have played a role in hastening deforestation and changing the natural character of the CHT forests.

Sal Forest

The traditional Sal forest used to extend over Madhupur Tract, as well as the districts of Dhaka, Mymensingh, Rangpur, Dinajpur and Rajshahi. Now the Madhupur Sal forest is the largest Sal forest patch in the country. In the Sal forest, 70-75 per cent of the trees are Sal (*Shorea robusta*) and the soil looks yellowish-red in color. The other commercially valuable trees in the Sal forest are Koroi (*Albiura procera*), Chambal (*Artocarpus chaplasha*), Harotaki (*Terminalia chebula*), Bahera (*Terminalia belerica*) and Banja (*Zanthoxylum rhetsa*). Most of the Sal forest has been denuded, degraded and encroached upon by people or used for plantation of rubber monoculture and mostly exotic commercial fuel-wood species. The demand for Sal and other forest products seems unlimited. Even though now the supply has decreased drastically, Sal trees including the stumps are still used as fuel in brick kilns and for industry.

Reed-Land Forest

The reed-land forest situated in Sylhet comprises a total area of 23,590 hectares. The forest ranges from swamp forest to mostly reed or Nal (*Phragmites karka*), Kash (*Saccharum spontaneum*) and Ikra (*Saccharum ravinae*) and in some areas there are also permanent water bodies. The reed-land areas are also very rich in faunal diversity. A survey reported 27 mammals, 49 birds, 22 reptiles and 9 amphibians from the reed-land forest. All of them are used as food, medicine, bait, for commercial trade and recreation. The reed-land flood plains are also rich in fisheries resources. Due to indiscriminate harvesting, the reed populations are declining. The rate of depletion is as high as 60 per cent in particular areas. Therefore, proper management is necessary to protect the reed-land forest.

Mangrove Forest

Bangladesh has one of the most biologically resourceful and unique forests known as the Sundarbans. The Sundarbans is the largest mangrove forest in the world. Mangrove forests have a unique combination of terrestrial and aquatic ecosystems. The mangrove forests serve as a natural fence against cyclones and storm surges, stabilize coastlines, enhance land accretion and enrich soil near the aquatic environment. The Sundarbans Reserve Forest occupies an area of 601,700 hectares of which, 406,900 ha are forests, 187,400 ha water (rivers, rivulets, ponds and canals), 30,100 ha form wildlife sanctuaries and 4200 ha are sand bars. It is home to several uniquely adapted flora and fauna and provides feeding and nursery grounds for many animals. Many animals spend their entire life in the mangroves, whilst others spend some part of it.

The mangrove forest is very rich in bio-diversity and supports 334 species of plants, as many as 77 insects of different orders, 7 crabs, 1 lobster, 23 shrimp/prawns, 400 fish, 8 amphibians, 35 reptiles, 270 birds and 42 species of mammals. There are about 12 and 23 species of orchids and medicinal plants, respectively, found in the Sundarbans. It is also the largest honey-producing habitat in the country with giant honey bees (*Apis dorsata*). The best tree for producing honey in the Sundarbans is Khulshi (*Aegiceras corniculatum*). The Sundarbans is the only remaining habitat of the famous Royal Bengal Tiger (*Panthers tigris*) and estuarine crocodiles (*Crocodylus porosus*) occur extensively in the rivers. The forest harbors large numbers of threatened wildlife species including Python, King Cobram Adjutant Stork, White-bellied Sea Eagle, Clawless Otter, Masked Fin-foot, Ring-lizard and River Terrapin. The Sundarbans is also home of thousands of spotted dear (*Axis*).

Out of 26 species of mangroves, the two dominant ones are the Sundari (*Heritiers fomes*) and Gewa (*Excoecaria agallocha*). Among the trees, Gewa and Goran (*Ceriops roxburghiana*) are being used in newsprint mills for paper production, as well as for fuel-wood. The Sundari and Keora (*Sonneratia aoetala*) are used as timber woods. Leaves of gol pata (*Nypa fruticans*) are used for thatching. At present, there is no commercial timber felling due to a moratorium imposed by the Government of Bangladesh, with the exception of Gewa and Goran. Another mangrove forest totally about 900 ha of land at Chokoria Mangroves in Cox's Bazar has been destroyed mainly due to uncontrolled logging, agricultural expansion and shrimp culture.

4.7.2 Biodiversity

Because of its geographical settings and climatic characteristics, there are many rivers and streams existing in the country covering a length of 22,155 km. In addition to the regular inland waters, seasonally a large part of the country remains submerged for 3-4 months during monsoon. The country is rich in fish and aquatic resources and other bio-diversity Table-4.15. Bangladesh's inland water bodies are known to be the habitat of 266 species of indigenous fish, 13 exotic fish, 56 prawns, about 26 freshwater mollusks, 150 birds.

Table 4.15: Flora and Fauna and Species in Bangladesh

Category	Total number of Species
Flora	
Angiosperms	5000
Gymnosperms Algae/seaweed	5
Algae/seaweed	168
Fauna	
Sponges	3
Corals	66
(Marine + freshwater) Mollusks	(336+26) 362
Insects	2493
Mites	19
Shrimp/prawns	56
(Marine + freshwater) Crabs	(11+4) 15
Lobsters	3
Echinoderms	4
(Marine + freshwater) Fish	(442+266) 708
Amphibians	22
(Marine + inland) Reptiles	(17+109) 126
Birds	628
(Marine + inland) Mammals	(3+110) 113

Source: Khan, 1991: Ahmed and Ali, 1996; IUCN, 2000

The marine water bodies (200 nautical miles off the coast) are also remarkable for being habitat of 442 species of fish. There are at least 36 species of marine shrimps. About 336 species of mollusks, covering 151 genera have been identified from the Bay of Bengal. In addition, several species of crabs and 31 species of turtles and tortoises, of which 24 live in freshwater, are found in Bangladesh (Sarker, 1998; and Ali, 1997). Ahmed and Ali (1996) published a species list of 168 seaweeds, 3 sponges, 15 crabs, 3 lobsters, 10 frogs, 3 crocodiles, 24 snakes, 3 otters, 1 porcupine, 9 dolphins and 3 species of whale found in Bangladesh. There are numerous invertebrates in the country that are yet to be identified. Various authors have recorded about 70 species of bees and many species of wasps (Alam, 1967).

In Bangladesh only about 8-10 per cent of the land area is under good canopy cover. It supports approximately 5000 species of angiosperms, out of which about 300 species are being cultivated. The list of medicinal plants is currently being revised at the Bangladesh National Herbarium (BNH) and is expected to exceed 5000 species. Mia and Haque (1986) showed that there are 224 species of timber-yielding plants found in Bangladesh. Khan and Mia (1984) described 130 species of indigenous fiber plants.

The IUCN Bangladesh Red Data Book (2000) has described 226 species of inland fishes, 442 marine fishes, 22 amphibians, 109 inland reptiles, 17 marine reptiles, 388 resident birds, 240 migratory birds, 110 inland mammals, as well as 3 species of marine mammals in Bangladesh. According to the Red List of IUCN, there are 54 species of inland fishes, 8 amphibians, 58 reptiles, 41 resident birds and 40 mammals, which are threatened throughout the country. Among the marine and migratory species of animals, 4 fishes, 5 reptiles, 6 birds and 3 mammals are threatened. So far, the Red Data Book on plants, which is under preparation at BNH, lists 96 seed-bearing plant species that are threatened.

The depletion of bio-diversity is the result of various kinds of human development interventions and activities, especially in the areas of agriculture, forestry, fisheries, urbanization, industries, chemicals, minerals, transport, tourism and energy. Both flora and fauna are threatened by the loss of habitat resulting from increasing human populations and unwise bio-resource utilization Table-4.16. Increasing demand for timber and fuel-wood, encroachment for other purposes and *Jhum* (shifting) cultivation in the hilly districts, might be the aggravating factors in the annual rate of deforestation and degradation. The unplanned rapid urbanization and industrialization are leading to waste and pollution problems that affect natural ecosystems. As the land and water-based ecosystems are environmentally compromised, the flora and fauna populations are being seriously affected.

Table 4.16: Major Threats to Bio-diversity

• Destruction of habitat
• Overexploitation of flora and fauna
• Indiscriminate use of agro-chemicals
• Industrial waste disposal
• Oil spills
• Encroachment into the natural forests
• Change in land use pattern and land use conflict

Several wildlife species have become extinct in Bangladesh and many more are threatened. Most of the economically important local plants, medicinal plants, etc., are also under equally great pressure and are likely to be lost due to habitat destruction and unsustainable harvesting.

Causes for Depletion of Wildlife Diversity

Till end of the 19th century, wildlife was holding ground over sizable area of Bangladesh (Hussain 1974). All the forest types and village groves had a rich fauna. At least 18 species of vertebrate animals became extinct during the last century from their natural habitats in Bangladesh (Table-4.17). Still species diversity is quite good although population status of important species is unsatisfactory. Besides, information on invertebrate animals is insufficient for their high diversity, lack of studies and limited resource personnel. A list presented by the IUCN (2000) shows that many animals are threatened and the position is quite delicate especially for the mammalian fauna (Table-4.18). A sharp decline of wildlife took place for various reasons such as:

- *Indiscriminate hunting*
- *Poaching of animals*
- *Export of animals*
- *Habitat destruction*
- *Lack of people's awareness*
- *Poor management of protected areas and reserved forests*
- *Lack of a plan for compatible forest and wildlife management*
- *Inefficient implementation of law for wildlife conservation*
- *Natural calamities like flooding, storm surge, etc.*

Table 4.17: Extinct species from Bangladesh during the last century

English Name	Scientific Name
Reptiles	
Marsh Crocodile	*Crocodylus palustris*
Birds	
Pink headed Duck	*Rhodonessa caryophyllacea*
Burmese Peafowl	*Pavo muticus*
Greater Adjutant	*Leptotilos dubius*
King/Black Vulture	*Sarcogyps calvus*
Bengal Florican	*Euphodotis bengalensis*
Mammals	
Great one-horned Rhinoceros	*Rhinoceros unicornis*
Lesser one-horned Rhinoceros	*R. Sondaicus*
Asiatic two-horned Rhinoceros	*Didermocerus sumatrensis*
Blue bull/Nilgai	*Boselaphus tragocamelus*
Wild Buffalo	*Bubalus arnee/bubalis*
Gaur	*Bos gaurus*
Banteng	*Bos banteng*
Swamp Deer/Barasingha	*Cervus duvauceli*
Hog Deer	*Axis porcinus*
Wolf	*Canis lupus*
Marbled Cat	*Felis marmorata*
Golden cat	*Felis temmincki*

Source: Hussain, 1992

Table 4.18: Status of wildlife and fish fauna in Bangladesh compared to India and the world

Class	No. of Species		No. of species in Bangladesh	Bangladesh share in India (%)	Bangladesh share in world (%)
	World	India			
Mammalia	4,629	372	123	33.06	2.66
Aves	9,682	1228	632	51.47	6.534
Reptalia	5,680	446	154	34.53	2.71
Amphibia	5,145	204	23	11.27	0.45
Pisces	21,723	2546	735	28.87	3.38

Source: Siddiqi, 1996

Table 4.19: Status of inland and resident vertebrates of Bangladesh

Group	Total No. of Living Species	Extinct	Threatened				Data Deficient	Not Threatened
			Critically Endangered	Endangered	Vulnerable	Total		
Fishes (fresh water and brackish water)	366	0	12	28	14	54	66	146
Amphibians	22	0	0	3	5	8	7	7
Reptiles	109	1	12	24	22	58	39	12
Birds	388	2	19	18	4	41	158	189
Mammals	110	10	21	13	6	40	53	17
Total	859	13	64	86	51	201	323	371

Source: IUCN, 2000

4.7.3 Vulnerability

Official estimates reveal that about 17.8 percent of the total land in Bangladesh is currently covered by forests and woodlands (BBS, 1997). However, the area under forest cover is shrinking rapidly due to over exploitation of forest resources and gradual conversion of forestlands for other uses. Results of available studies on climate change impacts on vegetation are inconclusive. In Neilson (1998), the IPCC reports that under some scenarios of climate change for late in the 21^{st} century, Bangladesh would become a savanna/woodland, whereas under other scenarios, conditions would become wet enough to support tropical broad-leaf forests (such as those now found in Assam and Meghalaya), The modeling results are inconsistent on whether the density of vegetation will increase or decrease. Studies on vegetation changes in Bangladesh under scenarios corresponding to the first half of the next century are not available. It is, however, reported that climate change induced additional flooding would adversely affect the Artocarpus species (Ahmed et al., 1998) especially Artocarpus heterophyllus (jackfruit, the tree bearing the national fruit of Bangladesh). Similarly, other flood vulnerable species including Azadirachta indica, Cajanus cajan, Leucaena leucocephala would be affected. It is also feared that the Sal forest ecosystems in the Madhupur and the Barind Tract areas would face additional moisture stress. Further water stress due to increased groundwater demand for irrigation would have compounding effects on the regeneration process of the species in those areas. Tea production in the Sylhet region might also decline due to uneven rainfall in winter and due to extreme weather events.

Bangladesh contains 18 threatened species of mammals, 30 threatened bird species, and 24 threatened plant species (WRI, 1998). A change in climate could lead to the extinction of these species, although such risks have not been assessed for the country. Sea level rise may inundate the habitat of many of these species, whereas drier conditions could reduce moisture supplies. Huq et al. (1996) concluded that the Haor wetlands would also be at risk from climate change.

Bangladesh has a relatively large fishing industry. During 1993-95, the country annually produced 250,000 metric tons of fresh water fish from aquaculture. During that period, a total of 713,000 metric tons of fresh water fish and 389,000 metric tons of marine fish were caught (WRI, 1998). Fisheries are also one of the important sectors for Bangladesh in terms of supply of protein and foreign exchange earning. More than 80 percent of the animal protein intake of Bangladeshis comes from the consumption of fish.

Sea level rise poses a severe threat to the Sundarbans. A possible 50 cm sea level rise by the year 2050 could inundate 75 percent of the Sundarbans (Qureshi and Hobbie, 1994). While the sea level rise may be counterbalanced by natural uplift, the extent of uplift is highly uncertain. It is also reported that, climate change induced higher evapo-transpiration, and low flow in winter would increase salinity. As a result, growth of fresh water loving species would be impaired. Eventually, non-woody shrubs and bushes would gradually replace the species offering dense canopy cover. It is also feared that the overall productivity of the forest would decline significantly (Ahmed 1998). Once the quality of the forest is degraded it may be concluded that the rich diversity of forest flora and fauna would also face degradation in a warmer world.

The Sundarbans is home to the Royal Bengal tiger as well as marine turtles, crocodiles, frogs, and fresh water dolphins. With the loss of the Sundarbans, habitat for these species would also be lost. Whether these valuable species would survive elsewhere is not known.

4.7.4 Adaptation

The following adaptations may be considered as part of sustainable management of ecosystems in Bangladesh. In considering protection of the Sundarbans; in addition to strengthening the ongoing activities under Sundarbans Bio-diversity Programme (SBP), Sustainable Environmental Management Programme (SEMP) and Bangladesh Environmental Management Program (BEMP), a sustained flow of water is required in the Gorai-Madhumati system of at least 250 m^3/s. This adaptation is connected with freshwater availability. Since the feasibility of the construction of the proposed Ganges Barrage is not yet ascertained, some other techno-economically feasible, environmentally sound and socially acceptable options should be sought. The excavation of the Gorai River has been implemented. However, its effectiveness and downstream effects are still to be thoroughly evaluated. Regular dredging seems to be a requirement. It is not known whether the sediment creates a problem to the important three species in the Sundarbans, and the brackish water fish species including the tiger prawn.

Creation of coastal greenbelts as an adaptation measure in the bio-diversity sector scores high both in terms of effectiveness. Present agro-forestry development programs could be further expanded.

Adaptation to conserve the 14 ecologically critical areas of the country is absolutely necessary to ensure the sustainability of the society and food self-sufficiency. To slow the rate of depletion of organic carbon content from the topsoil, efforts should be given to replenish it by adding organic fertilizers (dung, green manure etc.) along with inorganic fertilizers. The Fertilizer Recommendation Guide, periodically published by BARC, could disseminate such ideas with appropriate dosages and application advice. Introduction of "alien" species / genetically modified organisms as practiced in the country is highly questionable, and only mentioned here to highlight the need for more research prior their introduction.

Reduction of habitat fragmentation and development of migration corridors and buffer zones are identified as possible adaptation options. Geographic habitat fragmentation may threaten the ability of species to migrate or adapt to changing climate. Habitat fragmentation could be reduced through incentive programs for multiple-use management, or through the protection of important land parcels from development. Buffer zones around current reserve areas could favor protection. In the outer buffer zones or corridors more uses are allowed (Benioff and Warrant, 1996). While development of buffer zones is considered under SBP, climate change considerations remain to be incorporated. Some researchers believe this adaptation would not be a feasible measure for Bangladesh.

Introduction of integrated ecosystem planning and management reduces the institutional fragmentation and focuses on protecting a variety of species and natural systems in connection with their users. Potential effectiveness of such methods is high, and could be attempted under ICZM or CZDP. Stimulating awareness, participation of local communities and users, and community-based management are crucial adaptation measures for the ecosystem of densely populated Bangladesh. Community-based adaptation, i.e. the local community decides on how to share the limited common resource, could be part of the protection of ecosystems., fishing resources and mangrove belts.

Breeding of threatened species has been tried successfully in some countries. For example, breeding of (controlled) game farming enhances bio-diversity by incorporating wildlife in traditional ecosystem management practice (Markham and Malcolm, 1996). This has been practiced for certain fish types in the Haor Wetlands. Applicability of such adaptation for the different important species of the Sundarbans may be examined.

With the exception of studies on the effects of low flow induced increased salinity in the Sundarbans, there have not been much studies on the effects of changes in temperature, precipitation, and climate extremes on endemic species and ecosystems in Bangladesh. Studies on risks from climate change to endemic species and ecosystems would facilitate adaptation under a warmer world.

4.8 Fisheries

4.8.1 Background

Bangladesh is located in the delta of the world's three major river systems having the reputation of being very rich in inland open water capture fisheries production. Inland water fish used to be caught practically by most of the people, particularly those living in the rural areas. Men, women, and children at their doorsteps could capture a large number of fish and prawn during the monsoon, when all the low-lying areas of the country remain under floodwater. According to the World Bank (1989), Bangladesh is the world leader with 4,016 kg/km^2 of freshwater fish production.

Fisheries play a major role in nutrition, employment, foreign exchange earning and the other areas of the economy of Bangladesh. Fish alone supplies about 80% of animal protein and about 1.2 million people are directly employed by this sector. Another 11 million people indirectly earn their livelihood out of the activities related to fisheries. Fisheries sector contributes 3.5% of the country's GDP (World Bank, 1991). Within the agriculture sector, fisheries accounts for about 10% of the gross value added. About 9.5 million households i.e. about 73% of all the households in Bangladesh get involved in the seasonal or part-time fishing in floodplains during the monsoon months (Source: A Brief on Department of Fisheries – Bangladesh, GoB, July, 1999). The share of fisheries in total export earnings is about 77% (Source: Fisheries Resources Information of Bangladesh, 2000-2001) and currently occupies the third highest position after jute and readymade garments (Source: CPP-II, FAP-7, May 1992). The inland fish production of Bangladesh ranks third in the world after China and India (Ref: Stocking water bodies Gazi N. Alam, The Bangladesh Observer, March 9, 1997).

From habitant points of view, three principal habit forms exist from which fish are harvested. These are (i) major rivers and their floodplains (ii) ponds, lakes, beels & haors and (iii) estuaries. Among them area under rivers and their floodplains and estuaries are 90 and 8 percent of inland open water, respectively. The water area of both inland and marine fisheries is shown in Table 4.20 and Table 4.21 respectively.

Table 4.20: Water Area of Inland Fisheries (Year: 2000-2001)

Type	Area (ha)
(a) Closed water body	**388341**
Ponds and ditches	241500
Oxbow lakes	5,488
Shrimp farms	141,353
(b) Open water body	**4,920,316**
Rivers and Estuaries	1,031,563
Beels	114,161
Kaptai lake	68,800
Flood plains	2,832,792
Polders/Enclosures	873,000

Source: Fisheries Resources Survey System (FRSS), DoF, MOFL, GoB (-2000-2001).

Table 4.21: Water Area of Marine Fisheries (Year: 2000-2001)

Type	Area
Territorial water (upto 12 nautical miles from baseline)	2,640 sq.n. miles
Exclusive Economic zone (200 nautical miles from the base line	41,040 sq. n.miles
Continental shelf (up to 40 fathom depth)	24,800 sq.n.miles

Source: Fisheries Resources Survey System (FRSS), DoF, MOFL, GoB (2000-2001).

In the inland open water system of Bangladesh, there exist 260 species of finfish belonging to 55 families (Rahman, 1989), about 63 species of palaemonied and penaeid prawn and several species of crab belonging to the family Potamonidae. Besides 31 species of turtles and tortoises are found of which 24 live in freshwater (Sarker and Sarker, 1988). Fish species available in Bangladesh and presently fishermen involved in this sector is presented in Table-4.22.

Table 4.22: Fish species and Fishermen in Bangladesh (Year: 2000-2001).

Type	Numbers
Fish Species	
Freshwater fish species	260
Exotic fish species	12
Fresh water prawn species	24
Marine fish species	475
Marine shrimp species	36
Inland Fishermen	770,000
Marine Fishermen	510,000
Fry collectors	445024
Shrimp fry collectors	443,024
Fish spawn / fry collectors	2,000

Source: Fisheries Resources Survey System (FRSS), DoF, MoFL, GoB (2000-2001).

In the year 1987-88, the area of inland fisheries totaled 4.3 million ha, of which 94% was open water capture areas (which accounted for 71% of inland fish production) and the remaining 6% was closed water culture fisheries (29% of inland fish production). In case of marine fisheries, Bangladesh has a coastal belt of 710 km. Fishing area is estimated to be 14,000 km^2. Marine fish catch is divided into industrial and artisanal. The artisanal fishery extends up to a depth of 40m in the Bay and harvest more than 95% of the total marine fishery landing.

The fish intake and demand in Bangladesh (Year: 2000-2001) is shown below:

- per capita annual fish intake : 12.04 kg
- annual total fish demand : 2.30 million mt.
- per capita annual fish needed : 18.00 kg

Source: Fisheries Resources Survey System, DoF, MOFL, GoB (2000-2001)

From the above picture it appears that Bangladeshis are still running deficiency in meeting individual fish intake demand. Per-capita consumption of fish has declined from some 12 kg in 1964-69 to about 7kg in 1989-90. The decline in consumption is more evident in rural than in urban areas. The fish production status of Bangladesh is shown in the Table-4.23.

Table 4.23: Year-wise Fish production in MT of Bangladesh (1990-1991 to 1999-2001)

Source	1990-91	1991-92	1992-93	1993-94	1994-95	1995-96	1996-97	1997-98	1998-99	1999-2000
A. Inland Fisheries	654,397	706,605	770,162	837,566	908,218	988,238	1,085,764	1,190,761	1,242,620	1,321,151
(a) Inland open-water (Capture)	443,404	497,742	532,419	573,376	591,145	609,151	599,900	615,949	649,418	672,059
River & Estuaries	135,355	124,843	138,746	143,425	152,782	165,637	159,660	156,894	151,309	167,478
Sundarbans	6,651	6,297	6,939	7,127	6,951	7,265	9,225	7,031	11,134	12,235
(Beel (Depression)	47,923	49,201	53,019	55,592	58,298	60,768	62,798	67,812	69,850	81,866
Kaptai Lake	4,392	4,216	4,142	6,635	5,556	6,148	5,764	5,932	6,689	8,135
Flood Lands	249,083	295,185	329,573	360,597	367,558	369,333	362,453	378,280	410,436	402,345
(b) Inland Close Water (Culture)	210,993	226,863	237,743	264,190	317,073	379,087	485,864	574,812	593,202	649,092
Ponds	181,018	195,034	202,167	222,542	267,282	307,974	403,830	483,416	499,590	547,677
Baors (Ox bro-lake)	1,544	1,682	1,803	2,201	2,460	2,764	3,014	3,378	3,536	4,940
Shrimp Farms	28,431	30,147	33,773	39,447	47,331	68,349	79,020	88,018	90,076	96,475
B. Marine Fisheries	241,538	245,474	250,492	253,044	264,650	269,702	274,704	272,818	309,797	340,000
(a) Industrial	8,760	9,623	12,227	12,454	11,715	11,959	13,564	15,273	15,818	16,450
(b) Artisanal	232,778	235,851	238,265	240,590	252,935	257,743	261,140	257,545	293,979	323,550
Country Total	**895,935**	**952,079**	**1,020,654**	**1,090,610**	**1,172,868**	**1,257,940**	**1,360,468**	**1,463,579**	**1,552,417**	**1,661,151**
Annual Growth Rate	4.72	6.27	7.20	6.85	7.54	7.25	8.15	7.58	6.07	7.06

Source: FRSS, DOF, 2000-2001.

4.8.2 Vulnerability

Fisheries of Bangladesh would be affected by the global warming and sea level rise. The level of impact of climate change will vary widely and will also depend on attributes of the species. Ali (1998) attempted a speculative assessment that revealed that fish growth and production might face some adversities under climate change. Low flow conditions in the winter would reduce wetland areas and might cause-declining fish stock in the remaining wetlands. Sea level rise could also push saline waters further into the GBM delta, reducing habitant for fresh water fish. Increased water temperature could cause reduction in the concentration of dissolved oxygen, thereby decreasing the habitat suitability for the fish, especially for the hatchings. Increased risk of cyclone induced storm surges in the coastal areas would reduce fisheries activities including culture fisheries. Major impacts on fisheries due to climate change are briefly described below.

Climatic Elements

Rainfall, temperature, humidity and solar radiation-all affect fish growth and production. Climate variables affect the growth and economic production of particular species of fish at specific locations. Furthermore, growth and yield may fall/rise abruptly when extreme conditions of drought, flood or high temperatures occur. However, in Bangladesh the critical aspects of climate in relation to fish culture depend on (a) the start and reliability of the pre-monsoon rains; (b) the reliability, amount, distribution, and end of the monsoon rains; (c) the rise, duration, and recession of floods. Among the climatic elements, rainfall is the key factor that affects fish growth and yields directly and is also associated with other climatic variables. The seasonal and regional distribution of rainfall is an important consideration for fish production since it is the primary determinant of fish life and is the main source of variation in the fish environment of Bangladesh. The monthly distribution of rainfall is essential in planning understanding fish culture. During two to four months of dry spell, careful planning of fish culture is required. With five to six dry months, continuous culturing during this period without water supply is risky. Climate change in Bangladesh will likely lead to increase in precipitation, increased frequency and intensity of flood during monsoon months resulting in the escape of the fishes. These factors are deterrent for aqua-culture development in the country.

Impact on Marine And Estuarine Capture Fisheries

Climate change and consequent sea level rise is likely to affect the water temperature and salinity regimes in the upper Bay of Bengal. Enhanced water temperature may affect the reproductive physiology of many of the marine fishes. Increased water temperature is likely to advance the sexual maturation process and timing of spawning of the adults of *Hilsa ilisha* populations. This may upset the timings of their spawning migration into the freshwater rivers and estuarine components. This may alter the abundance of Hilsa populations in the fishing grounds in the estuaries and in the freshwater rivers. Other important fisheries are based on the populations of Bombayduck (*Harpondon nehereus*) Pomfret (Pampus chinensis), and Pampus argenteus and Indian Salmon or Lakhua (Polydactylus indicus). These are all very popular as food fish and occur both in the Bay of Bengal and in the estuaries. This wide range of habitat adaptation of these fishes will likely allow them to adjust themselves to changed salinity conditions. Increased temperature may also bring about changes in the reproductive physiology and season of spawning.

All the major rivers meet the Bay of Bengal in the south of the country. Near the confluence of the sea and the rivers, freshwater is replaced by mix of saltwater and freshwater producing brackish water, and forming a distinct estuarine zone. A wide range of salinity gradients is encountered in the rivers up to a considerable distance upstream from the shoreline of the Bay of Bengal. Along the coast in the south, an estimated 2.5 million ha of low-lying lands are subject to tidal inundation. These areas provide, during high tides, temporary nursery and grazing grounds for larvae, fry, and juveniles of different marine fishes and shrimps (Tsai et al., 1978).

In the southwestern region, the principal ecological feature is the presence of the largest mangrove forest in the world, known as the Sundarbans. An intricate network of large and small rivers, canals, and creeks crisscrosses it. The total water area is estimated at 175,600 ha (Ali, 1991 b). The whole forest area in inundated by tidal water twice every day. Water is estuarine with a wide range of salinities. Rivers in the Sundarbans forests at their northern-ends receive freshwater inflow from upland while in the south they meet the saline waters of the Bay of Bengal. The water in the Sundarbans is rich in detritus and nutrients, supporting a large variety of both cartilaginous and bony fishes, shrimps, crabs etc.

Impact on Freshwater Capture Fisheries

Sea level rise will, in all likelihood, bring about a reduction in the freshwater habitat conditions particularly in the coastal rivers. In the event of such a situation, productions of freshwater fishes such as *cyprinids, anabantids*, and many others, which cannot tolerate any level of salinity in the water, are likely to suffer. Increased upper riparian freshwater flow into the estuaries and coastal areas will alter water salinity gradients of the estuaries and brackish water regions of Bangladesh. Such alterations may make the habitat conditions for various shrimps and fish inhospitable and inaccessible.

Impact on Freshwater Borrow Pits and Pond Culture of Fishes

Pond culture of indigenous major carps (*cyprnids*) such as Rohu, Catla, Mrigal and Kalabaush and exotic carps such as silver carp is practiced extensively in the coastal districts of Cox's Bazar, Chittagong, Noakhali, Feni, Lakshmipur, Bhola, Jhalokati, Patuakhali, Borguna, Pirojpur, Bagerhat, Khulna and Satkhira. During the year 1995-96 (July 95 to June 96), total productions of 105.5 thousand metric tons of major and exotic carps were obtained from freshwater ponds of the aforesaid districts. In the event of sea level rise, these ponds are likely to be submerged under seawater that will lead to the total loss of this major carp production. However, this production can be sustained if constructing embankment with appropriate height can prevent submersion.

There are about more than half a million ponds with a total area of 18,700 ha. Many of these are borrow pits resulting from homestead site preparation. The DOF classifies ponds as cultured (49.1% by area), cultivable (22.8%) and derelict (28.1%). Pond culture will be affected by increased flooding unless pond banks are properly strengthened.

Impact on Brackish Water Shrimp Farming in the Coastal Districts

The rivers, canals and creeks in the coastal region of Bangladesh are tidally influenced and remain so round the year. The salinity level in the waters of these rivers, creeks and canals increase during the dry months from December to April when post-larva and juveniles of marine shrimps such as tiger shrimp (Panaeus mondon), Brown shrimp (*Metapenneus monoceras, M.brevicomis*), etc. travel from the deep sea into the brackish water rivers, creeks and canals. During their sojourn in the brackish water rivers and canals, they are captured and reared in brackish water ponds and enclosures (*ghers*) in the southwestern and south western and southeastern districts.

In view of the worldwide demand for brackish water shrimp, this form of shrimp farming has become popular and such farming is increasing. Table 4.24 presents the year wise figure of shrimp farm areas and production. From the table, it is seen that brackish water shrimp production is increasing steadily. The production in 1989-90 was 27,505 mt and this increased to 68,349 mt in 1995-96. These farm-produced shrimps are mostly exported to earn foreign exchange. It is seen that earnings from shrimp export are also increasing. In the recent year, export of shrimp has become a major source of foreign exchange earning of Bangladesh. It is apprehended that once the sea level rises, all these shrimp farms will go under the sea. Consequently, such a lucrative shrimp farming practice will disappear, making the country lose the foreign exchange earning for good.

Fishery Industry

The shrimp activities are running along the coastal belt of Bangladesh especially in southeastern and southwestern part. Shrimp farming activities are particularly in these parts. It is assumed that the fishery industry too would be affected by the impacts of global warming and sea level rise. A temperature rise of about 2^{0}C may have substantial impacts on the distribution, growth and reproduction of fish stocks. Commercially important fish stocks may change their spawning areas and distribution patterns. A given population within a species is adapted to a hydrodynamic environment of specific temporal and spatial characteristics. Therefore, changes in the ocean circulation way lead to the loss of a certain population of or the establishment of new ones, particularly at the periphery of the areas of species distribution. Fishery, which would be affected include beach seine fishery, sea ranching in coastal areas, stilt fishery, boat landing site, and fisher folk settlements along the beach.

Coral reefs

Rising ocean temperatures will systematically bleach fragile coral reef systems. Ocean temperatures calculated by model projections indicate that thermal tolerances of reef building corals are likely to exceed within the next few decades. Increase in ocean temperature has imposed a severe stress on coral reefs against their tolerance levels. Damage to coral reefs will depend very much on whether coral reef systems can adopt with the rate of change of ocean temperature.

Table 4.24: Brackish water Shrimp farm areas in the coastal districts of Bangladesh and total production of shrimp from the farms

	Years						
Brackish water shrimp farm areas (ha)	1989-90 108,280	1990-91 108,280	1991-92 108,280	1992-93 108,280	1993-94 137,996	1994-95 137,996	1995-96 137,996
Total production of shrimp (MT)	27,505	28,431	30,147	33,773	39,447	47,831	68,349

Source: Fisheries Resources Survey System (FRSS). Department of Fisheries, Bangladesh

4.8.3 Adaptation Responses

As described earlier, due to climate change the fisheries sector will be affected. Besides the extreme events of natural disasters like flood of 1988 and 1998 and catastrophic cyclonic storm surges of 1970 and 1991 brings untold sufferings of millions of people and results in large number of human and livestock deaths, damaged standing crops of large areas, destroyed physical and economic infrastructures, damaged fish and shrimp ponds and hatcheries etc, causing economic loss of several billions of US Dollars of Bangladesh. Under the context as stated above the following adaptation responses have been considered: i.e. Physical and Institutional.

Physical adaptation includes:

- Infrastructure development: construction of embankment, suitable sluice gates where necessary, drainage improvement, excavation and re-excavation of silted khals to facilitate normal flow of water.
- Strengthening and raising of the dykes of the homestead ponds.
- Construction of strong and suitable shrimp gher with appropriate height.
- Stocking of floodplain with rapidly growing fish fingerlings.

- Introduction of poly-culture of carp sp. in culture ponds.
- Introduction of new fishing techniques and constructions of hatcheries.

Institutional Adaptation

Institutional aspects are also important. This aspect includes the following:

- Banning on catch of baby and brood female fish and PL.
- Water management and fish conservation strategies (scientific and modern package used to be introduced).
- Avoiding of water pollution (from agricultural toxic insecticide/pesticide runoffs and industrial and municipal waste)
- Ensuring of fisheries extension services (training and credit)
- Introduction of new package of fish culture technology
- Avoiding of over-fishing and determination of fish stock assessment to maintain MSY (maximum sustainable yield).
- Creation of local association (fishermen, farmers, landless, women, school teacher and service holders) to develop coastal fisheries.
- Awareness creation with regard to flood, cyclone etc. preparations through the participation of NGOs.
- Management of monitoring and evaluation by the members of the local association NGOs & GOB office.
- Conducting sectoral assessment on climate change impacts on fishery development including fishery harbors fishery settlements, and sustainable use of fishery resources as a basis for long term planning.

4.9 Human Health

4.9.1 Background

Throughout the world, the prevalence of particular diseases and threats to human health depend largely on local climate. Extreme climate can directly cause the loss of life. Moreover, several serious diseases appear in warm areas. The warm temperature can increase air and water pollution, which in turn harm human health (Our Environment 2002).

Bangladesh is already vulnerable to many infectious diseases. The warmer and wetter conditions as has been predicted in the future scenarios could make the potential of spread of these diseases greater. The increase of temperature and rainfall over Bangladesh will make the climate more warm, humid and suffocating. According to IPCC (2001), the global warming would enhance the vector-borne and water-borne diseases in the tropics. In addition, the heat stress and heat waves would cause more health problems and the morbidity and mortality would increase especially in the least developed countries like Bangladesh. The anticipated increase in the number and intensity of floods and tropical cyclones would cause more number of deaths, injuries and epidemics in Bangladesh. Thus the human health will be highly vulnerable to climate change resulting from the global warming. The average life expectancy in Bangladesh is 61 years, which is lower than the neighbouring countries. 2/3 of the children under five are malnourished (under weight) and infant mortality is 67 per thousand (BBS 1996).

The access to healthcare is highly limited especially in the rural areas where there is only one doctor for every 4147 people. Only 48 percent of the population has the access to adequate sanitation facilities (WRI, 1998).

The data on the disease profile of Bangladesh have been shown in Table-4.25 (Kabir, 2001).

Table 4.25: Disease Profile 1988-1997: Percentage distribution of diseases by year Records at the District Level and Below

Percentage

Name of Disease	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
Diarrhoeal Diseases	14.14	13.38	17.09	15.05	17.12	14.49	12.46	13.41	14.41	15.90
Skin Diseases	8.06	7.64	5.30	7.03	11.01	9.60	8.90	12.85	9.30	10.47
Intestinal Worm Infestation	9.76	10.31	16.34	9.30	10.88	8.88	10.11	11.52	12.30	7.38
Peptic Ulcer	7.78	7.67	3.36	7.44	9.24	8.28	9.09	7.61	5.55	1.63
Acute Respiratory Infection	6.57	7.07	12.58	7.12	8.36	7.14	6.65	5.15	5.43	6.10
Anaemia	6.81	6.91	4.28	6.74	7.94	6.74	7.99	6.84	9.85	9.92
Deficiency Diseases	5.00	5.19	10.84	8.37	6.39	3.39	6.60	4.44	5.27	6.63
Pyrexia of Unknown Origin	3.66	4.08	1.94	4.99	6.08	4.46	4.57	5.32	4.27	4.06
Eye Diseases	4.05	3.53	2.03	3.66	3.70	3.02	2.97	2.85	3.35	4.36
Injuries	2.29	2.51	1.18	2.70	3.34	2.69	2.58	2.91	3.19	4.35
Ear Diseases	2.29	2.39	1.13	2.46	2.94	2.43	2.20	2.42	2.19	3.28
Asthma	1.31	1.21	0.49	1.26	1.73	1.47	1.43	1.48	2.59	2.31
Dental Diseases	2.08	2.18	0.03	2.53	1.64	1.96	1.93	2.17	2.04	1.89
Obs. Gynae. Complication	0.85	0.93	0.45	0.99	1.21	1.24	0.84	1.13	2.50	0.22
Clinical Malaria	0.67	0.70	0.28	0.53	0.76	0.63	0.62	0.87	1.33	0.67
Hypertension	0.34	0.30	0.12	0.31	0.38	0.31	0.29	0.40	0.88	0.54
Night Blindness	1.19	0.83	0.27	0.44	0.25	2.31	0.21	0.52	0.33	0.17
Whooping Cough	0.88	0.52	0.12	0.26	0.24	0.07	0.02	0.03	0.24	0.02
Hepatitis	0.40	0.30	0.08	0.18	0.17	0.26	0.08	0.08	0.09	0.07
Diabetes	0.14	0.10	0.04	0.11	0.17	0.13	0.08	0.17	0.09	0.11
Poisoning	0.12	0.08	0.04	0.09	0.11	0.08	0.10	0.13	0.14	0.56
Filariasis	0.06	0.04	0.03	0.05	0.05	0.04	0.03	0.02	0.12	0.04
Tuberculosis	0.05	0.22	0.04	0.03	0.05	0.06	0.26	0.28	0.03	0.11
Mental Diseases	0.08	0.06	0.03	0.05	0.04	0.03	0.05	0.14	0.23	0.06
Measles	0.41	0.19	0.04	0.05	0.04	0.02	0.02	0.02	0.16	0.03
Chicken Pox	0.04	0.03	0.03	0.02	0.04	0.01	0.01	0.09	0.02	0.01
Kala-Azar	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.10	0.01
Tetanus	0.03	0.02	0.00	0.01	0.01	0.004	0.005	0.01	0.02	0.01
Diphtheria	0.01	0.01	0.001	0.03	0.00	0.001	0.001	0.003	0.002	0.01
Other Diseases	20.88	21.62	20.85	18.12	20.28	17.22	19.90	17.39	16.30	19.08
Total	3794603 (100.00)	39183667 (100.00)	42825414 (100.00)	42692925 (100.00)	40526413 (100.00)	45689854 (100.00)	46052138 (100.00)	46906768 (100.00)	48796429 (100.00)	56353652 (100)

The reporting of the causes of the morbidity to prepare disease profile of Bangladesh began in March 1987 for 31 selected diseases. The reported diseases with highest incidence of morbidity are the diarrheal diseases, skin diseases, worm infections, vector borne disease mainly malaria and dengue, other communicable diseases and nutritional deficiencies. Women and children below 5 are at particularly high risk of these illnesses. The diarrheal disease, skin disease and worm infections alone account for more than 35% of the total diseases reported.

The diseases like diarrhea, skin diseases, asthma, hypertension and malaria and dengue are found to have higher incidence in the warm season and have been found to have a increasing trend of the incidence in the recent years. The impact and vulnerability of global warming on human health in Bangladesh and adaptations have been discussed based on the data and information available.

4.9.2 Approach

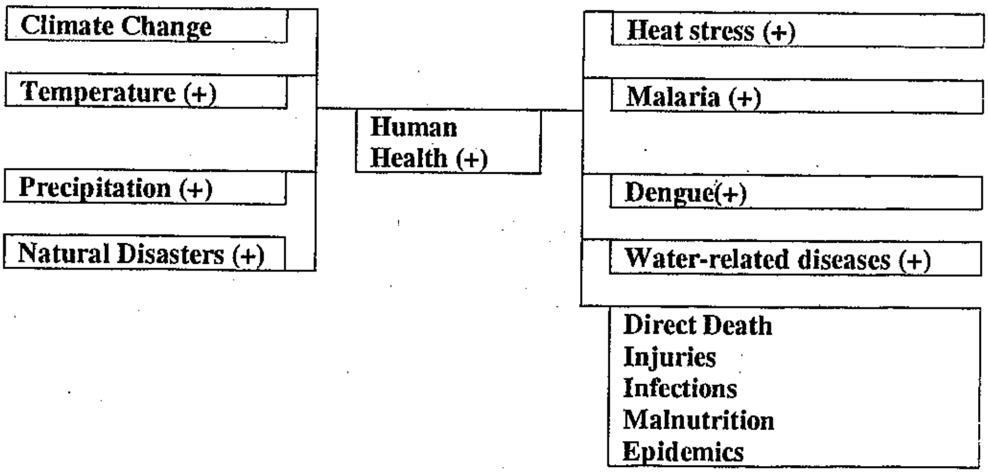
The human health poses a highly complex system depending on the climatic, ecological and environmental factors, social conditions, level of economic development, state of sanitation and public health systems and many other factors. Thus correlating the human health with the climatic variables alone is a difficult task and this may not always produce the reliable results to satisfy the objectives. On the other hand, it is highly difficult to consider all the climatic and socioeconomic variables together to come up with the appropriate functions, which would describe the impact and vulnerability of climate change on human health. Therefore, a simple approach to perform comprehensive impact assessment on human health is adopted based on the general principles as provided by the IPCC guidelines (1996) and UNEP Handbook (1997) along with the application of the expert judgement as and when necessary. The conceptual and graphical analysis of the available data related to human health and climatic variables for Bangladesh during the recent decades have been used. The expert judgment using the existing knowledge in this sector has been applied for qualitative assessment of the vulnerability and adaptations. The historical climate data such as temperature, rainfall, humidity and the Southern Oscillation Index (SOI) have been used along with the data on human health. The mortality / morbidity data on diarrhea / cholera, dengue, malaria , heart and respiratory problems have mainly been considered. The vulnerability and impacts of these diseases and of disasters on human health have been discussed along with the possible adaptation options.

4.9.3 Vulnerability

Based on the UNEP Handbook (1997) and IPCC Report (2001) the climatic impact on human health has been investigated with specific attention to the following environmental conditions and diseases:

- *Heat Stress*
- *Health hazards originating from extreme events / disasters like tropical cyclones and floods*
- *Arsenic contamination in ground water*
- *Vector borne diseases*
- *Malaria*
- *Dengue*
- *Water borne diseases*
- *Diarrhea and Cholera*
- *Skin Diseases*

The study on the impact of and vulnerability to climate change was limited on the above conditions of the environment and diseases. Many of the issues have cross cutting relations, as a result, may have repetition in the discussions. A schematic presentation of potential impacts of climate change on human health is shown below.



Heat Stress

The temperature of Bangladesh has been found to increase in the recent decades. The temperature of the cities like Dhaka and Chittagong has been increasing at high rate. As per the scenarios provided earlier (WB 2000), both the temperature and rainfall would increase in Bangladesh. This will lead to warm and humid climate during the wet seasons. The dry season would be drier due to enhanced evapotranspiration caused by higher atmospheric temperature. Following are the impacts of heat stress on human health which have been assessed based on literatures such as, UNEP Handbook (1998), IPCC Third Assessment Report of Working Group II (IPCC, 2001), information obtained from other various sources and expert judgments.

The most direct effect of climate change on human health would be the hotter temperatures themselves. Extremely hot temperatures increase the number of people who die on a given day for many reasons. Excess mortality during heat waves is greatest in the elderly people and those with the pre-existing illness (Sator et al. 1995; Semenza et al. 1996; Kilbourne, 1997; Ando et al. 1998a,b). Much of this excess mortality from heat waves is related to cardiovascular, cerebrovascular and respiratory diseases. People with heart problems are vulnerable because one's cardiovascular system must work harder to keep the body cool during hot weather. Heat stroke, heat exhaustion and some respiratory problems increase due to high air temperature (Faunt et al., 1995; Semenza et al., 1999).

Higher air temperatures also increase the concentration of ozone at ground level. A warming by four degrees (F) could increase ozone concentrations by about 5 percent. The natural layer of ozone in the upper atmosphere blocks harmful ultraviolet radiation from reaching the earth's surface; but in the lower atmosphere, ozone is a harmful pollutant. Ozone damages lung tissue, and causes particular problems for people with asthma and other lung diseases. Even modest exposure to ozone can cause healthy individuals to experience chest pains, nausea, and pulmonary congestion.

Statistics on mortality and hospital admissions show that death rates increase during extremely hot days, particularly among very old and very young people living in cities. The higher temperature in the dry season will accelerate the evaporation and the surface water will dry up quicker than normal. This would cause the scarcity of surface water, which will affect the human health. Higher temperature in the winter will decrease the severity of cold waves in Bangladesh. This is a positive impact in the winter.

Extreme Events and Weather Disaster

Major impacts of climate change on human health are likely to occur via changes in magnitude and frequency of the extreme events, which trigger natural disaster. These are tropical cyclones, tornadoes and the El Nino related events such as floods and droughts. Some of the major impacts of global warming are the increase in Sea Surface Temperature (SST) and rise in Sea Level (SL). A modeling exercise by Quadir (2002) has shown that the intensity of tropical cyclone would increase and the intensification would be faster in the warmer SST condition. It has further been reported that the SST of the Bay of Bengal is increasing during the last few decades. Moreover, it is very likely that in the warmer SST condition more number of severe tropical cyclones would form. Thus, the storm surges would be higher in a warmer SST condition due to the combined effect of sea level rise and stronger wind speed of the relatively strong tropical cyclones. As a result the adverse effect on the environment and human life will be worse in a warmer condition.

The coastal area of Bangladesh is densely populated. About twenty million people living in the coastal zone are vulnerable to the tropical cyclone. The poor condition of the population over these areas makes them more vulnerable. The rainfall in the catchments of the big rivers is expected to increase due to global warming. Such impacts of global warming have already been noticed and the floods of 1987, 1988 and 1998 may be cited as examples. The number of droughts in Bangladesh is also expected to increase in the future due to global warming and the severe droughts are likely to occur in association with the strong El Nino events.

The increase of vulnerability to extreme weather is primarily caused by the combination of population growth, poverty and environmental degradation (Alexander 1993). In Bangladesh, the concentration of population and poverty in the high-risk floodplains and coastal zone has increased the vulnerability. The health impacts of natural disasters in the Bangladesh context may be generalized as the following:

- Direct loss of human lives
- Physical injury and infections
- Decrease of nutritional states
- Outbreak of diarrhea and respiratory diseases due to lack of access to potable water and from overcrowding of survivors often in the limited shelters.
- Impact of mental health, in some cases may be long lasting
- Increased risk of water related diseases as a result of disruption of water supply and sewage system and contamination of surface water.

The impacts of major disasters on human health are discussed below in details.

Floods

It has been found that the rainfall in the pre-monsoon and monsoon period has been increasing during the recent decades. As per the present trends and the projected scenarios, the monsoon rainfall will increase in the future. This increase will be more over the northern part of Bangladesh and in the adjacent territories of India, Nepal and Bhutan, which would drain over Bangladesh. As a result more frequent and severe floods are feared to occur in Bangladesh in changed scenario of climate. The floods in Bangladesh cause injuries and deaths due to drowning. The sources of the potable water are contaminated by the floodwater. As a result, the waterborne diseases like cholera, hepatitis-A spread very fast due to ingestion of contaminated water. The skin disease also spread due to contact with the contaminated water. Besides, the respiratory diseases also prevail due to overcrowding in the shelters.

A study in populations displaced by catastrophic flood of Bangladesh in 1988 found that diarrhea was the most common illness, followed by respiratory infection. Water diarrhea was the most common cause of death for all the age groups under 45 (Siddique et al., 1999). The number of severely malnourished children had increased after flooding (Choudhury and Bhuiyan 1993). In the aftermath of flooding, molds and fungi may grow on interior surfaces, providing a potent stimulus to allergic persons (American Academy of Pediatrics. 1998). In the future, since more frequent floods of much bigger scale than those occurred in 1987, 1988 and 1998 might occur as per the present trend, the impacts of the floods on human health would be more severe.

The humidity is expected to increase because of high temperature in association of higher rainfall and probable higher frequency of severe floods. The enhanced humidity is likely to increase the occurrences of heart and respiratory diseases and mortality rate from these diseases. The impact of extreme summer heat on human health may be exacerbated by the increase of humidity (Gaffen and Ross, 1998; Gawin et al., 1999).

The excessive precipitation and the resulting floods can transport terrestrial microbiological agents in the drinking water sources. Significant correlation between the cumulative monthly distribution of cholera cases and the monthly distribution of precipitation has been observed in Guam (Borroto and Haddock, 1998). In many of the countries including Bangladesh, handling of the sewage is not separate from the drainage system for storm and floodwater. As a result, the drain water occasionally overflows the drainage system and flows over the surface contaminating the surface water and drinking water and their sources.

Tropical Cyclones and Storms

The coastal areas of Bangladesh are highly vulnerable to tropical cyclones. Many of the most serious impacts of the tropical cyclones in the 20th century has occurred in Bangladesh because of the combination of the meteorological and morphological condition along with the inherent vulnerability of the low income and high poverty of the population. The high rainfall produced by the tropical cyclone can cause flash floods and landslides over the hilly areas of the eastern side of Bangladesh. The deaths are mostly caused due to drowning by the storm surges. The scarcity of food, drinking water, medicine and no shelter of the survivors cause serious problems. The diarrhea and other water borne diseases break through ingestion of the infected water due to drowning and due to using the infected water during post disaster period because of the unavailability of the potable water. The post disaster epidemics become the cause of huge number of deaths.

It has been found that the loss of lives and outbreak of epidemics have reduced in the recent years to a large extent because highly efficient monitoring and warning system are now operating in Bangladesh. Besides, the disaster management system has been strengthened. A good number of cyclone shelters have been constructed in the high-risk zones so that the vulnerable population can take shelter in those shelters. Besides, rescue teams with food, water, shelters and medical services organizedly participate in the rescue and rehabilitation operations. The rescue workers can now reach the sufferers within shorted possible time because of improved communication system.

Arsenic contamination of ground water

During the recent years it has been found that the ground water, which the rural people are drawing through hand-tube-wells and using as drinking water, are contaminated by arsenic poisoning at many locations in Bangladesh. People are getting sick with ultimate fate of deaths due to such contamination. Though this might not be connected with the global warming issues, however, this problem has been detected as one of the gravest problem of the country and probably caused due to excessive extraction of the ground water. In the changed scenario of the warmer climate of Bangladesh in the future and with much higher population the water use in the dry season will increase further; which may be required to meet from the ground water sources leading to more aggravated situation.

Diarrheal Diseases

Cholera is a water and food borne disease and has a complex mode of transmission. In tropical areas, the cases are reported year round, but are more prevalent in the warm season. A new serogroup (V. Cholera o139) appeared in 1992 and is responsible for large epidemics in Asia (Kabir2001).

Vibrio cholerae is often found in the aquatic environment and is part of the normal flora of brackish water and estuaries. It is often associated with algal blooms (plankton), which are influenced by the temperature of the water. It has been reported that the algal blooms occur due to the SST rise favoring the V. Cholera bacterial activities to increase. The IPCC 2001 reported that the SST and rich nutrient load in major river deltas would support extended phytoplankton blooms in selected coastal areas of temperate and tropical Asia. These phytoplankton blooms are the habitats for the survival and spread of infectious bacterial diseases. The cholera outbreak in Bangladesh during 1993 has been attributed to the presence of extended phytoplankton blooms (Colwell, 1996). This phytoplankton bloom in the Bay of Bengal coast is assumed to be linked with the warmer SST associated with strong El Nino activities during that period.

Table 4.26: Cholera cases reported to WHO, 1950-1998

Years	No. of Cholera Cases	Years	No. of Cholera Cases	Years	No. of Cholera Cases
1950 1969	239667	1981	-	1993	12
1970	7419	1982	-	1994	-
1971	2342	1983	-	1995	-
1972	1059	1984	-	1996	-
1973	1969	1985	-	1997	-
1974	5614	1986	-	1998	-
1975	4888	1987	-		
1976	957	1988	-		
1977	10403	1989	-		
1978	5576	1990	-		
1979	2154	1991	-		
1980	-	1992	-		

(Ref: http://www.who.int/emc-documents/surveillance/docs/whocdscsrisr2001.html WHO Report on Global Surveillance of Epidemic-prone Infectious Diseases WHO/CDS/CSR/ISR/2000.1)

Some historical data of Cholera cases for Bangladesh may be seen in Table-4.26. The data were obtained from WHO report (2000). From the above table it is seen that good number of cholera cases were reported in the seventies, but during the eighties and nineties there is no report of cholera except 12 cases in the 1993. In the seventies, it can be seen that the high values occurred in 1970 and 1974 when there were big floods except 1977. These years had strong La Nina situations and the years immediately before had strong El Nino situation. The extreme high figure in 1977 and 12 cholera cases in 1993 coincided with the El Nino situations of relatively longer durations.

According to the above data it appears that cholera transmission is high in the flood years. It is also high in the El Nino years when the weather is relatively dry and warm. Thus, the occurrence of the diarrheal diseases in Bangladesh is high during the hot spells which are generally linked with El Nino phenomenon. On the other hand the incidence of diarrhea is also high during the abnormal floods.

Dengue

Dengue is a disease that is caused by four closely related viruses that are maintained in a human Aedes aegypti-human cycle in most urban centers of the tropics (Gruber, 1997). Dengue is primarily an urban disease. In tropical areas of the world, dengue transmission occurs year-round but has a seasonal peak in most countries during months with high rainfall and humidity. Major factors causing epidemics include population growth, rapid urbanization, lack of effective mosquito control, and movement of new dengue virus strain and serotypes between countries (Gubler 1997, 1998).

For the vulnerability assessment on the transmission of Dengue in Bangladesh, the available data on the occurrences and epidemics of Dengue in Bangladesh and the information provided by the IPCC guidelines and reports have been used. The history of Dengue cases from 1956-1995 is given in Table 4.27.

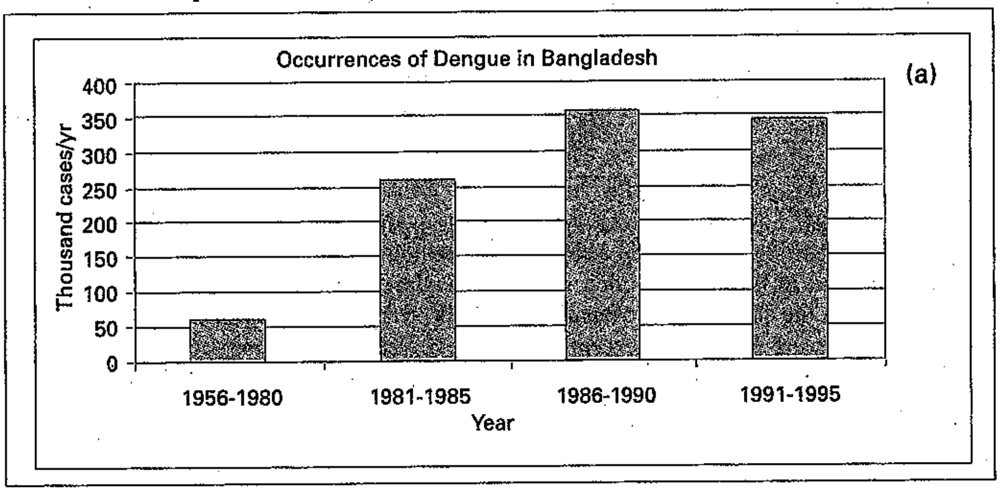
Table 4.27: Number of Cases of Dengue Fever (DF) and Dengue Hemorrhagic Fever (DHF)

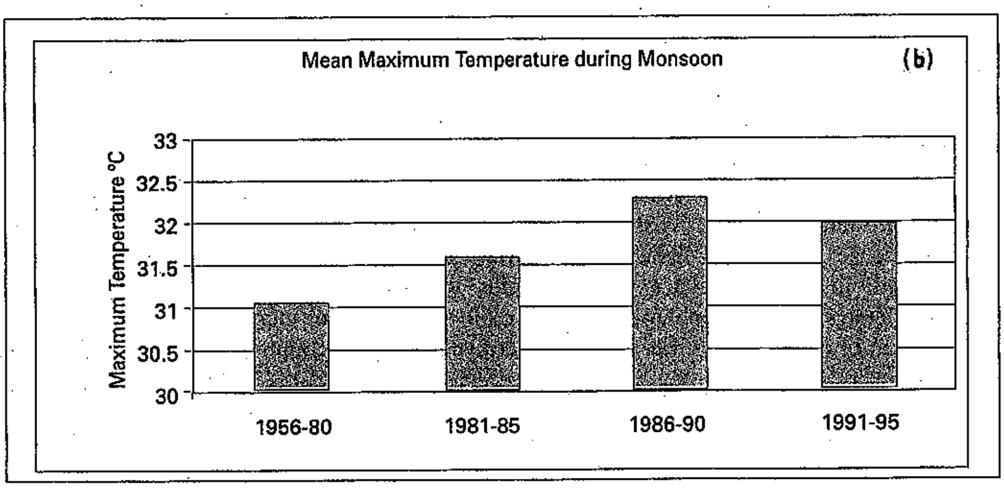
Period	Total no. of cases	Cases/year
1956-1980	1547760	61910
1981-1985	1304305	260861
1886-1990	1776140	355228
1991-1995	1704050	340810

(*Source: http://denguebd.swasthyalook.8k.com/DENGU.html*)

The first number is the aggregated value for the period 1956-1980. The yearly average occurrences of dengue during the period 1956-1980, and five years interval between 1981-1985, 1986-1990 and 1991-1995 have been shown in Figure-4.5. It can be seen from these figures that the increasing trend and variation of dengue occurrences are consistent with the corresponding trend and variation of temperature, which infers that the anticipated future warming in Bangladesh might enhance the dengue occurrence.

Figure 4.5: The occurrences of Dengue in Bangladesh and corresponding mean maximum temperature during monsoon season





The Table 4.28 shows the history of dengue epidemics in Bangladesh.

Table 4.28 Dengue outbreak history in Bangladesh

Period	Description
1964	First documented out break of dengue in Bangladesh
1977-78	Few cases of DF was found in Survey.
1982-83	Out of 2456 blood samples taken, 278 found DEN-1
1883-84	21 samples collected, 3 found positive by HI Test
1997	Cross sectional serological survey at CMCH tested 255 paired sera in which 35 were positive cases.
1999	A few death cases were reported in DHF
2000	Currently an epidemic

Source: http://denguebd.swasthyalok.8k.com/DENGU.html

Comparing this table with the Southern Oscillation Index (SOI) records, it has been found that El Nino Southern Oscillation (SOI) has a good correspondence with the dengue epidemics. It has been shown earlier that the positive anomaly of temperature is observed over Bangladesh mostly during El Nino years (Quadir et al-2002). The dengue epidemic was first reported in 1964. In that year the SOI situation was changing phase from El Nino to La Nina. The rest of the years 1977-78, 1982-83 and 1997 when there were reports of dengue epidemics were El Nino years. The period 1984-86 had dengue epidemics when the SOI were mostly negative but did not experience strong El Nino. In 1999 the SOI substantially decreased but were near to zero. The Dengue was also reported this year. Thus it has been found that there is no report of dengue epidemic in the strong La Nina cases. From the above, it can be concluded that dengue epidemics outbreak in the El Nino conditions. It can happen also in a situation when SOI values are small and lie around zero (positive or negative).

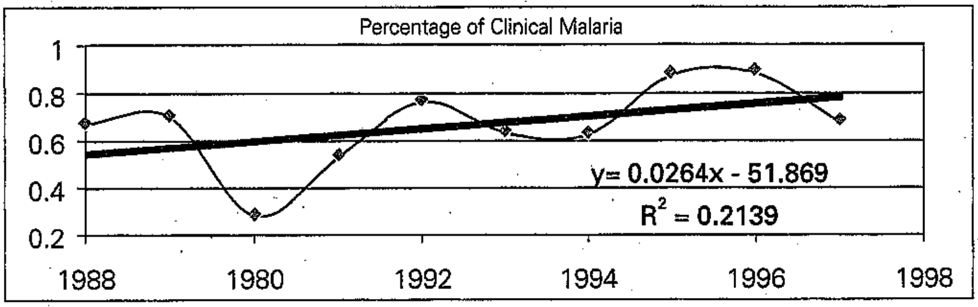
Malaria

Malaria is a vector borne tropical disease and is one of the worlds most serious and complex public health problems. The disease is caused by four distinct species of plasmodium parasite transmitted between individuals and Anopheline mosquitoes. The IPCC 2001 reports that the number of occurrences of malaria and its area extent towards the higher latitude may take place due to global warming.

The biological models have been introduced to estimate the impact of climate change on the potential transmission of malaria. On a global scale, all biological models show net increase in the potential transmission zone of malaria and changes in seasonal transmission under various climate scenarios (Martens et al, 1995, 1999; Martin and Lefebvre, 1995). Some local distribution of Malaria has also been predicted to occur where decline of rainfall would limit mosquito survival. The outputs of these malaria models are very sensitive to assumptions about the minimum rainfall or humidity levels needed for malaria transmission. In Bangladesh, such a model has not been used, however, the knowledge about the sensitivity of climate change on malaria transmission as obtained in the IPCC 2001 report has provided conceptual guidance to perform the impact study in the context of Bangladesh using the available malaria occurrence and climate data. The percent distribution of Malaria in Bangladesh from 1988-98 has been shown in Figure-4.6.

It can be seen from the figure that the malaria in Bangladesh is increasing. The mean temperature at various location of the country has also been reported to increase (Quadir et al., 2001). It apparently indicates that the malaria occurrence is linearly correlated with increasing temperature, however, this aspect needs to be further investigated to confirm this hypothesis.

Figure 4.6: The temporal distribution of Malaria (1988-98)



4.9.4 Adaptation

Physical Adaptation

The existing disaster monitoring and warning system needs further improvement. Appropriate number of cyclone and flood shelters, in excess of the existing ones, need also to be built for the vulnerable population. Heat-related impacts can be prevented by emergency measures to move the vulnerable people to air-conditioned buildings, and by reducing the emissions of the photochemical oxidants, which cause ground level ozone. Plants and the forests cover acts as the active shielding of the terrestrial surface from the solar radiation. Thus in order to keep the earth surface cooler, the plantation of trees in the settlement areas, roadsides and other vacant space would lower the surface temperature which would ultimately lower the heat stress and provide natural comfort to the lives. The raising of forest or plant coverage will also act as an important GHG mitigation measure.

In Bangladesh rural areas, thatched roofs are often used for building the dwelling huts, which are relatively cool inside. The design of the houses and the building materials may be so chosen that the insides of the houses could be kept relatively cooler. The mass people should be given proper training and instructions on how to prevent themselves from heat stress.

The mosquito growth is to be minimized by keeping the environment clean, improving the drainage system and also by applying insecticides if necessary for countering malaria, dengue or other vector borne diseases. The individuals will have to keep away from the mosquito bites keeping them inside the net or keeping the house free from mosquito. This will save the population from malaria and dengue.

Drainage system and the sewage lines need improvement. The portable water supply and storage systems are to be protected from any possible contamination due to the excessive rainfall and flooding. Mass people should be provided with the easy and effective technology to filter and disinfect the water for drinking and household use. Harvesting rainwater in the wet season would provide possibly be a partial solution.

The arsenic free water is to be made available for the rural population. Filtering devices for freeing the water from arsenic contamination are to be developed and provided to the people of the arsenic prone areas. Using surface water in rivers, lakes or ponds after purification by some easy means would be another suggested solution. However, these water sources are to be maintained to keep them free from pollution.

The industrial waste is another source of water pollution in Bangladesh. Recycling of such wastes, hence, is suggested to keep the environment free from industrial pollution.

Institutional Adaptation

Many of the impacts of climate change on health could be avoided through the maintenance of strong public health programs to monitor, quarantine, and treat the spread of infectious diseases and respond to other health emergencies as they occur. Bangladesh government has taken possible steps to strengthen the public health programme of the country. Improved health education, research on the causes and treatment of the diseases, investigation of the relations of diseases with climate variability to understand the impact more clearly using the historic records and modeling studies are required.

Mass education is effective for generation of awareness for health care and preventive measures. Improved disaster management system for adequate preparedness and safely measures and post-disaster rescue, shelter, food and medical supplies and health care. Reduction of community vulnerability to major health hazards. Awareness building and strengthening of national capacity building for health emergency management. Harnessing scientific knowledge on disaster related deaths and injuries and their contributing risk factors for addressing critical knowledge gaps and applying this knowledge for reduction of health consequences of disasters and emergencies. Undertake appropriate poverty alleviation steps and provide improved nutritional facilities to acquire more resistance to the disease and better protection against the disasters.

4.10 Socio-Economic Impacts of Climate Change in Bangladesh: Vulnerability Assessment and Adaptation Measures.

This section highlights the socio-economic impacts of climate change in Bangladesh. The section starts with the definition of vulnerability followed by the impacts and adaptation measures suggested in the text. The term vulnerability refers to the social, economic, physical and cultural disadvantages to cope with adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.

4.10.1 Background

Bangladesh is known for its high sensitivity to natural calamities. Burdened by social and economic problems such as low levels of literacy, poor health delivery systems, low per capita income and high unemployment; Bangladesh faces many difficulties in achieving sustainable development. Possibilities of climate induced changes, including increases in frequency, duration and intensity of extreme events such as floods, droughts and cyclones, and their expected adverse impacts on the resource base and human activities, would take the country into an even more difficult position.

Climate influences the crop production, population distribution, vegetations, soil, water, animal resources, temperature, rainfall, and natural hazards like cyclones, flooding, drought, salinity changes, erosion, human health, industry, energy, infrastructure and communication, urbanization, food demand and supply upon which people depend on for their livelihood. Some Important Factors Increasing Bangladesh's Vulnerability to Climate Change are listed below:

Geography

Bangladesh is a broad deltaic plain with most elevations less than 10 meters above mean sea level.

Climate

Subject to severe natural disasters: riverine & coastal floods, tropical cyclones, storm surges, tornadoes, and droughts. Most rainfall is confined to the monsoon season, causing major floods. The winters are dry.

Population

2001 population 123.1 million; average annual grown rate 1.47% (1992-98). Latest projected growth rate 1.4% for 1997-2015; population density is very high at 850 person/sq.km. WRI (1998) projects 2020 population to be 190 million and 2050 population 218 million.

Economy

Bangladesh is one of the world's poorest and least development nations. GNP/capita in 1998: $350 and in 2000 US $ 363 whereas GNP/cap in South Asia $430. Agriculture, which is 30% of GNP, is particularly vulnerable to climate change, Bangladesh is in the process of developing its energy potential. Foreign investors may be discouraged by the threat of climate change.

Education

Bangladesh attained 62% literacy rate in June 2000 overtaking other South Asian countries, except Sri Lanka. Still, compared to developed countries, low literacy limits ability to adapt to climate change.

Human Health

Life expectancy at the birth: 61 years; infant mortality rate: 67 deaths/1,000 live births (1996); 56% under 5 are malnourished; 84% have access to safe water. Communicable diseases caused by poor nutrition and sanitation includes cholera, dysentery, diarrhea, measles, and tetanus. Parasitic diseases include malaria, dengue, filariasis, and helminthiasis. Malaria reemerged in late 1980s. The need to substantially improve the overall health and living conditions of the country makes it particularly vulnerable to climate change. The other important factor related to socio-economic vulnerability are discussed below:

Impact on Agriculture

- Agricultural crops are highly vulnerable to climatic events.
- Occurrence of unprecedented floods.
- Occurrence of flash floods.
- Occurrence of droughts.
- Emissions of methane gases through a variety of rice cultivation.
- Emissions of nitrous oxide, carbon monoxide and nitrogen oxides from agricultural residues.
- Due to decline in agricultural production the poor and vulnerable women are subject to isolation from the seed production, seed preservation and other processing activities.
- Small and marginal formers are vulnerable and no more self-sufficient.
- People feel and see the negative effects of the declined production system as the soil water, food and health are affected.
- Excessive emission of methane gas has been contributing to the global warming.
- The residual effects of climate change have been destroying the content of organic mater in the soil and also the protein sources.

Adaptation Measures

Physical Adaptation

- Improved Irrigation efficiency.
- Crop diversification.
- Conjunctive use of surface and ground water for irrigation.
- Changes in fertilization techniques.

Institutional Adaptation

- Improved of agricultural extension services.
- Enhance training programs and dissemination activities.
- Research and development of new salinity and drought resistant crops and new high yield verity crops:.
- Change practices.
- Expanded access to credit.
- Guidelines to incorporate climate change in future planning.

Impact on Forests

- Sea level rise poses a severe threat to the Sundarban Mangrove Forests.
- Climate change induced higher evapo-transpiration, and low flow in winter would increase salinity. As a result, growth of fresh water loving species would be impaired.
- Non-woody shrubs and bushes would gradually replace the species offering dense canopy covers.
- Overall productivity of the forests would decline significantly.
- The rich diversity of forest flora and fauna would face degradation in a warmer world.
- With the loss of mangrove forests, the habitats like marine turtles, crocodiles, frogs and fresh water dolphin species would be lost.
- With the disappearing of sal forests and hill forests due to the impact of climate change, rare wildlife and biological diversity would reduce quite rapidly.
- Human habitat, the life and culture of the forest communities on the brink would be severely affected because of shrinking forests.
- The effect of climate change on the Sundarban mangrove forests would be devastating due to decaling the fishing industry, increased flooding and loss of endangered animals, including the world's largest assemblage of Royal Bengal Tigers.
- The disappearance of the Sundarban Mangroves, the only resource stopping Bangladesh from sliding into Bay of Bengal, would be an ecological catastrophe.

Adaptation Measures:

Physical Adaptation:

- Coastal green belt forestry.
- Agro-forestry development.
- Homestead forestry development.
- Community forestry development.

Institutional Adaptation

- Integrated ecosystem planning and management.
- Management of ecosystems in the Sundarbans.
- Development of reserved/protected areas in different agro-ecological zones.
- Reduction of habitat fragmentation and promotion of establishment of migration corridors.
- Studies an e.g. risks to endomic species and ecosystem.
- Bio-diversity action plan to preserve ecosystem.
- Cooperative social forestry support services with the involvement of vulnerable women and men.

Impact on Fisheries

- Due to climate change low flow conditions in the winter would reduce wetland areas might cause-declining fish stock in the wetlands.
- Sea level rise could push saline water into GBM delta, reducing habitat for fresh water fish.
- Increased water temperature could cause reduction in the concentration of dissolved oxygen, thereby decreasing the suitability for the fish, especially for the hatchings.
- Climate variables affect the growth and economic production of particular species of fish at specific locations.
- The growth and yield of fish may fall/rise abruptly when extreme conditions of drought, flood or high temperature occur.
- The growth of fish is also associated with other climatic variables. For example, the seasonal and regional distribution of rainfall is an important consideration for fish production since it is the primary determinant of fish life.
- Climate change and consequent sea level rise is likely to affect the water temperature and salinity regimes in the upper Bay of Bengal, which enhance the water temperature and ultimately affect the reproductive physiology of many marine fishes.
- Sea level rise would bring about a reduction in the freshwater habitant conditions particularly in the rivers.
- Pond Culture would be affected by increased flooding caused by climatic change.
- Once the sea level rise due to climatic change, all the shrimp farms would go under the sea. Consequently the shrimp farming practice will disappear, making the country lose the foreign exchange earning for good.
- Rising ocean temperatures would systematically bleach fragile coral reef systems.
- A temperature rise of about 2°C may have substantial impacts on the distribution, growth and reproductions of fish stocks.

Adaptation Measures

Physical Adaptation

- Infrastructure development: Construction of embankment, suitable sluice gates where necessary, drainage improvement, excavation and re-excavation of silted khals to facilitate normal flow of water.
- Strengthening and rising of the dykes of the homestead ponds.
- Construction of stray & suitable shrimp gher with appropriate height
- Water management and fish conservation strategies (scientific and modern package need to be introduced).
- Banning on catch of baby and brood female fish and PL
- Avoid water pollution (from agricultural toxic insecticide/pesticide runoffs and industrial and municipal waste).
- Ensuring of fisheries extension services (training and credit)
- Introduction of new package of fish culture technology
- Avoiding of over-fishing and determination of fish stock assessment to maintain MSY (Maximum sustainable yield).
- Creation of local association.
- Awareness creation with regard to flood, cyclone etc. preparations through the participation of NGOs.
- Management of monitoring and evaluation by the member of the local association NGOs & GOB office.

- Conduct sectoral assessment on climate change impacts on fishery development including fishery harbors, fishery settlements, and sustainable use of fishery resources as a basis for long term planning.

4.10.2 Socio-Economic Impact Assessment

Impact of Climate Change on Human Society

With the introduction of advanced science and technology man has modified the conditions of physical environment to some extent. The modifications include the homes and cities, means of transport and communication, comforts and conveniences. It also includes the complex system of production both in industrial and agricultural sectors, trade, commerce and business. In the name of open market economy the whole world has become part of trade, commerce and business, which obviously has modified the physical environment. Due to change in physical environment lot of changes would take place in the society especially the institutions, organizations, regulations, traditions, customs, norms, values, rituals, folkways, morales, social heritage etc. The social conditions, which are part of our social life, are always influenced by climatically change. The changes in physical environment always affect the social environment. For example, the change of climate sets limits to the society and also provides opportunities for its development. The family, education, neighbourhood, friends, various persons in contact, social customs, norms, values, practices, institutions, traditions, etc. all are affected by climate. Due to change of climate, a man's temperament, attitudes, tendencies, ways of thinking, food habit, life style, personality etc. are affected. In the same way individual/group behavior, occupation, income, etc. are also affected by changing climatic conditions.

Land and Wealth

Some 84 percent of the population of Bangladesh is wholly dependent upon rural landholdings as landlords, owner-operators, tenants, sharecroppers, and as landless labourers. The proportion of rural households that are functionally below poverty line is about 42 percent. Though green revolution in agriculture has contributed to self-sufficiency in rice production, this has also adverse impact on landless poor due to highly skewed land-distribution in favour of large and absentee landlords. Therefore the important reason for the increasing number of landless people is the increasing control of land by the rich farmers. Other major reasons are the changing social structure, pressure on natural resources due to in equal distribution system, and the subdivision of land holdings in successive generations. Occurrence of frequent natural disasters also plays a part in landlessness and assetlessness. Moreover the introduction of capitalistic structure into agricultural production system has further increased the proportion of landless, vulnerable and destitute in rural Bangladesh who are also subject to vulnerability due to climatic variations and extremes.

The Coastal Zone : Sea level Rise and its Impacts

From the inventory it is evident that Bangladesh is a country, which is likely to be hard hit by SLR since one-half of the country has elevations of a less than five meters and the coastal plains, are monotonously flat. A 45 cm rise of sea level along the Bay of Bengal coast will submerge about 10% of the country's land area or about 15,666 sq.km. including nearly 75% of the Sundarban mangrove forests in the southwest. The populations to be displaced by the sea level rise and inundation is estimated as 5% of the national population provided there would be no intervention/structural measures.

Changes in the Population Distribution and Density Pattern

A rise in the sea level will inundate an extensive area of Bangladesh. The extent of inundation will depend on the degree of global warming and climate change. Any loss of land will mean inward migration of population. Scarcity of land and increased population pressure will mean additional burden on farming, habitation, industrialization, communication and other infrastructure development. As reported earlier, due to increased proportion of landless people in rural areas many villagers are forced to move to urban areas, where there is neither living space nor jobs and they end up living in slums under sub-human conditions. A redistribution of population through rural-urban migration induced by the loss of land caused by sea level rise will further aggravate the situation. The calamity of sea level rise will also have dramatic and traumatic repercussion on the socio-economic condition of the country.

Movement of Populations and its Impact

Induced, coerced, forced or spontaneous population movements have frequently been a direct cause of vulnerability, removing people from their accustomed resource base and creating conditions of dependency. Population movement therefore may be caused by two kinds of vulnerability: the first due to communities having being separated from their resource base, with reduced capacity for self-reliance and more dependence on external assistance for support than in normal time and the second, people habitat knowingly or unknowingly in hazardous location placing themselves at risk. These two sets of vulnerability exacerbation could be combined.

Impact on Human Health

Climate is one of the important factors that influence human health and human disease pattern in two ways. The first one is the heat stress. The second type of impact will be due to the increased incidence of particular types of diseases. Examples are the water-borne diseases and diseases spread by vectors like mosquitoes. Access to basic health care is often important to vulnerability to climate sensitive diseases. In Bangladesh with low per-capita income people especially the poor can not afford to proper medicare. Rather they depend on public health care system, which do not have proper and sufficient facilities for treatment.

Moreover, the epidemic patterns of diarrhea diseases like cholera have a marked seasonal pattern with the peaks usually occurring during the drier periods. The monsoons floods during the rainy season also help the bacteria to spread spatially through inter connected water bodies. The other diseases related to climate change are the mosquito-borne ones like malaria, dengue, filariqsis, and Japanese encephalitis. Climate appears to have some influence over the rates of development of malarial parasites, which increase with warmer temperature. Skin diseases may also increase. Two diseases cardiovascular and respiratory disorders are also related to heat, cold and air quality.

Impact on Infrastructure and Communication

In general, climate change will also affect infrastructure and communications. But some times the havoc created by natural hazards like floods, tornadoes and cyclones interrupt the normal transportation and communication system. Another concern would be the indirect influence of climate change, that is the possible sea-level rise, which can inundate and wipe-out the investments made and physical assets created in these sectors in the coastal zone to be affected.

Impacts of Water logging and Drainage Congestion

The coastal embankment initiatives and riverbank protection projects have been implemented to protect the resources from flooding, tidal surge, cyclonic storms and salinity. Water logging has long-term impacts on the local environment, society and economy. It particularly affects the agrarian community, landless and marginal people. Farmers engaged in framing activities are now compelled to change their occupational status due to water logging. People living in the area are facing serious energy crisis due to loss of trees, plants and crop residues. The ecology and environment as well as bio-diversity has radically changed due to water logging. Even the availability of livestock and poultry have declined due to the situation. The female members of the households especially the poor, destitute and vulnerable women face hard times who are primarily responsible for procuring drinking water and cooking fuel from locality. They have to travel longer distances to collect drinking water and fuel. Many children stop going to schools due to breakdown of communication resulting in the lower literacy rate.

The people inside the polder areas are faced problems due to drainage congestion. Many polders do not have adequate and affective drainage structures or due to lack of proper O&M these are inoperative. Pumping out water from the polders and closures cost huge resources.

Riverbank Erosion

The mighty rivers of Bangladesh are Ganges, Brahmaputra and Meghna. Erosion of riverbanks engulf enormous amount of agricultural fields, destroy hundreds of houses and make thousands of people homeless. Those affected by riverbank erosion especially the poor vulnerable and destitute, either take shelter on the nearly embankments or migrate to urban areas. Many victims become slum dwellers in urban cities and maintain an inhuman and substandard life in a shanty home without adequate food, shelter, health and sanitation facilities.

River bank erosion has considerable effects on the rural economy and society. Bank erosion not only damages valuable agricultural lands but also cause considerable permanent damage to tress, homes, roads, educational institutes, religious institutes and other types of socio economic facilities.

Climate Hazards

The change of climate is likely to intensify natural hazards like flooding, cyclones and droughts in Bangladesh. Normal flooding affects about 26 percent of Bangladesh each year but abnormal floods submerge more than 60 percent of the land damaging crops, property, disrupting economic activities and causing insecurity and loss of life. Similarly, cyclones, accompanied by storm and tidal surges destroy lives and properties and disrupt economic activities in the coastal regions of Bangladesh. Another hazard, drought affects the standing crops, water supplies and plant growth leading to loss of productions, food shortages and famine. Frequent natural hazards in Bangladesh severally affect the economy of the poor section of the society causing them poorer and helpless.

Gender Impact

Women in case of erosions and flooding face a number of problems during the monsoon. During the rainy season and abnormal floods, the level of water rises and many homesteads along with cultivable lands become subject to erosions. Floodwater also sometimes inundates the homesteads. As a result women especially the women of poor and marginal households become more vulnerable and distressed. Many women are unable to utilize their time and labour in productive activities due to absence of income generating environment. They also face acute problem in performing their domestic activities like cooking, caring of children, fetching water, earth cutting and raising of homestead platform, fish catching and processing, poultry and cattle rearing etc. Women who are subject to erosion and devastating floods suffer from lack of shelter, food and clothing.

4.10.3 Adaptation Measures Related to Human Society and Culture Other than Agriculture, Forestry and Fisheries.

Adaptation Mechanism

An understanding of the multi-sectoral and interrelated impact of climate change, which creates vulnerability at national, regional and local level, needs to be addressed from short, medium and long-term strategies. Towards this understanding the assessment of climate impacts needs to be made to be closely compatible with recognized and practiced monitoring and measurement of socio economic indicators. In this way the impact of climate will demonstrate both the social and economic vulnerability of the poor people.

Understanding of the socio-economic mechanisms and the impacts of climate change and its consequence such as hazards and disasters and to assist an equitable balance of response across and between social groups, governmental and non-governmental activities, and between institutions and organizations is crucial.

By an understanding of vulnerability due to climate change, a compound social, economic and political interrelationships – of a survival infrastructure as well as a protective structure should be developed within a spectrum of measures for a corresponding Spectrum of Conditions.

An important aspect of adaptation mechanism is likely to be the degree of decentralization and consequent local accessibility to resources and services. Decentralization facilitates the adaptation of national programs within various local conditions and changing or unanticipated circumstances, and in local context of cultural, socio-economic and political factors.

Physical and infrastructure development may be required to save lives, property, animals but as more lives are saved, livelihoods will also need to be preserved for sustained survival and recovery.

Social development programs should include programs for community development, integration of non-governmental organizations, women in development, disaster preparedness, framing preventive medicine and health services, maternity and child care, nutrition monitoring and small credit systems.

Disaster adaptation process will be more effective if we reform the institutional participation of the community. The community participation is possible in following ways.

Self-Participations: This type of participation is self-motivated. Volunteers from the community always organize and identify problem with the help of community participation.

Awareness Participation: In this type of participations voluntary man, organization and development workers may create awareness in people. After awareness, people are interested and those people identify and solve the problem.

Change of Location: Use of movable housing materials including thatch, bamboo, and wood and corrugated iron sheets. The structures made of these materials are moveable and thereby less vulnerable to natural hazards such as floods, cyclonic storms, tidal surge and salinity. In case of emergency, the structure can be easily dismantled and moved away within short time.

Community Effect: In Bangladesh, people generally live in cluster villages. The clustered settlement approach helps the settlers to mobilize necessary manpower and assistance, incase of any emergency arise, rapid removal of housing structures. Moreover, it also gives a strong psychological affinity and attachment and emotional unity from protecting the community from any hazard effects.

To minimize the loss of lives and properties during disastrous events, it is essential to implement the measures required from disaster prediction which depends on some essential elements: the period in which the event would occur, the area location and the near surface geological conditions, the magnitude range, a statement of the odds that a disaster of the predicted kind would occur by chance alone and without reference to any special evidence.

Similarly, during disasters rural people may adapt many copping strategies, which are related to the socio-economic position of people. Because of strong division of labour, women may assigned to do certain tasks for example, collect water, aquatic plants, medicinal herbs for their households. Through neighbouring and kinship network, rural poor may borrow small amounts of money, food, platform materials, fuel fodder etc. During floods, tube wells, wells and latrines are inundated and water from different sources becomes contaminated. Disaster affected people face difficulties reaching health centers due to the breakdown of the communication system. However, the village people try their best to cope with this difficult situation. They use traditional knowledge and techniques to keep the water germ free. Many villagers prepare medicine from herbs.

Early Warning and Disaster Preparedness

There are mechanisms to forecast disasters. Development of the capacity of the community peoples especially the community leaders for promotion of family and community level disaster preparedness.

The issues to be emphasized at the institution organization levels:

- Early warning receipt and dissemination procedures.
- Formation of community level local groups.
- Teaching and Motivation of the change agents (religious leaders, teachers, ward members, social elite etc.).
- Massive public awareness programs
- Contingency plans for evacuation, shelter, emergency survival relief, rehabilitations, logistic support, coordination etc.

Rehabilitation and reconstruction programs

- Employment creation.
- Credit grant for: shifting of homes, reconstruction of homes, income generation support for agriculture, petty business, poultry rearing etc., purchase of household goods etc.
- Provision of pure drinking water.
- Repair and reconstruction of roads.

Preparation of information, education and communication materials

As part of massive public awareness program the following materials may be designed and developed.

- Posters.
- Leaflets.
- Audio Publicity.
- Video Publicity.

An exploration into indigenous adjustment strategies

The non-structural adjustments to disasters include adaptive actions taken by communities before and during disasters to mitigate loss, and other potential human actions without involving major engineering works, such as forecasting and warning systems, disaster insurance and disaster relief and rehabilitation.

Most of the indigenous adjustments are of a corrective type; some of them are related to social organizations and relationships, others are associated with material response at an individual level. The adjustment mechanism is an informal but predominant social grouping based on kinship, social and religious interests of its members. It is the primary forum within which members interact frequently and are mutually involved in network of social and emotional links and interdependent.

What is further required is indigenous provision for basic needs in a human ecological and sustainable approach to development. Basic needs for human survival and its continuation are:

- food and cooking facilities.
- potable water .
- Shelter and warmth.
- Treatment of injuries, health, welfare.
- Information: the occurrence, what action to take and where to go for assistance.

Finally, climate change threat for Bangladesh is integrally related to the country's sustainable development. The case of Bangladesh is unique in the sense that: unlike other vulnerable island countries, this country will eventually face the multidimensional manifestations of climate change (e.g. flood, cyclone, sea level rise, drainage congestion, salinity, drought etc). Rather than being mutually exclusive, adapting to climate change should be seen as a requirement for sustainable development, and mainstreamed in developmental endeavors. Climate change is not just an "environmental" concern but really a "development" concern for Bangladesh. This means that climate change as an issue must take center stage as a major development problem that the country will have to face in the coming days.

5 MITIGATION

5.1 Introduction

Bangladesh is not a major emitter in GHGs as amply demonstrated in the section on emission in this report. She is more a victim of such emission by others. There is, however, an increasing realization that Bangladesh should give emphasis on preparing an appropriate mitigation policy for at least three reasons.

Firstly, as a signatory to the United Nations Framework Convention on Climate Change (UNFCCC), the country is pledge-bound to take measures as appropriate to reduce the net release of GHGs. Secondly, her consumption of energy and consequently the emission of green house gases, particularly of CO_2, is likely to increase fast due to economic growth and industrialization. The third reason has been Bangladesh's dependence on imports for a large part of her supply of fossil fuels where the domestic supply of natural gas is likely to dwindle to insignificance in a matter of decades. A strategy to lower energy consumption through raising efficiency in production, distribution and consumption of energy would thus serve the purpose of limiting of GHG emission while conserving energy and saving at the same time scarce foreign exchange resources. On each of these three counts therefore, one should have a well thought-out mitigation strategy.

In the mean time, few works has been carried out for the development of a mitigation strategy in the country. This section reports on the results of an effort under the preparation of national communication in response to the UNFCCC project.

A mitigation assessment involves a national level analysis of the potential costs and impacts of various technologies and practices that have the capacity to mitigate climate change. Two key goals of an assessment are (i) to provide policy makers with an evaluation of those technologies and practices that can both mitigate climate change and also contribute to national development objectives, and (ii) to identify policies and programs that could enhance their adoption. An initial mitigation assessment would logically be followed by more detailed evaluation of specific policies, programs, or projects designed to encourage adoption of selected technologies and practices.

The mitigation assessment would include studies in a number of sectors like energy (demand and supply), forestry, agriculture and waste management. For each sector, two scenarios would be considered. These are baseline scenario and mitigation scenario. A baseline or reference scenario is a description of a plausible future in which no specific policy actions are taken to encourage actions that reduce GHG emissions or enhance carbon sinks. A mitigation scenario describes a future that is essentially similar to that in the baseline scenario with respect to overall economic and social trends, except that it assumes that policies or programs are implemented that encourages adoption of measures that will reduce GHG emissions or enhance carbon sinks.

5.2 Principles of Mitigation

In the literature, the possibility of CO_2 mitigation is described in two ways: between source-oriented measures and sink-enhancement measures. The former includes energy conservation and efficiency, fuel switching, recourse to renewable and nuclear energy while the latter includes capture and disposal of CO_2 and enhancing forest sink. There are, however, many exotic ideas regarding mitigation which include geo-engineering, orbital shades, iron fertilization, creating algal blooms and weathering rocks. While, on the one hand, these are yet to be demonstrated to be practicable in large application, these are also likely to cause very large and adverse environmental impacts, on the other.

The measures involving energy conservation and efficiency, fuel switching, recourse to renewable and nuclear energy can be put in their context with the help of the Kaya identity (Yamaji et al:1991). The identity is shown as

$$C = (C/E) \times (E/G) \times (G/P) \times P \quad \text{............(1)}$$

Where C = carbon,
E = energy,
G = gross domestic product (GDP),
P = population,
C/E = carbon intensity of energy use/supply,
E/G = energy intensity in the economy,
G/P = per capita GDP.

From equation 1, it can be visualized that carbon emission can fall, if any of the following, viz., carbon intensity of energy, energy intensity of GDP, GDP per capita or population falls. Similarly, the rate of change in the emission of carbon is an additive function of the rates of change of the four components on the right hand side of the identity.

Among the four broad factors, it is hardly ever likely that population will fall although its rate of growth can be substantially slowed down. On the other hand, most of all developing countries, would wish a faster growth in GDP per capita. This leaves only decarbonization of energy production/use and lowering energy-intensity as the only major ways in which carbon emission can be abated.

Decarbonization means switching to less carbon intensive fossil fuels (e.g. from coal to natural gas in production processes or consumption) or to energy production processes, which are carbon-free (e.g. nuclear and renewable energy including biomass when periodic consumption balances production over a given period). Only the switch to natural gas and balanced use of biomass are of relevance in the Bangladesh's present context.

In any country, potentials for decarbonization of energy use is often dependent on the availability of specific sources of energy. As a result, much of the attention in the literature has been given to energy-intensity which is influenced by, apart from waste reduction, two, factors, viz., energy-efficiency of the technology of production, distribution and consumption and the structural shifts in the economy.

Developing countries are generally in the material production phase of the development process (an energy demanding process) while many are also in the most energy-intensive industrial growth phase. Such a situation precludes a general possibility of lowering energy consumption through a structural shift in the economy. Thus, for an initial understanding of the scope for lowering energy use and mitigation in developing countries such as Bangladesh, one needs to look at energy intensity and energy efficiencies at national, sectoral and individual industry/activity levels.

5.3 Objective of the Study

The broad objective of the mitigation study is to understand the prospects and consequences of a policy to limit the net release of GHGs into the atmosphere either through reduction of emission or enhancement of sinks. Their prospects and consequences, of necessity, will have to be judged from the angle of more important societal objectives of poverty reduction, income growth and employment generation.

There are two major sources of GHG emission in Bangladesh. One is CO_2 due to energy production, distribution and consumption while the other is methane due to non-energy activities (Ahmed et al. 1996). Here the focus is on the former and on commercial energy consumption and supply.

Analysis of energy end-use may consider industrial demand, residential and commercial demand, transport demand and agricultural demand. Attempts have been made to consider each of the types of end-use, though not necessarily with equal rigor which was constrained due to data availability and their quality. In each of these cases, the general principle is to

- characterize the technology in use;
- characterize the nature of demand of the output of the sector;
- investigate how changing demand for these outputs along with possible changes in end use technologies (with or without mitigation) may lead to future emissions of GHGs.

A major problem in operationalising these principles has been with the very first one, particularly in case of industrial technology as there are numerous types of techniques in use varying by sub-sectors and vintage. In case of transports, a similar situation obtains in case of vintage, if not the technology of transportation vehicles. Among the energy supplying sectors, in-depth investigation have been made for power and natural gas.

Due to the problems of availability of data of fair quality and in some cases inadequate, the mitigation research team has focused on the energy demand in various sectors as stated above and also energy supply, viz., power generation and gas supply. Among these only the energy use and production/distribution activities have been studied in-depth and the emphasis is almost exclusively on commercial energy.

During the mitigation study it was felt that, short of a full-fledged bottom-up inventory backed-up by primary survey in energy use and several types of activity by demand device, one may not really have a well-planed and workable mitigation strategy. Particularly, without such a survey and its analysis, it is difficult to establish a benchmark against which all future changes in emission are to be measured. Thus, any analysis that may be done with the help of information that now existing may be inadequate. It has been decided therefore neither to use any modeling exercise nor to evaluate the strategy in quantitative terms.

5.4 Methods

5.4.1 Methodology

The methodology of the present mitigation assessment is to

- describe and analyze the GHG emission by sectors and sources;
- decide upon a time frame for analysis;
- decide upon at least two future scenarios, a "reference" or baseline scenario and one with certain mitigation options;
- qualitatively evaluate the implications of the mitigation measures keeping in view as far as possible, the cost effectiveness of the specific measures.

5.4.2 Time Horizon for the Project

As per guidelines of the study, the benchmark year is taken to be the year 1994. Based on the collected data a time horizon on which the study specifically focuses upon are from the years 1994 to 2000.

5.4.3 Data Collection

The requirement of data for analysis may vary by the type of approach (top-down or bottom-up). For this purpose, the following types of information are generally needed:

Demand and supply (including imports and/or exports) of energy by type, by sector, by end-use by technology type and vintage and their costs; and

Demand for agricultural, industrial, forest and livestock products and transport services (including modal choice) and their supply (including exports and imports); population, urbanization, national income, consumption and investment.

All these information are required for critical analysis of mitigation optious. These may be available from secondary sources in a scattered ways however, all necessary information are not available through which a sophisticated analysis could be made.

5.5 Greenhouse Gas Emissions and Energy Use

Green house gas emission in Bangladesh in 1994 has been estimated to be 15,152 Giga grams of carbon di-oxide which is the major such gas. Methane is the next important gas. Others are of little significance as yet. The source of CO_2 is mainly from the use of energy in one form or other. In case of methane, however, livestock rearing and rice cultivation appear to be the main sources although biomass burning also contributes significantly. It is of interest to note that land use changes in terms of increased forest through tree cover have a significant sink effect.

5.6 Natural Gas Supply and Use

Supply : There are 20 natural gas fields (19 on shore and 1 offshore) in Bangladesh. The total gas in place is around 37.08 TCF of which 25.66 TCF (69%) is recoverable. Recently, new gas fields have been discovered at Bhola with an estimated reserve of 0.5 TCF and another 0.4 TCF at Saldanadi. By world standards, these are certainly not very high reserves or rates of production. Yet, the consumption of gas has increased rather fast over the past few years. If such consumption rate continues, the reserve may not be expected to last beyond the next few decades, unless new large fields are discovered. Total Production of natural gas was 6338 mn. Cu. meter in 1994 of which 41% used in Electricity generation, 9% in industry, 33% in fertilizer production, 7% in domestic uses and only 1.25% used in the commercial purpose.

Consumption: Over 1989/90 to 1997/98, the consumption of gas has increased by nearly 40%. In the year 19997/98 nearly half of the total gas output is used for generation of electricity while more than a third is used for producing urea. However, the industrial and domestic consumers consume much of the rest.

5.7 Electricity Generations and Supply

The dominant technology in electricity generation in Bangladesh is steam turbine in terms of installed capacity of actual generation (Table 5.1) but in reality Bangladesh is mainly dependent on natural gas as fuel for electricity generation. However, only a little electricity is produced in the country from hydroelectric power plant.

Bangladesh is facing problem in electricity distribution because of large gap between net generation and sales. Net generation in 1994 was 9,784 GWh while sales were just about 7,448 GWh. The gap between net generation and sales is just about 24% of net generation. This gap comprises with system loss and station use although much of the system loss is really theft. Of course part of this loss is unavoidable technical loss of various kinds.

Table-5.1: Characteristics of the power sector

Technology type	No.	Installed capacity (MW)	Generation capacity (MW)	Total generation (GWh)	Total fuel cost (Mill. Tk)	Efficiency range (%)
Hydroelectric	1	230 (10.3)	230 (11.3)	884.21 (11.5)		
Combined cycle (CC)	1	90 (4.1)	85 (4.2)	509.62 (6.6)	233.02 (0.46)	26.85
Combustion turbine (CT)	11	536 (24.2)	416 (20.4)	1168.98 (15.1)	1118.88 (0.96)	18.09-26.16
Steam turbine (ST)	7	1248 (56.3)	1234 (60.5)	5048.03 (65.4)	1717.96 (0.34)	20.06-37.37
Others	8	113.19 (5.1)	76.05 (3.7)	108.12 (1.4)	70.36 (0.65)	11.96-35.45

Source: ADB, 1995
Note : Figures in parentheses are percentages of the relevant column total except in the column on fuel costs where such figures indicate cost of fuel (in taka) per KWh generated.

5.8 Future Energy Use, Supply and Investment

In the literature several projections are available for the future demand for energy. It is not always clear how these projections have been made. In any case, the approved Energy Policy of the Government has recently made a projection of such future needs.

Two scenarios have been constructed in The Energy Policy: a low growth (i.e. the business as usual case) and a reference growth (with moderate rate of growth of economy) scenario. In the former case the demand for energy is expected to grow from 2.56 PJ in 1990 to 2050 PJ in 2020 with the energy intensity increasing from 13 MJ/$ of GNP to 27 MJ/$ of GNP over the same period. For the reference growth scenario the energy use is expected to increase to 3055 PJ by 2020 while the energy intensity may rise rather slowly to 21 MJ/$ GNP. While there may be debates over the estimates, the reference growth situation indicates the influence that even a moderately high rate of growth of the economy may have on the demand for energy. Demand and supply profile of various forms of energy in Bangladesh are depicted in the following sections.

5.9 Natural Gas

Demand : All types of fuels do not have similar rate of growth of the projected demand in energy production, nor is it going to be the same across sectors. The cause for the rise in demand for natural gas can be explained in two ways, firstly due to an increase in the demand for final consumption and secondly as an intermediate input mainly in industries both as fuel and as feedstock and in the power plants. An ADB document (ADB, 1990a) shows that for the Reference Scenario while it is the power generation where the consumption may be expected to be more than double over 15 years such dynamism will also be shown by small industries and also the domestic sector both of which would show similar relative growth.

Supply : The only question of gas supply is that can this demand be met. Earlier it has been pointed out that the gas reserve may be exhausted nearly by 2010. Bangladesh, however, has a high success rate in gas exploration and future exploration may seem to be as fruitful as before. It may be noted here that recently, two new gas fields have been discovered, all with possible good reserves. Thus, the demand may not simply be met; the recoverable reserve may as well go up in the future.

5.10 Electricity

Demand : In the ADB report it is projected that under a reference (business as usual) scenario, the power demand may rise from more than 4,000 GWh to more than 29,000 GWh i.e. by a factor of 6 over 1990 to 2015 (ADB, 1996a). This may happen with little change in the proportions demanded by various broad consumer categories. It is observed that, the share of the domestic households is to be static at about 40% while that of industry is only somewhat higher. The commercial and other sectors accounts for rest of the demands.

Supply : The adequate generation of electricity is a must to supply the necessary power. Recent projections show that net generation over 1990 to 2015 may go up from more than 7,000 GWh to 49,000 GWh. Apparently, then net generation may just keep pace with the growth in demand. However, it is a known fact that there has a major percentage of system loss. If this loss includes, then there may be a narrow margin, if at all, of supply above demand. It is expected that gross generation to go up in a similar fashion in tune with net generation.

5.11 Petroleum Products

Demand : From the available projections it is envisaged that the demand for petroleum products as a whole may double between the periods 1990-2010. Differences however exist regarding where much of the demand would arise. According to one projection, the demand for diesel both due to irrigation demand and for transport is likely to grow most although the rate of growth would be much less than in case of most other fuels. According to another, the demand for gasoline would increase fast and this may be if one look at the present import policies regarding reconditioned vehicles.

Supply : It is observed that, the demand for petroleum products would grow although little prospects as yet exists regarding indigenous supply of the same. However, there is a scope that the crude petroleum products may be imported and refined in the country.

5.12 Coal

Demand : The use of coal in Bangladesh is still import-based, and not yet locally mined. The demand for coal use is minimal in Bangladesh as there had so far been little economic exploitation of this fuel in the country. The projected growth in coal consumption is also not high. Given the supply from the potential mines, however, the situation may change and an optimistic scenario projects that by 2015, Bangladesh may be producing and consuming upto 8 mn tons/year. Coal is mostly used in the brickfield as well as in the industry sector. Total consumption of coal was 59000 m. ton in 1994 of which 80% of the coal used in the brickfield.

Supply : Coal reserves have been discovered in three locations: Jamalganj (Bogra), Barapukuria (Dinajpur), Peerganj (Rangpur). At present, the most signification reserve at Jamalganj is 1000 million tons located at depth of about 1000 meters, which is too deep for exploitation, by known mining methods. However, other less significant reserve but at a much shallower depths (about 160 meters) are Barapukuria and Peerganj coal reserves estimated to be 250 million and 400 million tons respectively. These, of course, can become a source of coal bed methane if technological improvements in deep mining occur over the long run. Planning for a 300 MW capacity power plant using coal reserves of Barapukuria is already in progress.

5.13 GHG Mitigation Options

The latest national GHG inventory and mitigation options for Bangladesh were prepared as part of the ALGAS project, using 1990 as the base year. The mitigation opportunities at different sectors are subsequently presented in Table 5.1 to 5.3. For the present project, the GHG emission inventory is prepared for a period of 1994 – 2000 (Result presented in Annex -1) and several mitigation options are identified using 1994 as the base year. Reviewing the ALGAS report and present GHG emission inventory data, it is evident that the energy sector is the most important source of CO_2 emissions in the country and also it can be observed that the trend in CO_2 emissions for different sub-sectors for the base year 1990 and 1994 are similar in nature, excepting the higher values for the later case which is anticipated as development activities continues in Bangladesh. The results also indicate that the Industry sub-sector of energy sector is the single most important source of CO_2 emission in Bangladesh. In terms of CH_4 emissions, agriculture sector is the largest contributor followed by waste sector. Regarding forestry sector a significant lower value in GHG emission is observed. In this case, a calculated amount of GHG emission of 7897 Gg is found instead of 19738 Gg. So, for the enhancement of sink capacity of CO_2 in the forestry sector different variety of tree plantation should be encouraged.

Table 5.2 Summary of potential GHGs mitigation opportunities in the energy sector in Bangladesh.

(ADB-GEF-UNDP, 1998. Asia least-cost Greenhouse Gas Abatement Strategy: Bangladesh National Report. Manila: Asian Development Bank.)

Sl. No.	GHGs emissions reduction option	Potential introduction	Estimated investment cost of options, $/unit	GHGs emissions reduction, tonnes of CO_2 equivalent /yr
	SUPPLY OPTIONS			
1.	Combined cycle	1999	140 million (210 MV)	67,320
	DEMAND OPTIONS			
	EFFICIENCY IMPROVEMENTS			
1.	4-stroke 3-wheelers	1999	2,900	0.17
2.	Improved biomass cookstoves	1999	3.5	0.18
3.	Improved kerosene lamps		1.9	0.005
4.	CFL	2002	21	0.036
5.	Efficient refrigerators		750	0.04
6.	Efficient air conditioners	1999	920	0.37
7.	Gas boilers			
	Retrofit (improved)	2002	11,500	26
	Efficient	2002	15,000	38
8.	Improved coal boilers	2002	9,200	31
9.	Improved fuel oil boilers	2002	9,200	26
10.	Improved biomass boilers	2002	6,900	2.1
11.	Efficient motors			
	< 1 HP	2002	80	0.05
	1 – 10 HP	2002	190	0.15
	2. DEMAND-SIDE MANAGEMENT			
1.	Metering of natural gas	1999	70	0.18
2.	Solar reflective glass window	1999	330	0.06
3.	Housekeeping + Energy man	1999	11,000	238
	3. PROCESS IMPROVEMENT			
1.	Brick making	1999	700,000	495
2.	Paddy Parboiling	1999	250	0.9

a. These are initial assessment results and NOT modeled results
b. This is only suggestive because the introduction is dictated by MARKAL
c. This is the initial investment cost of the mitigation options and NOT incremental cost
d. GHGs emissions reduction compared to the baseline option.

Table 5.3 Features of forest sector mitigation options

(ADB-GEF-UNDP, 1998, Asia Least-Cost Greenhouse Gas Abatement Strategy: Bangladesh National Report. Manila: Asian Development Bank)

Suitable land	Global Goals	Rotation Period, Years	Mean annual increment, m³/ha	Mitigation potential per ha, tC abated	Investment $/tC abated
Long Rotation: Artificial Reforestation (LR)					
Hill Forestland	Conserving Forest C sink. Storing C in long-term products	40	7.5	116	1.0
Medium Rotation: Artificial reforestation (MR)					
Hill Forestland	Conserving Forest C sink. Storing C in long-term products	20	12.5	92	1.2
Short Rotation: Artificial Reforestation (SR)					
Hill Forestland	Conserving forest C sink	10	15	34	4.4
Medium Rotation: Sal Plantation (MR-Sal)					
Inland forestland	Conserving forest C sink Storing C in long-term products	20	12.5	98	1.5
Medium Rotation: Participatory coastal plantation (MR-PCP)					
Littoral Forest land/Newly Accreted Char Land	Conserving Forest C sink Storing C in long-term products	20	7	63	1.3
Short rotation: Participatory woodlot plantation (SR-PWP)					
Littoral Forestland	Conserving Forest C sink	10	15	34	3.4

Table 5.4 Features of Mitigation Options in rice Production and Livestock Rearing

(ADB-GEF-UNDP, 1998: Asia Least-Cost Greenhouse Gas Abatement Strategy: Bangladesh National Report. Manila: Asia Development Bank.

Mitigation Option	Features of alternative practice	Methane emission reduction potential per ha, or per animal	Impact on yield of milk or rice grain, percent change	Feasible target area or groups or Population
Rice agriculture				
Regulating flooding in completely flooded land	Reduce CH_4 Emissions	40 kg/ha (20%)	5% increase	Completely flooded area under irrigation project
Draining of fields twice	Reduce CH_4 Emissions	32 kg/ha (20%)	5% increase	Rainfed flood prone and 50-100 cm standing water area

Mitigation Option	Features of alternative practice	Methane emission reduction potential per ha, or per animal	Impact on yield of milk or rice grain, percent change	Feasible target area or groups or Population
Wheat cultivation in place of Boro rice	Reduce CH_4 Emissions	40 kg/ha (100%)	Per ha yield is less than HYV rice	Except coastal area of Bangladesh
Livestock				
Molasses-urea block / liquid	Reduce CH_4 Emissions Increase in milk production Easy to handle	7 kg/animal (25%)	20% increase in milk	Improved dairy cattle in Bathan and Nonbathan area
Urea treated straw	Reduce CH_4 emissions	2.3 kg/animal (10%)	20% increase in milk production	Local dairy cattle

In the following section the sector-wise GHG mitigation options and their recommendations in respect of least cost mitigation options are summarized.

5.13.1 Energy Sector

The energy sector is comprised of the major energy demand sectors (industry, residential and commercial, transport and agriculture), and the energy supply sector, which consists of resource extraction, conversion, and delivery of energy products. GHG emissions occur at various points in the sector, from resource extraction to end use, and accordingly, options for mitigation exist at various points. The following list shows possible economically attractive technology options for reducing greenhouse gas emissions in the energy sector.

End-use

Lighting

- Commercial facilities: replacement of standard fluorescent tubes with lamps with electronic ballasts and reflectors.
- Residential: replacement of incandescent bulbs with efficient fluorescent and compact bulbs.

Motors

- Use of high-efficiency motors and adjustable-speed drives in industrial facilities

Refrigeration

- Residential: replacement of old home refrigerators with new high efficiency models.
- Commercial: replacement of standard compressors with high-efficiency compressors or multiplex compressors.

Industrial Processes

- Encouraging cogeneration for provision of electricity and process heat. Waste products from industrial processes could also be usable for combustion in a cogeneration process. For example, wood waste can be converted to bagasse.

- Industrial processes often have very high cost-effective energy efficiency potential, but their process-specific nature often precludes generic programs. Industrial audits are necessary to identify the most appropriate measures, and a financing mechanism should then perhaps be put in place to encourage actual equipment retrofits following audits.

Cooking

- Use of improved woodstoves and other more efficient cooking devices.
- Substitution of wood fuels in cook stoves in institutions such as rural schools, hospitals, and other centers.

Water Heating

- Replacement or reduction in use of electric resistance heating. Greater use of natural gas or simple solar systems.

Supply Side

- Combined-cycle natural gas and high efficiency simple cycle gas turbine operations to replace coal-and oil-fired boilers for electricity generation.
- Combined heat and power production systems.
- Hydropower: large-scale systems have significant environmental impacts. Smaller-scale run-of-river systems may often be attractive.
- Wind power in places with favorable climate.
- Small-scale photovoltaic can be competitive especially in remote areas with no grid access. In general, small-scale renewable in rural areas can be cost-effective and also reduce deforestation by reducing reliance on local biomass. Options include solar cooking stoves, biogas plants, small-scale wind systems, and small run-of-river hydro installations, Large-scale photovoltaic are not yet competitive against traditional generation in areas with a developed transmission grid.
- Fuel substitution.
- Establishment of infrastructure: power transmission, natural gas pipelines.

5.13.1.1 Detailed Mitigation Technology Options

Actions by industry that can reduce emissions from energy use include more efficient use of energy fuel switching and optimum use of materials that reduce energy requirements. In addition policies that lessen the demand for energy-intensive commodities can reduce industrial energy consumption.

Energy efficiency is the most important category for mitigation analysis. There are many technologies and practices that could enhance industrial energy efficiency. Minor operational changes, such as housekeeping and maintenance, are typically the cheapest, easiest to implement, and least risky, but usually yield the smallest energy and cost savings. Production equipment changes and energy conservation add-on technologies involve larger investments, and may or may not be justified by reduced energy costs alone. Major process changes often require building a new facility and are usually justified only by strategic market development concerns.

Due to the nature of decision-making in the industrial sector, two technical options would be considered: (1) actions for which energy cost savings are the dominant criteria (energy-cost-sensitive options), and (2) actions for which broader criteria such as overall production cost and product quality are the dominant criteria (non-energy-cost-sensitive options).

Energy-Cost-Sensitive Options

Energy-Cost-Sensitive Options include low to medium-cost improvements to the energy efficiency of existing capital stock, production and use of more energy-efficient equipment, and fuel switching.

Measures for existing processes.

Some examples of energy-cost-sensitive measures that can enhance energy efficiency in existing plants are described bellow.

Housekeeping, equipment maintenance and energy accounting: Good housekeeping includes activities such as carrying out inspections to encourage conservation; scheduling energy-intensive activities; turning off equipment when not in use; installing and using energy monitoring equipment; wrapping tanks and pipes with insulation; and repairing leaks. Regular equipment maintenance can prevent the loss of efficiency that can occur over time. Energy accounting systems can be used to help motivate energy-conservation activities.

Energy management systems can be used to systematically turn off or turn down process equipment, lights and fans.

Motor drive system improvements include use of high-efficiency motors, improved motor rewinding, power conditioning, drive control (especially with adjustable-speed drives), and use of more efficient associated equipment (pumps, fans, compressors).

Improved steam production and management includes use of economizers and other heat recovery systems, attention to steam distribution systems and use of more efficient boilers.

Industrial cogeneration allows the substitution of waste heat from electricity generation for steam that would otherwise be raised in a boiler using fuel (this describes its most common application, the "topping cycle"). Cogeneration is an important option for industries with large process heat requirements such as pulp and paper, chemicals and food processing. It is particularly attractive where there are on-site energy sources that are not being utilized.

Heat recovery may involve transferring heat from high-temperature waste heat sources to more useful media such as steam, or raising the temperature of low-temperature streams so they can be useful as heat sources.

Measures for new equipment

Adoption of more energy-efficiency new equipment is an option for devices widely used across industries, such as electric motors, pumps, fans, compressors and boilers. It is an especially important option in countries where industry is growing rapidly and the manufactured equipment is outdated.

Reduction of emissions from vehicles by fuel switching

This includes advanced engine designs such as fuel cells, which may also increase fuel efficiency, fuel switching to fuels derived from renewable resources, such as ethanol, and to electricity, all with lower emissions per unit of service (vehicle-kilometer traveled, tonne-kilometre of freight lifted). Specific actions may also include measures to ensure production and distribution of fuel, measures to ensure availability of vehicles to use the fuels, and measures to maintain the vehicles and fuel systems, with the specifics depending on the type of fuel and degree of market penetration sought. Some types of fuel switching, such as to battery power, will reduce emissions from vehicle tail pipes, but may have high enough emissions in the production and distribution stages that total emissions for the fuel cycle will offset these reductions partially or totally. In particular the impact of switching to electric vehicles is strongly dependent on the electricity generation resources mix. Fuel switching may also be applicable for railroads, which may consider switching from coal to diesel or electric locomotives, or switching from diesel to electric.

Encouraging shifts towards modes with lower emissions includes measures to promote walking, bicycling, public transportation, and railroad freight relative to automobile and truck traffic; measures to avoid creating barriers to modes with lower emissions when developing, managing, or operating infrastructure for motor vehicles, measures to increase infrastructures devoted to low emissions modes; increase the cost of using motor vehicles relative to modes with lower emissions; increase licensing requirements for motor vehicles relative to modes with lower emissions; increase licensing requirements for motor vehicles; promote modes with lower emissions via public information campaigns or improvements in the quality of service (e.g., dedicated rights-of-way for buses, increased frequency of services).

Opportunities for switching to lower-carbon fuels vary among countries depending in the available resources. The most important options in a mitigation analysis are switching to natural gas or renewable energy sources (e.g., word from managed plantations for boilers, or solar thermal energy for low-temperature process heat demands).

Reduction of emissions from vehicles by trip reduction

As suggested above, reducing the number of trips taken by individuals or the amount of freight transported one must target mitigation options at several sources: 1) reducing the number of vehicles, 2) increasing the capacity utilization of vehicles, 3) reducing the number of trips per person or ton of freight.

***Reducing the number of vehicles*:** This can be accomplished in the short and medium run by a variety of instruments, such as vehicle sales taxes, fuel taxes, and road charges. These instruments either reduce the demand for vehicles or make the price of trips more expensive, thereby creating incentives for individuals to place less reliance on personal vehicles and switch the mode of: travel on some trips from private to less costly alternatives and public transportation and to non-motorized means of travel and higher capacity forms of freight vehicles, and to optimize trip planning. In the long run, better urban redesign and development of inter and intra city mass transit systems can also reduce the demand for private vehicles.

***Increasing capacity utilization*:** This can be accomplished by better route planning for public transportation, by instruments to stimulate car pooling, through economic instruments (i.e., taxes and charges on vehicles and fuel) to create incentives for individuals to more fully utilize available transportation, and by subsidies to public transportation, where and when needed, to reduce the price of public transportation relative to personal vehicle travel.

***Reducing the number of trips per person*:** This can be accomplished, in the short-and medium-run, through better route planning by individuals and firms, by combing trips for multiple purposes. In the long-run, better urban planning can lower the number of trips people take by personal vehicles through spatial arrangements that make it easier to combine trips, and will be seen, reduce the distance of trips from home to work.

Reduction of emissions from vehicles by increasing fuel efficiency

The options available for increasing fuel efficiency include:

Changes in technology to incorporate fuel savings features in new vehicles: Technical measures for new vehicles include: reduction in vehicle weight, drag, or rolling resistance, improvements in engine, transmission and drive train performance. For some types of vehicles another option involves switching fuels (e.g., heavy trucks from gasoline to diesel).

Shifting the mix of new vehicles toward more efficient models: This includes options for improving the technical efficiency of vehicles that are produced assembled domestically, or imported. Vehicle-producing countries can influence fuel efficiency by fuel efficiency standards and fuel taxes. At present, most developing countries do not exercise direct control over the design of the vehicles they import or assemble. However, they can influence the mix of vehicles that they import though trade regulations, tariffs aimed at fuel efficiency, domestic fuel taxes, and they can negotiate with suppliers of vehicle components or vehicle designs assembled domestically to increase the fuel economy of the final product.

Changes in existing fleet efficiency: Changes in existing fleet efficiency improves the fuel efficiency of all vehicles in operation through proper maintenance. This include:

1. Better engine maintenance, and driver training
2. Changes in road surfaces.
3. Better tires/tire maintenance
4. Changes in traffic flow through improve traffic signal timing limiting the mix of vehicles or access on some routes or other measures to reduce congestion or increase average speed and load.
5. Increasing vehicle load factor by ride sharing, changing routes or schedules, or increased backhauling, and improve operating training and performance.

Non-Energy-Cost-Sensitive Options

Non-Energy-Cost-Sensitive Options include major modifications to existing production capacity and addition of new production capacity that incorporates state-of-the-art technology. These options are usually specific to particular industries. Improved use of materials (through recycling and process yield improvements) can be considered in this category.

Major modifications to existing plants: This option can vary from industry to industry. Some examples are improvements to electric are furnaces (steel), revamping open-hearth furnaces where they are still viable (steel), installing an improved aluminum smelter, improved ethylene cracking, and conversion from semi-dry to dry process or installation of pre-calcinations (cement). Across industries, automated process controls based on new sensor technologies can improve product uniformity and quality, and reduce waste from the product stream.

Installation of new production capacity: New capacity is more productive and usually more energy-efficient than existing capacity. The degree of difference depends on the nature of the new technology, which may be a slightly improved version of existing technology or an entirely new technique, the design of new systems, and the age and condition of existing plants. New capacity allows for application of improved technology, design, and process control. Major energy savings are often possible with process integration, which involves designing processes so that the number of heating and cooling steps is minimized. Proper sizing of equipment and matching of components can yield significant savings, as can use of controls and sensors.

Promoting adoption of state-of-the-art technology is an important option over the 10-20 year time horizon during which capital sock is replaced and updated. Near term adoption of advanced technology is probably not a realistic option for most developing and transition countries, but may be viable if one is considering long-term potential.

More efficient use of materials: Recycling scrap, whether from downstream fabricators or post-consumer wastes, by passes the most energy-intensive steps of manufacturing – the conversion of ores and feed stocks into basic materials. The largest energy savings are available in aluminum production. Smaller, yet significant, savings are possible for steel and glass. Process yield improvements and quality controls save energy by reducing the amount of material that must be processed to provide the desired output. Continuous casting in the steel industry is an example of a yield-improving technology that saves large amounts of energy. Automated process controls and sensors are integral part of most yield-improving technologies.

5.13.2 Forestry Sector

Forestry mitigation options refer to those measures and policies that can lead to a reduction in the emission of greenhouse gases from forestry and/or increase carbon sequestration in forests, long-term wood products and other tree vegetation. Mitigation options for the forestry sector may be classified into two basic types. One type involves expanding the stand of trees and the pool of carbon in wood products. Expansion withdraws carbon from the atmosphere and maintains it on land. The second type involves maintaining the existing stands of trees and the proportion of forest products currently in use. Maintaining existing stands, whether achieved through reduced deforestation, forest protection or more efficient conversion and use of forest products, keeps the avoided GHG emissions from entering into the atmosphere for the duration of the pool maintenance. The expansion and maintenance of carbon pools in standing trees, forest soils and forest products are very effective mitigation options. But their implementation would be difficult because the alternative use of the land upon which the carbon is stored by the tree plantation is often more valuable to local inhabitants.

The forest and land use sectors are here defined to include activities which affect GHG emissions or carbon storage on forested land, as well as the conversion of land from (or to) forests from (or to) other land uses. This includes activities that both affect the stock of carbon in forests and the demand for wood products, including energy and substitute wood products. There is one exception: the growing of short-rotation biomass crops on agricultural land is covered in the chapter on non-energy agriculture. Soil carbon storage, specifically on agricultural lands, is also dealt with in that chapter.

There are many potential inter-linkages between forests and land use activities, agriculture and the energy sector and the boundaries between these two sectors therefore must be carefully defined. The following two examples illustrate that.

First, take the case of a country where most of the primary fuel that is consumed comes from cutting down natural forests and using the wood for cooking and, perhaps, lighting. The land that is cleared is used for subsistence agriculture. Energy sector policies to promote electrification would probably reduce the pressure on deforestation, provided that the dominant end use was correctly targeted. Another example is the classic case where more efficient wood stoves to reduce wood fuel use are subsidized. Such programs have had mixed results. In some cases, the wood stoves were sold to raise cash. In others, people tended to increase wood fuel use because the implicit price of the end use activity had fallen, making cooking cheaper.

Implicit in all of these examples are the impacts of policies in one sector on the price of wood fuel, the implicit price of the end use activities associated with that (or some other, substitute) end use, and the marginal value of forests land in relation to other uses. These types of substitution effects are largely unavoidable. In terms of analyzing mitigation options, the potential presence of these effects implies that studies of forest, agriculture and energy sector must be closely co-coordinated. The system boundaries for the forest and land use sectors should according to that are set with regard to the following factors.

- major land uses that compete with forests should be included
- energy and non-energy markets that compete directly with forest product markets should be included.
- markets where consumer demand will be influenced by mitigation policies in the land use and forestry sector.

5.13.2.1 Mitigation Options

There is a number of different ways to classify mitigation options in the land use and forest sector. The one used here is a combination of the classification schemes developed by Houghton (1996), Sathaye et al. (1995) and Richards (1994). The types of mitigation options that are listed below should not be considered definitive. On the other hand, if one of the options that one selects does not contain similarities to any of those enumerated below, then there may be some cause for concern, and that option should be reviewed carefully to determine if it is indeed feasible. This study identifies the following broad types of measures.

- Reduce the rate of deforestation;
- Increase forested area (afforestation);
- Increase of stocks of carbon in existing forests;
- Increase in wood use and efficiency;
- Substitute wood for fossil fuels.

Reducing the rate of deforestation

The measures, which would reduce the rate of deforestation, include reduction in the source of the demands that lead to deforestation, primarily the demand for fuel wood and agricultural products. In the 1980s, the rate of deforestation was approximately 15.4 million ha, or about 1% of the forested area of the globe. Over the period, 1980-1990, the net release of carbon from deforestation averaged about 1.2 PgC per year, all of it concentrated in the tropics (Houghton, 1996). This process could be slowed down by a variety of measures. These include:

Switching to sustainable energy resources : The primary use of forests in many developing countries is as fuel wood. Programs that can reduce end use demands for fuel wood, through substitution to other so called "sustainable" fuels. Such as biomass, solar and wind energy, have the potential to reduce both the clearing of forests and net carbon fluxes. Measures to promote conversion to conventional fossil fuels can reduce deforestation, but they will almost invariably increase net GHG emissions, and so are not considered here.

Increasing the efficiency of fuel wood use : In many developing countries, wood is burned as a cooking fuel in open hearths. Energy losses are substantial. Increasing the efficiency of fuel wood use in satisfying end-use demands, again, has the potential to reduce both the clearing of forests and net carbon fluxes.

Measures to increase agricultural productivity : Much of the land that is deforested in developing countries is subsequently used for agricultural purposes. In the long run, dramatic increases in global agricultural productivity have helped developed countries to reduce rates of deforestation. There is also a growing body of evidence showing that these increases in global agricultural productivity have helped to slow down rates of deforestation in developing countries in recent decades, particularly in Latin America. By reducing the demand for agricultural land, increases in agricultural productivity can help to slow deforestation. But this type of measure can be counter productive results, for example. if it makes a country a low cost producer in an international export market. In that case, increases in productivity will actually fuel higher land demands from agriculture.

Other measures to reduce conversion of forest to agricultural land : Forest land is converted to agricultural land because the net return from agriculture is higher than in alternative forest uses. There are a variety of ways to affect the relative profitability of land. These include:

- Regulations to promote environmental quality, such as requiring replanting after harvesting, which effectively make it more expensive to convert land to agricultural purposes.
- Changes in land tenure practices which take into account environmental values.
- Taxes on land conversion.
- Export regulations.
- Other market mechanisms

Increasing the area of existing forests

Afforestation in developing countries is a relatively new phenomenon. The increases of planted forest areas in the tropics were relatively modest in the 1980s. However, beginning in the late 1980s, increasing attention has been focused on planting forests in developing countries for environmental purposes, often to satisfy environmental regulations in developing countries, which allowed certain industries to offset GHG emissions by actions taken elsewhere.

Increasing stocks of carbon in existing forests

A third approach to increase carbon storage through land-use changes is to enhance the storage of carbon in existing forests. This includes projects that either maintain or expand the existing pool of carbon in soils and vegetation. Technically, afforestation falls into this latter category. These measures also include:

Forest Protection and conservation : These measures can preserve the carbon and other GHGs in both the vegetation and soil. However, increasing the area of protected forest, whether through legislation, land purchases by NGOs, and by other market methods, increases the cost of access to these resources and, as such, creates the potential for carbon leakages. This is because these types of programs increase the scarcity of land, often causing other substitute lands to be brought into agricultural cultivation. Such measures are often included in projects, which are devoted to non-carbon resource management purposes, such as wildlife protection soil conservation, water catchments, and recreational reserves. Other "no regrets" measures include improvements in wildfire protection and reduced forest losses from insects and diseases.

Timber stand improvement : This includes measures to increase the intensity of management on existing stands and encompasses a wide range of measures from reforestation of existing forests land to simply increasing the intensity of management on existing stands. It should be recognized that not all such measures result in increases in the carbon pool. Birdsey (1992a) examines the case where conversion of natural stands to planted pine plantations would result in a net loss in carbon storage, although it would increase merchantable timber supplies. Other measures include.

- Hardwood controls.
- Pre-commercial thinning
- Firewood harvests
- Fertilization
- Pest and disease protection.
- Mechanical site preparation
- Site preparation burning
- Chemical site preparation

Agroforestry : One set of measures that has received much attention in developed countries involves intercropping and the planting of windbreaks and shelterbelts. These measures may also be cost-effectiveness in developing countries.

Increasing carbon in agricultural soils : Conversion of forest to agricultural land generally results in losses of carbon. However, these losses can be reduced by methods to increase carbon storage in soils, by selectively planting crops and adopting tillage methods that increase soil carbon. However, there are limited data about the effects of management on carbon in soils in developing countries to support such analyses and the resultant gains may be quite small. Also advanced tillage systems, such as low till and no till systems are extremely capital intensive and cost-effective only for commercial agriculture.

Urban and community forestry : Forest management, practiced in large contiguous blocks generally to produce wood products, is a rural activity. Development of community-based forestry systems can increase carbon storage if the systems are sustainable. However, community based forestry must be targeted at developing countries with dispersed populations. When forestry is practiced in an urban setting, it provides an entirely different set of benefits. Urban forestry can influence greenhouse gas emissions by modifying the urban environment in two ways. Trees can directly reduce summer temperatures in their immediate surroundings. They can also reduce the electricity consumed for heating and air conditioning when placed at strategic locations around buildings. In addition, three growths can capture carbon dioxide from the air in the form of woody biomass.

Increased efficiency of wood use and enhanced utilization of wood

Options that fall under this category involve increasing the ratio of biomass (i.e., carbon) in wood products to biomass harvested. This can be accomplished in two different ways, as follows:

- Increasing the technical efficiency of wood recovery through improved harvesting and milling techniques that reduce the amount of waste.
- Increasing the merchantable uses of wood from existing harvests.

The intent of these options is to turn wastes from current harvest and milling practices into longer-lived products. However, policy makers must be cautious in how they implement these options because they may well increase the profitability of harvesting natural forests. In that case, deforestation may actually increase (due to higher harvest levels) although the source of the demand for this increase would shift from agricultural products to forest products. These options, like many others, look attractive when they are evaluated from the standpoint of engineering calculations and direct cost outlays, but may have unintended consequences due to wider, market effects.

Substitution of wood for fossil fuels

There are two means of substitution. The first involves the direct substitution of biomass fuels from plantations for fossil fuels. Biomass energy plantations occupy an intermediate position between forestry and annual agriculture. With woody biomass crops, harvesting occurs approximately every 5-12 years and regeneration is accomplished by coppice methods that rely on re-growth of new stands from the rootstock of the harvested stand. The harvested material can be used directly as a boiler fuel: it can be converted into biofuels, such as ethanol and methanol; or it can be gasified. The second includes indirect substitution, whereby new wood products replace other products that are more energy intensive, such as steel creation of large biomass plantations for fuel and feedstock purpose has been identified as among the most cost-effectiveness methods of mitigating GHG emissions in developing countries.

5.13.3 Agricultural Sector

There are many different sources of GHG emissions from agricultural activities. These sources and their contribution to GHG emissions are discussed in detail in IPCC (1990, 1996) and US Country Studies Programs (Sathaye & Meyers, 1995). The primary sources of GHG emissions in this sector include livestock rearing, rice cultivation, fertilizer application, and soil carbon in cultivated soils. The latter are also a potential carbon sink. Since the factors that affect N_2O emissions from nitrogen application are not yet completely understood and also there are uncertainties in the estimates of CO_2 emissions from cultivated soils, the GHG emissions and their mitigation options from these sources are disregarded. So, the primary objective of the development of the mitigation options in agricultural sector is to abate CH_4 emission from the livestock rearing and rice cultivation in wet condition.

5.13.3.1 Overview of Mitigation Options

This section focuses on mitigating GHG emission associated with four general forms of agricultural activity.

1. Rice production: Rice production results in methane emission from the decay of organic material in ponds.

2. Animal husbandry: Animal husbandry results in CH_4 emissions from two sources:

   - enteric fermentation by ruminant livestock, and
   - anaerobic fermentation associated with the decay of manure from livestock operations.

3. Carbon storage on existing agricultural lands (CO_2). Carbon fluxes from agricultural land can be increased by several methods:

   - cropland and grazing land management to conserve soil carbon.
   - use of biomass crops as fuels that displace existing (CO_2) emissions from existing fossil fuels in a sustainable way, and
   - creation of windbreaks and shelter belts.

4. Fertilizer application (N_2O). The application of organic and inorganic fertilizers to soils influences nitrous oxide emissions.

Rice production

Methane is produced in the soil by the anaerobic decomposition of organic substances promoted by the action of bacteria (methanogenics) that require highly reduced conditions for their development, such as the ones found in flooded rice paddy soils. Flooded rice paddies are one of the most important anthropogenic sources of methane (CH_4). The global emission rate of this gas in irrigated rice fields was estimated at 20 to150 Tg per year, which corresponds to 5-20 per cent of the total emissions from all sources (IPCC, 1996c). Among the factors influencing methane from cultivated rice paddies that can be manipulated through mitigation options are: Cultivated area, period of flooding, variety of plant, plant nutrients.

Reduction in period of flooding

Another, more effective and less costly, way to reduce methane emissions is through intermittent flooding and drainage of rice paddies, or by increasing the percolation rate of the soils. For example, a recent study on China (Kern et al., 1995) estimated that introducing intermittent drainage on 33% of the properly drained soils used for rice production would reduce methane emissions by roughly 10%. Although intermittent drainage has been shown to reduce methane emissions, this option is limited by several practical factors, including the area of rice that is relatively easy to drain and re-flood and the need for secure and controllable water supplies. The need for controlled flooding and drainage is particularly important for avoiding yield losses due to under-irrigation. Further, it is important to keep in mind the fact that the controlling factor is the reduction in the period of time anaerobic conditions exist in the field. If drainage is poor, then the reduction in irrigation inputs may have a smaller impact on methane emissions than under good drainage conditions.

Introduction of new plant varieties

Another way of effectively reducing methane emissions is by adopting plant varieties that mature more quickly and so require less flooding. Newer varieties of paddy rice mature from 10% to 15% more rapidly than traditional varieties in some parts of the world, without sacrificing yields. While these varieties were developed to conserve water, their adoption can also lead to reduced methane emissions at relatively low cost.

Nutrient management

In many parts of the world, rice is grown using abundant organic fertilizers and straw. A number of studies have shown that methane production in rice paddies is heavily influenced by the amount of green manure (Lauren et al., 1994) and straw (Neue et al. 1994 and Nouchi et al. 1994) that are added to provide plant nutrients. Substituting inorganic fertilizers for organic nutrients can slow the rate of anaerobic decomposition. A study in the USA by Lindau (1994) indicated that methane emission could be reduced by as much as 50% by substituting commercial fertilizers for organic fertilizers. However, these types of reductions are highly dependant on soil conditions, water regime, and other biogeochemical factors. Moreover, the introduction of sizeable quantities of commercial fertilizers may also be quite costly in some developing countries and could also lead to increases in N_2O emissions.

Animal Husbandry

Enteric fermentation : Methane is produced in herbivores as a by-product of enteric fermentation, a digestion process by which carbohydrates are broken down by microorganisms into simple molecules for absorption in the bloodstream. Both ruminant animals (like cattle and sheep) and some non-ruminants like pigs produce methane. The amount of released methane depends on the type, age and weight of the animal, the quality and quantity of the feed and the energy expenditure of the animal.

Methane emissions per animal can vary widely – from 501/day to 5001/day depending on the above factors. However, under a wide variety of every day conditions, these emissions are a relatively constant fraction of the diet consumed, about 6% of diet energy or 2% of the diet by weight. Most of the options used to reduce methane emissions from ruminant livestock focus on decreasing the feed intake required per unit of product – milk, meat and work – by means of simultaneous improvements in diet quality and animal productivity. The effectiveness of this strategy is based on shifting feed intake from maintenance to production. The feed required to maintain livestock is approximately the same for a low producer as for a high producer. However, when productivity is increased, the proportion of feed going to maintenance is reduced, and methane emissions per unit of product decrease. For example, for a 400 kg dairy cow an increase in productivity from 2.2 to 4.4 kg/day can reduce methane emissions by 40% per kg of milk. This means that one can produce the same amounts of milk, meat and work as in the baseline scenario from fewer animals. By cutting the herd size, while maintaining production at baseline scenario levels, methane emissions are reduce.

The range of options available for reducing methane emissions from enteric fermentation in ruminant animals include:

1. Mechanical and chemical feed processing: These measures generally involve chemical treatment of straw, using alkali/ammonia and copping of low quality straw. Assuming that feed digestibility is increased by 5%, methane emissions per unit of product may decrease around 10 to 25% depending on management practices.
2. Strategic supplementation: These options include using molasses/urea supplements, rumen bypass product, bioengineering of rumen micro biota, and mineral supplements. Using these methods can reduce methane emission by 25 to 75% per unit of product.
3. Enhancing agents: Methane emissions per unit of product can be reduced substantially by using bovine somatotropin, anabolic steroids, and other agents.
4. Genetic improvement: Crossbreeding and upgrading (especially in developing countries), as well as genetic improvements in the stock and genetic engineering are among the methods than can be used to increase animal productivity.
5. Reproductive improvement: Methods that improve animal productivity indirectly reduce the numbers of animals needed to produce offspring, and this leads to reduced methane emissions. However, there are direct measures, which can achieve the same result, including twining, embryo transplants, artificial insemination, and estrus synchronization.

Anaerobic fermentation : Methane is also produced from the decomposition of organic components in animal waste due to anaerobic fermentation. The amount of released methane depends on the quantity of waste produced and the portion of the waste that decomposes anaerobically. When the animal waste is stored or treated as a liquid (as in lagoons and pits) it tends to decompose anaerobically and methane can be produced. This means that the principal sources of methane emissions from this process are liquid/slurry storage facilities (pits and tanks) and anaerobic lagoons. When the waste is handled as a solid (as in stacked piles) or when it is deposited on pastures, it tends to decompose aerobically and little or no methane is produced. This has important implications for developing countries in which manure is managed as a solid, either as a fertilizer or a fuel. In these cases, mitigating methane emissions will not be very cost-effective, because the reduction in methane emissions will be quite low and the cost of replacement fertilizer may be high. However, dry manure than is deposited on fields may be associated with N_2O emissions from the nitrogen cycle.

The options for reducing this type of methane emissions all involve recovering the methane from anaerobic fermentation and using it as a gas. The recovered methane gas can be used directly on the farm to supply various energy end uses, or can be collected and sold, or it can be used to fuel boilers that provide the energy to generate electricity. The remaining by-products of anaerobic decomposition, contained in the slurry or liquid effluent, can be used as crop fertilizer, animal feed and as supplements for aquaculture.

The main mitigation options include

1. Small-scale digesters. Digesters are basically containers into which manure and water are placed. They maintain suitable conditions for bacteria to digest the biologically active component of the manure resulting in the production of biogas, which is 60-80% methane. Small-seale digesters are appropriate for small and medium sized rural farms. Typical fixed dome small-scale digester sizes range from a 4-5 m^3 total capacity design suitable for small farms, to 70-100 m^3 total capacity designs. For a family of 6 in the developing world, digester systems of size 4-6 m^3 can meet daily biogas requirements, estimated at 2.9 m^3 for all local residential and agricultural uses. Efficient digesters with gas recovery systems may reduce methane emissions up to 70%, with larger reductions achievable at longer retention times.
2. Large scale digesters. Large scale digesters operate on the same principle as small scale digesters, but are considerably larger and are appropriate for relatively large, intensively managed farms. Such systems are capable of handling the manure output of operations with a few hundred to several thousand, ore more, head of cattle or swine, or roughly 0.5 million poultry. Gas recovery rates depend on ambient temperatures throughout he year and vary depending on the farm's geographic location. A typical digester will produce 0.25 – 0.6 m^3 biogas per kg of volatile solids, operating at 30 to $35^{\circ}C$. Efficient digesters with gas recovery systems may reduce methane emissions by 70%, or greater in cases of longer retention times.
3. Covered lagoons. Methane from lagoons can be captured by placing a floating, impermeable cover over the lagoon, sealed at the edges to prevent influx of air. Gas recovery rates depend on ambient temperatures and the farm's geographic location. Average gas recovery at US dairy farms range from 187-375 m^3 biogas/1,000 kg of volatile solids handled. Assuming 10 kg of volatile solids produced daily by an average US dairy cow and a 60% methane content in biogas, daily recovery rates at dairy farms handling 100% of the manure produced can range from 112-225 m^3 methane / 100 head.

Use of biomass crops to produce fuel

Biomass is currently being used to produce liquid fuels such as ethanol, methanol, and biodiesel as well as a fuel to produce electricity. Biomass crops can be woody (short rotation woody biomass), herbaceous perennial (for example, switch grass), or herbaceous annual (such as corn or sorghum). These crops are grown under intensive management, generally with high nitrogen requirements, and are most suited for developing countries that have a developed, commercial agricultural sector. These crops and be substituted for existing crops to reduce CO_2 emissions.

The production of biomass has an impact on carbon emissions in three different ways. First, it can substitute for fossil fuels. The conversion of biomass to energy releases CO_2 into the atmosphere. The photosynthesis process recycles CO_2 from the air and converts it into biomass. Therefore, any quantity of biomass substituted for fossils fuels will reduce the net increase of CO_2 in the atmosphere that would occur from combustion of the fossil fuel. Second, the difference in fuel and agricultural chemical requirements to produce biomass versus other crops will have an impact on carbon emissions to the atmosphere. The third impact of producing biomass is the sequestration of carbon in the soil. On the average, there is less soil disturbance in the production and harvesting of biomass crops than for annual crops. This should reduce oxidation and harvesting of biomass crops than for annual crops. This should reduce oxidation and release of carbon to the atmosphere and help sequester carbon in the soil (except if the biomass crop is an annual such as energy sorghum).

Planting of windbreaks and shelter belts

Windbreaks are composed of rows of progressively taller vegetation established perpendicular to the predominant wind flow; the lowest vegetation is on the windward side and the tallest on the downstream side of the flow. This vegetation is a mixture of low – to mid-level bush and low-to tall-growing trees. As these plantings mature, they offer significant resistance to wind flow and reduce net CO_2 emissions by sequestering carbon in wood and the soil. Windbreaks and shelterbelt are grown mostly to slow winds during the growing season, thus stopping wind erosion and plant desiccation. They can also be used to shelter the farmstead, thus reducing fuel required to heat and cool the buildings, thus reducing the energy requirements for heating and cooling farm dwellings.

Fertilizer application N_2O

Nitrous oxide is produced naturally in soils by the microbial processes of nitrification the oxidation of ammonia to nitrate (NO_3) – and denitrification – the reduction of nitrates or nitrites (NO_2) to gaseous nitrogen. The application of commercial nitrogen fertilizers provides and additional source of nitrogen that can enhance natural nitrous oxide emission from the soil. In well-aerated conditions, where soil moisture content does not limit aeration, nitrous oxide emissions from the nitrification of ammonium-based fertilizers can be substantial. The nitrogen cycle is subject to considerable variability from a wide variety of sources, and the impacts of management practices on denitrification vary widely, as a result. Unless a great deal of information is available from field studies on this topic, the assessment of mitigation options should be considered highly preliminary. Nevertheless, there are number of potential "no regrets" management options which, if adopted, can promote sustainable agriculture while at the same time leading to potential reduction in N_2O emissions.

The basis for mitigating N_2O emissions as a no regrets option is that high-yield production agriculture can be sustainable agriculture. They are not mutually exclusive. As conservation and agronomic practices are adapted, nutrient use efficiency increases, erosion is slowed, the potential for non-point source water pollution drops, and crop yields go up. The efficiency of nutrient use in agriculture can be greatly improved as a result of farmer implementation of science-based technologies, including conservation tillage practices to reduce erosion hold more nutrients in the soil, and improve infiltration. Some of the ways farmers can ensure that applied nutrients are used more efficiently include:

- Testing and plant analysis to determine N needs;
- use of precise application equipment to ensure optimal timing and placement of nutrients in order to match nutrient levels to crop needs;
- encapsulating fertilizer to slow the release of nitrogen and using nitrification inhibitors to reduce nitrous oxide emissions, and
- better irrigation water management to reduce leaching of N into the groundwater where it is lost as a source of plant nutrients.

Adding nitrogen to the soil results in some nitrous oxide emissions, which is a very effective greenhouse gas. But how much is emitted depends upon many factors, including the quantity, the acreage, the form in which nitrogen is added, the manner of application, and the frequency of application. Nutrient contents of manure's are low compared to commercial fertilizers, so large quantities of manure must be applied to each acre. In commercial agricultural setting, this requires significant amounts of fuel and is usually labor intensive. While all forms of nitrogen added to the soil result in the formation of nitrous oxide, the efficient application of commercially available sources of N can have two potential effects on greenhouse gas emissions:

- direct reductions in the amount of N_2O produced per unit product, so that less cropland is needed relative to the baseline scenario to meet food demands, and
- indirect increases in carbon sequestered in native ecosystems, which do not have to be converted into crop, pasture, or grazing lands to meet food demands in the baseline.

5.13.4 Waste Management Sector

The primary sources of GHG (only CH_4) emissions in this sector include landfills and wastewater treatment. There are two approaches in reducing methane emissions from landfills: (1) the methane generated in landfills can be recovered and used to produce energy; and (2) the quantity of land filled waste can be reduced through source reduction, recycling and other waste-management practices. Although the factors affecting methane emissions from wastewater treatment remain very uncertain, yet providing (1) effective aerobic treatment; and (2) recovery and utilization of methane from anaerobic digestion of wastewater or sludge would help in reducing emissions.

Solid waste mitigation options

There are two approaches to reduce the methane emissions from landfills: (1) the resultant methane can be recovered and then either flared or used to produce energy, or (2) the quantity of land filled waste can be reduced through source reduction, recycling or other waste management practices.

In addition to reduce methane emissions to the atmosphere, the recovery of landfill gas creates other benefits, such as:

- Improved landfill safety. In recent years several accidents have resulted from explosions of methane in houses situated close to landfills.
- Reduced emissions of other Volatile Organic Compounds (VOC).
- Reduced odor problems.

Recovery of methane from landfills

The recovery of methane from landfills has been attempted since the mid 1970s, when the first plants were built in the US. More than 400 plants have since been constructed worldwide, with more than 100 of these in the US. In the UK, plants of this kind have been one of the successful technologies under the NFFO (Non-Fossil Fuel Obligation), and 60 plants totaling more than 80 MW have been constructed.

The landfill gas is extracted through a series of wells drilled into the landfill. The well shafts, typically 1-3 feet (30-90 cm) in diameter, are drilled from the surface to within a few feet of the bottom. A narrow, perforated plastic pipe is then inserted into the well. The shaft is backfilled with gravel or a similar permeable material and the top is sealed to prevent the inflow of air. Finally the pipe head is connected to the collection system, where the gas is processed and purified to remove water, particulates, halogen compounds and hydrogen sulphide (H_2S). The purified landfill gas is typically a 50:50 mixture of methane and carbon dioxide with a calorific value of $18 MJ/m^3$. A plant of this kind can extract 30-40% of the methane generated.

The gas recovery can be improved by covering the landfill with a membrane such as a layer of clay, or a thick layer of soil, possibly incorporating a plastic layer. Well-designed systems have achieved recovery efficiencies of 70-80%. The annual amount of gas collected from the landfill can then be calculated by multiplying the recovery rate with the amount of gas produced. The gas production is then calculated as the number of tons in the landfill multiplied with an average CH_4 emission factor based on the material fractions in the land filled waste.

5.14 Formulation of Mitigation Policy

5.14.1 Areas of Focus

In the principles of mitigation section, different aspects of the issues related to mitigation have already been described. It is very much clear that, the main mitigation activity is the lowering of energy intensity through increased energy efficiency; but its actual implementation depends on the identification of the sectors or the activity where one should introduce the mitigation activities. While one must investigate first whether there is a scope for efficiency improvement, it depends ultimately on case of adoption of a new practice, technology, costs of acquisition, domestic fuel availability.

It has been observed that power generation is not simply inefficient in general, even within the sector; there is a wide variation in efficiency. Furthermore, in comparison to many other sectors/sub-sectors the cumulative power demand is going to increase faster. Similarly other major areas where attention would be needed could be identified as industries, transport and the domestic sectors.

Industry is a very important sector in terms of GHG emission, as there is a large scope for improvement even with existing knowledge, because of wide variations in efficiency.

This has been found that, the residential sector, is not simply the largest consumer of energy by way of its demand for bio-mass, but also that it may the largest or second largest consumer of other energy forms. Thus the households must be a major, perhaps the most important, sector to focus and their energy use behavior must be investigated in-depth to find ways and means for energy efficiency improvement and conservation.

The importance of transport sector arises not because of it is the major consumer of petroleum products, but also that much or practically the whole of it is import-dependent. So, any increase in efficiency here is likely to help in the economy in terms of balance of payments improvement.

5.14.2 Nature of Improvement

For improving energy efficiency, generally there are several types of changes, which is very much essential. These include (in order of difficulty of adoption either due to costs or complexity of choice) housekeeping, retrofits and process improvements. Housekeeping refers to simple acts of maintenance and care (like putting off the light when not necessary and putting insulation in pipes leading from boilers). Retrofit refers to taking additional measures (like using waste heat for co-generation) which does not chance the basic technique of performing an activity (e.g. production). Process change refers to the change in basic technique of production and involves the most thoroughgoing changes in terms of technique and also probably organization of production in the shop floor possibly involving retraining of the production workers. Thus, the latter is not simply a decision to improve energy efficiency but as good as a new to investment decision of which energy efficiency may not even be a major part. If such process change is critical for energy conservation, one will therefore have to adopt policies to facilitate such investment decision. Obviously, for such potentials to be realized whether in use of electricity or in increasing efficiency in the industries would necessitate various promotional and incentive policies.

The following Table shows the some of the GHG abatement action program are being implemented in Bangladesh.

Table: 5.5 GHG Abatement Action Program

GHG Abatement Action Program	Key Targets of the Project	Priority Sector	Status
Gas Based Efficient Power Generation and conversion of open cycle to combined cycle power plant	Establishment of 8800 MW gas based power generation capacities by the year 2005.	Power Sector	A number of private companies are involved for natural gas exploration and setting up of new gas based power plants and conversion to combined cycle power plant.
Dissemination of improved cooking stoves in rural areas of Bangladesh	To replace 1 million traditional cooking stoves by improved ones	Domestic (energy use) & Forestry (resource conservation)	Present dissemination program is progressing slowly due to lack of motivation.
Phasing out of two-stroke engines with four-stroke engines for three wheelers	To replace about 14311 retiring two-stroke engines with four-stroke engines in auto-rickshaws	Transportation Sector	Within Sept'02 two-stroke engines would be banned and provision of tax holiday for encouraging four-stroke three wheelers
Conversion of petrol driven vehicles into CNG driven vehicles	Conversion of 17000 petrol driven cars into CNG-driven cars	Transportation Sector	Conversion process has been started with a limited capacity. Government owned vehicles are slowly converting to CNG driven.
Solar electricity with Photo-voltaic (PV) system	To disseminate PV electricity in about 100,000 rural households	Domestic lighting	The Rural Electricity Board is involved with pilot study and private entrepreneurs are coming forward for implementation.
Replacement of Incan-descent bulbs with Compact Fluorescent Lamps	To replace at least 50% of all incandescent bulbs with CFLs by the year 2020	Domestic, Industrial and Commercial lighting	The department of forestry under the MOEF is developed project for attracting local and foreign investment.
Improvement in Brick Manu-facturing Efficiency by changing wood fuel based kiln known as Bull Trench Kiln (BTK) to natural gas fired kiln known as Hoffman Kiln (HK).	Under this project 7 BTKs would be replaced by 1 HK. Within the 15 years of project tenure 54421 tonnes of CO_2 would be reduced per yr.	Industrial Sector	Project is under process.
In the Vegetable Cold Storage, for supplying reliable and economic source of electricity in cold storage industry.	0.5 MW electricity would be used from the grid (natural gas fired) to run 600 vapor compressor chillers for a total capacity of 100 tonnes of refrigeration along with waste heat utilisation.	Industrial Sector	Project is under process.
Promotion of Environmental Management System (EMS) in Industries	To train personnel of 52 industries along-with 52 gra-duates in implementing EMS those industries	Industrial Sector	A yearlong training program has been completed with 51 industries and most of them are implementing the training knowledge in their premises.

6 CLIMATE CHANGE RESPONSE STRATEGY

6.1 Climate Change Response Strategy

Government of Bangladesh has given due attention to understand the problems related to climate change impacts and vulnerability and to adopt appropriate coping mechanisms. While she is only a very minor emitter of GHGs, Bangladesh has also tried to understand the measures that may be adopted to mitigate climate change. It has undertaken the following steps, which directly or indirectly serve as response to climate change in addition to their role in environmental protection, nature conservation, disaster management and sustainable development.

6.2 Existing Strategies and Actions

Government of Bangladesh (GOB) has established the Department of Environment (DOE) under the Ministry of Environment and Forest (MOEF) as a key institution to address the issues of environmental degradations occurring naturally and due to human interference. MOEF, with technical support of DOE is dealing with the climate change issues nationally and internationally in addition to its normal functions dedicated to environment. DOE has been housed in its own campus, where a modern library and documentation center has been established. The publications on environment and climate change are available in the library and the documentation Centre.

Bangladesh is a member of WMO and IPCC and is signatory to most of the conventions, treaties and protocols (ICTPs) on environmental issues including UNFCCC; Kyoto Protocol; Convention on Biological Diversity; Montreal Protocol on Substances that Deplete the Ozone layer; Basel Convention on the Control of Transboundary Movement of Hazardous Wastes and their Disposal; International Convention to Combat Desertification with a view to taking part in the unified global steps to combat the degradation of environment. It attends the meetings and actively participates in the activities of all these forums. This very much indicates the sincerity and awareness of GOB in the climate change issues, which has facilitated its participation in the global activities on climate change and their impacts. This Initial National Communication on Climate Change of Bangladesh to UNFCCC is one of the response strategies.

Government of Bangladesh and a number of NGOs have completed a significant number of studies to understand the impact and vulnerability of climate change and adaptation strategies. The studies that have been completed include:

- Bangladesh Climate Change Study
- Asia Least Cost Greenhouse Gas Abatement Strategy, ALGAS (Bangladesh Chapter)
- Climate Change in Asia: Bangladesh
- Institutional Strengthening for the Phase-out of Ozone Depleting Substances (Phase-I and Phase-II)
- Vulnerability and Adaptation to Climate Change
- Conversion to CFC-free Technology in the Manufacture of Aerosol Products.
- Coastal and Wetland Biodiversity Management Project.
- Formulation of National Programme Based on Agenda-21 adopted at the Earth Summit in Rio de Janeiro, 1992.
- National Action Plan for Bangladesh on Control and Prevention of Air Pollution and Its Transboundary Effects.
- Preparation of Initial National Communication in Response to the UNFCCC.

Among the ongoing studies the following may be mentioned:

- Institutional Strengthening for the Phase-out of Ozone Depleting Substances (Phase-III).
- Air Quality Monitoring Project.
- Coastal and Wetland Bio-diversity Management in Cox's Bazar and Hakaluki Haor.
- Implementation of a National Program for Recovery and Recycling of Refrigeration.
- Several sub-projects under the Sustainable Environment Management Programme (SEMP).

Among the actions undertaken in disaster management, protection of bio-diversity and conservation of ecology & environment the following are worth mentioning.

- 25 studies under the Flood Action Plan (FAP) after the disastrous floods of 1987 and 1988 to achieve a permanent and comprehensive solution of the flood problems and to create an environment for sustained economic growth and social development.
- Project on "Forestry Resources Master Plan'.
- Projects on 'Integrated Coastal Zone Management (ICZM)' and 'Meghna Estuary Study (MES)'.
- Strengthening of the monitoring and warning systems of the disastrous events of weather, such as, tropical cyclones and floods in the respective concerned institutions.
- Construction of riverbank and coastal embankments to protect vulnerable areas from monsoon flooding.
- Construction of more than 2000 cyclone shelters for safety of the vulnerable population during cyclonic storms and associated surges.
- Steps to solve the transboundary water issues with India along the Ganges and signed a bilateral treaty with India on the sharing of Ganges water.
- Creation of reserve forests and sanctuaries for conservation and preservation of bio-diversity.
- Inclusion of climate change issues and other environmental concerns in the curricula of the general and specialized education system of the country.
- Restricting the use of old and dilapidated vehicles and three wheelers with two-stroke engines and initiating a project on use of Compressed Natural Gas (CNG) in the vehicles instead of gasoline to reduce the vehicular emission of CO_2 and other harmful airborne particles and air pollution. Though Bangladesh does not have an explicit GHG Mitigation Policy yet, the above actions have played due role in the GHG mitigation in the country.
- Conducting awareness campaign, in active cooperation of the civil society and the NGO Community, among the general masses through the news and electronic media, leaflets, posters, rallies, seminars, symposium, observance of various environment related days and discussion meetings about various environmental issues including climate change.
- Continuous drive toward roadside plantations and plantations on fallow lands. The Department of Forest has raised artificial mangroves in the coastal zonein an area of 113 thousand hectares. Besides, there is a program for plantation in the coastal zone aiming at the environmental and ecological conservation and income generation of the poor people living in those areas. One particular characetrsitics of the present drive towards tree planatation is the emphasis on planting of medicinal plants for deriving multiple benefits from such activities apart from their environment-friendly functions.

- Strengthening medical education, research and health care and health awareness programs. The mass awareness campaign for child immunization, health care, sanitation, use of safe drinking water is conducted through the mass media, leaflets, posters, etc. and seminars, symposiums, discussions and rallies.

6.3 Existing Policies

The Government of Bangladesh has adopted a good number of policies, legislations and measures toward protection of he environment, in general, and addressing the challenges of climate change, in particular.

A few of the important ones are given below:

a) The environment policy 1992 was an important development toward fulfilling the requirement of Agenda 21, the 1992 Rio Convention on Climate Change and Biological Diversity. Further, the Environment Conservation Act (ECA) 1995, the Environment Conservation Rules (ECR) 1997 and Environment Court Act, 2000 were approved by Bangladesh National Assembly to restrict and mitigate various environmental problems in the country.

b) Government has approved the National Environmental Management Action Plan (NEMAP) 1995. In NEMAP several major priority areas of environmental concern, including climate change, have been identified.

c) High priority has been given to the issues related to climate change. A high-level national committee has been constituted with representatives of stakeholders' ministries, agencies, NGOs and academia to provide guidance to the activities as follow-up of the UNFCCC and the Kyoto Protocol.

d) Given that the Sundarbans, the largest mangrove in the country, is under threat from inundation due to sea level rise as a consequence of global warming and thus may result in loss of biodiversity, the law to protect wildlife biodiversity, the Bangladesh Wildlife Preservation Act of 1974 has a major role to play in adaptation to climate change. A separate policy on Biodiversity is yet to be formulated. Bangladesh National Biodiversity Strategy and Action Plan is under preparation as national obligation to the Convention of Biological Diversity.

e) The Forestry Master Plan, 1992 is already in operation.

f) The National Water Policy (NWP) 1999 has been formulated providing for a comprehensive framework for sustainable use of water resources in the country. Based on the policy, the National Water Management Plan (NWMP) 2001 has been prepared.

g) An environmental friendly National Energy Policy has been adopted in 1995 providing for energy efficiency and encouraging renewable energy sources.

h) Government has given high priority to address the disaster management issues and has formed a National Disaster Management Council (NDMC), which establishes policies and provides overall direction for all aspects of disaster management.

i) All development projects in Bangladesh are subject to appropriate Environmental Impact Assessment (EIA).

6.4 Future plan of action under policies and measures

Considering the substantial gains that may be reaped through higher energy efficiency and also the possible adverse impacts of climate change such as enhanced intensity of monsoon floods as well as severe droughts, higher mean sea level, coastal inundation, inward extension of tides, intrusion of salinity and formation of more intense and frequent tropical cyclones and higher storm surges, measures may be adopted towards increasing the resilience of the people and the economy to climate change and reduce the impacts and consequent vulnerability as well as mitigating GHG emission. Some of these are listed as under. It should be noted that these are generic policies and measures and some do exist in some form or other, but may need to be reoriented in view of the climate change impacts and vulnerability.

Protection of Arable lands

The country's food production and food security depend on the cultivation of available arable lands. Such land therefore needs to be protected from erosion, inundation and degradation due to salinity and drainage congestion.

Improving Water Management

Improved and more effective water management system may be introduced for reducing flood in the monsoon season and improving water use efficiency in the dry season. Increased water use efficiency along with more suitable agronomic practices may help in reducing methane emission.

Improving Agro-technology and Research

The national agricultural research needs to be reoriented towards the consideration of carbon-enrichment, changed water regime and precipitation patterns for development of more suitable and improved variety of crops and crop cultivars to meet the ever-growing demand of food. This may also help in reduction of methane emission.

Formulating Land-use Policies

Land-use policies may be revised considering the impacts of climate change specially for the coastal zone, which is threatened due to increase of sea level and increased number of tropical cyclones.

Coastal Zone Management

Since the coastal zone of Bangladesh is highly vulnerable to climate change, the adaptation policies, programmes and projects may put more focus on that zone. To facilitate the adaptation measures, a suitable integrated coastal zone management system and required policies may be developed and implemented.

Food Security

Since the country may become more vulnerable to floods, droughts, salinity intrusion and drainage congestion due to climate change, crop and food production is likely to be adversely affected and food security may become a major problem in the future. Appropriate food security policy taking the climate-induced adverse impacts into account may be adopted. Appropriate food reserve management may be introduced.

Strengthening the Disaster Warning and Disaster Preparedness Systems

Bangladesh has a disaster monitoring and early warning system, which is a part of the broader disaster preparedness system. Both need to be strengthened further because of the increased frequency and severity of future natural disasters. Adequate resources, relief materials, food and medicine may be kept in ready stock for release when sudden disasters occur.

Transboundary Cooperation

The transboundary cooperation for exchange of data, knowledge and expertise needs to be strengthened. As 93% of the catchments of the GBM river system lies outside Bangladesh, this is essential for an effective management of the surface water system, which will be under threat due to climate change impacts. As a result the water related problems of Bangladesh should be regarded as the common problem of the countries within the catchment area. Thus, a strong framework for transboundary cooperation among the common riparian countries is necessary to face the challenges of climate change. While already there is a certain cooperation including water-sharing treaties among some of the countries in the region including Bangladesh, this need to be further integrated and developed with the regional and common climate change impacts in view. Regional investment and other necessary plans and policies may be formulated in this regard. Finance for the regional activities may be sought from the various funds that are being set up and also from various multilateral and bilateral development agencies and partners.

GHG Emission Reduction

Government would develop a GHG mitigation policy. The National Energy Policy that exists may be further strengthened with the incorporation of climate change mitigation issues. The efficiency of energy use is to be encouraged and Clean Development Mechanism (CDM) will be examined thoroughly for finding its suitable niche within such a policy. Other mechanisms that are coming into practice including JI, AIJ, carbon trading and carbon fund will all be examined thoroughly although most of these at the moment may not be applicable to Bangladesh.

All relevant sectors such as power generation,, industry and transport would be encouraged through suitable policies to increase energy efficiency thereby helping in the process of global effort at mitigation.

All environment, water and natural resource management policies, plans and acts may be reexamined for incorporation of climate change concerns.

Sustainable Development Programme

Projects would be undertaken for sustainable development and poverty alleviation, assessment of impacts of climate change and adaptations and implementation of the adaptation policies and plans. The present PRSP activity within the country will be reexamined for incorporation of environmental issues, in general and climate change vulnerability in particular.

Climate Change Policy

While certain elements of various policies and programmes have a kind of interface with climate change issues, the country lacks an integrated, coherent and internally consistent climate change policy. Such a policy may have interacting core elements focussing on five broad areas of concern, which are mitigation, vulnerability and adaptation, coordination with other sectoral policies, international negotiations and research and training. The issues of mitigation and adaptation and vulnerability, and their interface with other sectoral policies and programmes have already been touched upon. Indeed, coordination between and within sectors may be a major thrust of the policy. The policy particularly may specifically require provisions and mechanisms necessary to ensure the incorporation of climate change concerns and issues in all development and non-development programmes and projects. Furthermore, all sectors, programmes and projects may be required to provide climate change information to the planners and policy markers.

One of the major differences of the climate change concerns from other environmental issues is its global dimension and the consequent tough negotiations that are going on at present. It has reached a critical stage where within a foreseeable future a climate change protocol may be in force and binding. Bangladesh, therefore, will strive to play a proactive role in these and following negotiations, which is likely to result in substantial flow of resources for development activities. The future Climate Change Policy may, therefore, include international issues as a major element.

A major element of the Climate Change Policy may be the framework for climate change research and training. Both the activities may encompass the whole area of issues under climate change and include all related disciplines. The training may be both for general awareness and also for specialised and sectoral activities, for the purpose of planning and project designs and response to various proposals during the international negotiations.

Formulation of National Adaptation Plan of Action (NAPA)

High priority has been given to formulation of a National Adaptation Plan of Action. Experience of LDC Expert Group Meeting held in Dhaka during 19-21 September 2002 on the issue is being utilized for the purpose.

National Capacity Building

National capacity building is an important aspect for climate change research, formulation of mitigation, adaptation and response strategies, policy formulation and planning and implementation of the mitigation and adaptation policies and options. For this purpose, intensive training on a continuous and regular basis may be provided to the policy makers and planners. Such trainings may be for both short-term and long-term perspectives and more academic-oriented. Furthermore, climate change issues will also be focussed as a part of the on-going activity of incorporating environmental issues in the curricula in school and colleges.

Institutionalization: Creation of 'Climate Cell'

The formulation of a climate policy and its implementation needs continuous monitoring, interaction with various sectors and activities and specialised research and training activities. This is all the more important because of the critical stage of negotiations that the climate change convention has reached. The Government is, therefore, considering the creation of a Climate Cell or Wing under the Department of Environment to serve as the coordination and focal point for all climate change related activities.

7 CONCLUSIONS

7.1 Conclusions

This is the Initial National Communication of Bangladesh in response to UNFCCC. This has followed, as far as practicable, the prescribed format of national communication circulated by the UNFCCC. The Initial Communication includes reports on national circumstances, the status of GHG emissions, mitigation strategies, and vulnerability to climate change and adaptation strategies.

A comprehensive GHG inventory has been carried out on the basis of IPCC guidelines (1996) using the available data of the various sectors. The emission factors as provided by the IPCC have been used except for a number of cases where adjustments have been made based on expert judgements. The adjustments have been done mainly for estimation of emission from the Agriculture and Forestry and Land-use Change Sectors. The estimates show that the net emission of CO_2 from Bangladesh amounts to 24297 Gg (or 24.3 million metric tons). The estimated respective emissions of methane and nitrous oxide are 1211 Gg (i.e., 1.2 million metric tons) and N_2O 14.3 Gg (or 14 thousand metric tons). There are high potentials for mitigation of GHG emission through efficient use of energy, controlling of vehicular emission, and planting more trees in the country.

The Vulnerability and Adaptation to climate change has been analysed for the following resources, sectors and concerns.

- Three major river basins: Ganges, Brahmaputra and Meghna
- Freshwater resources
- Coastal-zone, coastal resources and coral reefs
- Agriculture and food security
- Forests, bio-diversity and ecosystems
- Fisheries and marine resources
- Human health
- Socio-economic impact

The analyses draw upon existing studies and secondary information. Lack of adequate resources precluded the generation of first hand need-based information. It must be noted that there are vast scopes for improving these estimates of both emission and vulnerability estimates. Particularly the net emission from land use and forestry activities remains black boxes. Even the comparatively easily available information on energy use may be improved substantially over time through study and research. Thus, there is a need for development of country specific emission factors for agriculture, forestry and land-use change and waste management. The emission factors needs also to be developed for CH_4 emission from rice fields under various conditions of inundation and agronomic practices. For the forestry and land-use change sector, the forest maps and inventories are to be prepared species-wise with an interval of at least 5 years. Moreover, detail sample survey and monitoring needs to be carried out for estimation of species-wise growth rates. Emphasis would, hence, be given on primary data generation to define the country specific values for subsequent National Communications. However, that shall require new additional funding. Otherwise, significant margins of error would persist in the results.

For Bangladesh, detailed studies on vulnerability and adaptation are prerequisite for defining its strategies towards addressing the impacts of climate change. It is expected that during preparation of National Adaptation plan of Action (NAPA) case studies will be conducted for the most vulnerable sectors. The description and analyses of adaptation for the present national communication, therefore suffers from specific targeting and objective quantification including assignment of monetary values to the vulnerabilities and shocks and the benefits that may follow from appropriate adaptation.

The National Communication has also highlighted the response strategy the government has adopted so far in various fields and sectors. It has also outlined the policy measures for future actions. Two particular issues of capacity building and of financing mechanism for carrying out these activities are important in this regard. A strengthened and appropriate national institutional capacity to analyse climate change issues and prepare plans and programmes of actions in response will prepare the country better. On the other hand, inadequacy of resources constrains many of the desired activities. Bangladesh shall strive in future to tap the various financing mechanisms that are being set up or proposed in the climate change conventions.

Bangladesh considers that, as the impacts of climate change are all pervasive, negotiation should focus not merely on technical, but also on societal adaptation-economic, social and institutional. As poverty and vulnerability to climate change reinforce each other, it calls for a compulsive need for climate change policies to work in concert with poverty reduction and sustainable development strategies and actions. This warrants the mainstreaming of mitigation and adaptation in the country's planning process.

Subject to the formulation of various policies and strategies, several actions may be initiated right away either because these are win-win situations or that sufficient information are available for moving on several fronts. Bangladesh considers that the National Adaptation Plan of Action (NAPA) will be a means through which the prioritized projects are to be implemented, for which immediate mobilization of fund from GEF should be necessary.

It may be noted that to study the impacts of climate change on the environment, ecology and economy of Bangladesh, up-to-date maps and information on the drainage basin of the river systems, high resolution topographical elevations data and detail information on terrain features are needed. The information available at present are not up-to-date and do not fully represent the present situation. The Government feels that projects are to be undertaken to fill-in the data and information gaps. Such information will be of immense value to various sectoral activities apart from their use for preparedness against climate change.

The Communication has highlighted a good number of policy options, action plans and strategies in Chapter-6, which needs to be adequately addressed in order to have better understanding of the climate change processes, impacts and adaptations.

The Communication particularly identifies the need for rigorous studies for ensuing climate change policies and measures. It further stresses the undertaking of climate change studies and projects for sustainable development and poverty alleviation. A good number of projects have been suggested in the field of climate change and adaptation and sustainable development.

The Communication strongly urges for the creation of national institutional capacity, development of skilled manpower , awareness generation and improvement of disaster warning and monitoring system necessary for effective adaptation to the impacts of climate change. Addressing these issues involve huge budgetary demand, which needs to be given proper attention. The international funding mechanisms under the Climate Change Convention transfer of technology and all other such avenues must be explored to prepare Bangladesh to effectively combat the impending adverse impacts of climate change on the society, economy, environment and ecology of the country.

ANNEX-A

Table A-1: Carbon Emission Factors for Different Types of Fuels

Fuel type	Carbon emission factors (TC/TJ)
Gasoline	18.9
LPG	17.2
Kerosene	19.6
Diesel	20.2
Light Diesel Oil	20.2
Jute Batching Oil	20.2
Furnace oil	21.1
Lubricants/Grease	20.0
Jet petrol	19.5
Octane	18.9
Bitumen	1.6
SBP/MT	20.0
Coal	25.8
Natural Gas	15.3

Source: IPCC 1996

Table A-2: Fraction of Carbon Stored in Manufacturing Industries and Construction

Fuel type	Carbon Stored (%)	Amount stored (Gg C)
Natural gas used as feedstock	50	563.6
Bitumen	100	0.109
Lubricants/Grease	50	2.643
LPG	80	7.373

Source: IPCC 1996

Table A.3: Fraction of Carbon Oxidized for energy industries

Fuel type	Fraction of carbon oxidized
Coal	0.980
Oil and Oil products	0.990
Gas	0.995

Source: IPCC 1996

Table A.4: Emission Factors of CH_4 from Fuel combustion by source categories in kg/TJ

Activity			Coal	Natural Gas	Oil		Wood/ Wood Waste	Charcoal	Other Bio-mass and Wastes
Energy Industries			1.4	0.1	0.6		4	4	4
Manufacturing Industries and Construction			10	5		2	30	200	30
Transport	Domestic Aviation					2			
	Road				Gasoline	Diesel			
				0.1	0.6	0.6			
	Railways		1.4			0.6			
	National Navigation		1.4			0.6			
Other Sectors	Commercial/Institutional		1.4	0.1		0.6			
	Residential		1.4	0.1		0.6			
	Agriculture/ Forestry/ Fishing	Stationary	1.4	0.1		0.6			
		Mobile		0.1		0.6			
Other (not elsewhere specified)				0.1		0.6			

Source: IPCC 1996

Table A.5: Emission Factors of N_2O from Fuel combustion by source categories in kg/TJ

Activity			Coal	Natural Gas	Oil		Wood/ Wood Waste	Charcoal	Other Bio-mass and Wastes
Energy Industries			1.4	0.1	0.6		4	4	4
Manufacturing Industries and Construction			1.4	0.1		0.6	4	4	4
Transport	Domestic Aviation				2				
	Road				Gasoline	Diesel			
				0.1	0.6	0.6			
	Railways		1.4			0.6			
	National Navigation		1.4			0.6			
Other Sectors	Commercial/Institutional		1.4	0.1		0.6			
	Residential		1.4	0.1		0.6			
	Agriculture/ Forestry/ Fishing	Stationary	1.4	0.1		0.6			
		Mobile		0.1		0.6			
Other (not elsewhere specified)				0.1		0.6			

Source: IPCC 1996

Table A.6: Default Emission Factors of CH_4 from Oil and Gas Activities (kg/PJ)

Emission Factor	
Oil	
Production	300
Transport	745
Refining	200
Storage	50
Gas	
Production/Processing	288000
Transmission and Distribution	118000
Other Leakage	87000

Source: IPCC 1996

ANNEX-B

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Under CERP (Coastal Embankment Rehabilitation Project) BWDB recently completed the construction/renovations of about 700 km sea-facing embankments (mechanically compacted). These embankments are found very effective against erosion due to wave rush-up and rush-down. The embankments are maintained well with community participation. For its role in saving lives and property, this has been slotted as a high priority future incremental action. For quick evacuation of people and livestock to the shelters and other safe places from the vulnerable area during storm surges, road networks need to be improved. In considerations of climate change situation drainage networks and structures are to be improved and new one need to be constructed to drain out rapidly the surge water from the polders. It has been found that mangroves and forest belts act as effective barriers against winds and storm surges and facilitate accretion. New mangroves and forests in the fore shore areas, sides of embankment and around the homestead areas should be built. Such activities in Bangladesh need to be streamlined by ensuring people's participation in maintaining and benefit sharing.

Institutional Adaptation

Institutional adaptations include improving monitoring, forecasting and warning systems and evacuation procedures, adapting appropriate land use & development policy, and maintaining existing and future coastal infrastructures (embankment, drainage structures, cyclone shelters etc.). These responses relate to an improved emergency preparedness for cyclones and storm surges etc., and could reduce risks to health and property.

Improvement of the monitoring and warning system of tropical cyclones and prediction of the associated storm surges would give more reliable advance warning about the landfall of cyclones. The research on these aspects should be strengthened. Dissemination system of the warning should be improved to alert the coastal residents about the severity of storms. The cyclone preparedness program may be further strengthened and the vulnerable people should be provided with appropriate training for self and community preparedness to face the disasters.

4.6 Agriculture

4.6.1 Background

Bangladesh is predominantly an agrarian society and the agriculture sector contributes about 30 percent to the national GDP. Nearly 75 percent of the population is directly or indirectly dependent on agriculture. Though the contribution of agriculture towards GDP is declining (even now it stood at 30%), but it is still the highest and is the main user of water, and its share in water demand will further increase concurrently with efforts to attain food security. Land is the most basic resource in Bangladesh and is the main factor in crop production. Presently, the country has about 8.50 million hectares of cultivated land of which over 7.85 mha is under agriculture.

Within crop sub-sector, food grain, particularly the rice crop dominates the country's agricultural scenario in respect of both cropped area and production claiming a share of 77 percent and over 80 percent respectively in 1999 and 2000. Thus, development of rice crop has substantial impact on the sector's performance and food self-sufficiency. There has, however, been shift in the composition of agriculture over the past few years as indicated by gradual decline in the share of crop agriculture and increase in the share of non-crop agriculture (NCA), which consists of livestock, fisheries and forestry.

Of the net cultivable area, 37% percent is single cropped, 50% percent double cropped and 13% percent triple cropped. The overall cropping intensity is 176% percent. The three cropping seasons