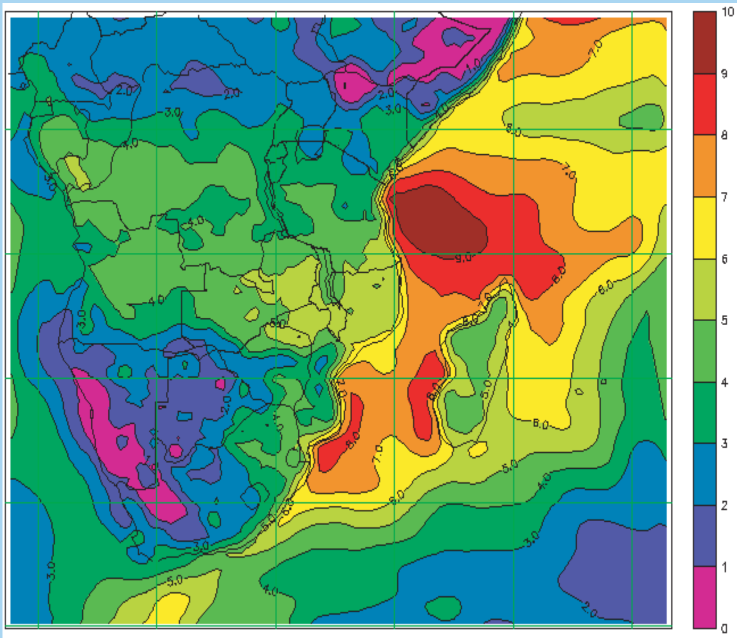
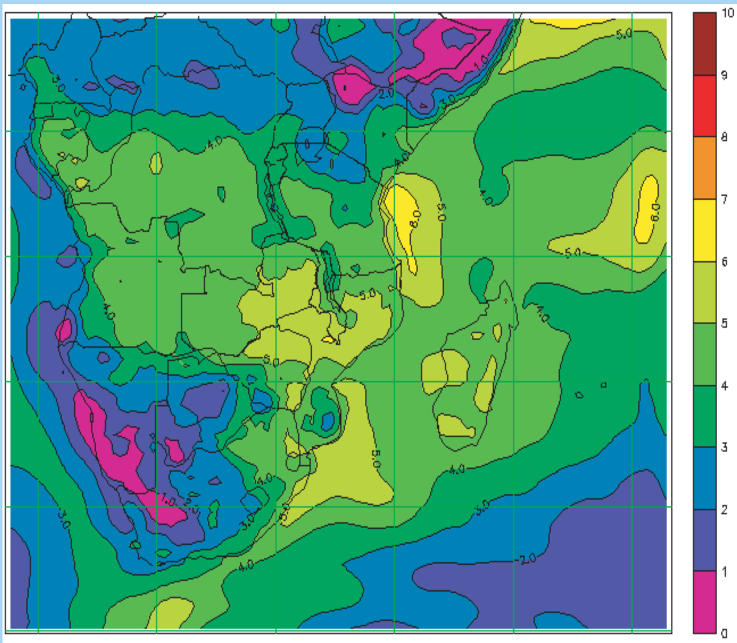
# Workshop on
# Climate Change Impact Modeling
# Report and Presentations




Organized by
Climate Change Cell, Department of Environment
Component 4b, Comprehensive Disaster Management Programme (CDMP)
Government of the People's Republic of Bangladesh

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# Climate Change Impact Modeling
# Report and Presentations

BIAM Foundation
Dhaka

26-27 February 2006

*Organized by*
Climate Change Cell
DoE

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Department of Environment
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**Workshop on Climate Change Impact Modeling Report & Presentations**

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*Credits*

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## Acknowledgement

I thank all the participants who represented various sectors and successfully voiced needs of the respective sectors from the modeling exercise.

Acknowledgement is due also to the professionals from the modeling community and institutes who devoted their attention in understanding the needs of the users, and accordingly accommodate their respective model outputs to support the need and expectation of the user community.

I express my gratitude to the distinguished experts who, as panelists provided valuable insight on matching needs with modeling results, and for providing guidance to sustain the modeling initiative to support overall development processes.

I would like to specifically mention, Ian Rector, CTA,CDMP and Khondaker Rashedul Haque, phD, DG, DoE Mohammad Reazuddin, Director, DoE and Comonent Manager of the Cell, and Ralf Ernst, Technical Adviser, Climate Change Cell. Their continued support and inspiration provided the motivation to plan and organize the event.

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Finally, Mirza Shawkat Ali, Md. Ziaul Haque, Abdullah Al-Mamun, Shamim Ara Begum and Nasimul Haque from the Cell extended support to organize and materialize this workshop. I thank and look forward to their continued support in the process.

Abu M. Kamal Uddin

# Acronyms

AOGCM Atmosphere-Ocean General Circulation Model
AMHC Available Moisture Holding Capacity
BARC Bangladesh Agricultural Research Council
BCAS Bangladesh Centre for Advanced Studies
BELA Bangladesh Environmental Lawyers Association
BIAM Bangladesh Institute of Administration and Management
BIDS Bangladesh Institute of Development Studies
BMD Bangladesh Meteorological Department
BPC Bangladesh Parjatan Corporation
BUET Bangladesh University of Engineering and Technology
BWDB Bangladesh Water Development Board
BWE Back Water Effect
CBO Community Based Organizations
CCC Climate Change Cell
CCSLR Climate Change & Sea level Rise
CDMP Comprehensive Disaster Management Program
CEGIS Centre for Environmental and Geographic Information Services
CEH Centre for Ecology & Hydrology
CERP Coastal Embankment Rehabilitation Programme
CFAB Climate Forecasting Applications in Bangladesh
CHT Chittagong Hill Tracts
CLASIC Impact of Climate and Sea Level change in part of the Indian Sub-Continent
CM Component Manager
CROPSUIT Crop suitability model
CS Civil Surgeon
DAE Department of Agriculture Extension
DEM Digital Elevation Model
DFID Department for International Development
DMB Disaster Management Bureau
DSS Department of Social Service
DOE Department of Environment
DRASS Drought Assessment
EU European Union
FD Forest Department
FF Flood Forecasting
FFWC Flood Forecasting and Warning Center
GBM Ganges, Brahmaputra & Meghna
GCM Global Circulation Model
GIS Geographic Information System
IWM Institute of Water Modeling
IWFM Institute of Water & Flood Management
IPCC Intergovernmental Panel on Climate Change
ICZMP Integrated Coastal Zone Management Programme
LRI Land Resources Inventory
NOAA National Oceanic & Atmospheric Association
NWMP National Water Management Plan
NAPA National Adaptation Programme of Action
OGDA Options for Ganges Dependent Area
RegCM Regional Climate Model
SPARSSO Space Research & Remote Sensing Organization
SRDI Soil Resources Development Institute

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# Executive Summary

Bangladesh is already experiencing climate related hazards like floods, droughts, cyclones and others which will aggravate following climate change and changes in climate variability. A significant part of the coastal region is threatened by salinity intrusion and submersion due to sea level rise. The general predictions are - more floods, untimely floods, more droughts, drainage congestion, salinity intrusion, more cyclones with higher intensities.

To understand climate impacts and risks, some key questions need to be answered: Will these hazards become more frequent and intense? Will their magnitude increase? Which locations are most vulnerable? When will hazards occur? And what shall be possible impacts? For example: A farmer would like to know likely precipitation patterns while planning his crop calendar, preparing his land, sowing, harvesting, etc. Obviously the development practitioners, professionals and policy makers need to gather this knowledge to provide extension and other services to the primary stakeholders. Worldwide, modeling provides useful prediction of impacts of climate change in seeking answers to the questions above.

The Climate Change Cell of the Department of Environment under the Comprehensive Disaster Management Programme organized a Workshop on Climate Change Impact Prediction Modeling at BIAM Foundation, Dhaka, during 26-27 February 2006. The workshop aimed at outlining pathways for climate change and climate variability related modeling in Bangladesh matching development needs and existing modeling practices.

A large number of professionals from Government agencies, institutes, academic institutions, NGOs and the private sector participated in the technical sessions. Participants were from both the modeling communities (supply side) and also users of the modeling output for the development persuasion in the country (demand side).

An objective of the workshop was that professionals from different sectors could identify their specific needs of impact predictions from the modeling. The modeling exercises could then concentrate on addressing these needs. The resolution and precision of the outputs from models can thus be more user-specific and demand driven.

The 1st technical session surfaced the needs and expectations from the modeling to pursue sustainable development in the country. In the 2nd and 3rd technical session the modelers presented various models they use and what they can offer in the light of the demand placed by the users. In the panel discussion, there was concern regarding quality and consistency of data and it was suggested to focus on basin wise modeling. Suggestions were made for establishing multi-disciplinary teams (land, water, environment, socio-economic) for modeling and results interpretation and necessary feed back processes. Models are really useful for predicting future scenarios of hazards. But the data used for the models needs to be updated regularly. Models that were developed in other countries need to be updated with local parameters to adjust them to local needs and conditions. Models have a wide range of applicability, ranging from scenarios of future precipitation patterns and the extent of salinity intrusion in the groundwater of coastal areas to the economic impacts of climate change.

The workshop outcome has provided the basis to pursue analyses of the findings (matching needs and outputs), explore compatibility of various models and deliverables, engage with modeling institutions and professionals, develop profiles of the institutions engaged in modeling; identify an institutional home for climate, geo-physical and application modeling, initiate a data cleaning mechanism immediately, and facilitate capacity building for climate modeling.

The workshop has also been successful in generating thoughts and ideas to chart a road map for future activities.

# Workshop Proceedings

## Introduction

The Workshop on Climate Change Impact Modeling was held at BIAM Foundation, Dhaka, Bangladesh, on February 26-27, 2006. The aim of the workshop was outlining pathways for climate change and climate variability related modelling in Bangladesh matching development needs and existing modelling practices. It was organized by the Climate Change Cell of the Department of Environment under the Ministry of Environment and Forests (MoEF).

The Climate Change Cell has been established in the Department of Environment in 2004 under the Comprehensive Disaster Management Program (CDMP) of the Government. It responds to the recognition that Bangladesh is particularly vulnerable to the effects of climate change, and that the number and scale of climate-related disasters are likely to increase. The objective of the Climate Change Cell is to enable the management of long-term climate risks and uncertainties as an integral part of national development planning. The Cell is operating as a unit of the Department of Environment (DoE) under the Ministry of Environment and Forests (MoEF).

The workshop started with the Inaugural Session on 26th February 2006. Introductory and welcoming speeches were given by Mr. Khandaker Rashedul Haque PhD, Director General, DoE; Mr. Md. Reazuddin, Director, DoE; Mr. Jafrul Islam Chowdhury, Honorable State Minister, Ministry of Environment and Forests; Mr. Tariqul Islam, Honorable Minister, Ministry of Environment and Forests and the chair Mr. Jafar Ahmed Chowdhury, Secretary, Ministry of Environment and Forests. Mr. Md. Reazuddin, Director, DoE chaired the 1st technical session on Needs and Expectations for Adaptation. Presentations were given by Mr. Ralf Ernst, Technical Advisor on Climate Change, CDMP, DoE; Mr. Abu M Kamal Uddin, Climate Change Cell, CDMP, DoE; Dr Zahurul Karim, Former Secretary, Government of Bangladesh and Executive Director, Arrannayak Foundation Dr. Latif Khan, CDMP. In the afternoon the 2nd technical session on Modeling for Predictions of Impacts of Climate Change in Bangladesh was chaired by Dr. Mahfuzul Haque, Chairman, Bangladesh Parjatan Corporation. The presenters of this session included Dr. Md. Nazrul Islam, Associate Professor, BUET (on behalf of working group); Mr. Zahirul Haque Khan, IWM; Dr. Anowar Ali, Ex-Chairman, SPARSSO; Jalaluddin Md. Abdul Hye PEng, IWM; Kazi Farhad Iqbal, Lecturer, SUB (on behalf of Dr. Sk Ghulam Hussain, BARC) and chaired by Dr. Mahfuzul Haque, Chairman, Bangladesh Parjatan Corporation (BPC).

The 3$^{rd}$ technical session was held on the morning of the second day (27$^{th}$ February). This technical session was in continuation with the 2$^{nd}$ technical session where some specific model based studies were presented by Dr. Ahsan Uddin Ahmed, Bangladesh Unnayan Parishad; Arpana Rani Datta, Institute of Water & Flood Management (IWFM), BUET (on behalf of project team members), Jahir Uddin Chowdhury, Institute of Water & Flood Management (IWFM), BUET, Dhaka and Ahmadul Hassan, Division Head, R&D – Training, Centre for Environmental & Geographic Information Services (CEGIS), Dhaka.

A Panel Discussion was arranged after the completion of the 3$^{rd}$ technical session with Dr. Quazi Kholiquzzaman Ahmed, Chairman, Bangladesh Unnayan Parishad as the Chair. The panellists who took part in the discussion included Dr. Asaduzzaman, Research Director, Bangladesh Institute of Development Studies (BIDS); Dr. Jahir Uddin Chowdhury, Professor, IWFM; Dr.Zahurul Karim, Executive Director, Arrannayak Foundation; Mr. Giasuddin Ahmed Choudhury, Executive Director, CEGIS; Mr. Emaduddin Ahmed, Executive Director, IWM and Dr. Quazi Kholiquzzaman Ahmed, Chairman, Bangladesh Unnayan Parishad.

## Objective

This workshop aims at outlining pathways for climate change and climate variability related modelling in Bangladesh matching development needs and existing modelling practices.

## Participants

A large number of professionals (list attached at the end of these proceedings) across the sectors participated in and contributed to the workshop during both days. These included professionals from the demand side (representing the sectors that shall use modelling output) and the supply side (modelling community). A total of 54 participants from BUET, BWDB, SPARSSO, BMD, DMB, LGED, BIDS, WARPO, PWD, MoWR, DoE, DAE, BARC, FD, IPSU, DoE, F&R, UBINIG, Practical Action, IWM, CEGIS, NSU, BCAS, BELA, KU, JU, DEBTEC, ICZMP, IUCN and SUB actively participated in the workshop.

## Outcome

**Inaugural Session**

The Inaugural Session was held in the morning of 26th February 2006. Introductory and welcoming speeches were given by Mr. Khandaker Rashedul Haque PhD, Director General, DoE; Mr. Mohammad Reazuddin, Director, DoE; Mr. Jafrul Islam Chowdhury, Honorable State Minister, Ministry of Environment and Forests; Mr. Tariqul Islam, Honorable Minister, Ministry of Environment and Forests and the Chair Mr. Jafar Ahmed Chowdhury, Secretary, Ministry of Environment and Forests.

### Address of Welcome, Mr. Khandaker Rashedul Haque PhD, Director General, DoE

The Director General of DoE said in his speech that the global climate is changing. This change is impacting all spheres of the earth. Physical, natural, social and economic domains, lives and livelihoods of people are affected. Bangladesh is particularly vulnerable to the adverse impacts of climate change. A general prediction is that Bangladesh will experience additional natural hazards like more floods, untimely floods, erratic precipitation, more rain in monsoon and less rain in the dry season, drought conditions, heat spells, cold waves, drainage congestions and water logging, salinity intrusion, cyclones (more in number and intensity), storm surges (more frequent and in magnitudes).

To adapt with such erratic climatic conditions, it is essential to predict impacts. We need to generate specific predictions of hazards including their frequencies, magnitudes and intensities, and to locate where hazards are going to impact and when. We need predictions well in advance to consider how climatic conditions are likely to affect the overall development process while ensuring safety and security of people, their life, livelihoods and properties.

Modelling exercises for climate prediction are instrumental in this respect. It is critical that such models are user-driven or to put it better, “user-led”, so that their scope, limitations and outcomes are consistent with the needs on-the-ground. This workshop initiates a process of interaction between the user community and the modelling community. Impacts of climate change is a cross cutting issue and is important for all development sectors. It is necessary to address climate changes in an integrated and holistic approach. To enable this, the Ministry of Environment & Forests has established the Climate Change Cell in its Department of Environment to serve as the platform and would like to offer assistance to development agencies, practitioners, professionals, NGOs, CBOs, and at large to all stakeholders.

Mr. Haque requested for the active participation and useful contribution of all in this workshop. He expressed his belief that through collective efforts, the workshop will be able to deliver the desired objective and outcome. He drew conclusion by saying that to facilitate better understanding on climate change related risks and vulnerability, impacts, and possible response measures, proper utilization of the Climate Change Cell is necessary.

## Keynote address on Overview of Modelling Needs, Mr. Mohammad Reazuddin, Director, DoE

Bangladesh is considered a vulnerable region due to its location and other natural conditions. A considerable area including the Sundarbans will be submerged into the sea with a sea level rise of 1m. We are generating 0.3 tons of greenhouse gases per year and capita compared to about 20 tons by the Americans. Developing countries like Bangladesh are facing negative impacts of greenhouse gas emissions and other pollutions created by the developed countries.

## Address by Special Guest, Mr. Jafrul Islam Chowdhury, Honorable State Minister, Ministry of Environment and Forests

The special guest expressed the view that such a comprehensive workshop on Climate Change Impact Prediction Modeling is first of its kind in Bangladesh. The scenario of climate change and its dangerous impacts is being observed worldwide. Changes in the climate system, land use, bio-diversity, are taking place as they are all interrelated. Sea level rise, which is one of the negative impacts of climate change, would submerge low lying areas of Bangladesh causing displacement of people and settlements and decrease in agriculture and forest areas. In addition there are risks of continuous coastal erosion, vulnerability due to cyclones and floods, changes in the rainfall pattern, problem in drainage and irrigation and intrusion of saline water into groundwater, agricultural land, river etc. As a result, it may cause damage to ports, coastal embankments and infrastructures, cyclone shelters, agricultural land, mangrove forests, fish resources etc.

The impact of natural disasters is not only dependent on the nature and extent of disasters but also on the institutional capacity to prepare and respond, availability of protective measures and active participation of community based organizations. The loss of lives and property due to disaster can be minimized through proper and timely forecast and warning and integration of government, non-government and community-based organizations. The Honorable State Minister hoped that through this workshop ideas for generating a timely and user friendly model would be developed which will help keep disaster risks within tolerable limits.

## Address by Chief Guest, Mr. Tariqul Islam, Honourable Minister, Ministry of Environment and Forests

Mr. Tariqul Islam, Honorable Minister, Ministry of Environment and Forests welcomed everyone and thanked the organizers for arranging such a timely workshop. Climate change is a global phenomenon. The scientific evidence to verify the impact of climate change in Bangladesh is growing. No single nation is responsible for the disastrous impact of climate change. Therefore an all out coordinated effort is required to prevent or minimize risks. He mentioned that Bangladesh is committed to the successful implementation of activities as a signatory of Climate Change Convention and Kyoto Protocol. The Ministry of Environment and Forests has taken up a participatory afforestation program under the guidance of the honorable Prime Minister Begum Khaleda Zia. Measures have been taken up to control pollution created from brick kilns, industrial waste, ship breaking yards and prohibit the plying of three wheelers and use of polythene bags etc. Prior information on rainfall, temperature, cyclone, flood, drought etc can help take precautions and preventive measures to face the hazards. Climate change modeling can play an important role in predicting speed, extent, time and place of occurrence of various hazards. The chief guest concluded his speech hoping that through the workshop the professionals will come up with new ideas to predict future scenario of hazards with the use of timely and precise data and information.

## Address by the Chair, Mr. Jafar Ahmed Chowdhury, Secretary, Ministry of Environment and Forests

The chairperson acknowledged that the Climate Change Cell has taken the initiative to run a Regional Climate Impact model (PRECIS) to determine the future impact due to climate change in association with BUET, BMD and SPARRSO. It is vital that disaster management consider climate change. The impact due to climate change has to be faced by all ministries and development organizations. In this respect the Ministry of Environment and Forests will provide necessary assistance as the focal point for managing the problems due to climate change and will come forward for preparing integrated planning and its implementation.

Mr. Jafar Ahmed Chowdhury hoped that the modelers present at the workshop would share their ideas. He expressed the view that the modelers should develop user-friendly models so that people can learn about the impacts due to climate change beforehand and lead their life and livelihood accordingly. Adaptation is the best way to minimize problems due to climate change. He also said that the Department of Environment is working as a platform to help achieve the objective of this workshop. He concluded wishing success of the workshop.

## *Technical Session I*

### Climate Change Modelling and the Comprehensive Disaster Management Program (CDMP), Mr. Ralf Ernst, Technical Advisor on Climate Change, CDMP, DoE

Mr. Ralf Ernst gave an overview of Climate Change Modelling and the Comprehensive Disaster Management Program (CDMP). The Comprehensive Disaster Management Program (CDMP) started implementation in 2004 as a joint programme of the Government of Bangladesh, the United Nations Development Programme (UNDP) and the British Department for International Development (DFID). In early 2006, the European Commission joined the programme as well and programme partners encourage all donors and institutions working in the area of disaster management to join the framework of CDMP.

The CDMP aims to bring a paradigm shift in disaster management in Bangladesh from the conventional response and relief practice to a more comprehensive risk reduction culture. The vision of the CDMP is to reduce the vulnerability of the poor to the effects of natural, environmental and human induced hazards to a manageable and acceptable level. The strategy includes an all-risks-and-all-hazards approach. In this sense, climate change was recognized as a factor that will have significant influence on risks and hazards in Bangladesh in the future.

In order to address climate change and incorporate climate change considerations into the CDMP, a Climate Change Cell was established at the DoE. The Climate Change Cell aims to establish a mechanism that facilitates management of long term climate risks and uncertainties as an integral part of national development planning.

### Setting context: Expectations from the workshop, Mr. Abu M Kamal Uddin, Climate Change Cell, CDMP, DoE

The presentation of Mr. Abu M Kamal Uddin reflected on the expectations from the workshop. Our climate is changing. Global warming induced changes in precipitation and temperature is already happening in different geographical regions. Untimely rain, flood, dry periods, storms, cyclones are occurring more frequently in greater intensities. Changes in the climate are likely to take place more rapidly over the next few decades, as different model generated predictions describe.

Bangladesh is already experiencing climate related hazards like floods, droughts, cyclones and others which are aggravating following climate change and change in the climate variability. A significant part of the coastal region is threatened by salinity intrusion and submersion due to sea level rise. The general predictions are - more floods, untimely floods, more droughts, drainage congestion, salinity intrusion, more cyclones with higher intensities.

To understand climate impacts and risks, a number of key questions need to be answered:

- What are the hazards to be taken care of following climate change and change in the climatic variability?

- Will these hazards be more frequent, more intense, and more in magnitude?
- Which locations are vulnerable to climate hazards?
- When will impacts occur? (Could we know year? month? dates?)

All risks need to be reduced. Answers to the above and other relevant questions such as what possibly is going to happen in future are needed in advance. For example: a farmer would like to know the precipitation pattern while planning his crop calendar, preparing his land, sowing, harvesting, etc. The road/flood dyke manager would require the changed flooding pattern and redistribution of flow among the rivers to design the infrastructures and for monitoring during the disastrous events.

To combat as well as cope with climate change impacts, it is necessary to know the location, nature, intensity and magnitudes of impacts. Knowledge in this area is growing. Although the planet essentially has a single climate system, there are a number of different modeling initiatives in practice. Climatic changes need to be identified regionally, nationally and ultimately locally, let's say, "in the farmer's neighborhoods".

Modeling exercises are being practiced worldwide including Bangladesh to predict impacts of climate change and climate variability. IPCC is preparing its Fourth Assessment Report, which will include latest modeling results in climate change and climate variability. There are some 23 global circulation/climate models (GCM), around 7-8 regional models (RCM) and a number of country specific models are in operation.

To provide relevant actors, institutions and stakeholder groups in Bangladesh with the predictions of the impacts of climate change and climate variability, the following two broad areas are required to be addressed:

- Down scaling of climate models to user levels
- Interfacing climate model outputs with bio-physical models (flood, drought, cyclones etc) as well as bio-physical models with livelihood models (economic models)

It is essential that professionals from different sectors identify their specific needs of impact predictions from the modeling. The modeling exercises could then concentrate on addressing these needs. The resolution and precision of the outputs from models can thus be more user-specific and demand driven.

## Needs and Expectations of the Agriculture Sector from Modeling, Dr. Zahurul Karim, Former Secretary, Government of Bangladesh and Executive Director, Arrannayak Foundation

Dr. Zahurul Karim highlighted the needs and expectations of the agriculture sector from impact modelling:

- Creation of a database for setting nutrient models on crop productivity
- Land use modeling for sustainable farming practices: Within the next 30yrs 20% of the cultivable area will be lost. Therefore, potential options based on long term indicators are required for sustainable practices.
- Assessing impacts of climatic extreme variability on crops, livestock, fisheries and forestry: some models are available for the agriculture sector. But there are no models for other sectors such as fisheries, livestock etc. Models can be developed to

predict the migration pattern of hilsha fish because it has high economic value. Also long term prediction on the impact on salinity intrusion is required.

- Agro-economic modeling based on future climate change scenarios: different crops have different economic value. Based on the market value, models may be developed which will help decide on what crops will generate high income.
- Climate change impacts on pest management and predictions: integrated pest management is used for better production of crops. Models can help predict the impacts of climate change on pest management.
- Model for management of land resources: 43% of the land in Asia is facing land degradation. Model for land degradation is required for proper management of land resources.
- Potential of agricultural diversification in different agro-ecological regions
- Crop tolerance models for coastal saline areas with frontier technological packages can assist in managing salt tolerant crops.
- Prediction model of reduced soil moisture due to climate change on rabi cropping and rain fed farming-model may be developed for crops adaptive to different moisture content of soil.
- Model for assessing loss of agro-biodiversity in the severe vulnerable areas: in this case the endangered species of crops may be taken into consideration.
- Priority setting model for strategic planning for food security of the poor in the agro-economically adverse areas: Higher level strategic planning based on models are required for national planning. Vulnerability maps may be used for identifying the vulnerable areas.

## Needs and Expectations for Risk Reduction, Dr. Latif Khan, CDMP

Dr. Latif Khan mainly discussed the CDMP structure, Go/NGO integration of disaster management strategies, the National Risk Reduction Framework, relation between comprehensive disaster management and climate change and the Disaster Management Model of Bangladesh. According to the presenter, DMB requires scientific information which will be used in managing the disaster i.e. climate adaptations. This information is very important for

- Identifying Risk
- Climate Information
- GIS Mapping
- Scientific Analysis

This information will have an impact on all hazards like flood, drought and riverbank erosion. This information will also have an impact on sectors like:

- Agriculture
- Education
- Health
- Infrastructure
- Communication
- Livelihood security

Risk reduction planning and implementation shall be in Union level and logically the risks have to be delineated in that level ultimately to be treated.

## Needs and Expectations from Participants-Through VIPP cards

VIPP cards were distributed among the participants following the presentations of Technical Session I so that the modellers could gather knowledge about the needs and requirements of all participants.

Participants comments and expectations

- There is a need for integration of climate modelling and application modelling. No one suggested any mechanism for integration. What is the role of the Climate Change Cell in integration?
- How will climate change impact on the energy sector in Bangladesh?
    - impacts on energy demand (e.g. due to increased temperature)
    - impacts on energy generation, distribution, infrastructure
- Location specific variability should be addressed in the model (e.g. barind, coastal)
- Modeling should be cluster-based backed by existing homogenous parameters (TRACT, zonal, etc)
- Community participation should be associated in real sense in building modeling
- Digitized Elevation Model (DEM) should capture rightly toward addressing risk and uncertainty
- Early warning system should be meaningful
- Establish institutional framework for dissemination
- Micro climatic fluctuation at local levels
- Database format for microclimate and related environmental parameters regarding Union – Sub-Union level
- It is important to design livelihood programmes for poverty reduction
- What changes are likely in the climatic elements at Union level and for Mouza's, and what impacts are likely?
- GIS – digital topographical/elevation data
- Database should be created, consolidated in respective government departments, and they should be easily accessible, so that any individual or agency can obtain relevant data as and when required
- Flood Forecasting – at least three months in advance
- Salinity Intrusion – even on groundwater
- Groundwater – modeling
- Forest – modeling of salinity intrusion impact and its impact on Sunderban
- Need for high resolution updated bathymetry data of the North Bay of Bengal to predict coastal inundation due to storm surge associated with tropical cyclones
- Need to develop long-term prediction model for climatic extremes, local severe storms, etc.
- Coordination of all relevant sectors/departments is needed
- BIDS has generated detailed level standard loss … (e.g. household, industry, building, roads, etc) at local level for flood loss modeling, and for increased precision
- Need detailed elevation data at micro-level that can be updated
- Sectoral needs should be identified first
- A core of modelers building on existing ones and future manpower should be developed with CCC coordination
- Phased program/action plan should be developed
- Must have serious and exhaustive follow-up program immediately after this seminar

- A digital map showing the settlement areas and population with number of people living in an area for the whole country is very much necessary with a possibility to update regularly. This should also include the cropland available in an area, communication facilitation, etc. The map should be in GIS format
- This will help identify the disaster affected/prone/or vulnerable areas and number of population/crop area affected. How can risks be reduced during and after flood/cyclone?
- We have a large area in the coastal region potential for shrimp cultivation and aquaculture. What steps we should take to adapt with sea level rise?
- Not to make new policies or plans where law already prevails in the particular field. Please apply existing law
- Education sector – need some basic research about modeling. Raw data and upgrading models in all sectors including fisheries
- Meteorological Department – has to establish some micro-level weather station to get actual and large variable data in whole Bangladesh
- Early warning on drought and flood (at least 30 days ahead) for better decision making on farmers' end.
- To learn actual progress we have made so far on climate change prediction modeling
- Are there initiatives to develop different models to serve different purposes? Has any database be created for this purpose? If not, then by when?
- Although work on climate change has continued for some time, do the dedicated scientists/researchers have a database? Are there processes drawing on a set of experts, researchers, analysts, etc to address the specific needs and demands
- Beside DoE, has any other related organization established a climate change cell, identified focal points, or institutionalized otherwise?
- Successful model development effort should be accompanied by detailed and accurate data collection and updating program
- New models under development in this initiative must be based on accurate DEM, and accurate physical situation (at present accurate data is not available)
- Existing models which are working should be upgraded, used and interfaced, where applicable
- Climatic issues are regional, sub-regional. WARPO is an apex macro-planning organization, which should be involved in this kind of model development effort
- Use existing water modelling capacity of IWM instituted through a number of government initiatives and entrusted responsibilities of water modelling for the country by the Government

## Climate Prediction Model PRECIS: Application for Bangladesh, Dr. Md. Nazrul Islam, Associate Professor, BUET

Dr. Nazrul Islam revealed the findings of application of Providing Regional Climates for Impacts Studies (PRECIS) in Bangladesh. PRECIS has a horizontal resolution of 50 km with 19 levels in the atmosphere (from the surface to 30 km in the stratosphere) and four levels in the soil. The present version of PRECIS has the option to downscale to 25 km horizontal resolution.

The validation of Providing Regional Climates for Impacts Studies (PRECIS) regional climate model in Bangladesh is performed with the surface observational rainfall data from Bangladesh Meteorological Department (BMD) and Bangladesh Water Development Board (BWDB). Model simulated maximum and minimum temperatures are also compared with the observed data collected by BMD. The BMD data are used for the duration of 1961-1990 whereas BWDB data are used from 1963-1990. The BMD observed data are available to use at 26 stations throughout the country from 1961-1990. Out of 26, only 4 stations data are there for full duration without any missing. In case of BWDB data, 118 stations are found useful out of 304 stations for the period of 1980-1990. The number of data stations reduced to only 9 for the period of 1963-1990 because of data missing.

It is found that regional analysis provides overestimation of PRECIS values in Bangladesh because of downgrading observed data when girded from asymmetric data network. Data extracted at some particular locations (observational points) provide better performance of PRECIS. Overall, PRECIS can calculate about 92% and 96% of surface rainfall in case of blsula for BMD and BWDB data respectively. Model performance increases substantially with the increase of analysis duration. Performance of era15 is found much better than other baseline categories. It is found that systematic cold bias existed for the maximum temperature where as random bias persisted for minimum temperature. PRECIS can be used for predicting rainfall and temperature in Bangladesh using the look-up table proposed in this analysis. However, it is suggested that observational data should be checked with the Meta data before using the model for application. The PRECIS working group in Bangladesh is ready to generate future scenarios using the current version of PRECIS in 50 km horizontal grid resolution as well as 25 km, depending on user demands. Using the validated and proposed look-up table, future scenarios of PRECIS might be useful in different sectors of the country from any smaller spatial scale to point location.

## Salinity Intrusion, Coastal and Fluvial Flood Modelling, Zahirul Haque Khan, IWM

Mr. Zahirul Haque Khan presented available mathematical modelling tools and models developed over last 16 years in the Institute of Water Modelling and their applications in assessing the impact of climate change on flooding and salinity intrusion, and also for flood, drainage, erosion, land reclamation, navigation and irrigation management. The model results on climate change induced impacts on water resources would enable the multidisciplinary team to ascertain additional impacts on agriculture, forest fisheries, domestic and industrial water use and navigation.

Salinity intrusion and flooding are important issues in natural resource management and sustainable development in Bangladesh. Assessment of salinity intrusion and coastal flooding has been made using available Bay of Bengal and Regional models for the climate change scenario of National Adaptation Program of Action (NAPA). Any rise of sea level will propagate into the river system. High tide level on the Shahbazpur channel near Bhola Island is increased by 30cm and 80 cm for SLR of 32 cm and 88cm SLR respectively. Water level increase on the Lower-Meghna at Chandpur is about 50 cm for 88 cm rise of sea level and 15cm for 32cm SLR.

Drainage congestion may become more severe threat than higher flood risk. Analysis for polder 27 shows that drainage congestion area for 3days duration and more than 30cm depth in polder 37 is increased from 0.0ha to 10,000ha with the SLR of 88cm. Water level over tops embankment of 17 polders out of 35 polders in the southwest region due to SLR of 88cm.

Saline water intrusion is highly seasonal in Bangladesh and during dry season deep landwards intrusion occurs through the various tidal rivers in the western part of the delta, and through the Lower Meghna estuary. Sea level rise would increase the extent of salt water intrusion by pushing the saline waterfront landwards. The combination of sea level rise and low upland flow will change the present spatial and temporal variation of salinity, which eventually would cause damage to agriculture, fisheries and total echo-system of the coastal area. The only freshwater pocket in the Tentulia river is lost with SLR of 88cm. The 5ppt isohaline intrudes 9km to landwards for 32cm SLR and about 90km for 88 cm SLR in the Tentulia river. The intrusion of 5ppt isohaline in the Baleswar river is 9km and 33km due to SLR of 32cm and 88cm respectively. Salinity at Khulna is increased by 0.5 to 2 ppt for 32 cm and 88 cm sea level rise, whereas at Mongla, the increase of salinity level is higher compared to Khulna, which is in the range of 1 to 3 ppt for SLR of 32cm and 88 cm respectively.

The available models in IWM are the Bay of Bengal Model and Six Regional models that cover the whole Bangladesh. IWM has been in the pioneering role with the support provided to Flood Forecasting and Warning Center (FFWC) of BWDB in maintaining and updating/upgrading the these Regional Models to support FFWC to forecast water levels with reasonable accuracy. The available tool for Flood Forecasting are Flood forecasting model, FLOOD WATCH-a integrated modeling tool with the MIKE 11 HD, MIKE 11 FF, together with the Arc View GIS. Efforts are on to increase the lead-time of flood forecasts from the current 2~3 days to 7~10 days in the Climate Forecast Application for Bangladesh (CFAB). The present forecasting of 1-10 days WL on major rivers of Bangladesh is expected to be 10~20 day Forecast in future by using Mathematical & Weather Modelling technique. Mr. Zahirul Haque Khan emphasized that the available scientifically based and proven models in IWM need to be utilized for application of any future climate change scenarios to assess vulnerabilities and adaptation measures.

## Mathematically Predicting the Impacts of Climate Change & Sea Level Rise on Storm Surges in the Bangladesh Coastal Region, Dr. Anwar Ali, Ex-Chairman, SPARSSO

This paper briefly describes the basics of TCs and SS with particular reference to Bangladesh and see how models can predict the future behaviour of SS under CCSLR, so that CCSLR may be mainstreamed in the development process (which is, for example, one of the objectives of the National Adaptation Plan of Action-NAPA of Bangladesh) and in the overall disaster management of the country, particularly in the context of the CDMP (Comprehensive Disaster Management Programme).

A series of numerical experiments were done with cyclones (with different wind speeds, atmospheric pressure changes, tracks, etc.), astronomical tides, fresh water discharge from rivers (including back water effect), monsoon wind, etc. both separately and in different combinations of them. The Bay of Bengal configuration in most cases was based on the NOAA satellite images to better represent the coastal boundary and positions of islands, rivers, etc. Some of the findings as discussed by the presenter are

- Wind Effect: Wind is the main contributing factor (~90%) to storm surge generation.
- Shallow Water Effect and SLR: Storm surge is mostly a shallow water phenomenon. SLR tends to reduce the surge heights if wind speed remains constant.
- Convergence Effect: Surge water that hits the coastline of Bangladesh travels much inland. Storm surge height is directly proportional to convergence.
- Tidal Effect: Tide and surge interact non-linearly.
- Tide vs. Fresh Water Discharge: Flood/fresh water from rivers
    - Decreases the high tide value
    - Increases the low tide value (absolute)
    - Shortens the flood-tide period
    - Increases the ebb-tide period
- Coriolis Effect: For example-when a cyclone hits the western coast of Bangladesh, significant surge is observed in the Meghna estuary. SLR may also influence the Coriolis force through changes in the current velocity and through increase of water area in the north.
- The coast of Chittagong and the coastal island Effect amplifies or modifies the surge
- River effect: Rivers have a negative effect on surge amplification
- Back Water Effect : BWE is caused by flood water, storm surges, strong SW monsoon wind, high astronomical tides, SLR and tsunamis. SLR almost doubles by an increase of 2 m/s in the monsoon wind speed.

## Cyclonic Storm Surge Modelling in Designing Coastal Embankment, Jalaluddin Md. Abdul Hye PEng, IWM

The presentation of Mr. Jalaluddin Md. Abdul Hye, PEng was on Cyclonic Storm Surge Modelling in Designing Coastal Embankment. Cyclones and storm surges are common phenomenon in the coastal area of Bangladesh. The area has over 700km of coastline on the main land and several offshore islands in the Bay of Bengal. 145 numbers of polders having more than 5000km of embankment were constructed in the sixties to protect the coastal low-lying area from saline inundation from regular tide in order to increase agriculture production without consideration of safety against cyclonic surges. Historical record shows that more than 14 severe cyclones are generated in the Bay of Bengal in every ten years, several of which strike the coast of Bangladesh. Extremely strong storm surges with more than 10m of water elevation hit the coast of Bangladesh in the year 1970. Within the last four decades around 800,000 lives of the country have been the victims of the cyclones by overtopping or breaching of coastal embankments.

Complexities of the Bangladeshi coastline with numerous inlets, large estuaries, numerous polders and offshore islands require use of numerical modelling to determine the surge dynamics realistically in the shallower region. Cyclone Storm Surge Modelling has been carried out during 2000 – 2001 in connection with Second Coastal Embankment Rehabilitation Project (a study carried out by Institute of Water Modelling for Bangladesh Water Development Board funded by World Bank). These models were based on development exercises carried out since 1990s through EU funded Cyclone Shelter Preparatory Studies, Cyclone Protection Project and Dutch funded Meghna Estuary Study.

The modelling was carried out to study the impacts in terms surges in consideration of all the major cyclones that had land falls from 1960-1991.

These models and the model development tools are now maintained by IWM for use in:

- Risk area delineation for Cyclone Shelter Planning: increasing safety 30 year to 100 year
- Revisit the Emergency Response Procedure of all the industries and installations
- Understanding hydrodynamics of estuaries and bay, impact of land reclamation
- Examining surge and wave height, cyclone flooding and salinity,
- Planning afforestation in coastal embankment rehabilitation
- Tool for cyclone induced flood forecasting
- Optimization of the engineering design of polders to support the shrimp culture and agriculture
- Understanding the eco-hydraulics for conservation of bio-diversity
- Prediction of the position and volume of spilled oil on surface water and apply the model as a useful tool for making contingency plan and monitoring, assessment of the risk, response and clean-up operation
- Assessment of the impacts of climate change and sea level rise for planning development activities

He emphasised on having real time surge monitoring system in our coastal fringes and real time surge forecasting system based on the models already developed in IWM as have been done for the Flood Forecasting and Warning System. This would make the present community based disaster management system more cost-effective.

## Agriculture Water Demand and Drought Modelling, Kazi Farhad Iqbal, Lecturer, The State University of Bangladesh (on behalf of Dr. Sk Ghulam Hussain, BARC)

The presentation mainly focused on Agriculture Water Demand and Drought modelling. Drought is water deficit related stress. The consequence of drought on crops is physiological stress, hampering natural phonological and reproductive cycle and yield reduction. There are 2.20 million hectares of Kharif Drought Prone Area and 1.2 million hectares of Rabi Drought Prone Area.

The agricultural production system of the country is greatly influenced by the event in different seasons of the year such as Rabi (dry or winter) season, Pre-Kharif (per- monsoon) season, Kharif (wet or monsoon) season. Drought prone soils are dominated by light textured top layers and heavy texture in the subsurface horizon, less available moisture holding capacity and slow to rapid permeability. Moisture availability varies from 100 to 200 mm within the effective profile depth, this is not adequate to meet the evapotranspiration demand of most of the rabi crops like wheat, mustard, potato etc.

Global average surface temperature has increased by 0.6 to 0.2°C over the last 140 years. By the year 2100 the globally averaged surface temperature is projected to increase by 1.4 to 5.8°C. There are also increases possible in global mean rates of precipitation and evaporation. Larger year-to-year variations in precipitation are very likely (90-99% chance). Due to the impact of climate change the frequency of droughts of different intensities would increase, especially in the drier regions due to uneven distribution of rainfall. Further impacts include higher evapo-transpiration accelerated by increased temperature, low humidity, and high wind speed.

GIS was used to produce Kharif (T. Aman) drought prone area map, Rabi drought prone area map, and Pre-Kharif drought prone area map. The time periods of data analysis are for Rabi: 1st decade November to 1st decade of March, Pre-kharif: 2nd decade of March- 1st decade of June and for Khraif: 2nd decade of June- end of October for the T. Aman Crop. The factors that were considered are Available Moisture Holding Capacity (AMHC), percolation rate was deduced based on texture data of LRI (LRI -Land Resources Inventory and SRI Mapping), Reference Length of Growing Periods, Decadal Water Balance, Kharif Season Percent Dry Decades Percent Dry Sub-humid.

The paper suggested the following adaptations

- Drought related vulnerability could be minimized by supplemental irrigation
- Develop drought resistant varieties of crops for drought prone areas of the country
- Drought tolerant crops and varieties - maize, sorghum, millet, kharif pulses and oilseeds - matching with the land and climatic requirements
- Effective use of minimum tillage as a management practice under rain fed conditions - wheat, cowpea, field pea, chickpea, lentil, grass pea and water melon
- Minimum tillage utilized for many years with such practices as over-seeding mustard and pulses immediately after harvesting of transplanted Aman rice crop
- Mulching with straw or water-hyacinth
- Use of deep-rooted crops and low-water consuming crops
- Increase water use efficiency through varietals and irrigation management

There are many more aspects of natural and human systems, which would be vulnerable to climate change; some of them would be directly impacted, others indirectly. Only drought and its modelling aspects have been considered in this article giving more emphasis on the impact of climate change on agriculture because it would be the most vulnerable sector. On the other hand, this sector has the most potential to counteract the impacts.

# *Technical Session III*

## Climate Prediction Model RegCM, Dr. Ahsan Uddin Ahmed, Bangladesh Unnayan Parishad

Dr. Ahsan Uddin Ahmed gave an overview of the Climate Prediction Model RegCM. Climate variability and change may be modelled by the use of mathematical models. In recent times, there have been tremendous advancements in the field of climate modelling, primarily due to increased levels of understanding regarding physical processes and also due to increased access to higher end computers. General circulation models (GCM) have been used for modelling of large-scale climate variability and change. Advanced GCMs could estimate physical processes which can define climate systems for large areas based on atmosphere-ocean interaction and feedbacks. However, researchers have taken relentless strides to improve the physics behind the AOGCMs, incorporated feedbacks of meso-scale physical processes into the AOGCM equations, which have culminated into the development of meso-scale Regional Climate Models (RCM). A number of RCMs actually are nested in GCM, and resolve equations at much finer levels, which provide climatic information up to 25Km X 25Km resolution, at even three hourly time-steps. RegCM is one of many such regional climate models, which is now being tested for reproducing the monsoon system over South Asia, and more specifically, over Bangladesh.

From initial results, RegCM provides appreciable results in terms of capturing basic climate signals such as rainfall as well as temperature variability, both in spatial and temporal scales. Over South Asia, the model successfully captures large rainfall around the Western Ghat as well as the northern Bay of Bengal and northeastern Bangladesh. The diurnal behaviour of rainfall over Bangladesh is also captured well. The seasonal progression and departure of monsoon fronts are also well captured over the South Asia domain. The temporal temperature variability is well captured, while there exists about 2°C cold bias systematically over the entire Bangladesh. Similar cold bias is also observed over the whole of South Asia. It is found that Grell convection scheme performs much better for the regional rainfall patterns. Grell convection scheme in conjunction with Arakawa-Schubert closure assumption reduces cold bias only slightly, while the combination of Grell CS with Fritsch-Chappel closure assumption resolves the rainfall variability better than the former combination. Despite such improvement in model option, the pre-monsoon seasonal rainfall appears higher than observed total rainfall, while the monsoon rainfall appears lower than the observed total rainfall. The Model can pick up extreme climatic events such as cyclone. Examining the model outputs, it may be inferred that RegCM may be used primarily as a diagnostic toll to understand climate change for Bangladesh. It may also be used, with appropriate correlation with observed data sets, to generate future climate scenarios at much higher resolution than the GCMs.

## Modelling Approach of Water Availability Assessment in CLASIC Project, and Arpana Rani Datta (on behalf of Dr. Jahir Uddin Chowdhury), Institute of Water & Flood Management (IWFM), BUET

The presenter discussed the findings of CLASIC Project. A research project entitled 'Impact of Climate and Sea level change in part of the Indian sub-Continent (CLASIC)' was initiated at the end of August 2003. It is expected to be completed by March 2006. The lead agency is the CEH, UK. The project is funded by DFID, UK under its Knowledge &. Research (KAR) Programme. The purpose of the project is to investigate the implications of climate change on water resources availability from Ganges, Brahmaputra and Meghna basins in the Indian subcontinent with particular reference to Bangladesh. For this part of the study, Hadley Centre, IWFM and CEGIS are collaborating with CEH. The water resources model that is being used to assess the water availability, is the subject of this paper. Although the project purpose focuses on water availability, the project is also examining the possible impacts of climate change upon cyclonic storm surges in the Bay of Bengal, which affect low-lying coastal regions particularly Bangladesh

Some features of GWAVA model are

- GWAVA is grid based hydrological model
- Resolution is 55 km at GBM and 11 km for Bangladesh context
- Inclusion of groundwater availability for total groundwater assessment

## Impact of Sea Level Rise on Agriculture and Fisheries, Ahmadul Hassan, Division Head, R&D – Training, CEGIS

The paper of Mr. Ahmadul Hassan looked on the impact of sea level rise on agriculture and fisheries sector. Sea Level Rise is one of the most vital issues of global climate change. It will have multiple effects on agriculture, fisheries, forest and livelihoods especially in costal zones. To reduce vulnerability, proper landuse planning is required, which primarily depends on landuse suitability mapping of the possible affected areas. Considering the issues, CEGIS conducted comprehensive research on impact of sea levels rise on landuse suitability in southwest region of Bangladesh for the Ministry of Environment and Forest, Government of Bangladesh, financed by United Nation Development Programme (UNDP). Following the study, this paper presents the approach of landuse suitability mapping under different sea level rise scenarios, especially showing the impacts on agriculture (T. Aman and Boro rice) and fisheries (Golda and Bagda). Good ranges of deflections were observed regarding suitability of crops and shrimps with changing sea level rise scenarios. This study will show future pathway of sustainable landuse planning in environmentally vulnerable regions.

The objective of the study was to assess the Impacts of Sea Level Rise on Agriculture and Fisheries Landuse Suitability and to assess the Impact of Possible Adaptation Options on the Landuse Suitability. The study area was Satkhira, Khulna and Bagerhat with an area of 10,600 km2 and 5.7 million (in year 2001) population. Crops in the Study Area are Agriculture-T. Aman, Boro and Pulse and Shrimp- Golda (Freshwater Shrimp) and Bagda (Brackish water Shrimp).

Crop Suitability Model CROPSUIT was developed. According to the study options for land use adaptation are

- Long term measures – Ganges barrage (OGDA option 8)
- Mid term measure – Augmentation of Gorai flow (OGDA option 7)
- Construction of closures on main river systems (Pussur, Shibsha and Kobadak rivers)
- Raising embankments to prevent overtopping
- Rehabilitation of drainage systems

The strategies for land use adaptation are

- Environmental: to ensure land use as per land use zone based on physical suitability
- Social: to maximize the social preferences, for example maximizing paddy cultivation.

- Economic: to maximize economic return through credit facilities and other financial incentives to the farmer to grow most economically profitable crops-shrimp.

Impact on paddy and shrimp production under different SLR scenarios has been determined through this study. It is found that paddy production will decrease from an average of 236 (kg/capita/year) to 96(kg/capita/year) due to 32 cm sea level rise in the year 2050 and 30 (kg/capita/year) due to 88 cm sea level rise in the year 2100. Paddy Production under different adaptation options will increase from an average of 30 (kg/capita/year) to 180, 98, 133 and 33 (kg/capita/year). Shrimp Production will increase from an average of 39,186 (Ton/Yr) to 78,800 (Ton/Yr) due to 32 cm sea level rise and 130,097 (Ton/Yr) due to 88 cm sea level rise.

Land use suitability mapping will assist in
- reducing vulnerability
- proper land use planning in coastal zones
- developing efficient adaptation measures considering environmental, social and economical context

## Open discussion

Participants took part in an open discussion after the presentations were over. Following is a summary of some of the dialogues:

Q/C: BIDS has generated flood damage data for residential area in 2004. Union-based flood loss data can not be generated without detail Digital Elevation Model (DEM) for whole country.
A: Nation wide 300 meter resolution DEM data is available which is not suitable for preparation of flood loss data at union level. A detailed DEM is required especially for the flood plain area for that purpose and micro level planning.

Q/C: Dissemination of information is still lagging behind and information on national planning, research studies should be disseminated properly and timely. Information base will be rich if proper dissemination is done.
A: Dissemination of research studies is necessary. The data sharing capacity has recently increased. So there is scope for further data dissemination through different government agencies.

Q/C: National Water Management Plan (NWMP) developed by WARPO needs to be implemented.
A: The agencies involved in the water, environment and other sectors should take initiative to implement the plan as early as possible.

Q/C: How can the output of the PRECIS model be used?
A: Using the present validated and proposed look-up table, generated future scenarios by PRECIS can be developed for a particular location.

Q/C: What will be the quality of output data of models if updated DEM is not available?
A: A detailed updated DEM is required for generating good quality of model outputs.

Q/C: What is the relationship between sea level rise and storm surge? Is there any model for tsunami?
A: Storm surge decreases if water depth increases. There are models for flood, erosion forecasting. The present model may be extended to incorporate tsunami also.

Q/C: What is the difference between TINSHED and calibration?
A: TINSHED is a tool and calibration is a process.

Q/C: Is it possible to predict the water level during monsoon and to predict whether the crop will be inundated or not?
A: Through the use of last 10-20yrs data it is possible to model the humidity, rainfall, temperature of a particular month of present year.

Q/C: Will the model results be confined or disseminated?
A: Results will be disseminated. Integration at government level is required in this respect.

Q/C: Can the GWAVA model simulate coastal tidal flow and surge?
A: GWAVA is not a hydrodynamic model, rather it is hydrological model.

Q/C: Is GWAVA model supplementary to any other model?
A: The merits and demerits of GWAVA models compared to the others has not been studied yet in Bangladesh.

Q/C: Environmental parameters should have been considered in the application model of studying the impact of Sea Level Rise?
A. Only physical, economic and social parameters have been considered.

Q/C: Has the soil salinity been correlated with water salinity?
A: Surface water salinity data of SRDI has been used.

## Panel Discussion

A Panel Discussion was arranged after the completion of the 3rd technical session with Dr. Quazi Kholiquzzaman Ahmed, Chairman, Bangladesh Unnayan Parishad as the Chair. The panellists who took part in the discussion included Dr. Asaduzzaman, Research Director, Bangladesh Institute of Development studies (BIDS); Dr. Jahir Uddin Chowdhury, Professor, IWFM; Dr. Zahurul Karim, Executive Director, Arrannayak Foundation; Mr. Giasuddin Ahmed Choudhury, Executive Director, CEGIS; Mr. Emaduddin Ahmed, Executive Director, IWM and Dr. Quazi Kholiquzzaman Ahmed, Chairman, Bangladesh Unnayan Parishad.

**Dr. Jahir Uddin Chowdhury, Professor, IWFM**

Dr. Jahir Uddin Chowdhury mentioned the following three important points which need to be taken into consideration

I) Climate change modelling exercise should be basin wise. Proper prediction of climate change is not a problem. But the major problem lies with the data because the output/result will not be properly generated if the input data is not correct. Two problems are faced during preparation of models

a. Data inside and outside networking
b. Inconsistency within data of BMD and BWDB

II) The end product has impact on the following components:

- Land
- Water
- Environment
- Socio-economic sphere

Relationship among the above components needs to be established. Therefore a multi-disciplinary team needs to be formed to provide input, make analysis and generate the correct output or result from models.

III) Feedback process

Necessary feedback needs to be incorporated for the components such as Land, Water, Environment, and Socio-economic etc. The feedback process needs to be regularly updated.

**Mr. Emaduddin Ahmed, Executive Director, IWM**

The executive director noted that IWM is the only mathematical water modelling institute of the country set up by the Government of Bangladesh and it can provide the best assistance in taking stock of the in-country professional level capability of international standard. Models are really useful for predicting the future scenario in the areas of disasters originating from storm surge, basin wide flooding or river bank erosion. Due to the geographical location and changes in our hydrological calendar over a year, our river and coastal morphology is also affected. As such there is an urgency for updating our models with the recent data. Models are developed using standard software (often procured from professional developing agencies) so it needs to be customised with local parameters so that it is adaptive to local needs and conditions.

It is to be noted that Government of Bangladesh in setting up the Institute of Water Modelling through a four phase 15 year UNDP-DANIDA TA project (1986-2000) already has instituted world class hydraulic mathematical models of the river system (including floodplains) of the whole country, which have since been annually updated, validated and applied in almost all the nationally important projects. The present real time flood forecasting system and the National Water Management Plan are based on these models. Government issued several requests and circular to all the Government agencies advocating for making the best use of this capability. In one circular (enclosed), Government categorically discouraged import of any other similar software to check proliferation (can create confusion in decision making). These models also can take care of simulating transport of salinity, pollutants (including biodegradable) and sediment as well.

In the climate change related exercises, these models have already been applied in several instances (both in terrestrial and coastal areas), starting right from 1990s (BCAS report)– recently they have been used for predicting the impact of sea level rise in the coastal plain of Bangladesh (ICZMP), the Climate Forecast Application in Bangladesh (CFAB) and Climate and Sea level change in part of the Indian Sub-Continent (CLASIC). These well proven models have demonstrated capability of simulating run-off generated from inland rainfall as well as that coming from across our international borders. Most importantly through several applications these models have been tested in computing livelihood and decision (impact) variables in agriculture, environment and ecosystem. We are now in the process of developing a DSS for IWRM where the intricate relation between the bio-physical processes and socio-economic, environmental and sustainable development are being treated in more user-friendly manner.

There are about 100 modelers of IWM rendering services to clients operating in the country. IWM has a strong HRD and thus it can replace any personnel within short time. IWM is happy to note that the current status of models are fully capable to derive design conditions to support SLR issues. However, IWM would be pleased to be involved in any efforts of developing improved boundary conditions. IWM is aware of the global development in modelling and is continuously updating itself. IWM offers training to agencies in the appreciation of model findings and thus keep the national capacity updated in improved decision making. It has almost removed the dependence on the expatriates in the modelling.

With such capacity IWM has come a long way in application of models for forecasting of climate change.

**Mr. Giasuddin Ahmed Choudhury, Executive Director, CEGIS**

Mr. Giasuddin Ahmed Choudhury the Executive Director of CEGIS mainly gave an overview on the activities of CEGIS related to application of models in various sectors. Mr. Choudhury also emphasized the adaptation of models to the local needs. CEGIS has expertise as well as tools to assess the impacts on economy, society, and environment for different Climate Change conditions. CEGIS has working experience in developing physical models (e.g. hydrological, land and water resource, land and water use suitability). CEGIS have experience with GWAVA, STREAM, CROPSUIT models and other impact models. DRASS (Drought Assessment) Model has been developed by CEGIS to assess the drought and irrigation water demand. This model assists in making strategies for national level planning as well as determining the requirement of irrigation water for different types of soils at different agro-ecological climates. The computation framework for IWRM was developed by CEGIS. Bangladesh is moving towards the concept of an Integrated Water Resources Management (IWRM). The IWRM focus is on inter-sectoral resource balance; management and improvement of cross-border flows; basin wise development; and an optimal mix of the various structural and non-structural measures.

**Dr. Zahurul Karim, Executive Director, Arrannayak Foundation**

In his speech Dr. Zahurul Karim stated the following key points based on his overall idea of the workshop

1. Some organizations have capacity to use models. Still there is need to build up the capacity of the local institutes.
2. Projection is not fragile. It has specific utility. Potentiality of model has to be utilized. The applicability of models to predict the crop suitability for local economic crop using modern technology of increasing productivity of these crops such as jute, sugarcane has to be established.
3. Integration of data compilation and analysis at national level is required.
4. Model has to be customized according to the local conditions and needs. For this purpose data validation is necessary.
5. DoE should look for revenue generated fund

6. Program for higher studies may be taken up to provide financial support to the modellers.

**Dr. Asaduzzaman, Research Director, Bangladesh Institute of Development studies (BIDS)**

According to the speaker, a model is a simplified version of reality. Also, the data needs validation. For this reason two type of integration is required

1. Integration across the physical model
2. Integration among the socio-political components

Models have to be further developed and calibrated. This is a continuous process, which requires funding. Mr. Asaduzzaman further implied the necessity of the followings

1. Feasibility
2. Networking (Inside/Outside)
3. Publishing of results
4. Accessibility of data
5. Data quality

**Dr. Quazi Kholiquzzaman Ahmed, Chairman, Bangladesh Unnayan Parishad**

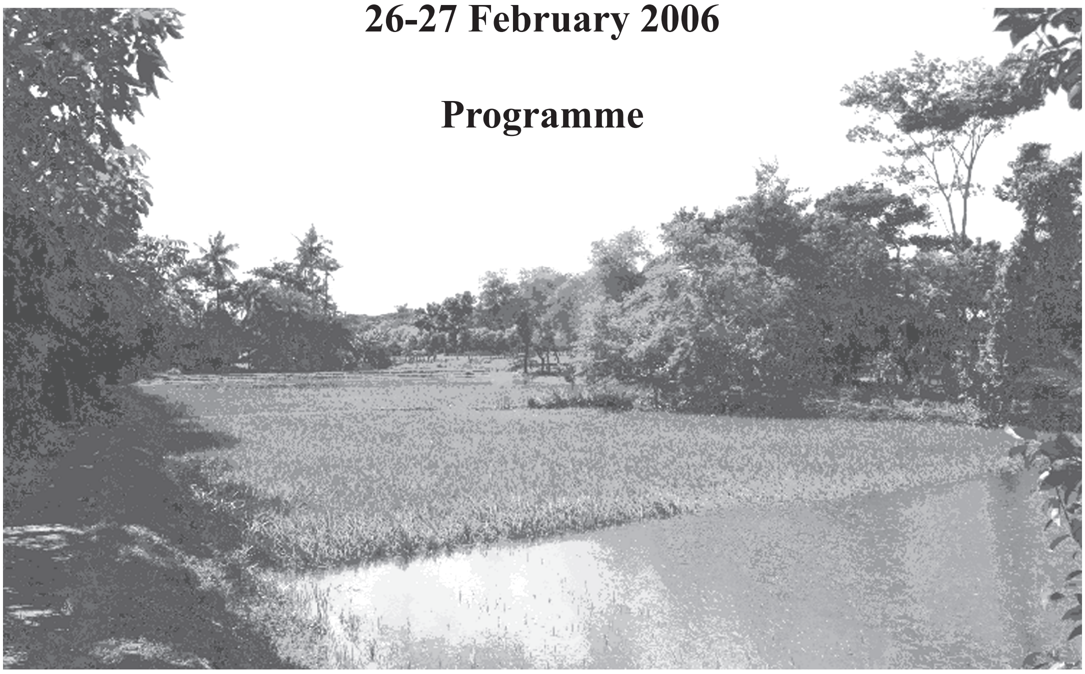
The panel discussion was followed by closing remarks by Dr. Quazi Kholiquzzaman Ahmed, Chairman, Bangladesh Unnayan Parishad. The chair of the panel discussion emphasized the need for user-friendly/specific models. Data is available but with no access. Access to data has to be increased so that people can access data when needed. Partnership and networking may be developed for a good cause.

*Annexure - 1*

Workshop on

# Climate Change Impact Prediction Modeling
## BIAM Foundation, Dhaka
## 26-27 February 2006

## Programme



*Wednesday, 26 February, at the Multipurpose Hall*

***Inaugural Session*** *Chaired by Mr. Jafar Ahmed Chowdhury, Secretary*
*Ministry of Environment and Forests*

09:00 hrs Registration

09:55 hrs Guests take their seats

10:00 hrs Address of Welcome by Mr. **Khandaker Rashedul Haque PhD**
Director General, Department of Environment

10:05 hrs Keynote Address: An Overview of Modeling Needs on "Climate Change Impact Prediction" to Pursue Development by Mr. **Mohammad Reazuddin**
Director, Department of Environment

10:20 hrs Speech by the Special Guest, **Md. Abdur Rashid Sarker**
Secretary, Ministry of Food and Disaster Management

10:30 hrs Speech by the Special Guest, **Mr. Jafrul Islam Chowdhury**
Honorable State Minister, Ministry of Environment and Forests

10:40 hrs Speech by the Chief Guest, **Mr. Tariqul Islam**
Honorable Minister, Ministry of Environment and Forests

10:50 hrs Speech by the Chair, **Mr. Jafar Ahmed Chowdhury**
Secretary, Ministry of Environment and Forests

11:00 hrs Tea Break

## Programme

### Day 1, Wednesday, 26 February, in Padma Hall

**1st Technical Session:** *Climate Change Impact Prediction Modeling: Needs and Expectations for Adaptation*
Chaired by Mohammad Reazuddin, Director, Department of Environment

11.30 hrs Climate change modeling in the context of CDMP, by Ralf Ernst, Climate Change Cell
11.40 hrs *Setting the Context: Workshop Expectations*, by Abu M Kamaluddin, Climate Change Cell
11.50 hrs *Needs and Expectation of the Agriculture Sector from Modeling*, by Dr. Zahurul Karim, Arannayak Foundation
12.05 hrs *Needs and Expectations for Risk Reduction*, by Dr. Latif Khan, CDMP
12.20 hrs *Needs and Expectations from Participants* – through VIPP cards
12.50 hrs Round up by the Chair
13.00 hrs Lunch/prayer

**2nd Technical Session:** *Modeling for Predictions of Impacts of Climate Change in Bangladesh*
*Chaired by Dr. Mahfuzul Haque, Chairman, Bangladesh Parjatan Corporation*

(20 min. presentation and 10 min. clarification and question answer for each presentation)

14:00 hrs Climate Prediction Model PRECIS: Application for Bangladesh, by Professor Nazrul Islam of Bangladesh University of Engineering & Technology BUET, on behalf of working group (BUET, SPARSSO, BMD, SMRC)
14:20 hrs Intrusion/Coastal Flooding, Fluvial Flooding, by Zahirul Haque Khan, IWM
14:40 hrs Cyclone and Surge Modeling Incorporating Sea Level Rise, by Dr. Anowar Ali, Ex Chairman, SPARSSO
15:00 hrs Cyclonic Surge Computation, by Jalaluddin Md Abdul Hye, IWM
15:20 hrs Agriculture Water Demand and Drought Modeling, by Dr Sk Ghulam Hussain, BARC
15:40 hrs Tea Break
16:00 hrs Clarification and Discussion
16:15 hrs Summary of the day and tomorrows work

### Day 2 Thursday, 27 February, in Padma Hall

**3rd Technical Session:** Chaired by Dr. Zahurul Karim, Executive Director, Arrannayak Foundation

09.30 hrs *Climate Prediction Model RegCM*, Dr. Ahsan Uddin Ahmed, Bangladesh Unnayan Parishad *Salinity*
09:50 hrs *Water Availability Model, CLASSIC/GUAVA*, by Prof. Zahiruddin Chowdhury, BUET & Arpana Rani Dutta, IWFM
10.10 hrs *Impact of Sea Level Rise on Agriculture, a Case Study*, by Ahmedul Hassan, CEGIS
10.30 hrs Open Discussion
11:00 hrs Tea Break

11:30 hrs
**Panel Discussion:** Chaired by Dr. Quazi Kholiquzzaman Ahmed, Chairman, Bangladesh Unnayan Parishad

*Panelists:* Dr. Ainun Nishat, Country Representative, IUCN-Bangladesh
Dr Asaduzzaman, Research Director, Bangladesh Institute for Development Studies
Dr Zahurul Karim, Executive Director, Arrannayak Foundation
Dr Atiq Rahman, Executive Director, Bangladesh Center for Advanced Studies

12:30 hrs
**Closing Session:** Chaired by Mr. Khandaker Rashedul Haque PhD, Director General, Department of Environment

12:30 hrs Rapporteur's Report on the Workshop Process and Outcome
12:50 hrs Summing Up by the Chair

# Participant List

| Sl. No. | Participants |
|---|---|
| 1. | Dr. Mahfuzul Haque, Chairman, Bangladesh Parjatan Corporation |
| 2. | Dr. Quazi Kholiquzzaman Ahmed, Chairman, Bangladesh Unnayan Parishad |
| 3. | Dr. Asaduzzaman, Research Director, Bangladesh Institute for Development Studies |
| 4. | Mr. Khandaker Rashedul Haque PhD, Director General, Department of Environment |
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| 8. | Dr. Muhammed Ali Bhuiyan, Professor, Department of Water Resources Engineering, BUET, Dhaka |
| 9. | Mr. A. Latif Khan, National Consultant (Training & Preparedness), Comprehensive Disaster Management Programme (CDMP), Disaster Management and Relief Bhaban, 92-93 Mohakhali Commercial Area Dhaka-1212. |
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| 34. | Mr. A. Z. M. Badrul Alam, Executive Engineer, PMU-ESPP, BWDB, Dhaka |
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| 68. | Sk. Naureen Laila, Research Officer, Institute & Policy Support Unit, Dhanmondi, Dhaka |
| 69. | Mr. Ralf Ernst, Technical Advisor, CCC, DoE, CDMP, Dhaka |
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| 75. | Mr. Md. Abdul Mannan, Meterologist, Bangladesh Meterological Department (BMD), Abhawa Bhaban, Agargaon, Sher-e-Bangla Nagar, Dhaka. email-mannan_u2003@yahoo.co.in |

# Papers Presented

### *Technical Session I*

- Climate change modeling and the Comprehensive Disaster Management Program (CDMP).
- Setting context: expectation from the workshop.
- Needs and Expectations of the Agriculture Sector from Modeling.
- Needs and Expectations for Risk Reduction.

### *Technical Session II*

- Climate Prediction Model PRECIS: Application for Bangladesh.
- Salinity Intrusion, Coastal and Fluvial Flood Modeling.
- Mathematically Predicting the Impacts of Climate Change & Sea Level Rise on Storm Surges in the Bangladesh Coastal Region.
- Cyclonic Storm Sur ge Modeling in Designing Coastal Embankment.
- Agriculture Water Demand and Drought Modeling.

### *Technical Session III*

- Use of High Resolution RegCM for Modeling of Climate Variabiity and Change in Bangladesh
- Modeling Approach of Water Availability Assessment in CLASIC Project.
- Impact of Sea Level Rise on Suitability of Agriculture and Fisheries.






Training on





Workshop
Climate Change Impact Prediction Modeling
26-27 February 2006
BIAM Foundation, Dhaka
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# Papers Presentation

Papers Presentation

# Climate change modeling and the Comprehensive Disaster Management Program (CDMP)

Ralf Ernst
*Technical Advisor on Climate Change, CDMP*

The Comprehensive Disaster Management Program (CDMP) started implementation in 2004 as a joint programme of the Government of Bangladesh, the United Nations Development Programme (UNDP) and the British Department for International Development (DFID). In early 2006, the European Commission joint the programme as well and programme partners encourage all donors and institutions working in the area of disaster management to join the framework of CDMP.

The CDMP aims to bring a paradigm shift in disaster management in Bangladesh from the conventional response and relief practice to a more comprehensive risk reduction culture. The vision of the CDMP is to reduce the vulnerability of the poor to the effects of natural, environmental and human induced hazards to a manageable and acceptable level.

CDMP strategies include an all-risks-and-all-hazards approach. In this sense, climate change was recognized as a factor that will have a significant influence on risks and hazards in Bangladesh in the future. In order to address climate change and incorporate climate change considerations into the CDMP, a Climate Change Cell was established at the Department of Environment. The Climate Change Cell aims *to establish a mechanism that facilitates management of long term climate risks and uncertainties as an integral part of national development planning.*

Climate change modeling is one strategy used by the Climate Change Cell to achieve this objective. Therefore, the Climate Change Cell established a working group with several institutions – BUET, BMD, SPARRSO and SMRC – that is chaired by the Department of Environment and aims to institutionalize the PRECIS Climate Change Model in Bangladesh.

Bangladesh has experienced many climate related disasters in the past including floods, droughts, cyclones and tropical storms. Climate change has the potential to increase the number and magnitude of such events. Climate change also the potential to create new risks and hazards, for example through the rise of sea-levels.

In order to prepare for and prevent climate related disasters, CDMP requires better information on future climate change and its impacts on the country and people's livelihoods.

PRECIS and other climate models will provide us with information about future changes in precipitation and temperatures. If we link climate change models with bio-physical and socio-economic models, we will hopefully be able to make more precise predictions about future climate change impacts on Bangladesh and the livelihoods of people in Bangladesh.

## Setting context
## Expectation from the Climate change impact prediction modeling workshop

Abu Mostafa Kamal Uddin
*Climate Risk Assessment & Adaptation Expert*

Our climate is changing. Global warming induced changes in precipitation and temperature is already happening in different geographical regions. Untimely rain, flood, dry periods, storms, cyclones, are occurring more frequently in greater intensities. Changes in the climate are likely to take place more rapidly over the next few decades, as different model generated predictions describe.

In Bangladesh we are already experiencing climate related hazards like floods, droughts, cyclones and others which are aggravating because of climate change and changes in variability. A significant part of the coastal region is threatened by salinity intrusion and submersion due to sea level rise. The general predictions are - more floods, untimely floods, more drought, drainage congestion, salinity intrusion, more cyclones with higher intensities.

To understand climate impacts and risks, a number of key questions need to be answered:

- What are the hazards resulting from climate change and changes in climatic variability?
- Will these hazards become more frequent and more intense?
- Which locations are particularly vulnerable to climate hazards?
- When will risks increase?
- What exactly are the impacts on the ground?

What do all these current and expected changes actually mean to a farmer, fishermen, primary producer, resource collector, development worker?

The farmer would like to know the precipitation pattern while planning his crop calendar, preparing his land, sowing, harvesting, etc. "Will there be erratic rainfall during cropping in his locality? If yes, does this present a risk for my crop? Will there be a drought this year? When exactly will this happen? What measures can I take to reduce and minimize risks for my livelihood?"

"Some of my land is in comparatively low elevation. Could I still crop the land or will that remain under water due to drainage congestion?"

"I am going to cultivate wheat; will there be a heat wave (say over 40 degrees Celsius for consecutive three days) that wheat will not withstand?

"Will there be increased water/vector borne diseases following water logging? More diarrhea?

"Is it possible to track the timing, intensity and magnitude of cyclones and storm surges?"

We need to reduce all these risks. We need to know in advance what possibly is going to happen regarding answers to the above and other relevant questions. To combat as well as cope with climate change impacts, it is necessary to know the location, nature, intensity and magnitudes of impacts. Knowledge in this area is growing. Although the planet essentially has a single climate system, there are a number of different modeling initiatives in practice. Climatic changes need to be identified regionally, nationally and ultimately locally, let's say, "in the farmer's neighborhoods".

Modeling exercises are being practiced worldwide including Bangladesh to predict impacts of climate change and climate variability. IPCC is preparing its Fourth Assessment Report which will include latest modeling results in climate change and climate variability. There are some 23 global circulation/climate models (GCM), around 7-8 regional models (RCM) and numerous country specific models in operation.

To provide the relevant actors and institutions, stakeholder groups in Bangladesh with the predictions of the impacts of climate change and climate variability, the following two broad areas are required to be addressed:

- Down-scaling of climate models.
- Interfacing climate model outputs with bio-physical models (flood, drought, cyclones etc) and bio-physical models with livelihood models (economic models)

It is essential that respective professionals from different sectors identify their specific needs of impact predictions from modeling. The modeling exercises could then concentrate addressing these felt and expressed needs. The resolution and precision of the outputs from models can thus be more user-specific and demand driven.

## Needs and Expectation of the Agriculture Sector from Modeling

Dr Zahurul Karim
*Former Secretary, Government of Bangladesh*
*& Executive Director, Arrannayak Foundation*

### Some ideas for modeler

- Development of models for agricultural vulnerability assessments like; Floods, Draughts, Tidal Surges and other Climatic Stresses
- Creation of database for setting nutrient models on crop productivity
- Land use modeling for sustainable farming practices
- Assessing impacts of climatic extreme variability on crops, livestock, fisheries and forestry
- Agro-economic modeling based on future climate change scenarios
- Climate change impacts on pest management and predictions
- Model for management of land resources
- Potential of agricultural diversification in different agro-ecological regions
- Crop tolerance models for coastal saline areas with frontier technological packages
- Prediction model of reduced soil moisture due to climate change on *rabi* cropping and rainfed farming
- Model for assessing loss of agro-biodiversity in the severe vulnerable areas
- Priority setting model for strategic planning for food security of the poor in the agro-economically adverse areas

## Needs and Expectations for Risk Reduction

*Dr. Abdul Latif Khan,*
*National Expert (Training and Preparedness)*
*Comprehensive Disaster Management Programme*

### GoB Vision on Disaster Management

- to reduce the vulnerability of people, especially the poor , to the effects of natural, environmental and human induced hazards to a manageable and acceptable humanitarian level

### MoFDM Mission

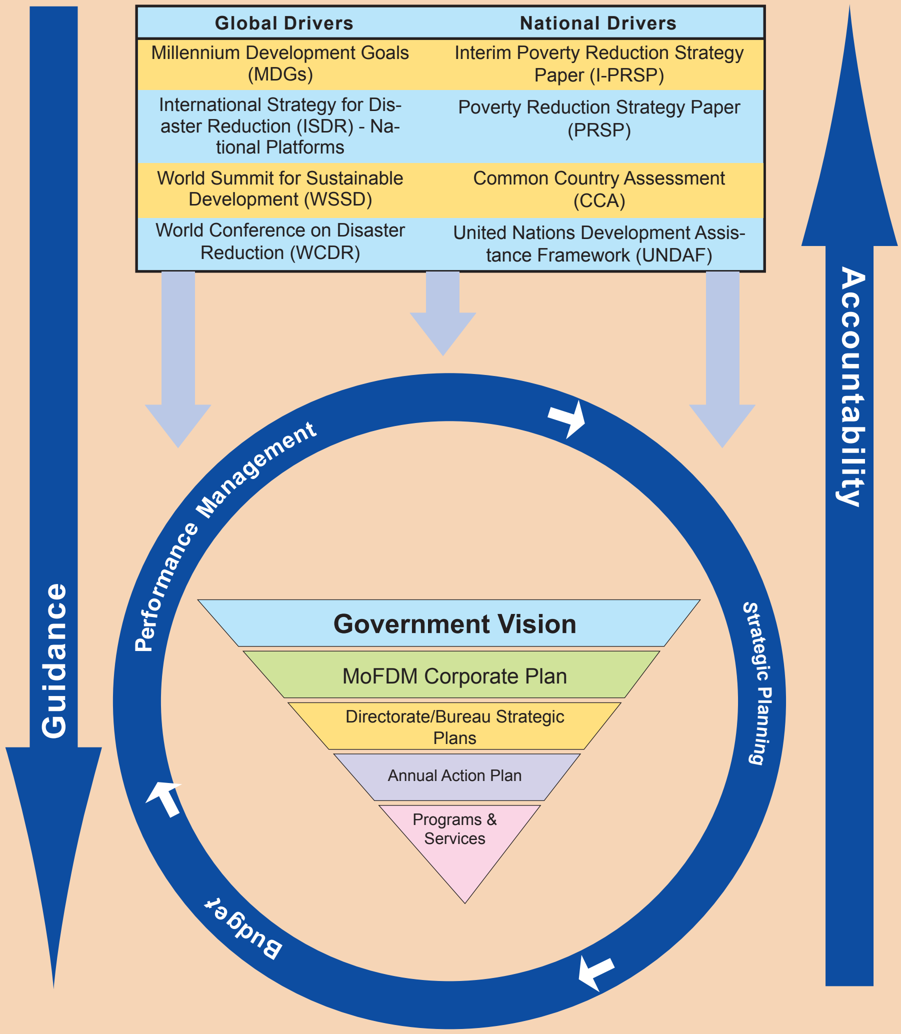
- to bring a paradigm shift in disaster management from conventional response and relief to a more comprehensive risk reduction culture and to promote food security as an important factor in ensuring the resilience of the communities to hazards

### Overall Objective

- to strengthen the capacity of the Bangladesh Disaster Management System to reduce unacceptable risk and improve response and recovery management at all levels and to effectively integrate and manage Bangladesh's food security system

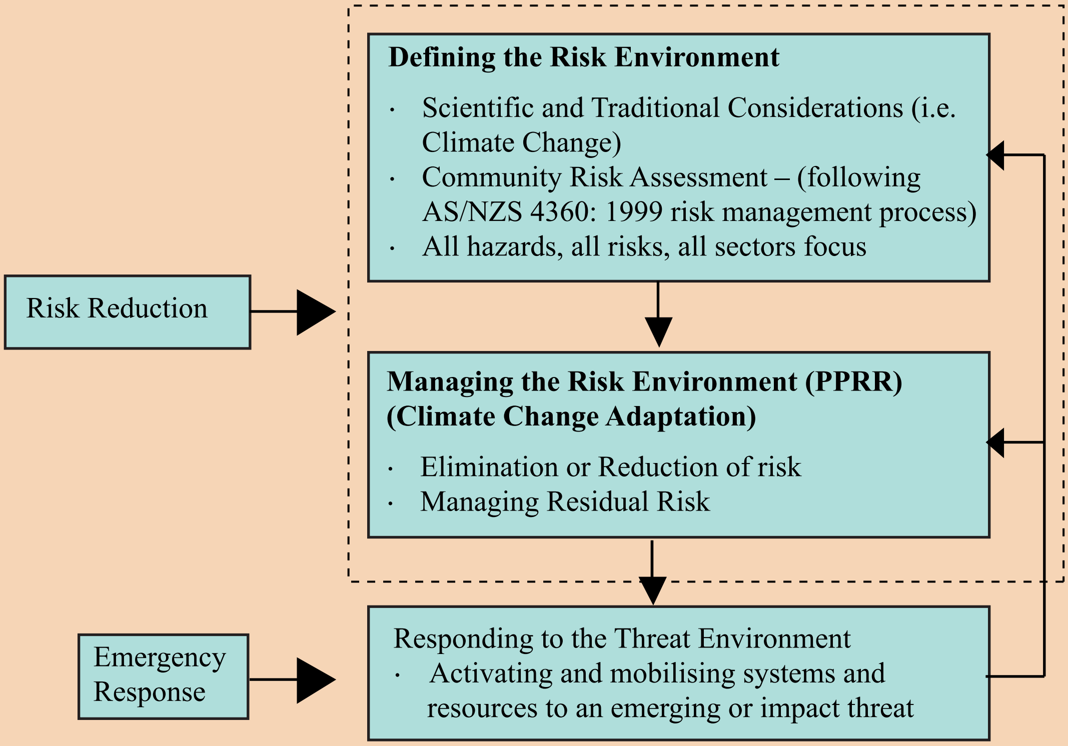
**CDMP Structure**

| Strategic Focus Areas | Corresponding components | Implementing agency |
|---|---|---|
| Professionalizing the DM system | C1a - PPPDU<br>C1b – Professionalizing the DM System | PPPDU<br>PPPDU |
| Partnership Development | C2a – Advocacy<br>C2b – Capacity Building | DMB<br>DMB |
| Community Empowerment | C3a – Programme Gap Analysis<br>C3b – Risk Reduction Planning<br>C3c – LDRRF<br>C3d – Livelihood Security (EC) | PPPDU<br>DRR<br>PPPDU |
| Expanding Preparedness programmes across a broader range of hazards | C4a – Earthquake and Tsunami Preparedness (EC)<br>C4b – Climate Change & Research<br>C4b(1) - LACC | DMB<br>BCD&FS<br>DoE<br>FAO/DAE |
| Strengthening emergency response capabilities | C5a – DMIC & Emergency Procedures<br>C5b – Expansion of DMIC (EC) | PPPDU |

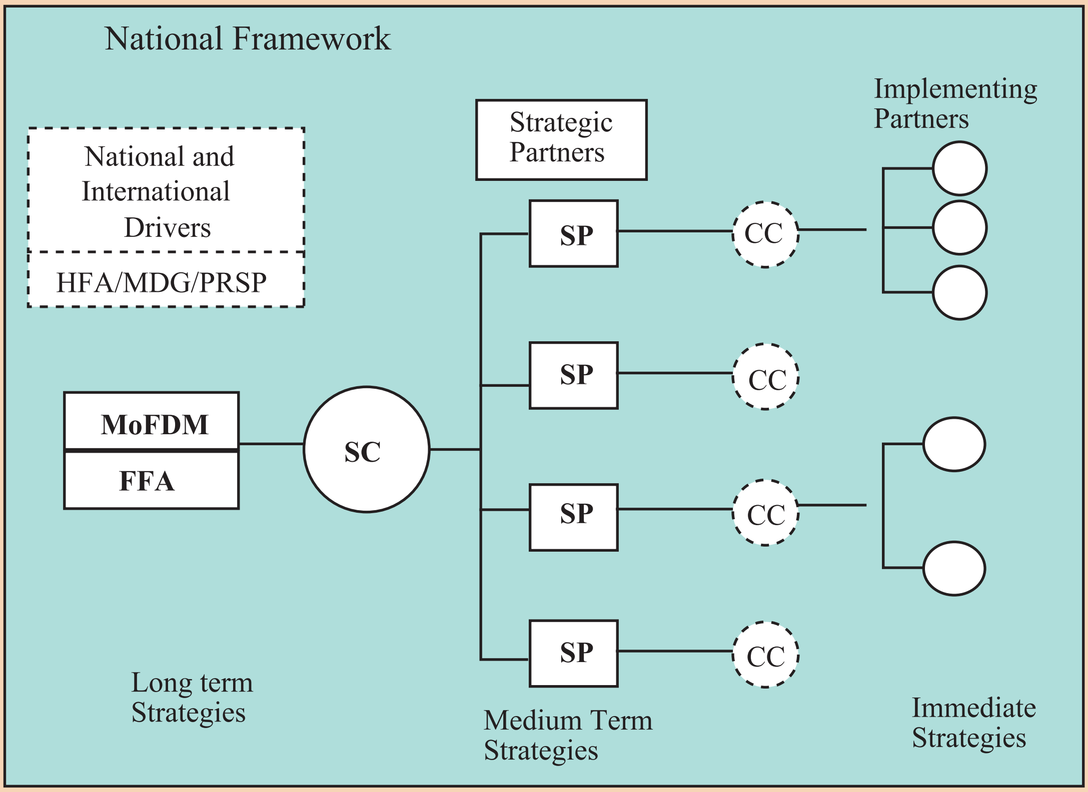



**Disaster Management Framework for Action**

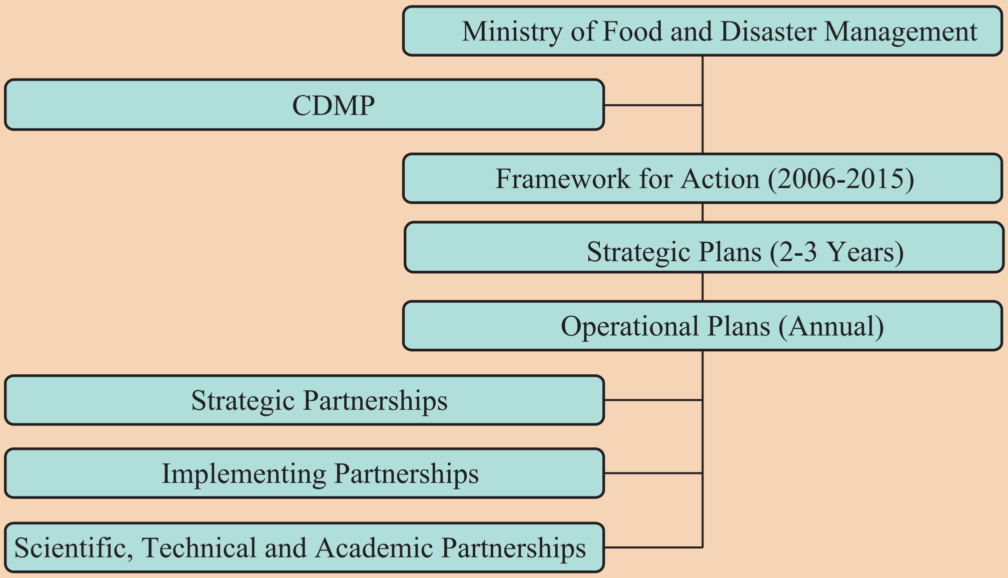
## Disaster Management Model - Bangladesh

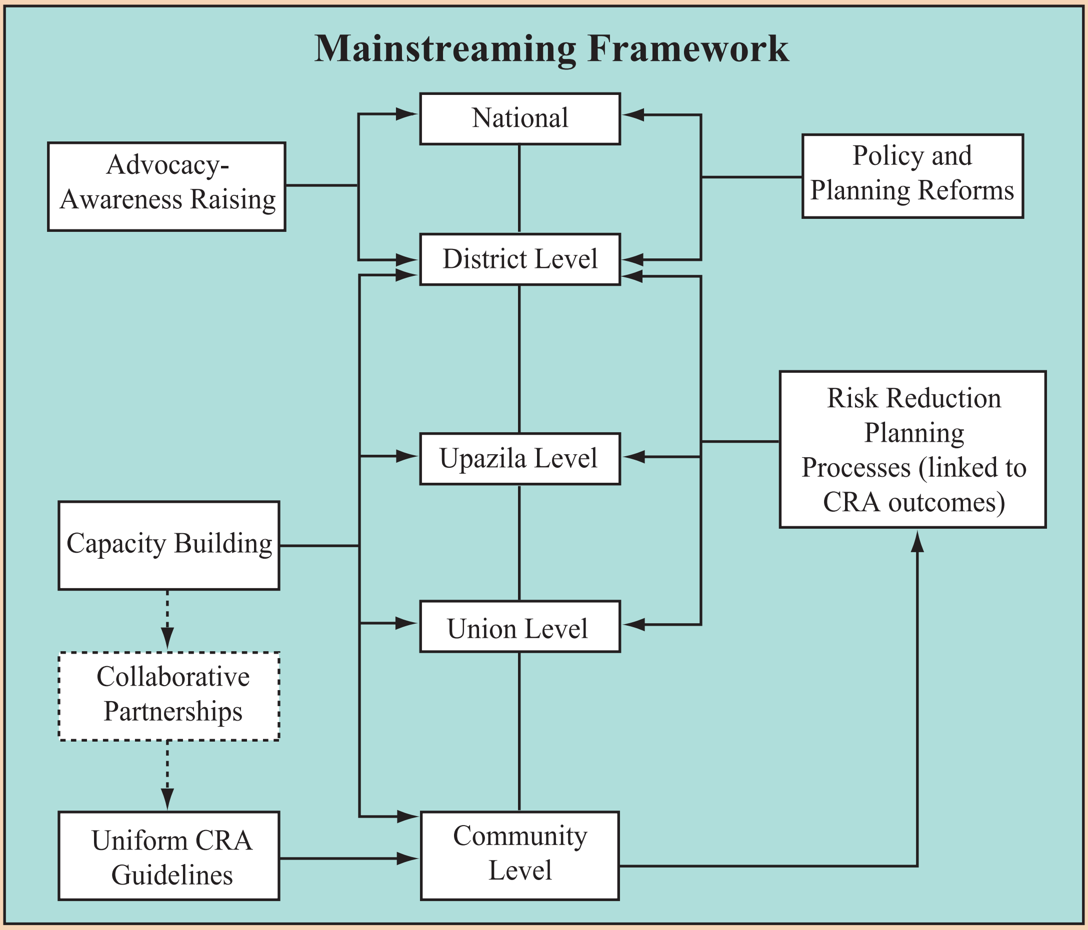



## WoG/NGO Integration of DM Strategies



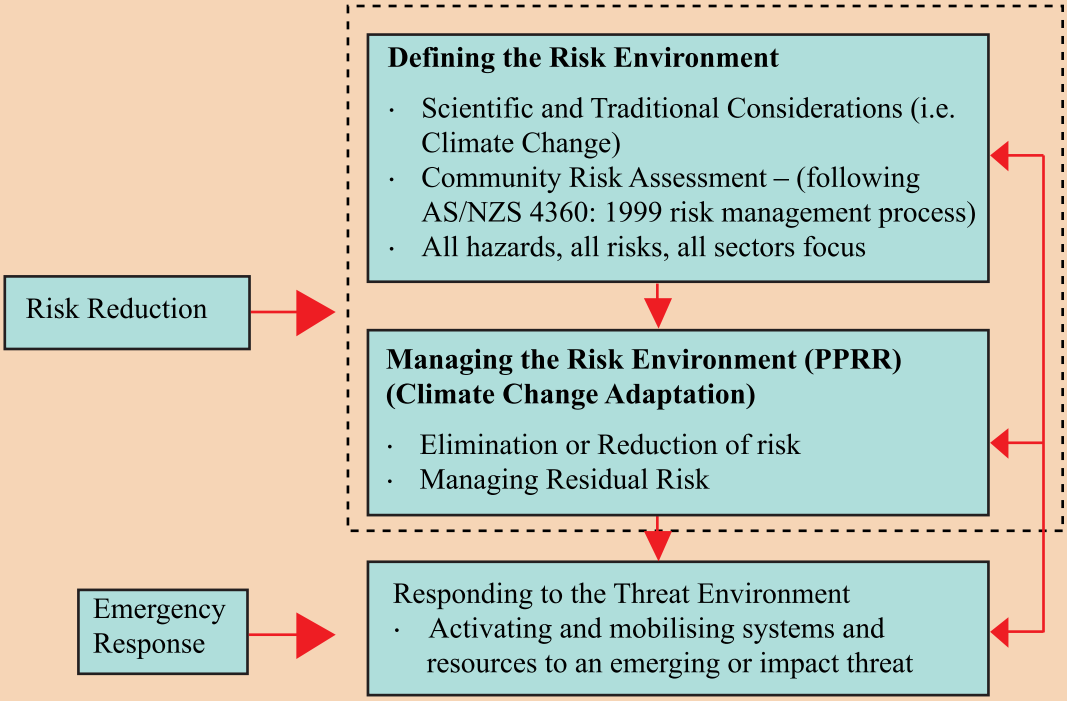
# National Risk Reduction Framework



## What is the relation between Comprehensive Disaster Management and Climate Change ?

### Disaster Management Model - Bangladesh




The Scientific information is very much important
□-In Identifying Risk
□-Climate Information
□-GIS Mapping
□-Scientific Analysis

This information will be used in managing the disaster which is climate adaptation

The rainfall will be increase by 30% during flood and the temperature will increase 7% during winter according to Global Circulation Model (GCM)

How this information will help us in identifying the risk and managing the risk?

This information will have an impact on all hazards like
□-Flood
□-Drought
□-Riverbank Erosion

As well as this information will have an impact on all sector like
□-Agriculture
□-Education
□-Health
□-Infrastructure
□-Communication
□- And livelihood security

# Climate Prediction Model PRECIS: Application for Bangladesh

Md. Nazrul Islam
*Department of Physics*
*Bangladesh University of Engineering & Technology (BUET)*

## Abstract

The validation of Providing Regional Climates for Impacts Studies (PRECIS) regional climate model in Bangladesh is performed with the surface observational rainfall data from Bangladesh Meteorological Department (BMD) and Bangladesh Water Development Board (BWDB). Model simulated maximum and minimum temperatures are also validated with the observed data collected by BMD. The BMD data are used for the duration of 1961-1990 whereas BWDB data are used from 1963-1990. The BMD observed data are available to use at 26 stations throughout the country from 1961-1990 where as only 4 stations data are available with out any missing. In case of BWDB data, 118 stations are found useful out of 304 stations for the period of 1980-1990. The number of data stations reduced to 9 for the period of 1963-1990 because of data missing.

It is found that regional analysis provides overestimation of PRECIS values in Bangladesh because of downgrading observed data when girded from asymmetric data network. Data extracted at some particular locations (observational points) provide better performance of PRECIS. Overall, PRECIS can calculate about 92% and 96% of surface rainfall in case of blsula for BMD and BWDB data respectively. Model performance increases substantially with the increase of analysis duration. Performance of era15 is found much better than other baseline categories. In the case of model, it is found that systematic cold bias existed for the maximum temperature where as random bias persisted for minimum temperature. The merits of PRECIS can be used in predicting rainfall and temperature in Bangladesh using the look-up table. However, it is suggested that observational data should be checked with the Meta data before go to use of model for application.

## Regional Climate Models in Bangladesh

### Background

Any natural event, which has an adverse socio-economic impact on the human being, is called natural disaster. Cyclone, flood and drought are common natural disasters in Bangladesh. These are naturally occurring phenomena that only become harmful due to the intervention of human infrastructure. The people in the developing countries like Bangladesh are at high risk than those of developed countries. Natural disasters are now being considered as one of the global importance and global efforts are being made to mitigate them. Tropical cyclones are usually destructive and affect Bangladesh and its adjoining areas. Among all the atmospheric disturbances, cyclones are the most destructive. Floods are more or less a recurring phenomenon in Bangladesh and often have been within tolerable limits. But occasionally they become devastating. From several studies, it is projected that by the year 2050 the low-lying areas of Bangladesh will be partially flooded as a result of global warming. Drought is also occurring in some parts of Bangladesh that hampered the food production in the agriculture sector of the country. The single most important factor in the annual agricultural cycle of south Asia is the rainfall brought on by the summer monsoon. At the continental scale, mean summer season rainfall is fairly constant from year to year but high spatial and temporal variability leads to localized flooding or even drought conditions. Within a given monsoon season phases of low activity occur, termed break periods, as do periods of high activity, termed active periods. The typical precipitation distributions during these regimes are in anti-phase: break periods are associated with dry conditions over most of the region apart from south-east India and Bangladesh whereas active conditions bring heavy precipitation only over central India. These phenomena create significant climatic impacts throughout the whole region. Because of the importance of global warming it is essential to know the predicted values of the climatic change in country scale as well as in regional scale for a better future plan in agriculture, food, water-management, health, infrastructure, fisheries, highway sectors. Not the subjective assessment natural disaster due to climate change, result from objective analysis is essential for proper plan. Real measurement can not predict anything in this world, only climate model can predict in different future time scale. To examine how faithfully the climate model represents the summer monsoon in this region, model outputs should be calibrated with ground-based surface data. Validation results from a number of regional climate models (RCMs) are available to discuss in the workshop.

### Status of RCMs in Bangladesh

There is a growing demand from many countries for regional-scale climate predictions. The Global Climate Models (GCMs) make predictions at a relatively coarse scale of a few hundred kilometres, but to study the impacts of climate change we need to predict changes on much smaller scales. Regional climate models (RCMs) have a much higher resolution than global climate models and as a result provide climate information with useful local detail including realistic extreme events. Predictions using RCMs will thus lead to substantially improved assessments of a country's vulnerability to climate change and how it can adapt.

***(a) MM5:*** As far as we know there is no RCM in Bangladesh before a couple of years. In the year 2002 first RCM named MM5 (Mesoscale Model) was installed at the Department of Physics, BUET to simulate the mesoscale systems developed in this region. The model is one of the tested and justified by more than 170 organizations all over the world.

The PSU/NCAR (Pennsylvania State University / National Center for Atmospheric Research) mesoscale model (known as MM5) is a limited-area, nonhydrostatic, terrain-following sigma-coordinate model designed to simulate or predict mesoscale atmospheric circulation. The model is supported by several pre- and post-processing programs, which are referred to collectively as the MM5 modeling system. The MM5 modeling system software is mostly written in Fortran, and has been developed at Penn State and NCAR as a community mesoscale model with contributions from users worldwide.
The Fifth-Generation NCAR/ Penn State Mesoscale Model is the latest in a series that developed from a mesoscale model used by Anthes at Penn State in the early `70's that was later documented by Anthes and Warner (1978). Since that time it has undergone many changes designed to broaden its applications. These include (i) a multiple-nest capability, (ii) nonhydrostatic dynamics, and (iii) a four-dimensional data assimilation (Newtonian nudging) capability, (iv) increased number of physics options, and (v) portability to a wider range of computer platforms, including OpenMP and MPI systems. The purpose of this introduction is to acquaint the user with some concepts as used in the MM5 modeling system.

Terrestrial and isobaric meteorological data are horizontally interpolated (programs TERRAIN and REGRID) from a latitude-longitude grid to a mesoscale, regtangular domain on either a Mercator, Lambert Conformal, or Polar Stereographic projection. Since the interpolation of the meteorological data does not necessarily provide much mesoscale detail, the interpolated data may be enhanced (program LITTLE_R/RAWINS) with observations from the standard network of surface and rawinsonde stations using a successive-scan Cressman or multiquadric technique. Then performs the vertical interpolation from pressure levels to the  -coordinate of the MM5 model. Alternatively, program 3DVAR may be used to ingest data on model  -levels. After a MM5 model integration, program INTERPB can be used to interpolate data from  -levels back to pressure levels, while program NESTDOWN can be used to interpolate model level data to a finer grid to prepare for a new model integration. Graphic programs (RIP and GRAPH) may be used to view modeling system output data on both pressure and  -levels.

***(b) RegCM3:*** In 2003, Bangladesh Unnayan Parisad (BUP) initiated to introduce RegCM3 through APN (Asia Pacific Network) Capacity build-up program. RegCM is a 3-dimensional, sigma-coordinate, primitive equation regional climate model developed by ICTP (International Centre for Theoretical Physics), Triesty, Italy. Version 3 of RegCM is the latest. It is developed and supported by scientists inside and outside of ICTP. In RegCM3, for Terrain & ICBC are preprocessing parts, DATTYP could be ECMWF, ERA40, FVGCM, Further NEST (FNEST), NNRP1, NNRP2 and the small_window_NNRP2 (NRP2W); SSTTYP could be OISST, GISST and the weekly OISST (OI_WK).

The subgrid BATS land surface scheme is added in the RegCM code, and the SUBEX and aerosol/chemistry packages are modified to improve the model performance. At present RegCM3 is running at BUET in different model parameterizations. In RegCM3, change of horizontal resolution with DOWNSTEP option is available for high resolution. At present RegCM3 is running at BUET. Some validation results of RegCM3 with a few cases on extreme events occurred in the last decade are available and generation of future scenarios for Asian Region are on going.

***(c) PRECIS:*** In July 2004 a research group from Bangladesh attended the PRECIS (Providing Regional Climates for Impacts Studies) workshop in Bhutan where PRECIS was introduced and later in January 2005 another research group from Bangladesh visited India and collect the PRECIS software with LBC for test run. After that PRECIS is installed in Bangladesh at BUET, BMD and SPARRSO. Test run has been done for a short period (one and half a year). The model output is compared with that of IITM runs. Results are the same. Then we take the advantage to use IITM PRECIS output to validate PRECIS in Bangladesh for 1961-1990 to save computing time. Validation of PRECIS with surface data are almost at the end. Once the obtained validation result give the confidence level of simulated outputs, future scenarios will be generated and climate change will be explained based on the present validation information. We are now ready for high resolution (downscaling) and future scenarios run for the impact studies of climate change in Bangladesh.

**PRECIS description-** The Hadley Centre of UK has developed PRECIS that can be run on a PC and can be applied easily to any area of the globe to generate detailed climate change predictions. Details of PRECIS can be found at their website: PRECIS has a horizontal resolution of 50 km with 19 levels in the atmosphere (from the surface to 30 km in the stratosphere) and four levels in the soil. The present version of PRECIS has the option to downscale to 25 km horizontal resolution. In addition to a comprehensive representation of the physical processes in the atmosphere and land-surface, it also includes the sulphur cycle. The intention is to make PRECIS freely available for use by developing country scientists involved in vulnerability and adaptation studies conducted by their governments. It is assumed that scientists in a group of neighbouring countries can work together so that they can configure the model over their own region and run their own regional climate change predictions. PRECIS developers advised to work based on groups of countries, as in many cases they have similar vulnerabilities and face similar impacts from climate change. The Institute of Tropical Meteorology (IITM), Pune, India runs PRECIS with 50 km horizontal resolution for present climate (1961-1990) using different base line local boundary condition (LBC) and for future scenarios (2070-2100) using IPCC (Intergovernmental Plan on Climate Change) Special Report on Emissions Scenarios (SRES).

Once PRECIS is installed on the PC and started, the user is presented with a graphical menu (shown below left) which allows the domain (area) of the model to be specified by choosing an appropriate central point and drawing a rectangular box around it (below right). It also asks the user to specify the length of simulation (10, 20 or 30 years) and the particular GCM driving fields to be used (for example, SRES A2 emissions scenario). The user will also have to decide what quantities from the model output should be saved, and how often. In principle, all the model quantities, at every grid point, from the surface to 30 km in the atmosphere, could be saved at every time step. However, this would produce an enormous amount of data that would be almost impossible to store on a PC.

The model prediction can then be started, and the model will step forward every five minutes of model time (about four seconds of real time), calculating the new state of the climate system at each step. During the prediction run the output can be monitored in a number of ways; for example, displaying a map showing rainfall or temperature patterns every model hour, or plotting a graph of temperature over a single grid square covering an area of interest (see page 9). Some technical parameters can also be displayed so that any problems can be quickly identified. If the prediction run is stopped part way through (either deliberately or because of a power failure, for example) then it can be easily restarted without loss of data. In addition to making data from the RCM predictions available for impacts assessments, it can be valuable in its own right to publish this information (with some simple analyses) in the form of maps and diagrams. For example, maps of changes in quantities (such as maximum and minimum temperature, rainfall, soil moisture) for each of the four seasons and as an annual average, for the period 2071-2100, can be easily generated by the RCM user (see case studies for examples). Further analysis can generate quantities such as change in number of days with heavy rainfall, with temperatures greater or less than a given threshold, or changes in the number of droughts. In the UK, we have found that, when combined with information on the current observed climate, a short booklet can be produced which is not only a source of information, but which can have the effect of making the issue of climate change more visible to government and other stakeholders.

## The response of the climate system

Because we have an imperfect understanding of the way the earth's climate system works, no climate model can give an accurate prediction of climate change. We do not know what the true uncertainty in predictions is, but we can make an estimate of this by taking predictions from a range of climate models. For example, the global mean temperature change resulting from A2 emissions ranges from 4.7 °C in the most sensitive model reported in the IPCC Third Assessment Report Technical Summary to 2.7 °C in the least sensitive. At a regional level, the spread in predictions from GCMs can be even larger. However, the 2001 IPCC Scientific Assessment has shown that agreement between GCMs on regional-scale seasonal-mean changes has improved. For example, models show consistency in relative warming in three-quarters of world land regions and in the sign of precipitation change in two-thirds of regions. Consistency is better at mid-and high-latitudes.

Because different global climate models (GCMs) represent the climate system in different ways, predictions that they make at a regional scale can be very different. As there is currently no assessment available of the quality of the GCM predictions, ideally an RCM should be driven by predictions from a range of GCMs to explore uncertainty.

# Salinity Intrusion, Coastal and Fluvial Flood Modelling

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## Abstract

The assessment of climate change induced vulnerabilities, identification and evaluation of potential adaptation measures for sustainable water resources development can only be made integrating the intricate water resources systems and incorporating climate change factors. This assessment approach needs the scientifically based and tested state of art mathematical modelling tools which can simulate the output of climate change models i.e. increase precipitation, evaporation and sea level rise for the assessment of impacts.

This paper presents the available mathematical modelling tools in the Institute of Water Modelling and their applications in assessing the impact of climate change on flooding and salinity intrusion, and also for flood, drainage, erosion, land reclamation, navigation and irrigation management. The model results on climate change induced impacts on water resources would enable the multidisciplinary team to ascertain the additional impacts on agriculture, forest fisheries, domestic and industrial water use and navigation.

Salinity intrusion and flooding are important issues in natural resource management and sustainable development in Bangladesh. Assessment of salinity intrusion and coastal flooding has been made using available Bay of Bengal and Regional models for the climate change scenario of National Adaptation Program of Action (NAPA). It has been seen that due to 88cm Sea Level Rise (SLR) increase of inundation ( >30cm) area is about 14% in the coastal area compared to present condition for an average monsoon flow (2.33 year). Any rise of sea level will propagate into the river system. High tide level on the Shahbazpur channel near Bhola Island is increased by 30cm and 80 cm for SLR of 32 cm and 88cm SLR respectively. Water level increase on the Lower-Meghna at Chandpur is about 50 cm for 88 cm rise of sea level and 15cm for 32cm SLR.

Drainage congestion may become more severe threat than higher flood risk. It has been found that due to sea level rise the deterioration of drainage condition is extensive in the polders where the current performance is satisfactory. Analysis for polder 27 shows that drainage congestion area for 3days duration and more than 30cm depth in polder 37 is increased from 0.0ha to 10,000ha with the SLR of 88cm. Water level over tops embankment of 17 polders out of 35 polders in the southwest region due to SLR of 88cm.

Saline water intrusion is highly seasonal in Bangladesh and during dry season deep landwards intrusion occurs through the various tidal rivers in the western part of the delta, and through the Lower Meghna estuary. Sea level rise would increase the extent of salt water intrusion by pushing the saline waterfront landwards. The combination of sea level rise and low upland flow will change the present spatial and temporal variation of salinity, which eventually would cause damage to agriculture, fisheries and total echo-system of the coastal area. The only freshwater pocket in the Tentulia river is lost with SLR of 88cm. The 5ppt isohaline intrudes 9km to landwards for 32cm SLR and about 90km for 88 cm SLR in the Tentulia river. The intrusion of 5ppt isohaline in the Baleswar river is 9km and 33km due to SLR of 32cm and 88cm respectively. Salinity at Khulna is increased by 0.5 to 2 ppt

for 32 cm and 88 cm sea level rise, whereas at Mongla, the increase of salinity level is higher compare to Khulna, which is in the range of 1 to 3 ppt for SLR of 32cm and 88 cm respectively.

The available models in IWM are the Bay of Bengal Model and Six Regional models that cover the whole Bangldesh. These models have been developed based on MIKE11 and MIKE21 modelling systems and have been applied since 1986 in various water and environment related projects to support at planning, design and implementation stages through evaluating the potential solutions in-terms of benefit and adverse impacts. IWM has been in the pioneering role with the support provided to Flood Forecasting and Warning Center (FFWC) of BWDB in maintaining and updating/upgrading the these Regional Models to support FFWC to forecast water levels with reasonable accuracy. Efforts are on to increase the lead-time of flood forecasts from the current 2~3 days to 7~10days in the Climate Forecast Application for Bangladesh (CFAB). The available scientifically based and proven models in IWM need to be utilized for application of any future climate change scenarios to assess vulnerabilities and adaptation measures.

## Introduction

The low lying delta of Bangladesh possesses great danger due to the climate changes. The economic activities of the country which is mainly revolved by her agricultural activity might face a subversive action due to climate change effects. The main threat of climate change to Bangladesh are increased flooding, drainage congestion, decrease of flow in winter, salinity intrusion, frequent cyclone and storm surge flooding. The assessment of climate change induced vulnerabilities, identification and evaluation of potential adaptation measures for sustainable water resources development can only be made integrating the intricate water resources systems and incorporating climate change factors. This assessment approach needs the scientifically based and tested state of art mathematical modelling tools which can simulate the output of climate change models i.e. increase precipitation, evaporation and sea level rise for the assessment of impacts.

Salinity intrusion and flooding are important issues in natural resource management and sustainable development in Bangladesh. Assessment of salinity intrusion and coastal flooding has been made using available Bay of Bengal and Regional models for the climate change scenario of National Adaptation Program of Action (NAPA).

## Climate Change Scenarios

The Third Assessment Report (TAR) of Inter Governmental Panel on Climate Change indicates that the global sea level rise is 0.09m to 0.88m from 1990 to 2100. National Adaptation Programme of Action (NAPA) team on the basis of 3rd IPCC report and prediction of SAARC Meteorological Centre has established the likely climate change scenarios for Bangladesh. Table 1.1 illustrates the climate scenarios for Bangldesh.

**Table 1.1: Climate Change Scenarios for Bangldesh (NAPA)**

| Year | Mean temperature Change (°C) | | | Mean Precipitation Change (%) | | | Sea Level Rise | | |
|---|---|---|---|---|---|---|---|---|---|
| | Annual | DJF | JJA | Annual | DJF | JJA | IPCC (Upper Range) | SMRC | NAPA |
| 2030 | 1.0 | 1.1 | 0.8 | 5 | -2 | 6 | 14 | 18 | 14 |
| 2050 | 1.4 | 1.6 | 1.1 | 6 | -5 | 8 | 32 | 30 | 32 |
| 2100 | 2.4 | 2.7 | 1.9 | 10 | -10 | 12 | 88 | 60 | 88 |

The NAPA scenarios have been simulated considering low upland freshwater flow for dry season and average flow during monsoon to assess the salinity intrusion and coastal flooding using Bay of Bengal Model and regional models.

## Available Models

IWM is maintaining two-dimensional and one-dimensional regional models, which cover the whole Bangladesh including Bay of Bengal, with continuous updating/upgrading and validating over 16 years under the different projects. Available models are Bay of Bengal, Northwest, Northeast, North Central, Southwest, Southeast, and Eastern Hill Regional models. All these models have been developed using MIKE11 and MIKE21 modelling systems developed by DHI Water and Environment, Denmark. Bay of Bengal and regional models simulates rainfall runoff, water level, water flow, erosion, accretion, salinity level and intrusion, water quality, tide, cyclone and storm surges. For salinity intrusion and coastal flooding, Bay of Bengal, Southwest and Southeast regional models have been applied. Brief description of the Bay of Bengal Model and Southwest Regional Model is provided in the following articles.

## Bay of Bengal Model

Bay of Bengal model comprises of the northern region of the Bay of Bengal with the coastal belt of Bangladesh and part of India and Myanmar, extended up to $19^0$ latitude. The area covered by the Bay of Bengal model is shown in Figure 2.1

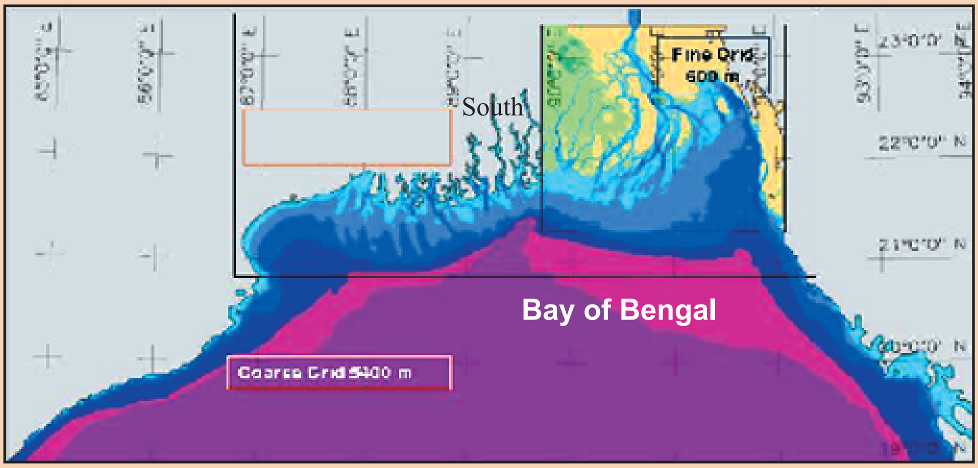



*Figure 2.1: Bay of Bengal model coverage*

The model has a wide, deep, open ocean boundary in the south situated along the line extending from the Coast of Orissa in India to the Coast of Arakan in Myanmar. Predictions on water levels have been made for the two extreme points along this boundary, i.e. Baruva in India and Searle Point in Myanmar, respectively. The water level along the open boundary is obtained by interpolating the two predicted water levels. To the north the model has a narrow, shallow, open boundary in the Meghna River. The boundary is about 30 kilometres north of the nearest water level station, Chandpur The model is two-way nested and includes three different resolution levels (grid sizes) in different areas. The Meghna Estuary is resolved on a 600m to 200mgrid. The model is based on the measured bathymetry (1999-2004) in the Meghna estuary and admiralty sea chart in the Bay of Bengal.

## Southwest Regional Model

The southwest region model (SWRM) is a complex network of tidal and non-tidal river systems, which covers the entire southwest part of Bangladesh. This model contains 189 river branches, polders and reulators. The detailed description and delineation of the catchments are provided in the Southwest Region NAM Calibration Report (IWM, 2003). The Southwest Region Model (SWRM) covers the rivers lying to the south of the Ganges and west of the Meghna estuary. The river model covers the same area as in the Rainfall-Runoff model. The model area is bounded on the north by the Ganges and the Padma River, on the east by the Lower Meghna and Shahabazpur River, on the west by the Indian border and on the south by the Bay of Bengal. The area covered in the region is approximately 37,330 $km^2$ and the length of rivers/channels included in the model is around 5,600 km. Figure 2.2 presents the river system included in the model. The hydro-meteorological characteristics and its contribution to the catchments of the southwest region have been generated using the Rainfall Runoff Model (NAM). The Rainfall-Runoff model, a module of MIKE 11, which calculates the runoff generated from rainfall occurred in the area along with other parameters.

## Salinity Instrusions And Coastal Flooding

The coastal area of Bangladesh is endowed with both fresh water and brackish water resources. There is enormous amount of fresh water during monsoon and in the winter freshwater becomes scarce. Saline water intrusion is highly seasonal in Bangladesh and during dry season deep landwards intrusion occurs through the various tidal rivers in the western part of the delta, and through the Lower Meghna estuary due reduced low flow. The saline water is fully flushed in the Meghna Estuary during monsoon with on rush of enormous fresh water flow. However, salinity is not fully flushed in the western part of the coastal area due to the less upland fresh water flow.

Climate change induced effect on decrease of low flow in dry season would deteriorate the saline water intrusion in the coastal area. Sea level rise would increase the extent of saline intrusion by pushing the saline waterfront landwards. The combination of sea level rise and low upland flow will change the present spatial and temporal variation of salinity, which eventually would cause damage to agriculture, fisheries and total eco-system of the coastal area.  The scenario of low upland flow and sea level rise has been simulated in order to find the salinity intrusion.

It appears from the Figure 3.1 that the landward intrusion of 5 ppt isohaline is quite significant in the Bhola, Patuakhali and Barisal districts with the SLR of 32 cm and 88 cm. The only freshwater pocket in the Tentulia river is lost with SLR of 88cm.

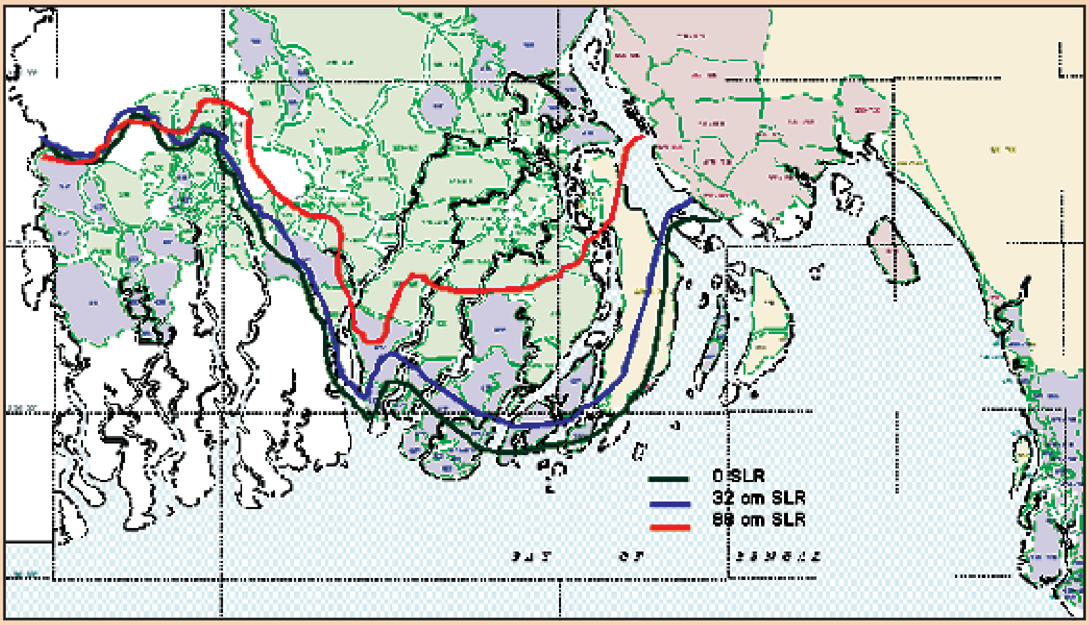



*Figure 3.1: Landward movement of equal salinity line (isohaline of 5 ppt) for different sea level rise during dry season*

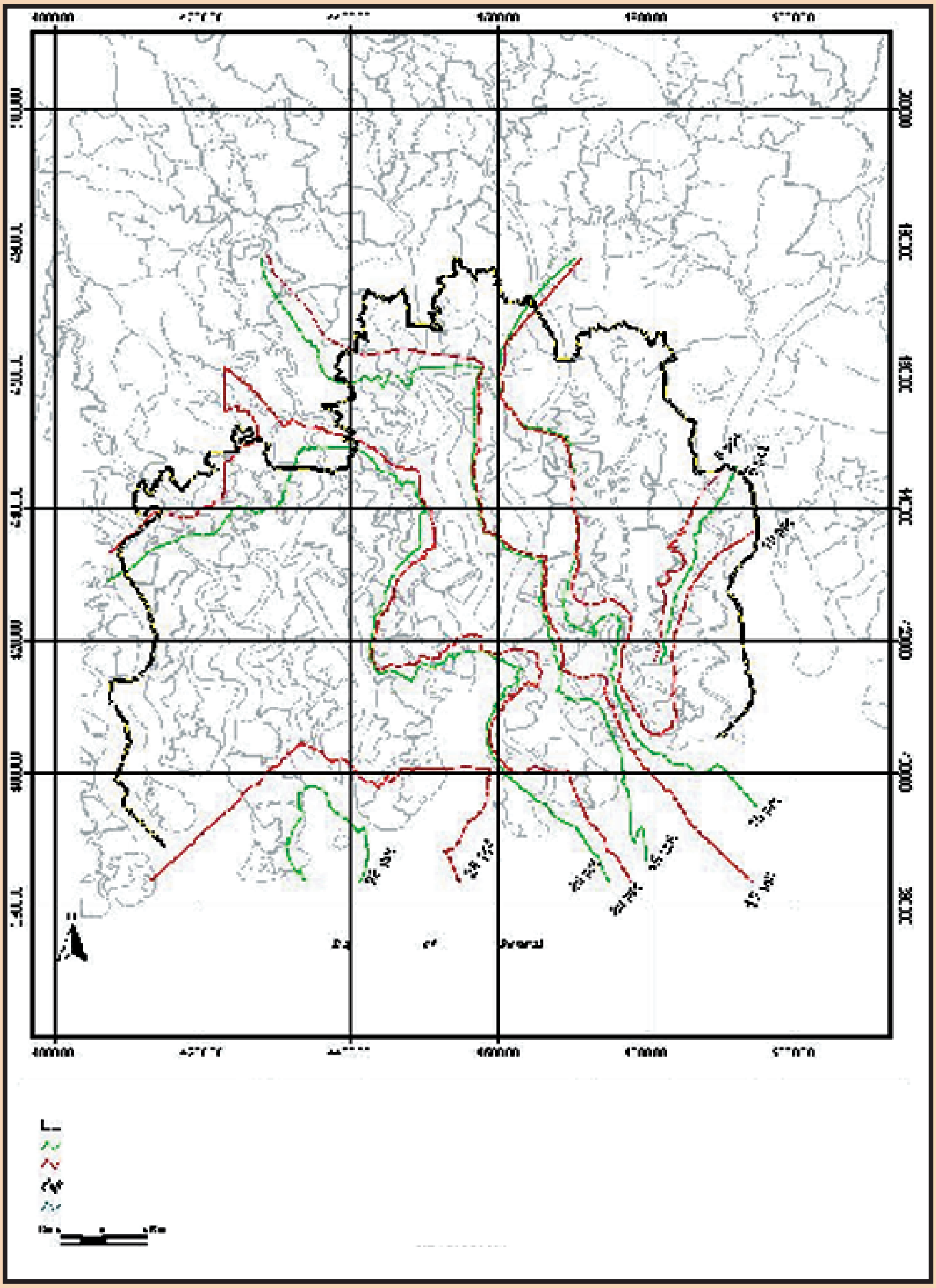
The 5ppt isohaline intrudes 9km from downstream to upstream for 32cm SLR and about 90km for 88 cm SLR in the Tentulia river. The intrusion of 5ppt isohaline in the Baleswar river is 9km and 33km due to SLR of 32cm and 88cm respectively. Salinity at Khulna is increased by 0.5 to 2 ppt for 32 cm and 88 cm sea level rise, whereas at Mongla, the increase of salinity level is higher compare to Khulna, which is in the range of 1 to 3 ppt for SLR of 32cm and 88 cm respectively.

Sea level rise will intrude more salinity in the Baleswar-Buriswar system. In the southeast corner of the area (excluding sundarbans) 4 ppt isohaline moves further inland by 4 km and 12 km due to sea level rise of 32 cm and 88 cm respectively. In the middle part of area the landwards movement of this isohaline be within the range of 6 to 8 km for same level of sea level rises. The movement of same isohaline in the southwest part is about 3 km and 4 km due to sea level rise of 32 cm and 88 cm respectively.

The sea level rise and reduced upland flow poses great threat to the Sundarbans. The Sundarbans has already been affected due to reduced freshwater flows through the Ganges river system over the last few decades particularly during the dry season. This has led to a definite inward intrusion of the salinity front causing the different species of plants and animals to be adversely affected. Increased salt water intrusion is considered as one of the causes of top dying of Sundari trees. The impact of sea level rise will further intrude the saline water to landward. The rate of salt water intrusion will also affect the ability of the ecosystem to adapt. Sea level rise of 32 cm shows 10 to 20 ppt salinity level intrude about more in the Sundarbans as shown in Figure 3.2

In the western part of Sundarbans the increased salinity with a rise of 88 cm SLR is in the range of 22 to 25 ppt, whereas at present the salinity is within 20 ppt. The low salinity zone is the eastern part of the Sundarbans, where salinity varies from 10 to 15ppt will be increased to 16 to 20 ppt for 88 cm sea level rise..

The change in salinity level, inundation depth, tidal dynamics and freshwater flow due to SLR would change the present dynamic balance between these factors, which might affect not only the productivity of the mangrove ecosystem but the entire bio-diversity of the Sundarbans.



Any rise of sea level would propagate into the upstream river system of the coastal area and would cause inundation and drainage congestions. Most of the coastal plains are within 3 to 5 m from Mean Sea Level but some areas are protected by polders. The result shows that with the 88 cm sea level rise 11% more area (4,107 sq.km) will be inundated ( inundation of any depth) with the average upstream flow condition. Table 3.1 illustrates the percentage increase of inundated area due to sea level rise in comparison to existing situation. This calculation is based on the scenario with average monsoon flood from the upstream rivers and sea level rise. It is found that most of the increases in the flooded area are in the shallow land, that is, land which has range of inundation depth 0 cm and 30 cm.

**Table 3.1 Increase of the inundated area in % in the coastal districts for different SLR**

| | Inundated area in % | Increase in inundated area in % | | |
|---|---|---|---|---|
| **District** | **2000 0 cm SLR** | **2030 14 cm SLR** | **2050 32 cm SLR** | **2100 88 cm SLR** |
| Bagerhat | 65 | 5 | 11 | 14 |
| Barguna | 53 | 1 | 9 | 16 |
| Barisal | 75 | 5 | 5 | 10 |
| Bhola | 13 | 0 | 1 | 1 |
| Chandpur | 52 | 0 | 1 | 1 |
| Gopalgong | 74 | 1 | 1 | 2 |
| Jhalokhati | 85 | 3 | 9 | 13 |
| Laxmipur | 27 | 2 | 4 | 18 |
| Noakhali | 42 | 3 | 4 | 7 |
| Patuakhali | 49 | 5 | 8 | 21 |
| Pirojpur | 72 | 6 | 13 | 18 |
| Shariatpur | 44 | 0 | 2 | 5 |
| Khulna | 54 | 3 | 6 | 15 |
| Jessore | 33 | 1 | 2 | 7 |
| Satkhira | 47 | 2 | 5 | 14 |
| Narail | 74 | 1 | 3 | 7 |
| **Total** | | **3** | **6** | **11** |

Note: 1. *16 coastal districts has been considered*

However, the increase of deeper inundation for more than 30 cm depth is 14% compare to existing condition. This is because during any average monsoon, flooding occurs for F0 type (0 to 30 cm inundation depth) land; thus increase of area for the inundation of the shallow land (F0 type) due to sea level rise is lower compare to deeper inundation (more than 30 cm).

The Sundrabans is not protected where land levels are varying from 1.5 to 2.5 m from the mean sea level and is largely influenced by tidal effects. In the monsoon, this tidal effect increased by freshwater flow from upstream. During monsoon, the mean tide level is increased by almost 0.75 m due to the influence of monsoon flow. At present, the mudflats in the Sundarbans area becoming flooded during high tide as land level varies from 1.5 to 2.5m above PWD (0.9 to 2.1 m above MSL, Figure 5.12), whereas Hiron Point high tide level varies from 3.5 to 4.4 m above PWD. However, due to the rise in sea level mudflats will tend to inundate and reduce the land area of the forest. Model result shows that due to 32 cm sea level rise, 84% of the Sundarban area becomes deeply inundated and for 88cm sea level rise, Sundarban will be lost. 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.

The drainage of coastal polders mainly depends on the tidal characteristics of the rivers surrounding the polders and degree of siltation in these rivers. Present study mainly focussed the change in the tidal characteristics of the surrounding rivers due to sea level rise and its impact on inundation area of the polder.

Model results shows that high water level at the surrounding rivers of polders increases in the range of 30 to 80 cm for seal level rise of 32 cm and 88 cm respectively. This rise would eventually hamper the smooth drainage of a number of polders.

The drainage congestion of a few polders with sea level rises is presented in Figures 3.3 and Table 3.2. It can be seen that due to sea level rise the deterioration of drainage condition is extensive in the polders where the current performance is satisfactory.

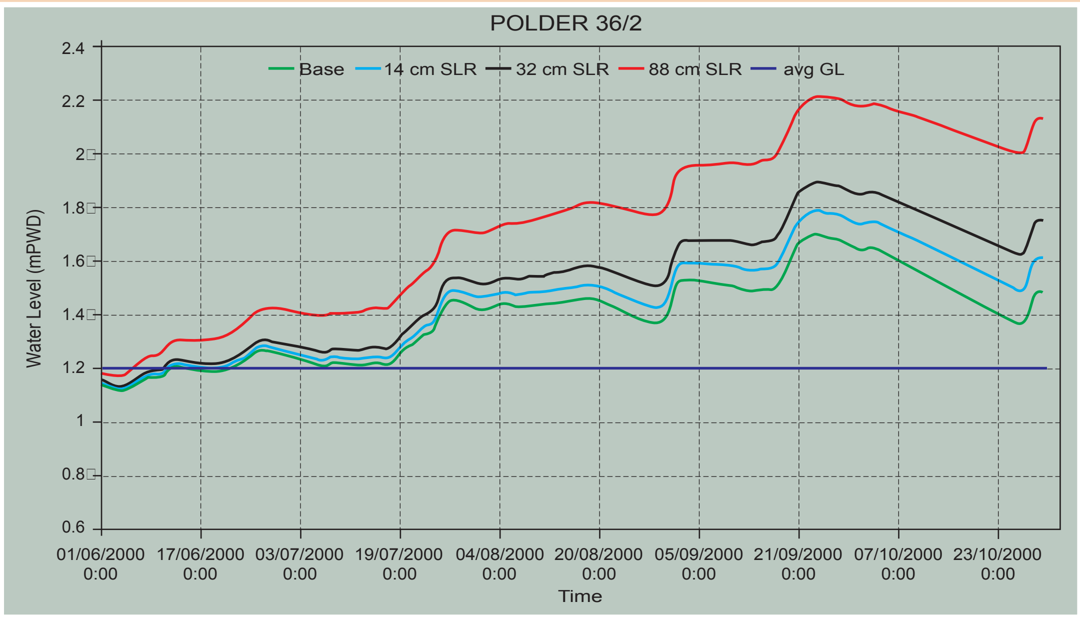



*Figure 3.3: Rise of water level inside polder 36/2 for sea level rise of 0, 14, 32 & 88 cm*

**Table 3.3: Maximum Inundation Area (3 Day duration) above 0.3 m in the Month of October**

| **Polder No. (ha)** | **Total Area** | **SLR 0 cm (ha)** | **SLR 32 cm (ha)** | **SLR 88 cm** (ha) |
|---|---|---|---|---|
| P-25 | 17,594 | 600 | 1,600 | 2,800 |
| P-36/2 | 13,322 | 3,000 | 5,300 | Whole area inundated |
| P-37 | 36,539 | 0 | 4,500 | 10,000 |

The combined effect of sea level rise, subsidence and increased rainfall will further deteriorate the drainage condition of the polders, which has not been assessed.

## Fluvial Flood And Flood Management

Bangladesh is the lowest riparian in the Ganges, Brahmaputra and Meghna (GBM) River Basins. Nearly 93% of the basin area lies outside Bangladesh in India, Nepal, Bhutan and China. Excessive rainfall in the upper catchments is the main cause of seasonal floods in Bangladesh. The rivers of Bangladesh drain about 1200 cubic kilometers of water through Bangladesh. Of the total flow, around 80% occurs in the 5 months of monsoon (June to October). Similar pattern is observed in case of rainfall also. As a consequence to these unique temporal distributions of river flow and rainfall, Bangladesh suffers from abundance of water in monsoon and water scarcity in other parts of the year. In the past flood management mainly focused on protecting agricultural lands from flood. The government is now promoting the concept of integrated management where all sectoral interest should be considered equitably.

Efforts are on to increase the lead-time of flood forecasts. In this context, the USAID sponsored program on Climate Forecast Application for Bangladesh (CFAB) started as a research project by a group of scientist of USA and active collaboration of FFWC, IWM, CEGIS and BMD. Substantial progress has been made by the CFAB team in the investigation on short-term (1-6 days) and long-term (1-6 months) flood forecasts potentials, further investigation is on to investigate the potential for mid-term (15-20 days) forecasts. Whilst CFAB research could demonstrate the potential of application of climate forecast products to flood forecasting, it also finds that climate forecasts may have more applications ranging from disaster management to day-to-day economic activities.

The natural sea-level variability will be superimposed on this gradual increase of sea level, which will cause prolonged retardation of discharge from rivers to the Bay, thus increasing the vulnerability due to floods. Recent analysis of extreme rain events suggests that the reoccurrence of 100-year rainfall extremes over the GBM Basins is shortened by a factor of 7. This means that 100-year rainfall events would occur every 15 years.

The damages due to floods depend on depth of flooding, duration of flooding and area of flooding. This can be seen in case of 1998 flood when both the duration of flood and flooded area were high as compared to other years and consequently damage was also high. In the year 1987, 1988, 1998 and 2004 the flood duration and flooded area were as follows.

| Parameters | Flood Year | | | |
|---|---|---|---|---|
| | 1987 | 1988 | 1998 | 2004 |
| 1.Total Flood Duration (days)<br>a. Bahadurabad 13<br>b. Hardinge Bridge 55<br>c. Chandpur 16 | <br>27<br>23<br>27 | <br>66<br>27<br>49 | <br>16<br>0<br>32 | |
| 2. Flooded Area in Sq. Km. 57,300<br>( % of the country area) (39) | 89,970 | 1,00,250<br>(61) | 56,000<br>(68) | <br>(38) |
| 3. Number of districts affected | 50 | 53 | 53 | 39 |

The flood damage can be assessed for increased flooding due to climate change applying available regional models for planning and design of the future development project.

IWM has in the past two monsoons (2003 and 2004) been actively involved in the experimental flood forecasts using Climate Forecast Application for Bangladesh (CFAB) information on discharge and rainfall to increase the lead-time from 3-days to 5-days in 2003 monsoon and 3-days to 10-days in 2004 monsoon. As can be seen from Figure 4.1 and Figure 4.2 that more work would be required to customize and fine tune the weather model being developed by Program on Oceanographic and Atmospheric Sciences (PAOS), Colorado University, Boulder, USA to produce representative results on discharge and rainfall that can be used for flood forecasting in Bangladesh and results disseminated to the end users and stakeholders.

**Bhagyakul: 5-day Forecast of Mean (year 2003)**

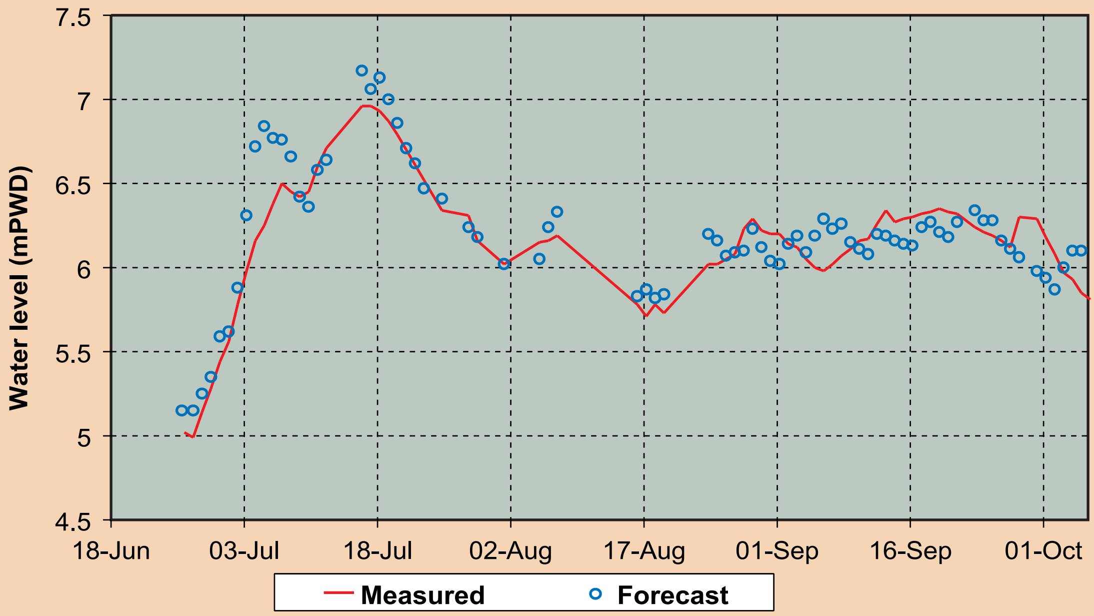



*Figure 4.1: Comparison of 5-day water level forecast with measured data (CFAB-FFS 2003)*

**Goalondo: 10-day Forecast of Mean (year 2004)**

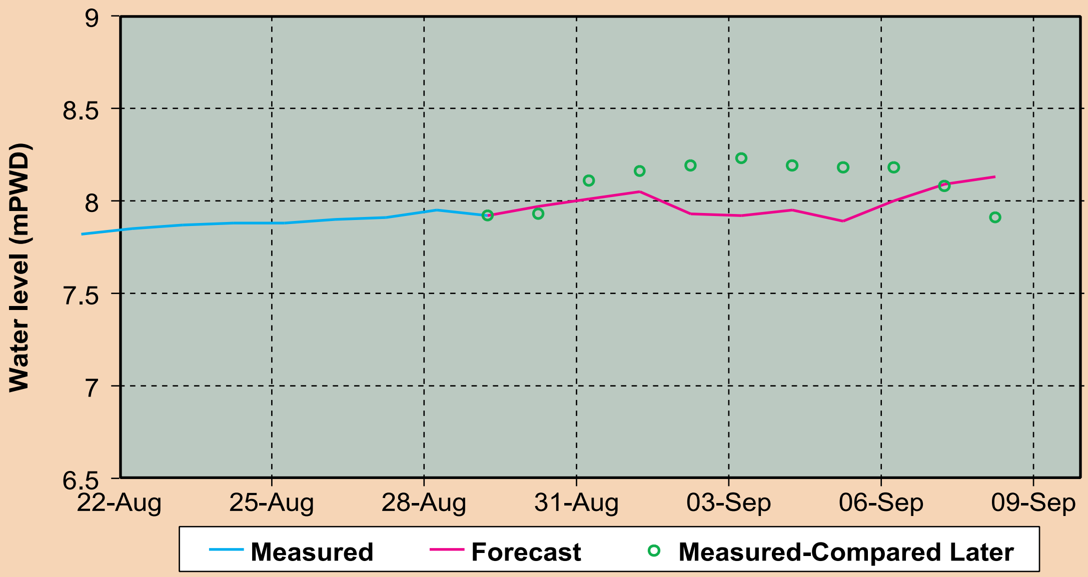



*Figure 4.3: Comparison of 10-day water level forecast with measured data (CFAB-FFS 2004)*

# Mathmatically Predicting the Impacts of Climate Change and Sea Level Rise on Storm Surges in the Bangladesh Coastal Region

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## Introduction

Almost every year, Bangladesh experiences natural disasters of one kind or other, such as tropical cyclones (TC), storm surges (SS), floods, droughts, coastal and river erosions, etc. These disasters cause heavy loss of lives and properties and jeopardize the development activities in the country, which is already beset with many problems like high population density, shortage of land to accommodate its people, food security, health care, illiteracy, and so on and so forth. Natural disasters make the solutions of these issues/problems all the more complicated and expensive. In the foreseeable future, Bangladesh is likely to be one of the most vulnerable countries of the world in the event of a climate change, a 'human-induced disaster'. The global warming due to the increase in the greenhouse gas concentrations in the earth's atmosphere mainly due to industrialization and the consequent sea level rise (SLR) will add fuel to the fire. Nearly every sector of socio-economic life in Bangladesh, as in many other countries of the world, will be affected by the climate change and SLR (CCSLR).

Most of the climate change impacts in Bangladesh are likely to come from the south, that is from the Bay of Bengal and the adjoining North Indian Ocean, which although is the source of life-giving monsoons, is the breeding ground of tropical cyclones and storm surges, cause of river and coastal erosions, source of flood water, cause of droughts, etc. We shall concentrate here on tropical cyclones and the associated storm surges only.

We shall try to briefly look at the basics of TCs and SS with particular reference to Bangladesh and see how models can predict the future behaviour of SS under CCSLR, so that CCSLR may be mainstreamed in the development process (which is, for example, one of the objectives of the National Adaptation Plan of Action-NAPA of Bangladesh) and in the overall disaster management of the country, particularly in the context of the CDMP (Comprehensive Disaster Management Programme).

## Tropical Cyclones

As is well-known, the Bay of Bengal is one of the favourable genesis areas of tropical cyclones. About 5.5% tropical storms (TCs with wind speed   62 km/h) of the global total form in the Bay but they cause heavy loss of life and property to the littoral countries. The country-wise break-up of the 5.5% tropical storms for the littoral countries of the Bay is as follows: Bangladesh is hit by about 0.93% (~1%) tropical storms of the world total, India by 3.34%, Myanmar by 0.51%, Sri Lanka by 0.22% and 0.50% dies in the Bay without hitting any country (Ali,1999).

It seems that Bangladesh is not a high risk cyclone prone area. Situation is, however, otherwise. If the world's TCs due to each of which the death tolls were 5,000 or more are considered, it is found that about 53% of the world deaths took place in Bangladesh (Ali, 1999). If the CCSLR causes any increase in cyclone activity, the situation in Bangladesh is likely to further worsen. Of late, in addition to threat to life, the threat to properties is on the rise due to the rapid development activities in the coastal area of Bangladesh.

Most of the cyclone disasters in Bangladesh, as in other places of the world, are caused by storm surges generated by tropical cyclones. One of the latest examples is the devastation caused by storm surges associated with the hurricane Katrina in New Orleans in the USA.

In order to safeguard ourselves against the approaching danger of tropical cyclones and storm surges in the event of a CCSLR and adapt to the situation, we need to understand, among other things, (i) the physics and dynamics of TCs and storm surges and (ii) their future behaviour. The understanding of the future behaviour needs the prediction of the future pattern. There is no alternative to mathematical modelling to predicting the changes in the behaviour of the TCs and storm surges (similar to the whole gamut of climate change) with the consequent impacts on the socio-economy of the country.

## Would the Cyclone Frequency Increase?

Why do we think that cyclone activity will change due to climate change, i.e. global warming. An answer can be found in the following:

One of the necessary but not sufficient conditions for tropical cyclone formation is that the sea surface should have a minimum temperature of about 26-27$^0$C over a large area and to a sufficient depth (about 50 m). This leads to the speculation that any rise in sea surface temperature (SST) due to climate change is likely to be accompanied by an increase in cyclone frequency. The role of SST in the genesis and intensification of tropical cyclones has been well demonstrated by many authors, e.g. Emanuel (1987), Gray (1979), Miller (1958), Saunders and Harris (1997) and Wendland (1977). The relationship between SST and cyclone genesis is now well established. Almost all tropical cyclones form in warm waters. The highest number of tropical cyclones, about 33% of the world total, form in the Western North Pacific which is a vast area of very warm waters, some about 30$^0$C. The area just west of Central America (in the Pacific) has the highest frequency of tropical cyclone genesis per unit area in the world; its average SST is about 29$^0$C. Positive correlations between the North Atlantic cyclone activity and SST immediately west of Africa have been established. Using SST data for the Bay of Bengal for the period 1951-1987, Joseph (1995) has shown that SST has been increasing since 1951. But an analysis by Ali (1995) and Ali and Chowdhury (1997) of all kinds of tropical cyclones forming in the Bay of Bengal between 1877 and 1990 and subsequently extended up to 1995 by Ali (1999) shows no corresponding increase in cyclone frequency. Similar results have been found by a few other authors. The last highest peak occurred in about 1970, and since then the Bay of Bengal has been experiencing a decreasing trend in the number of storms.

Although no trend in storm frequency could be established in relation to the SST increase in the Bay of Bengal, we can look at the cyclone frequency and SST relation from a different angle which is discussed below.

*Dead cyclones and frequency:*

About 365 cyclones forming in the Bay of Bengal from the years 1877 to 1995 died in the Bay without hitting any littoral countries. Many of them were either stationary or short-lived (less than a day) or had no well-defined tracks. If there were higher SSTs, some of these 365 cyclones could have further developed, and by striking the littoral countries, increased the frequency of landfalling cyclones and thereby causing more casualties and damages. In this sense at least, it may be crudely said that any future SST rise may very likely be accompanied by an increase in the landfalling cyclones even if the cyclone frequency does not increase in the Bay of Bengal area.

## Cyclone Intensity

It is almost certain that an increase in SST will be accompanied by a corresponding increase in cyclone intensity (wind speed). The relationship between cyclone intensity and SST is well discussed in literature. The influence of CCSLR on cyclone intensity is discussed later in more detail

## Storm Surges

Most of the disastrous effects of cyclones are associated with storm surges which is defined as the rise or fall of water above or below the mean sea level (MSL). A rise is called a positive surge and a fall a negative surge. It is the positive surge which is of main concern to us.

## Dependence of Storm Surges

Storm surges are dependent on a number of -

i) Cyclone-related (meteorological) factors and
ii) Non-cyclone-related (hydrological, oceanographic and other) factors

The ***Cyclone-Related Factors*** include

- Wind speed (intensity) (Maximum Sustained Wind Speed-MSWS)
- Pressure drop/change
- Rainfall
- Track
- RHS vs LHS
- Radius of maximum wind
- Time of landfall
- Place of landfall
- Translational speed
- Formation area
- Environment
- Duration
- Size/extent, etc.

The ***Non-Cyclone-Related Factors*** in respect of Bangladesh include

- Shallowness of the north Bay near Bangladesh coast
- Northward convergence of the Bay towards Bangladesh
- High astronomical tides, particularly in the Meghna estuarial region
- Coriolis effect
- Chittagong coastal effect
- Island effect

- River effect
- Short water waves
- Low and flat coastal topography
- Flood effect/back water effect
- Socio-economic factors, etc.

CCSLR is likely to have influence upon all of the cyclone and non-cyclone-related factors/parameters. Any prediction of the future behaviour of TCs and SS under CCSLR will need to take these factors into consideration. However, sufficient information and knowledge are not yet available on how these factors/parameters will behave under the changed situations. Continued and extensive research is needed to be done for better understanding of the physics and dynamics TCs and SS under CCSLR scenarios. Therefore, we do not intend to discuss here all of the factors, but rather confine ourselves to some of the important ones which are thought to be most relevant to Bangladesh situation. Discussions will be both model based as well as intuition based.

## Mathematical Modelling For Predicting Changes in Storm Surges

Usually, there are two ways to predict storm surges and changes in it: empirical and mathematical. There have been some scattered attempts in Bangladesh to develop empirical models (e.g. Choudhury and Ali, 1974). Empirical models are generally developed on the basis of past data, for example, by relating storm surge heights with maximum wind speed or pressure drop in a cyclone. The method cannot yield much success in the absence of a sufficient number accurately observed data, which unfortunately is the case with Bangladesh. Also the method cannot be used for a continuous forecast. Moreover, the complications involved in the generation and modification of surges due to various meteorological, oceanographic and hydrological factors cannot be taken into account in an empirical model. The model cannot also be used for each and every coastal station/point because data are not available for each of the points. The use of an empirical formula is equivalent to having ‘something’ instead of ‘nothing’.

The storm surge characteristics are better discussed with the help of hydrodynamic equations governing the motions of sea water. Analytical solutions of these equations are not possible without taking recourse to many simplifying assumptions. Unfortunately, much important information may be lost in the way of simplification. The only way then seems to be the solutions of the hydrodynamic equations with the help of computers. Since computers give the results in numbers or ‘numerics’, such models are more commonly known as ‘Numerical Models’.

The author has used a number of numerical models in studying storm surges and other related phenomena. The basic equations are the vertically integrated:

Continuity equation:

$$\frac{\partial \zeta}{\partial t} + \frac{\partial}{\partial x}(Hu) + \frac{\partial}{\partial y}(Hv) = 0 \quad \text{- - - - - - - - - - - - - - - - - - - - - - - - - - - -} \quad (1)$$

Momentum equations:

$$\frac{\partial}{\partial t}(Hu) + \frac{\partial}{\partial x}(Huu) + \frac{\partial}{\partial y}(Huv) - fHv = -gH\frac{\partial \zeta}{\partial x} - \frac{H}{\rho}\frac{\partial \Pi}{\partial x} + \frac{1}{\rho}(Fs - Fb) \quad \text{- - - -} \quad (2)$$

$$\frac{\partial}{\partial t}(Hv) + \frac{\partial}{\partial x}(Huv) + \frac{\partial}{\partial y}(Hvv) + fHu = -gH\frac{\partial \zeta}{\partial y} - \frac{H}{\rho}\frac{\partial \Pi}{\partial y} + \frac{1}{\rho}(Gs - Gb) - - - - (3)$$

In the above equations, the meaning of the symbols is:

x, y, z: describe a system of Cartesian coordinate system with x
counted positive eastward, y northward and z vertically upward
u, v: depth-averaged velocity in the x and y directions respectively
r : density of water assumed constant
g: acceleration due to gravity
t: time
f: Coriolis parameter
z= z(x,y,t) is the displaced free surface (storm surges)
z= - h (x,y) corresponds to the sea floor
H= h + z is the total depth of water
Fs, Gs: surface stresses in the x and y directions respectively
Fb, Gb: bottom stresses in the x and y directions respectively

The equations are fully nonlinear and different versions of them have been used by the author. Details of the models are not given here but these can be found in Ali (1980,1982,1995,1996), Johns and Ali (1980,1987,1992), Ali and Haque (1994) and Ali et al. (1997a,b).

The equations are written in finite difference form and computer coded using Fortran 77. A series of numerical experiments were done with cyclones (with different wind speeds, atmospheric pressure changes, tracks, etc.), astronomical tides, fresh water discharge from rivers (including back water effect), monsoon wind, etc. both separately and in different combinations of them. We discuss below some of the findings, which are by no means complete. The Bay of Bengal configuration in most cases was based on the NOAA satellite images to better represent the coastal boundary and positions of islands, rivers, etc.

## Wind Effect

Wind is the most disastrous parameter of a tropical cyclone. It has both direct and indirect effects. Through direct effect, it uproots trees, causes serious damages to ill-built houses, capsizes boats, ships, etc. Storm surge generation is the indirect and the most disastrous effect of TCs. Atmospheric pressure changes and rainfall has some negligible contribution.

*SST vs wind speed*:

Emanuel (1987) has developed some numerical relationship of maximum sustained wind speed with SST. If a lower bound of $2^0$C and an upper bound of $4^0$C rise in SST are assumed for the end of the century, the corresponding increase in maximum cyclone wind speed using Emanuel's table comes out to be 10% and 22% respectively with respect to that of the threshold temperature of $27^0$C (Ali, 1996). It may, however, be pointed out here that the cyclone intensification as mentioned above is not certified by observations and numerical experiments. Nevertheless, it indicates that a good number of depressions will become cyclonic storms and cyclonic storms will become severe cyclonic storms and severe cyclonic storms will become even more severe. As a consequence, the disastrous consequence of cyclones will increase manifold.

*SLR vs wind speed:*

SLR itself may also contribute directly to increase in wind speed: As a consequence of SLR, (if everything else remains constant) the shoreline will retreat causing a cyclone to traverse a longer path and hence to remain in water for a longer period, thereby getting more water vapour for its intensification.

*Wind speed vs storm surges:*

Wind is the main contributing factor (~90%) to storm surge generation. It exerts stress on the water underneath and generates surges. The stress exerted by wind is proportional to the square of the wind velocity. Thus, an increase in SST due to climate change will lead to higher storm surges and higher risk of disasters in low lying coastal areas of Bangladesh, where storm surge heights in excess of 10 m are not uncommon.

Ali (1996) considered the 1991 cyclone that had hit Bangladesh for modelling the impacts of CCSLR on storm surges. Three temperatures were used: current temperature ($27^0$C) and two future temperatures: $2^0$C and $4^0$C rises in SST. The maximum wind speed for the 1991 cyclone was 225 km/h. Under $2^0$C and $4^0$C rises in temperatures, the wind speed becomes 248 km/h and 275 km/h respectively. These three winds were used to generate storm surges in the Bay of Bengal using a linear version of equations (1) - (3), with quadratic stress laws. The results of the model calculation for a grid point corresponding to Chittagong is given in Table 1. It will be seen that SST rise substantially increases, as is expected, storm surges in Bangladesh.

**Table 1**

Storm surges (m) under different SSTs and SLRs . The values within the parentheses give % changes in surge height w.r.t. current temp (Ali, 1996)

| Temp ® | Present » $27^0$C | $2^0$C SST rise | $4^0$C SST rise |
|---|---|---|---|
| Wind speed (km/h) ® | 225 | 248 | 275 |
| Storm surge heights in m (% changes w.r.t 7.6 m surge) | | | |
| SLR = 0.0 m | 7.6 (0%) | 9.2 (21%) | 11.3 (49%) |
| SLR = 0.3 m | 7.4 (-3%) | 9.1 (20%) | 11.1 (46%) |
| SLR = 1.0 m | 7.1 (-7%) | 8.6 (13%) | 10.6 (40%) |

## Shallow Water Effect and Sea Level Rise

Bangladesh has a large and shallow continental shelf. The depth varies from about 500 m along the $20^0$N to less than 5 m along the coast. Storm surge is mostly a shallow water phenomenon. It is inversely proportional to water depth. The deeper the water, the lower is the surge and vice-versa. As water is driven by wind from deeper region to shallower region, water level is forced to go up because of continuity reason. As this amplified water approaches the coast, the coastal area becomes flooded leading to loss of life and property.

*SLR vs storm surges:*

Table 1 also gives storm surge heights under different SLRs: 0.0 m, 0.30 m and 1.0 m. Under no SLR, storm surge increases by about 21% and 49% for an SST rise of $2^0$C and

$4^0C$ respectively. These percentages decrease with rises in sea level. SLR tends to reduce the surge heights if wind speed remains constant.

Although SLR will apparently decrease the surge height, but because of the low topography of the country, it will convert the hitherto low land area into a part of the Bay which will then become a shallow water area where surge will get amplified. Thus although the SLR will apparently reduce the surge height in the present sea water, it will increase the surge height in the newly converted (from land to sea) sea area.

*Risk Zone vs SLR*:

Surge water that hits the coastline of Bangladesh travels much inland. On the basis of the penetration distance of surge water and the depth of inundation, MCSP (1992) has delineated the coastal area of Bangladesh into a Risk Zone (RZ) and High Risk Area (HRA). RZ is defined as the area where there is a risk that damages to properties may occur due to inundation by surge water. The HRA within the RZ refers to areas where there is a possibility of loss of lives due to substantial inundation by storm surges. The areas have been delineated by taking into consideration a number of factors like observed surge heights and penetration distance, topography and field survey, etc. Obviously, any increase in surge heights due to climate change and SLR will push further inland the RZ and HRA. And this may upset the management plan that has been undertaken on the basis of the MCSP (1992) delineation, such as construction of cyclone shelters.

## Convergence Effect

Storm surge height is directly proportional to convergence. Convergence, like shallow water effect (SWE), leads to amplification of surges. Because of northward convergence of the Bay, surge water is funneled towards north, particularly towards Bangladesh.

Now, any rise in sea level will push the northern coastal boundary further inland. An examination of the elevation contour lines indicates that SLR will make the eastern coast of Bangladesh more tilted towards the west, i.e. the convergence will increase. Hence surge heights will get further amplified.

## Tidal Effect (on Storm Surges)

Tides in the Bay of Bengal are mostly generated in the Indian Ocean and get amplified at the head Bay due to SWE, convergence, etc. About one-third of the country is under tidal excursion. Tides in Bangladesh have the highest range at the Meghna estuarial region (about 5 m) and is lower on both sides. When surge combines with tides, particularly high tides, situation becomes disastrous. Tide and surge interact non-linearly. Numerical experiments done by the author show that

(i) Pure storm surge curve is nearly smooth
(ii) Tide sets an oscillatory motion on surge
(iii) Surge also puts an influence on tides
(iv) Maximum elevation (tide + surge) has a tendency to occur at high tides
(v) Interaction is not same throughout a basin, because it depends on a number of factors like tidal range, water depth, bottom friction, amplitude and duration of surge, etc.

SLR will change the tidal dynamics and the scenario. Consequently, the storm surge phenomenon will be affected.

## Tide vs Fresh Water Discharge

Model calculations by the author show that flood/fresh water from rivers

(i) Decreases the high tide value
(ii) Increases the low tide value (Absolute)
(iii) Shortens the flood-tide period
(iv) Increases the ebb-tide period

## Coriolis Effect

Coriolis effect is caused by the earth's rotation on its own axis. It acts to the right (left) in the NH (SH). When surge water moves northward in the Bay, it gets deflected towards the right, thereby increasing the surge height along the east coast of Bangladesh (a kind of a Kelvin wave).

On different occasions, it has been seen that when a cyclone hits the western coast of Bangladesh, significant surge is observed in the Meghna estuary, which is apparently and partly due to Coriolis deflection towards the right.

SLR may also influence the Coriolis force through changes in the current velocity as well as through increase of water area in the north (i.e. more latitudinal area to the north).

## Chittagong Coastal Effect

The coast of Chittagong plays a significant role in surge amplification/modification:

i) The Chittagong coast makes the northern Bay funnel shaped, thereby contributing to the convergence of the Bay.
ii) Models show that if the eastern coast of the Bay is moved further east, then surge water in the Bangladesh coast decreases. If, theoretically, the Chittagong coast is replaced by an east-west coast, the surge water will be deflected towards the right due to Coriolis effect, thus reducing the height of surge in Bangladesh coast particularly near the Meghna estuary.
iii) Similar is the case in the west coast of Atlantic, where surge water has plenty of space to be deflected to the right.

## Island Effect

There are a number of islands in the Bangladesh coastal region with high population density. They are not much above the MSL and are easily inundated/over-run by surges. As for example, the Urir Char in the Meghna estuarial region went under water during the May 1985 cyclone, killing about 20,000 people in that island alone.

*A few possible effects*:

- Confine water between channels leading to amplification
- Act as barriers to free passage of surge water inland
- Retard outflow (backflow) of surge water from rivers after the cyclone passage, etc.

## River Effect

There are a large number of coastal rivers in Bangladesh. A river system can have a number of effects on surges and tides.

- Rivers allow a potentially deep inland penetration of surge water leading to flooding to areas adjacent to rivers
- Rivers lead to salinity intrusion inland
- Rivers have a negative effect on surge amplification
- Numerical models show that surges at the coast is higher without rivers than with rivers and
- Fresh water discharge from rivers modifies sea surface elevations resulting from surges and tides

## Short Water Waves

In addition to storm surges, which is a long wave (wave length much longer compared to water depth), cyclone wind also generates transient waves, which are called short water waves or local water waves. These water waves ride on the longer storm surge waves and moves at faster speeds (Phase speed = $(gh)^{1/2}$, which is also the speed of tsunami). They can be compared with 'wind gusts'. SLR is likely to increase the phase speed of such waves leading to early arrival of disastrous effects of surges.

## Low and Flat Coastal Topography

Most of the coastal area of Bangladesh is flat and low. The land height is mostly less than 4.5 m above MSL and is therefore easily flooded by storm surges, thus converting the coastal land area into a vast sea.

## Back Water Effect

Back Water Effect (BWE) plays an important role in coastal and inland inundation. It is defined as the retardation of river outflow by conditions at the mouth of a river or at the estuary. It may

- Cause water to accumulate inside the country
- Lead to fresh inundation
- Increase the depth of inundation
- Intensify flood misery

BWE is caused by:

- Flood water itself
- Storm surges
- Strong SW monsoon wind
- High astronomical tides
- SLR
- Tsunamis

Ali and Hoque (1994) and Ali (1995), for example, have studied BWE in Bangladesh using numerical models. Ali and Hoque (1994) found that sea level rise almost doubles by an increase of 2 m/s in the monsoon wind speed which is also likely to be affected by global warming. Table 2 gives the calculated flows across the Meghna estuary for (i) flood only, (ii) SW monsoon wind (5 m/s) only and (iii) both flood and wind combined, from the multilevel numerical model of Ali (1995). It is seen that a substantial amount of water is held inside the country due to BWE.

**Table 2**

Flow ($10^4$ $m^3/s$) across the Meghna estuary for different forcings (Ali, 1995)

| Flood water only: (1) | SW monsoon wind only (5 m/s): (2) | Flood water + SW monsoon wind: (1) + (2) |
|---|---|---|
| - 18 | 39 | 22 |
| - 36 | 39 | 4 |
| - 53 | 39 | - 15 |
| - 69 | 39 | - 33 |
| - 85 | 39 | - 50 |

*A negative sign indicates southward flow, i.e. from the river to the Bay*

SLR will reduce the present slope of water between the coastline and any point inside the country. This will produce substantial reduction in river outflow and increase the BWE in Bangladesh.

## Conclusions & Recommendations

Climate change and sea level rise will have significant impacts on cyclones and storm surges in Bangladesh. Numerical models amply demonstrate that. The advantages of mathematical models are that they are capable of identifying the contributions from each and every factor responsible for storm surge generation and amplification/modification. It is strongly recommended that more research in this direction is carried out. Such efforts will lead to more insight into the cyclone and storm surge dynamics and help equip us with better development planning through mainstreaming climate change into the development process of the country.

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# Cyclonic Storm Surge Modelling in Designing Coastal Embankment

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## Abstrac

Cyclones and storm surges are common phenomenon in the coastal area of Bangladesh. The area has over 700km of coastline on the main land and several offshore islands in the Bay of Bengal. 145 numbers of polders having more than 5000km of embankment were constructed in the sixties to protect the coastal low-lying area from saline inundation from regular tide in order to increase agriculture production without consideration of safety against cyclonic surges. Historical record shows that more than 14 severe cyclones are generated in the Bay of Bengal in every ten years, several of which strike the coast of Bangladesh. Extremely strong storm surges with more than 10m of water elevation hit the coast of Bangladesh in the year 1970. Within the last four decades around 800,000 lives of the country have been the victims of the cyclones by overtopping or breaching of coastal embankments. Complexities of the Bangladeshi coastline with numerous inlets, large estuaries, numerous polders and offshore islands require use of numerical modelling to determine the surge dynamics realistically in the shallower region. Cyclone Storm Surge Modelling has been carried out during 2000 – 2001 in connection with Second Coastal Embankment Rehabilitation Project (a study carried out by Institute of Water Modelling for Bangladesh Water Development Board funded by World Bank).

Key words: Cyclone, tide, surge, embankment, numerical modelling

## Introduction

Cyclones and storm surges are common phenomenon in the coastal area of Bangladesh having coastline of more than 700km. Cyclone induced storm surges causes huge loss of human lives as well as devastating impacts to the socio-economic condition of the region. In November 1970 the most severe cyclone in the last 50 years, with respect to surge height, inundation and loss of life occurred. The surge height was about 10 meters. The loss of life was estimated at 300,000-500,000.

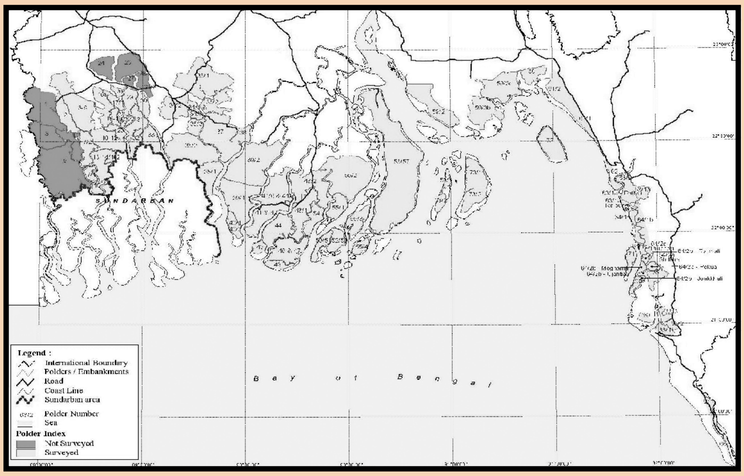



*Figure 1: Coastal area of Bangladesh with polders*

The northern bay region experiences significant seasonal water level variation (Azam *et al*, 2000). This is occurred due to heavy discharges from all the rivers and the wind blow during monsoon. Such variations keep modifying the tidal as well as the hydrodynamic characteristics over the year. The tidal current has a typical speed of 1-2m/s. Bangladesh Water Development Board (BWDB) and its predecessor, East Pakistan Water and Power Development Authority (EPWAPDA) constructed a series of polders (Fig.1) approximately 145 numbers with more than 5,000km in length in the coastal area from the mid-sixties to the mid seventies to protect the coastal low lying areas from regular saline inundation from tide in order to increase agriculture production. Over time, those embankments proved to be very effective in protecting life and property against tidal influx. However, the cyclone storm surges have caused several breaches in the polders creating serious concerns over the protection of life and property in the coastal region.

The complex tidal hydraulics of the extremely dynamic system of Northern Bay of Bengal, outfall estuaries of the world's largest rivers the Ganges the Brahmaputra and the Meghna and together with the world's larget delta's tidal river systems makes the process of determining the storm surge hydraulics extremely complex. While it is extremely difficult to forecast cyclone tracks and land fall locations, these have tremendous influence on the extent and magnitude of the surge inundation. With it has added the dangers from the climate change induced sea level rise phenomena.

"Hydraulic Modelling Study for Second Coastal Embankment Rehabilitation Project" (2$^{nd}$ CERP) carried out by Institute of Water Modelling (IWM) the former Surface Water Modelling Centre (SWMC) in association with DHI Water and Environment (DHI) and executed by Bangladesh Water Development Board (BWDB) has been a leap forward to determining safety standards by the quantification of surge height advanced numerical modelling technology.

## Cyclones in Bangladesh

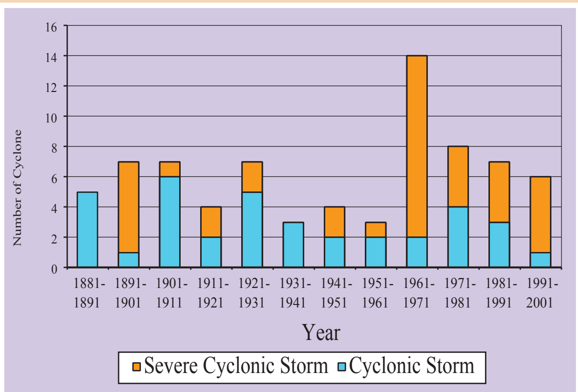



*Figure 2: Number of cyclonic storms landed on Bangladesh coast*

About one-tenth of the global total cyclones forming in different regions of the tropics occur in the Bay of Bengal. Not all of the tropical cyclones formed in the Bay of Bengal move towards the coast of Bangladesh.

About one-sixth of the tropical storms generated in the Bay of Bengal usually hit the Bangladesh coast. Figure 2 shows the number of cyclonic storms hitting the Bangladesh coast from 1881 to 2001.

## Measurements and Methods

The embankment data are specified on the basis of measurements as carried out during the 2$^{nd}$ CERP study.

Cyclone information received from Bangladesh Meteorological Department (BMD) contains time, location and classification of the cyclone. BMD classifies cyclonic disturbances according to Table 1.

The relationship between the maximum wind speed and the pressure drop in Table 1 is in accordance with Mishra and Gupta (1976). Mohal et al. (1998) evaluated the radius to be only 60% of the radius assumed from the BMD relationship. In the latter simulations described that the radius was reduced to only 60%, while the pressure was kept unchanged.

**Table 1: Relationship between the involved cyclone parameters**

| Classif-ication | Pressure Drop (mB) | Max. wind speed(km/hour) | Radius to max. wind speed (km) |
|---|---|---|---|
| D | 2-4 | 40-51 | 44 |
| DD | 4-6 | 52-61 | 48 |
| CS | 6-12 | 62-88 | 54 |
| SCS | 12-21 | 89-1 17 | 64 |
| SCSH | 21 ≥ | 1 ≥ 18 | 74 ≥ |

Note: D: Depression
DD: Deep Depression
CS: Cyclonic Storm
SCS: Severe Cyclonic Storm
SCSH: Severe Cyclonic Storm with a core of Hurricane winds

## Numerical Modelling

The following suite of mathematical model complex has been used for the study:

- A two-dimensional nested model complex of the Bay of Bengal and the coastal areas (BoBM) developed based on MIKE 21 software of DHI has been used for modelling the tidal hydraulics and the surge in the Bay and the coastal areas.
- A cyclone model developed based on the CYWIND modelling software has been used to simulates pressure and wind distributions all over the model areas and to provide a surface boundary condition to the BoBM.

## Bay and Coastal Hydrodynamic Modelling

The model is two-way nested as shown in Figure 3 and includes four different resolution levels (grid sizes) in different areas. The Meghna Estuary is resolved on a 600m grid. Information on the grids is given in Table 2.

**Table 2: model grid specifications**

| Model | Origin (degree) | Orien-tation (deg.) | Grid spacing (m) | Grid nos. |
|---|---|---|---|---|
| Coarse grid | Lon = 84.6400<br>Lat = 18.9100 | -1.74 | Dx = 5400<br>Dy = 5400 | 180 × 111 |
| Interme-diate grid | Lon = 86.7500<br>Lat = 20.8100 | -1.06 | Dx = 1800<br>Dy = 1800 | 321 × 153 |
| Fine grid | Lon = 89.9712<br>Lat = 21.3393 | +0.11 | Dx = 600<br>Dy = 600 | 396 × 357 |
| Local Sandwip | Lon = 91.0776<br>Lat = 22.3400 | +0.652 | Dx = 200<br>Dy = 200 | 375 × 270 |

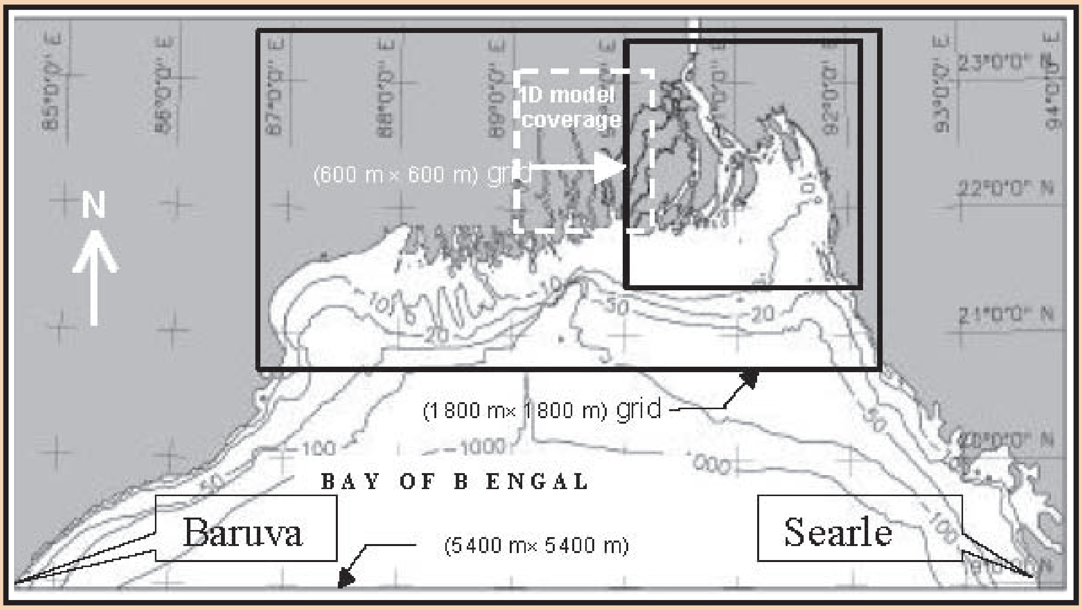



*Figure 3: BoBM nested model scheme*

The southern model boundary is generated from the tidal predictions on water levels made for the two extreme southern points Baruva in India and Searle Point in Myanmar (Fig. 3). The northern boundary has been generated by water level records of Chandpur.

## Cyclone Modelling

Cyclone modelling has been done to simulate the pressure and wind field required for the storm surge and wave simulations. For the description of the wind field and the pressure field, cyclone model has been provided information on:

- Radius to maximum winds
- Maximum wind speed
- Cyclone tracks, forward speed and direction
- Central pressure
- Neutral pressure

The Cyclone Model has been calibrated and validated for different cyclones. Figures 4 and 5 show the validation results against wind speed and pressure. The validated model has been used to simulate the seventeen major cyclones from 1960 to 2000. Figure 6 presents the cyclone wind and pressure field for 1970 cyclone at landfall time.

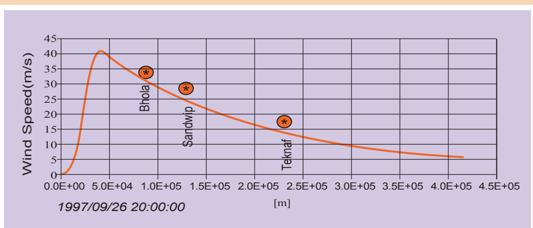



*Figure 4: Comparison of simulated and observed wind speed*

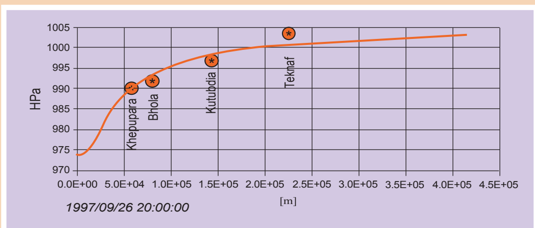



*Figure 5: Comparison of simulated and observed pressure*

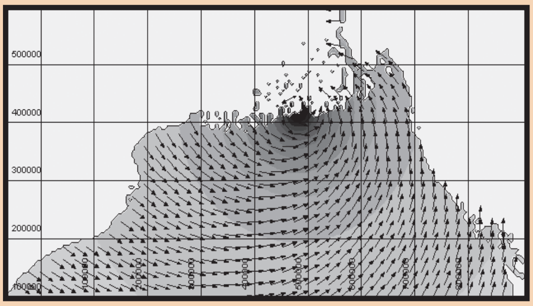



Figure 6: Wind and pressure field at landfall for

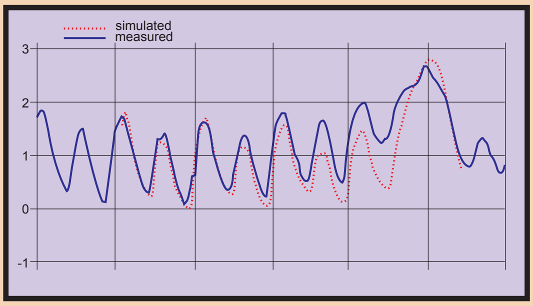



Figure 7: Comparison of simulated and observed surge levels at Dasmunia

## Storm Surge Modelling

The surge model has been developed on the basis of the calibrated hydrodynamic model and cyclone model. Prior to its application the surge model has been calibrated and validated against surge levels. Sample plot of comparison between simulated and measured surge levels is shown in Figure 7 for Dasmunia. A good agreement has been achieved between observed and simulated ones.

The calibrated and validated model has been applied for simulating the seventeen major cyclones from 1960 to 2000.

## Assessment of Storm Surge Levels

The most sensitive region as found from the analysis is the northern corner of the bay that covers the region around the Sandwip Island and the Meghna River mouth. The maximum surge level found is approximately 10m (Figure 8). The islands of Sandwip, Hatia and coastal areas of Noakhali District are flooded by surge level of more than 7m (PWD). In terms of physical vulnerability, Hatia and Sandwip are most vulnerable regions as the land levels in these areas are only 1-2m above the mean sea level. Funnelling effect and sudden change in depth close to the coast causes such amplification of surge height. Results show that the embankment at northern Bhola plays a very important role, as it obstructs direct inflow of surge into the island, which is more than 6m (PWD) in elevation. High surge levels also occur at the south of Bhola and Barguna.

Statistical analysis has been done to determine the surge levels for 100, 50, 20 and 10 year return period. The analysis shows that the region at the north of Sandwip Island is the zone of intense surge attack (Figure 9). The surge level exceeds 10m level (PWD) against 100 year return period and even rises more than 6m for return period of 10 years (Figure 10).

Kuakata, the area western side of the estuary and Cox's Bazar, the south- western coastline, are almost equally endangered in terms of surge height for all return periods. Surge elevations in these regions are relatively low, less than 3m for 10 year and about 5.5m for 100 year.

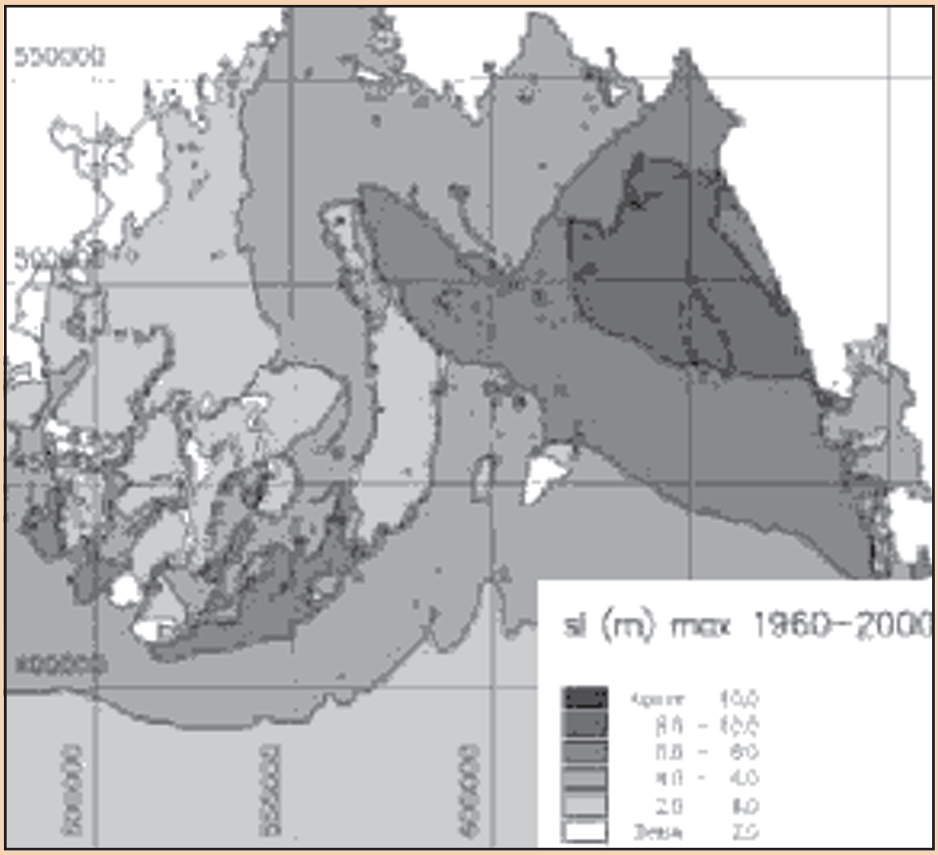
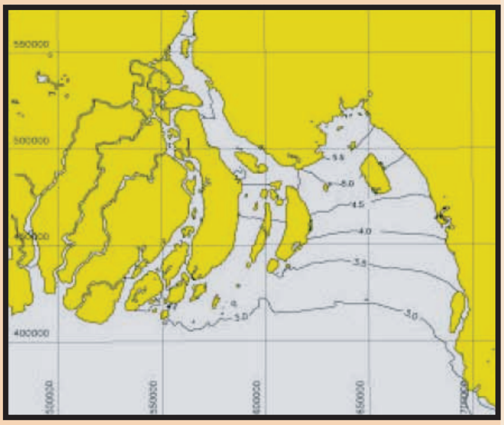



*Figure 8: Maximum surge levels*



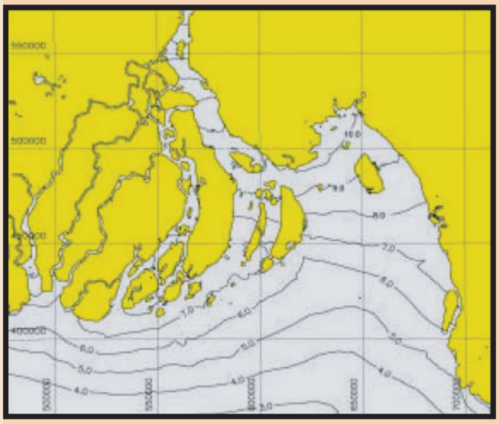


*Figure 9: 10 year return period surge levels Figure 10: 100 year return period surge levels*

## Assessment of Surge Depth

Figure 11 presents the maximum surge depth map of the bay area developed on the basis of the maximum surge depths of the mentioned cyclones. The maximum surge depth map shows that the most severely affected areas are Urirchar, Sandwip, Boyar Char, Char Bata, north of Hatia and south of Bhola.

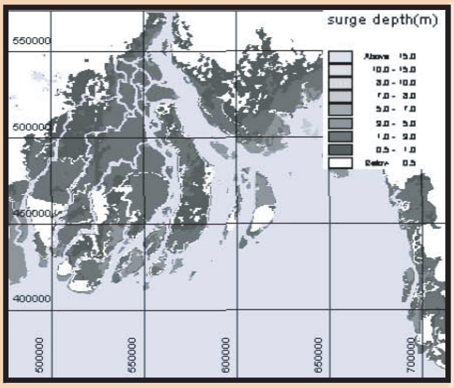



*Figure 11: Maximum surge depth for bay area*

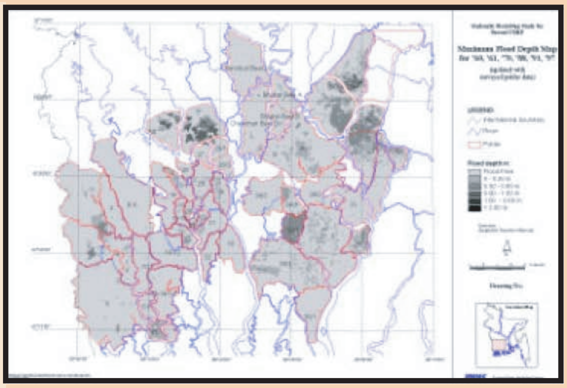


*Figure 12: Maximum surge depth for Sundarbans*

Figure 12 shows the maximum possible flooding of the polders north of the Sundarban Forest and Haringhata-Baleswar-Kocha-Swarupkati-Madhumati-Nabanganga river system due to the six cyclones as mentioned above (largely dominated by the 1970 cyclone) for the base condition. It shows that Polder 15 and 35/3 would have been submerged completely due to low embankment height. Depth of flooding would have reigned in the order of 0.5m on average in Polder 35/3, while a reduced depth of inundation would be experienced in Polder 15. Polder 24 and 25 would have partially been inundated by an average 0.5m depth of water. The figure also indicates that under the worst combination of cyclonic storm conditions, most of the polders in this part of the region would have remained flood free.

## Assessment of Cyclone Induced Near Shore Wave Height

The analysis of the wave results show that the possible maximum wave height at the eastern coast is more than 2.5m. The maximum wave height at the north of the Sandwip island is 1.25m to 1.75m. The wave height at the river mouths of Shahbazpur and Tentulia channel varies between 0.50m to 0.75m.

The statistical analysis shows that the wave heights at the eastern coast is more than 2.0m for 10 year return period and more than 2.5 m for 100 year return period (Figures 13 and 14). Unlike the surge height, the wave height is not very high at the north of the Sandwip Island. In the rivers and shallower region wave heights are less than 1.0m even for 100 year return period.

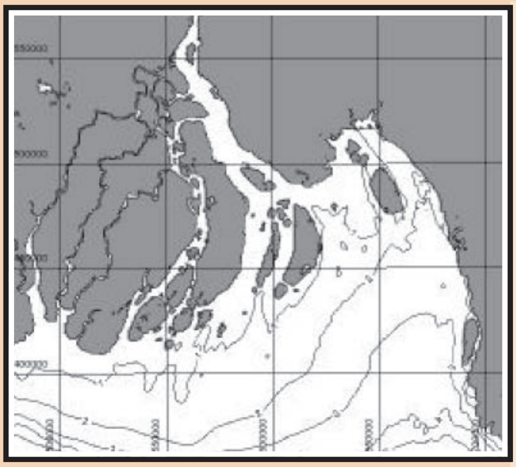


*Figure 13: 10 year return period wave height*

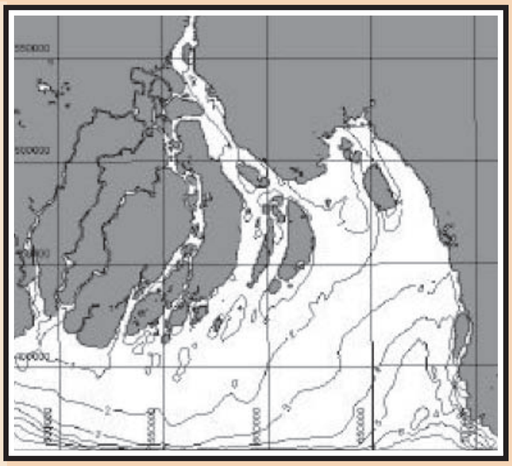


*Figure 14: 100 year return period wave height*

## Effect of Cyclonetrack on Surge

Surge wave generated at the deeper sea is driven towards the coast by the wind and propagates over land being amplified near the coast. Different magnitude of surges is generated mainly by the cyclones depending on the location of the landfall, cyclone parameters and coincidence with tidal peak. The degree of surge amplification is not same along the coast. This is because, the morphological features are not identical along the coast and hydrodynamic responses are changing from the eastern side to the western side of the coast.

## Effect of Land fall Location

In order to determine the effect of cyclone track on the surge height the cyclone wind field of 1991 has been applied to the hydrodynamic model by shifting its track positions (Figure 15) so that the variation of surge heights is understood for different landfall positions along the coast. Six synthesised cyclones have been simulated and maximum surge heights have been compared at five locations, i.e., Chittagong, Feni, Chitalkhali, Kochopia and Pathorghata as shown in Figure 16 for no-tide condition.

Results show that two cyclones, that hit the western side of the estuary, develop very high surges for all five locations. The cyclone hitting near Patharghata generates the surge of 12m at Feni and surge height close to 8m at Chittagong and Chitalkhali. Areas like Patuakhali, Barisal, Barguna, Hatia, Noakhali, and Sandwip become more susceptible to this type of cyclones. The cyclone with landfall point at the river mouth, creates highest surge at Chittagong, the eastern coast. The surge elevations are reduced as the cyclone track shifts eastward from the estuary. The cyclones hitting the east side of the river mouth are greater threat to the eastern coastline that covers the areas from Chittagong to Teknaf. For the cyclone with landfall point at Patenga only Chittagong experiences surge more than 2m among five locations observed.

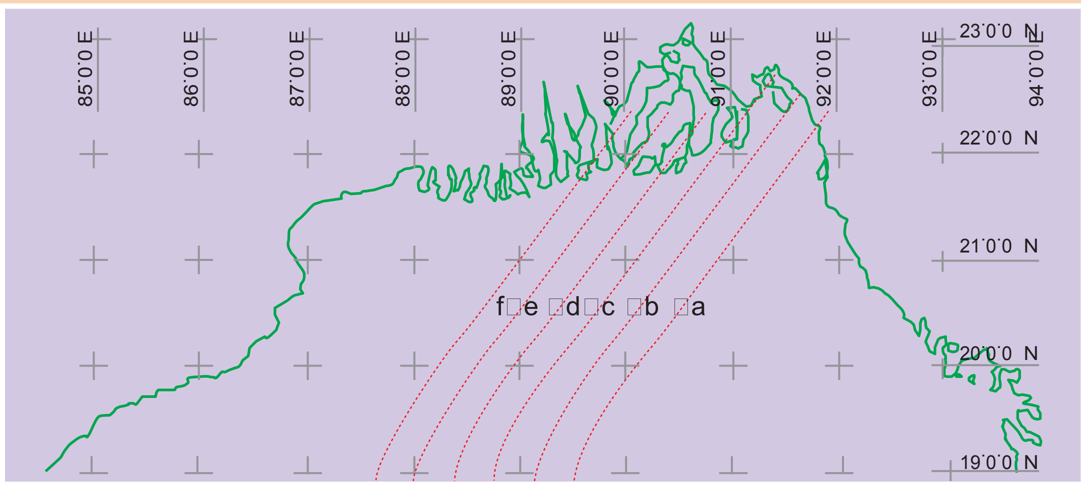



*Figure 15: Synthesized Cyclone tracks*

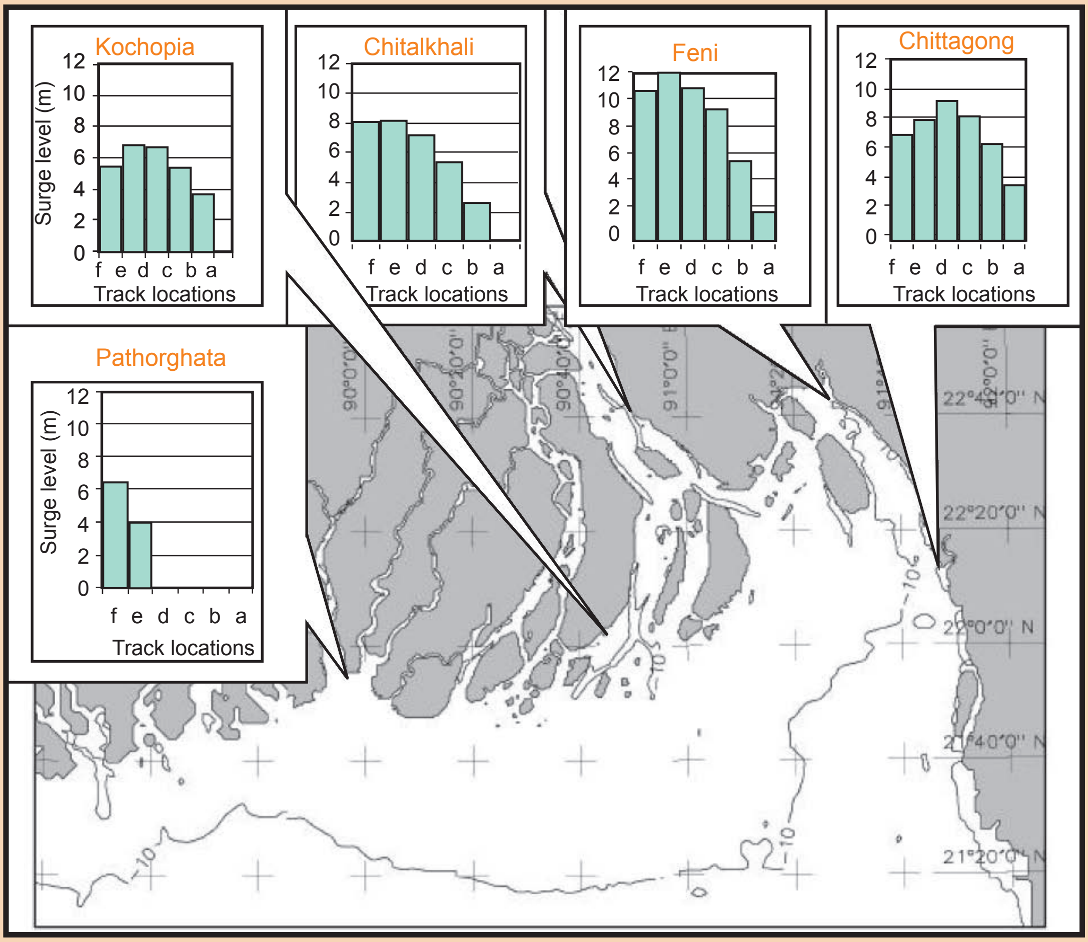



*Figure 16: Effect of Cyclone Track on Surge level*

## Effect of Track Angle

In order to determine the sensitivity of track angle the cyclone 1991 (track angle 215o with north) with landfall at Barguna has been oriented to three other angels 185o, 200o and 230o with north. The eastern coastline experiences little effect on variation of track angle (Figure 17). However, at the western side, the track angle has considerable effect on surge height. The elevation increases at the western side when the cyclone incoming angle deviated more from the south to the east. In the estuary, cyclone from the north created higher surge.

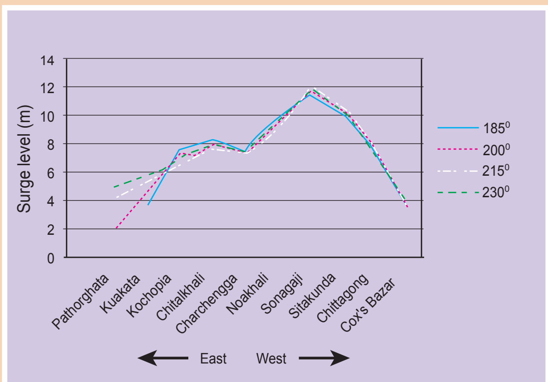
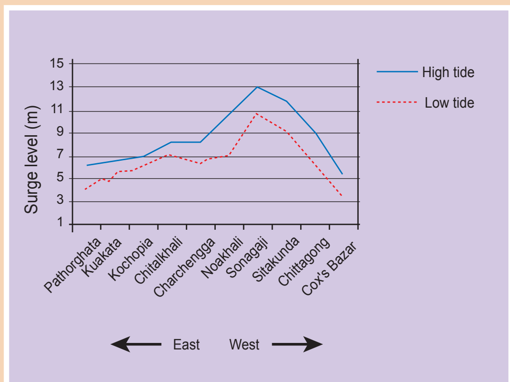



*Figure 17: Effect of Track Angle*




*Figue 18: Effect of Tide*

## Effect of Tide

In order to determine the sensitivity of tide on surge the 1991 cyclone with track angle 230$^o$ N, that created maximum surge height for non-tidal condition, is used along with tidal force in the model. The tidal phase is shifted with two-hour step for each surge simulation covering the whole tidal period. It is observed that highest surge level goes upto 13.0m at Feni for high tide and 11.0m for low tide condition (Figure 14). It is interesting to note that the tidal range in that location is more than 6.0m, but the surge level difference is only about 2.0m. Similar effect is observed for all the locations and shows that tidal level cannot be superimposed to the surge level to find the combined effect as nonlinearity of interaction prevails.

## Effect of Coastal Afforestation on Surge

The pilot model developed for south Hatia under the present study has attempted to assess the impact of afforestation on the surge height and to develop a basis for having the necessary engineering judgement in designing the minimum amount of forest cover to reduce the height of the embankment system. The findings of the study can help the planners and designers to compute the formation level of the polder with the consideration of afforestation.

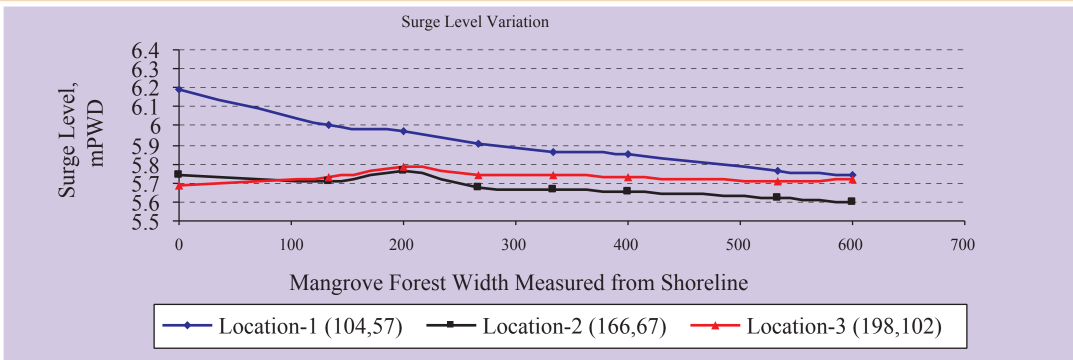



*Figure 19: Effect of width of mangrove forest on Surge*

The study shows that mangrove forest with width of 600m decreases the surge height of approximately 0.45m around the southern end of Hatia (Figure 19). The first 133m width of forest absorbs the thrust of the surge reducing it by 0.18m. No appreciable positive impact of afforestation was found at other selected locations at the south-eastern side and south-western side of the polder. At north-eastern corner, the afforestation causes reverse impact. The findings of the study can help the planners and designers to compute the formation level of the polder with the consideration of afforestation.

## Wave Information for Design of Coastal Revetment

The pilot model developed for Patenga under the present study has been applied to gain understanding on nearshore wave parameters in the context of Bangladeshi coastline. The study presents a qualitative impression on transformation of wind waves and application of modelling techniques for the purpose of analysis.

The study shows that wave height reduces as the bed slope becomes flatter but the change of wave height with change of bed slope is not appreciable. An appreciable reduction of wave height is found with the change of foreshore width. Wave height reduces by about

60% when the foreshore width is stretched from 100m to 500m. Increase of foreshore width beyond 500m has little effect on wave.

The study shows that angle of wave approach has much impact on wave transformation, wave setup and wave induced current. The magnitude of wave height at the breaking point increases with the decrease of wave inclination to the shoreline. The maximum height is obtained when the wave is close to normal to the coast. Wave setup grows with the decrease of inclination of wave approach angle with shore and attains up to 0.04m when the wave approaches with oblique angle of $15^0$. For varying wave approach angle it has been found that wave induced current becomes stronger with the increase of inclination of wave to the shore. For wave incident angle of $60^0$ with shoreline, the magnitude of long shore current increases upto 0.55m/s.

## Impact of Climate Change and Sea Level Rise

The present study with the climate change scenarios (Table 3) shows that the climate change and sea level rise by 30cm in 2030 would increase the 1991 surge height by 5 to 20 percent (Figure 20). The climate change will force the salinity intrusion further in the estuary resulting higher salinity at the river mouths.

**Table 3. Simulation for climate change scenario for Bangladesh in 2030 during monsoon**

| Year | Sea Level Rise (cm) | Increase in discharge in the Meghna estuary in percentage | Increase in precipitation in percentage |
|---|---|---|---|
| 2030 | 30 | 14 % during monsoon | 7.5 % during monsoon |

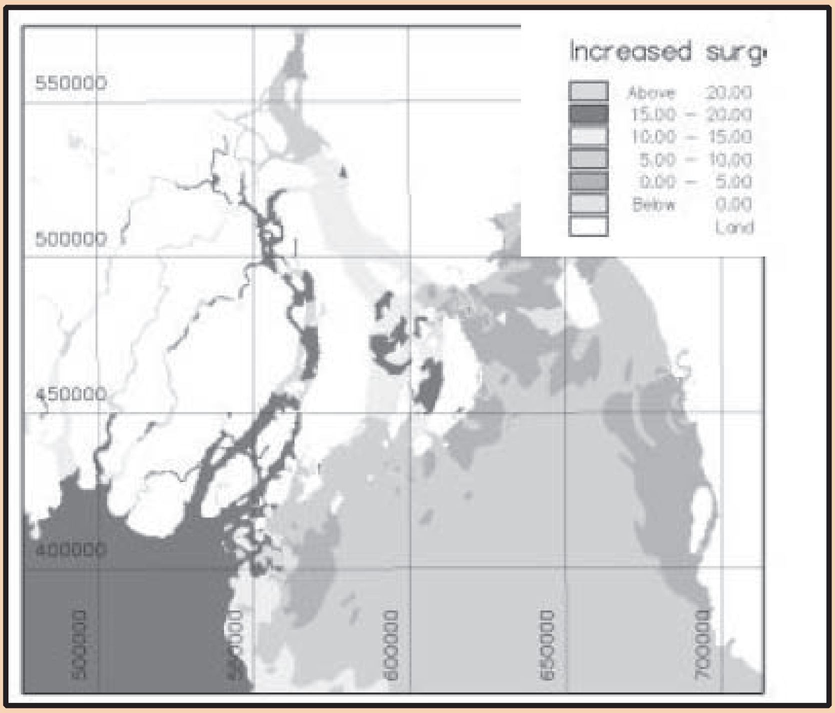



*Figure 20: Impact of climate change on monsoon flow speed*

## Conclusions

Historical records show that more than 14 severe cyclones are generated in the Bay of Bengal in every ten years in average. Several of them strike the coast of Bangladesh. Extremely strong storm surges with more than 10m of water elevation hit the coast of Bangladesh at least once in a century. Very strong surge attack results in emotional, physical and economical catastrophe of the country.

The Meghna Estuary is morphologically extremely dynamic with net annual accretion rate of 8 km²/year. Surge propagation and associated dynamics will not be same as a past event. Also, new land use pattern, increased coastal population and development took place in recent years have modified the degree of localised vulnerability. In this context, identifying a probable maximum surge and analysing the consequence will provide useful knowledge on the ground of safety and forecast.

Considering the complexities of the Bangladeshi coastline with numerous inlets, large estuary, offshore islands and chars, use of sufficiently high-resolution model is necessary to generate the surge dynamics realistically in the shallower region. The updated and developed CERP modelling tools have been applied with a success in the following field of activities:

- Assessment of baseline condition of the polders in regards of surge levels and surge depth
- Assessment of cyclone induced wave height
- Design of coastal afforestation
- Design of coastal revetment
- Generation of foreshore bathymetry
- Impact assessment of climate change and sea level rise

The updated model can be applied in the following contexts in order to support the proposed Coastal Zone Water Management Programme.

- To form an ICZ resource database
- To complete preparation of the ICZM plan
- To develop the necessary basis for the planning, design, implementation, management, operation and maintenance of the zone's infrastructure
- To design and initiate a systematic planning process to prioritise and select works for implementation and prepare feasibility studies and detailed design for those works
- To implement the high priority embankment system rehabilitation works identified and planned during programme preparation
- To develop and maintenance of ports
- To plan and commence of a network of safe heavens (shelters and/or raised areas)

## Acknowledgement

The authors acknowledges Bangladesh Water Development Board as all the measurements and analyses in relation to this paper were carried out under a contract to them.

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# Agriculture Water Demand And Drought Modeling

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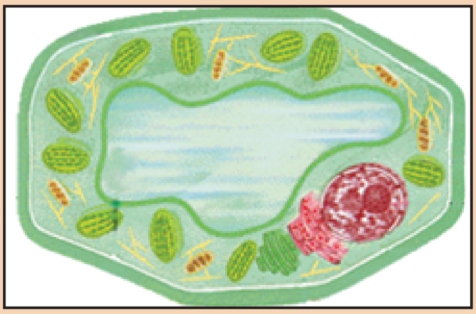
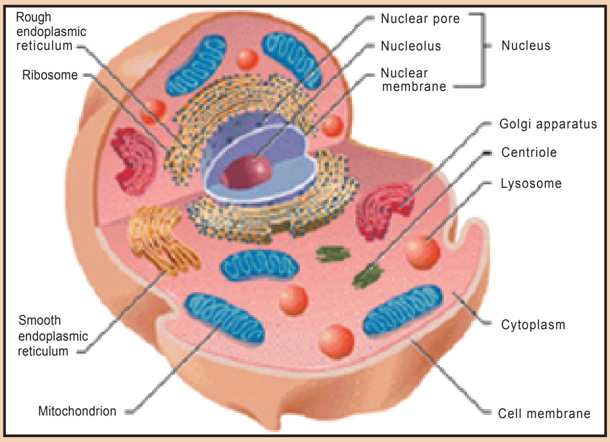
*Bangladesh Agricultural Research Council*

## Water is Life

- No Water No Life-In search of life on other planets we look for water
- Be it a plant or an animal cell-> 80 % water



Plant cell




Animal cell

## Droughts

- Too little water causes drought
- Almost in every year Drought appears in Bangladesh
- Agricultural production system of the country is greatly influenced by the event in different seasons of the year
  - *Rabi* (dry or winter) season
  - *Pre-Kharif* (per-monsoon) season
  - *Kharif* (wet or monsoon) season
- Drought prone soils are dominated by:
  - Light textured in top layers and heavy texture in the subsurface horizon
  - Less available moisture holding capacity and slow to rapidly permeable

- Moisture availability varies from 100-200 mm within the effective profile depth
- Not adequate to meet the evapotranspiration demand of most of the rabi crops like wheat, mustard, potato etc.

## Vulnerability of Crop Agriculture

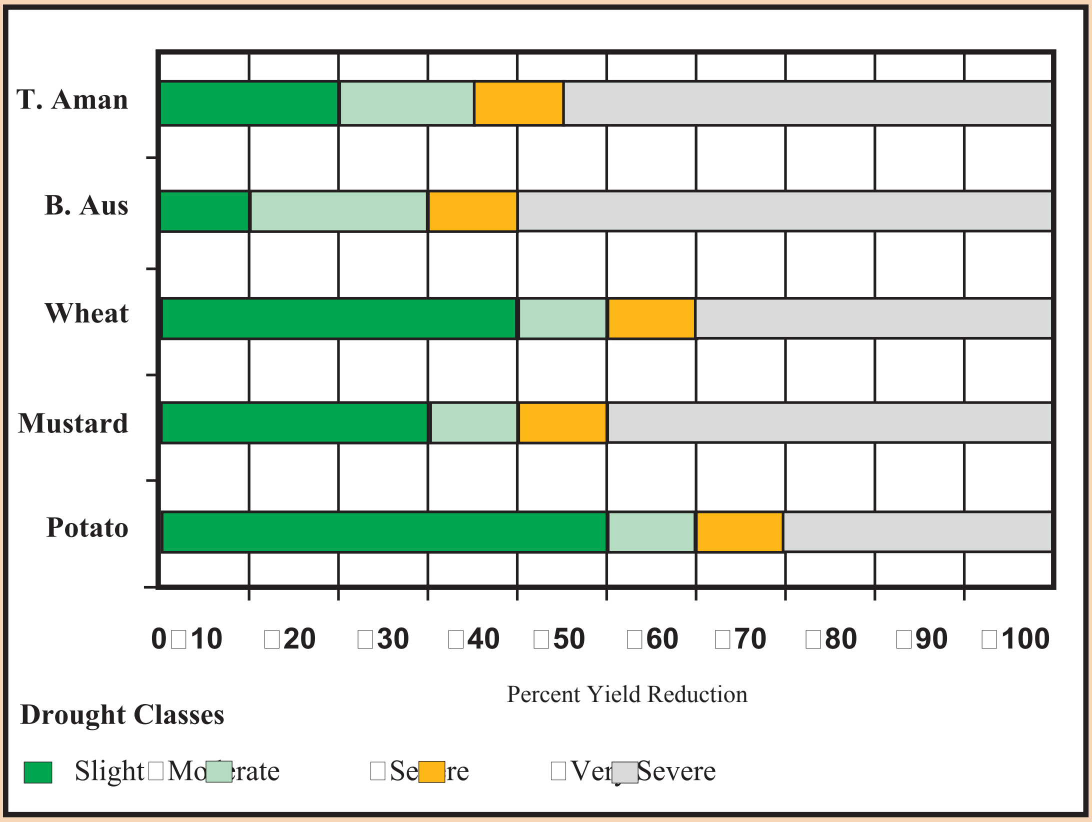
- Drought → Water deficit related stress
- Interactions with soil and diffusion of nutrients, micro-nutrients and water from soil to plant at the root zone
- The consequence of drought on crops

  → physiological stress

  → hampering natural phenological and reproductive cycle

  → Yield reduction

### Impact of Drought



## Drought Prone Areas of Bangladesh

Kharif Drought Prone Area: 2.20 million hectares
Rabi Drought Prone Area: 1.2 million hectares

## Global Climate Change

### Temperature

Global average surface temperature has increased by 0.6 ? 0.2℃ over both the last 140 years and 100 years

By the year 2100 the globally averaged surface temperature is projected to increase by 1.4 to 5.8℃

### Precipitation

Increases in global mean rates of precipitation and evaporation

Larger year-to-year variations in precipitation are very likely (90-99% chance)

*Source: TAR, IPCC (2001)*

## Impact of climate change

- Frequency of droughts of different intensities would increase, especially in the drier regions due to uneven distribution of rainfall
- Higher evapotranspiration accelerated by
  - increased temperature
  - low humidity, and
  - high wind speed

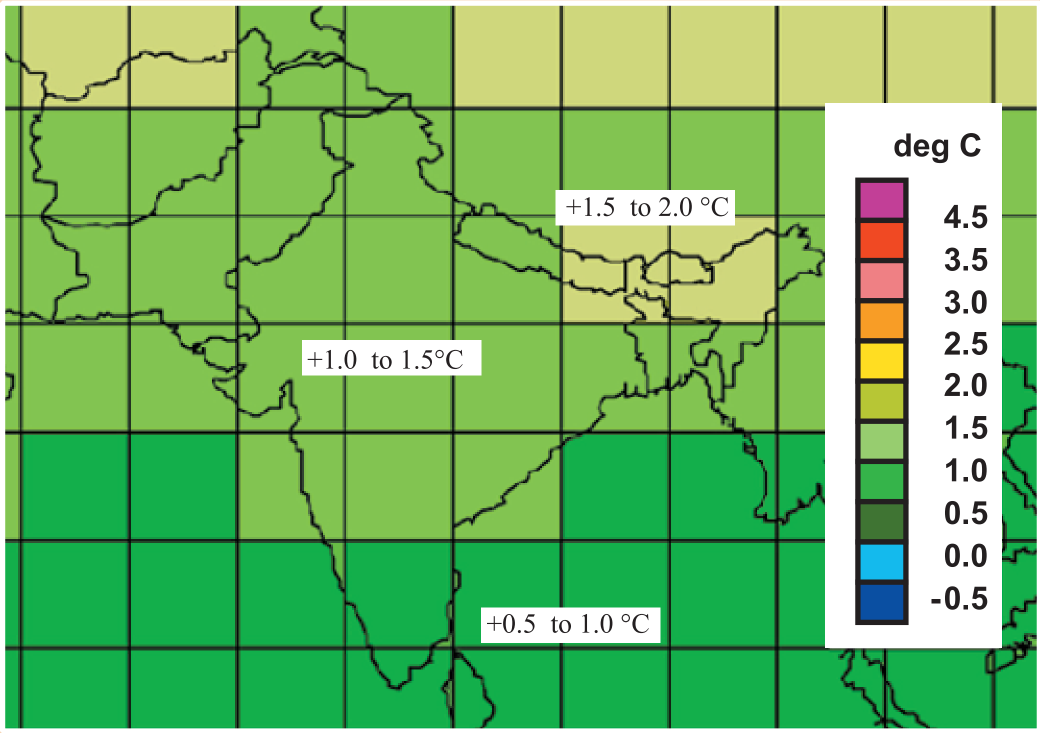
### Climate Change

| Parameters | 2030 AD | | 2075 AD | |
|---|---|---|---|---|
| | Winter | Monsoon | Winter | Monsoon |
| Temperature (°C) | 2.00 | 0.65 | 3.00 | 1.50 |
| Evaporation (%) | 10.00 | 2.00 | 16.00 | 5.00 |
| Precipitation (%) | -3.00 | 11.00 | -37.00 | 28.00 |

*Source: Ahmed and Alam (1999)*

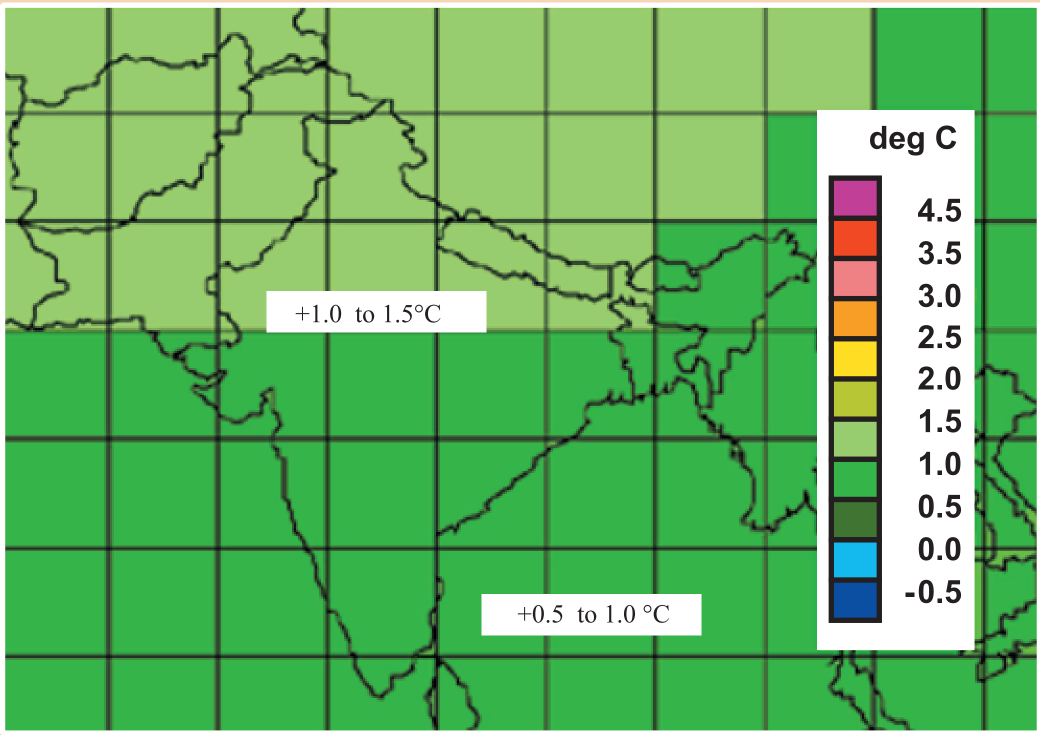
## Temperature – UKTR GCM, 2050

### Output from SCENGEN

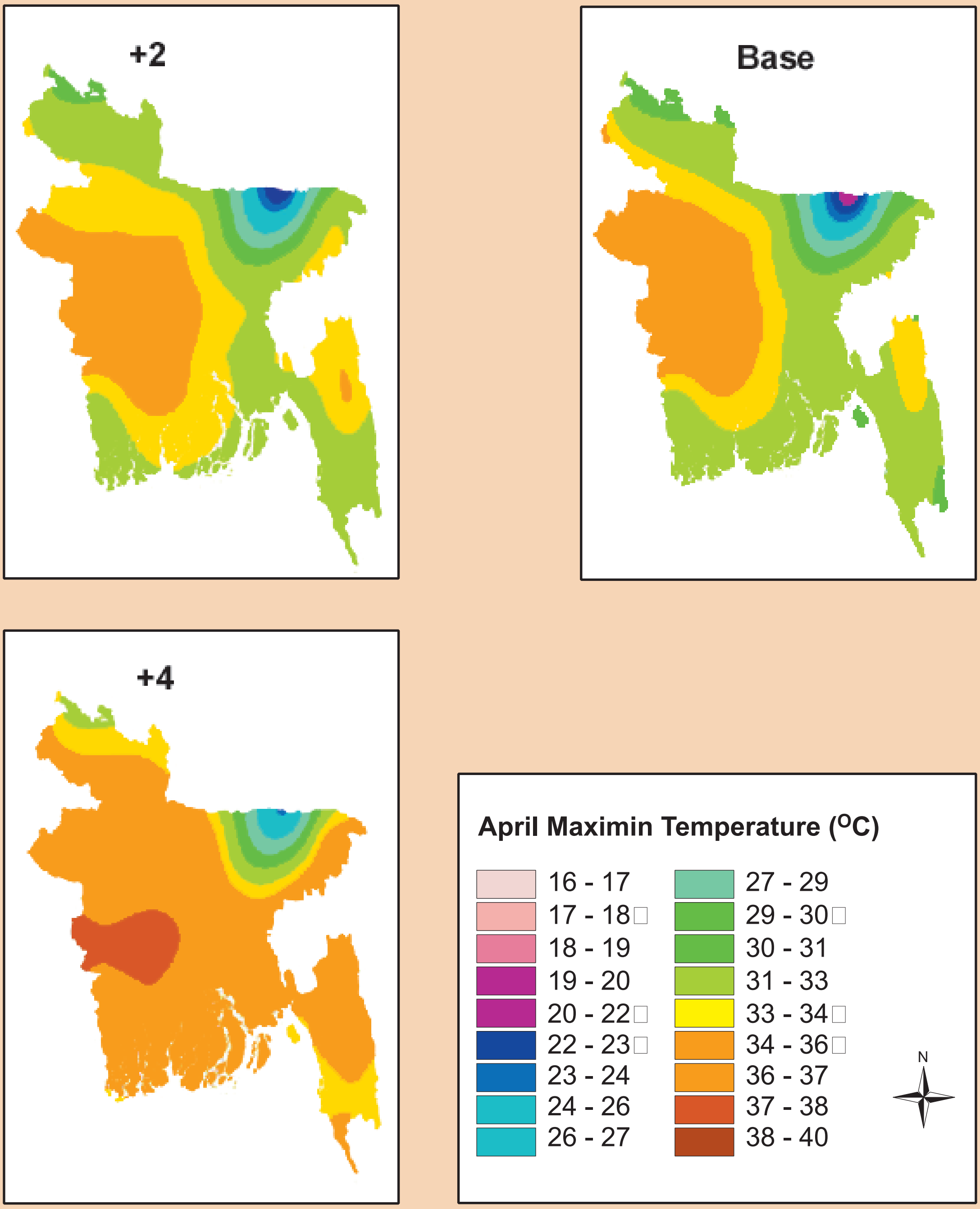



## Temperature – GFDL-TR GCM, 2050

### Output from SCENGEN

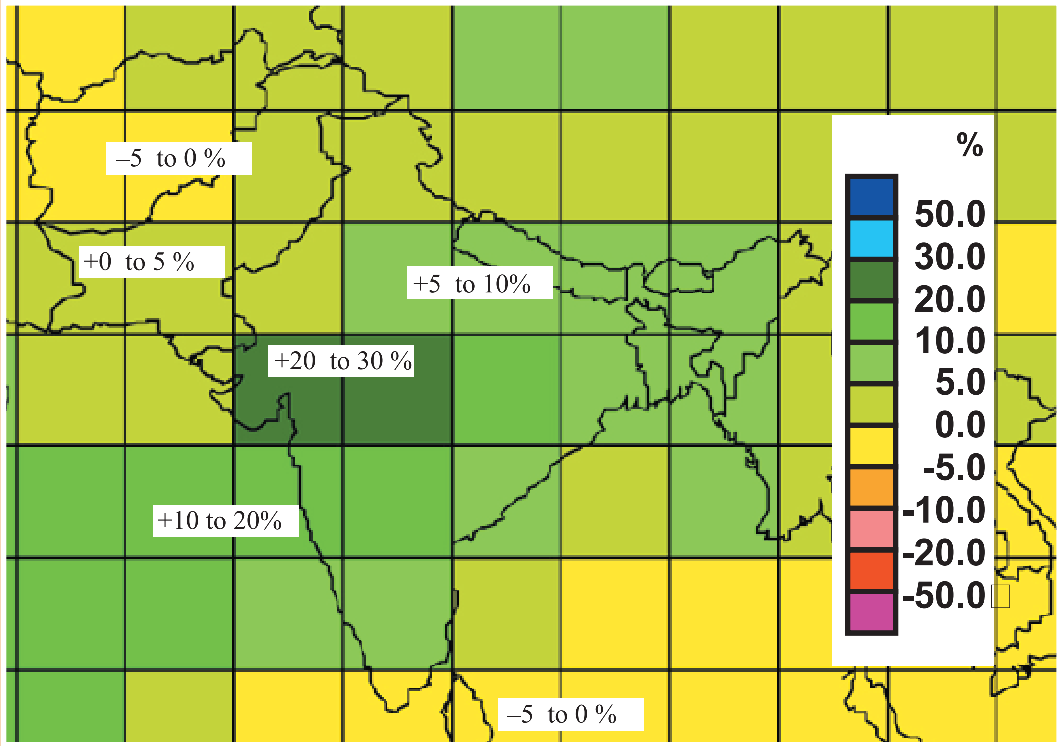


## April Maximum Temperature



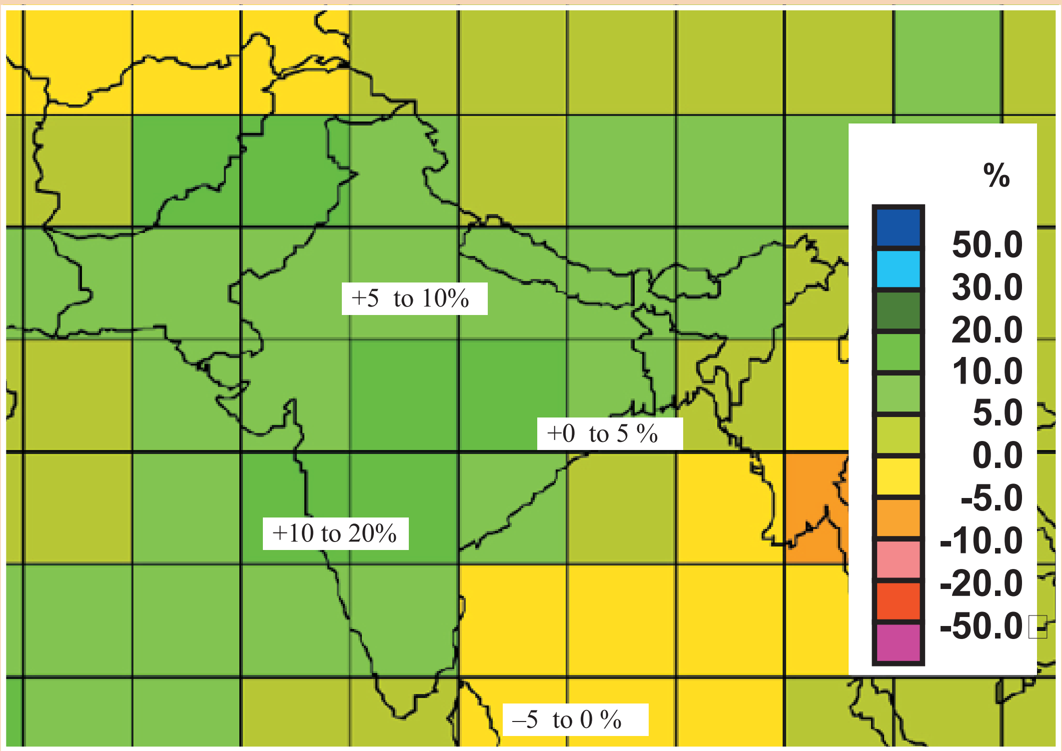
## Precipitation – UKTR GCM, 2050

### Output from SCENGEN

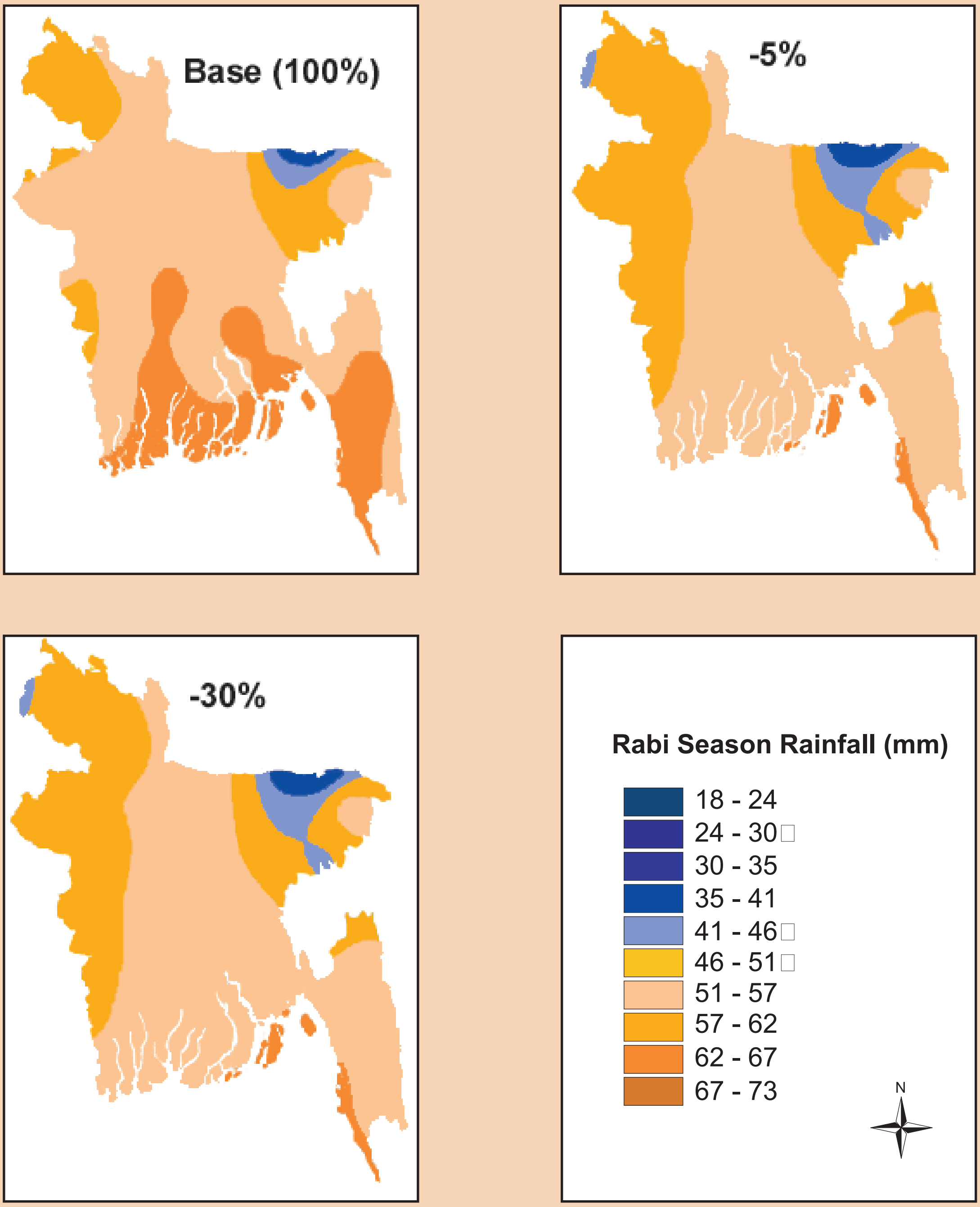



## Precipitation – GFDL-TR GCM, 2050

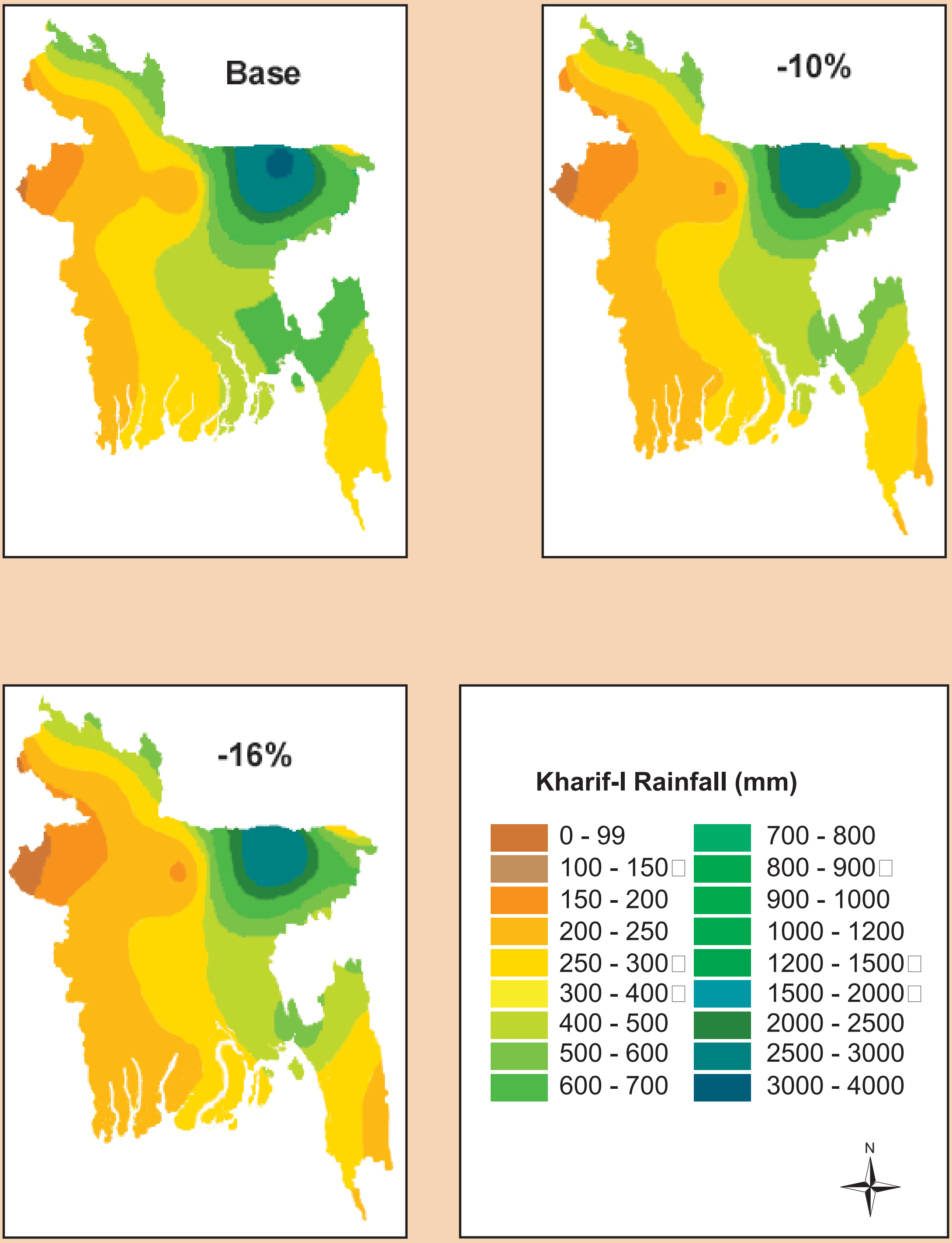
### Output from SCENGEN



## Rabi Precipitation



## Pre-Kharif Precipitation

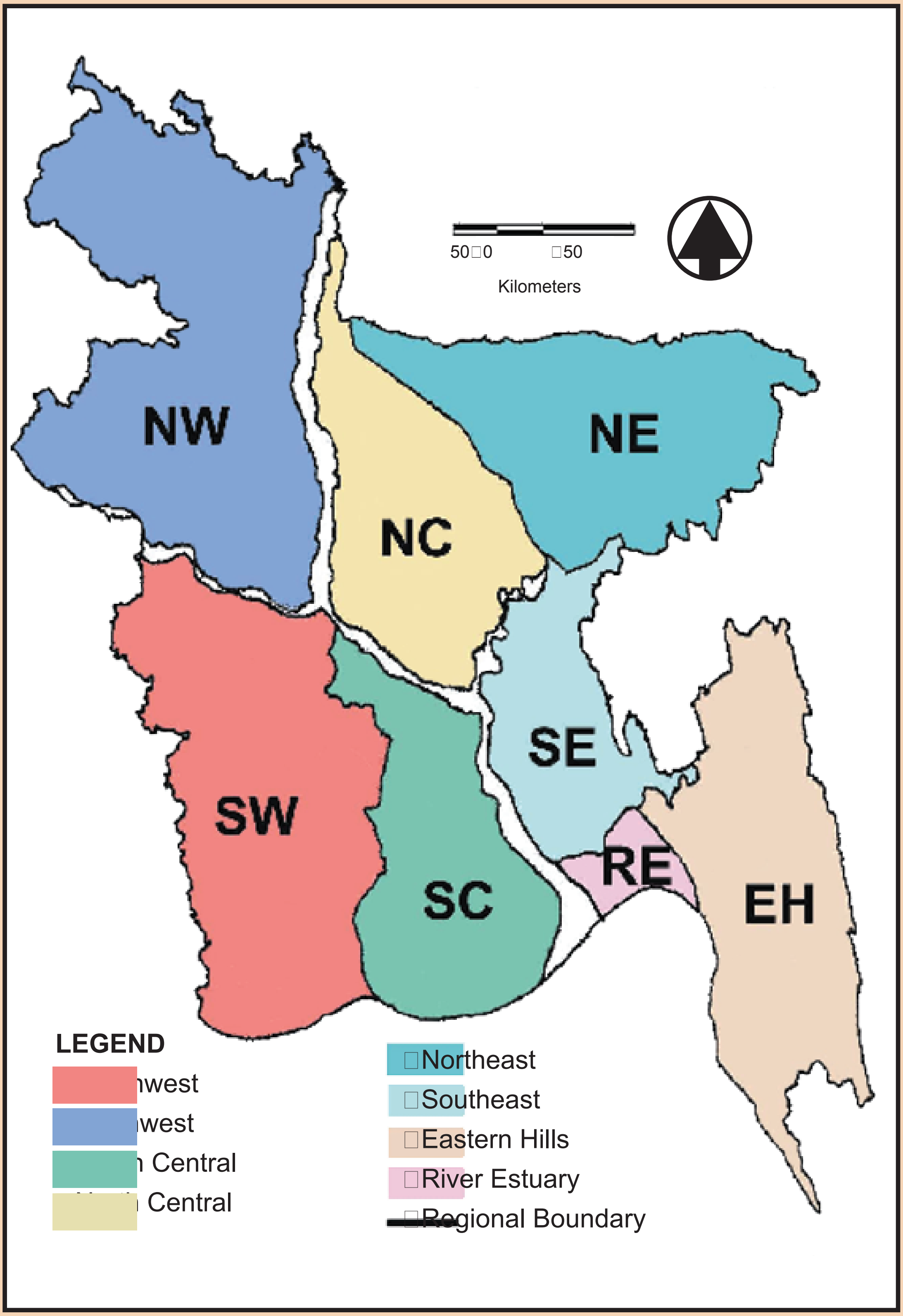


# Change in Boro Rice Yields under different Climatic Scenarios and Irrigation Levels

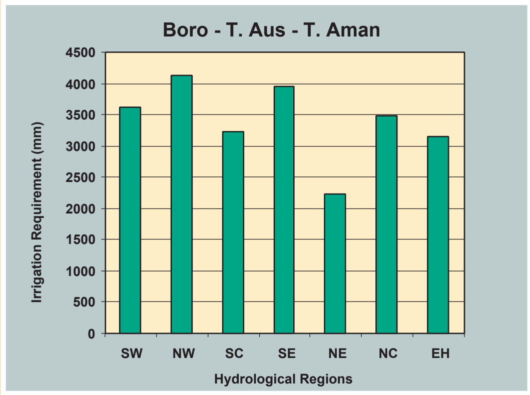
**Output from Decision Support System for Agrotechnology Transfer (DSSAT ver 3.5)**

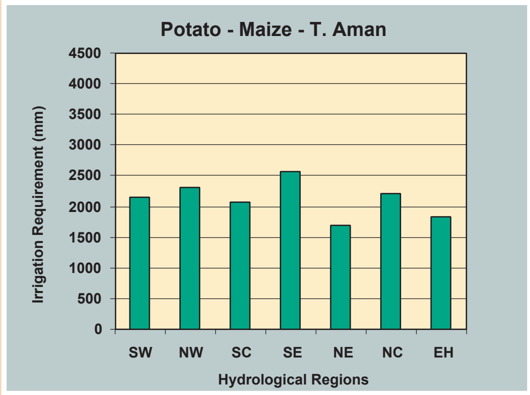
| **Simulation Jessore** | | **Rajshahi** | **Chittagong** |
|---|---|---|---|
| 330 $CO_2$+No Moisture Stress 0 | 0 | 0 | |
| CCCM +No Moisture Stress -9 | -3 | -7 | |
| CCCM +30 % Moisture Stress -35 | -34 | -18 | |
| CCCM +60% Moisture Stress -58 | -63 | -64 | |
| GFDL+No Moisture Stress -5 | -3 | -9 | |
| GFDL+30% Moisture Stress -33 | -25 | -16 | |
| GFDL+60% Moisture Stress -58 | -55 | -62 | |
| 330 $CO_2$+30% Moisture Stress -2 | -1 | -4 | |
| 330 $CO_2$+60% Moisture Stress -29 | -33 | -10 | |
| 660 $CO_2$+No Moisture Stress 22 | 26 | 16 | |
| 660 $CO_2$+30% Moisture Stress 17 | 16 | 12 | |
| 660 $CO_2$+60% Moisture Stress 10 | 3 | 15 | |
| 660 $CO_2$+ 4°C +No Moisture Stress 6 | 20 | 8 | |
| 660 $CO_2$+4°C +30% Moisture Stress -2 | 6 | 10 | |
| 660 $CO_2$+4 °C +60% Moisture Stress -32 | -32 | -19 | |

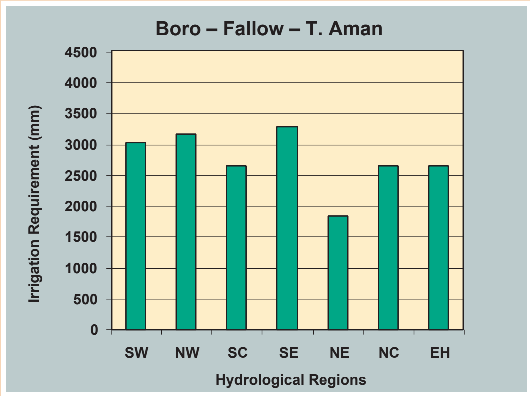
## Boundaries of Hydrological Regions

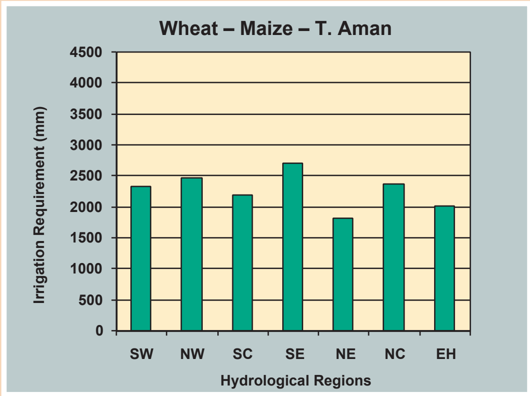


# Irrigation Requirement by Major Cropping Patterns




## Methodology for Drought Mapping

### GIS was used to produce

- Kharif (T.Aman) drought prone area map
- Rabi drought prone area map
- Pre-Kharif drought prone area map

### Time periods of Data Analysis

- Rabi: 1st decade November-1st decade of March
- Pre-kharif: 2nd decade of March- 1st decade of June
- Kharif: 2nd decade of June- end of October for the T.Aman Crop

## Methodology for Drought Mapping

Scenarios Considered:

- Soil Characteristics that represents average situation
- Climatic Characteristics (LGP-Length of Growing period) that represents average situation
- Rainfall Uncertainty (rainfall availability at 80% probability)

## Factors Considered for Kharif (T.Aman) Drought

| | | |
|---|---|---|
| Soil Factors | 1 | Available moisture holding capacity |
| | 2 | Soil percolation rate |
| Climatic Factor | 3 | Kharif Length of growing period (days)-K Values |
| Moisture Availability due to Rainfall uncertainty | 4 | Percentage of dry sub-humid (P<0.5PET) decades |
| | 5 | Percentage dry decades (decades of no rainfall) |

## Factors Considered for Rabi Drought

| | | |
|---|---|---|
| Soil Factors | 1 | Available moisture holding capacity |
| Climatic Factor | 2 | Rabi Length Length of growing period (days)-R values |
| Moisture Availability due to Rainfall uncertainty | 3 | Percentage of dry sub-humid (P<0.5PET) decades |
| | 4 | Percentage dry decades (decades of no rainfall) |
| External Water Supply | 5 | Ensured Irrigation (??) |

## Factors Considered for Pre-kharif Drought

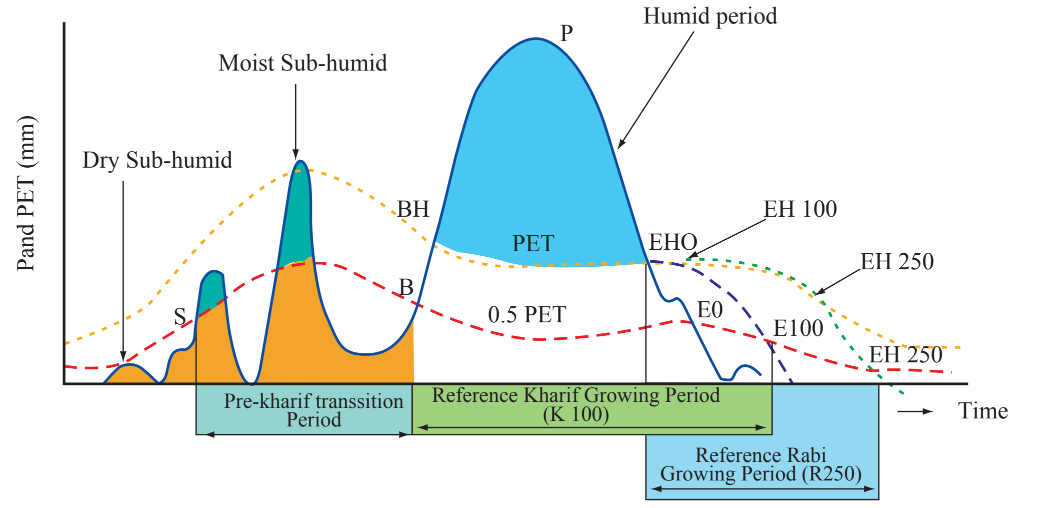
| | | |
|---|---|---|
| Soil Factors | 1 | Available moisture holding capacity |
| Climatic Factor | 2 | Pre-Kharif Transition period (days)-P values |
| | 3 | Total Length of Growing Period (days)-LGP |
| Moisture Availability due to Rainfall uncertainty | 4 | Percentage of dry sub-humid (P<0.5PET) decades |
| | 5 | Percentage dry decades (decades of no rainfall) |

## Determining the Factors

### Factors considered

- Available Moisture Holding Capacity (AMHC)
- Percolation rate was deduced based on Texture Data of LRI (LRI -Land Resources Inventory and SRI Mapping)
- Reference Length of Growing Periods
- Decadal Water Balance
- Kharif Season Percent Dry Decades Percent Dry Sub-humid

## Atmospheric Water Balance Model




P Precipitation

S Start of Pre-kharif Transition Period

BH Beginning of Kharif Humid Period

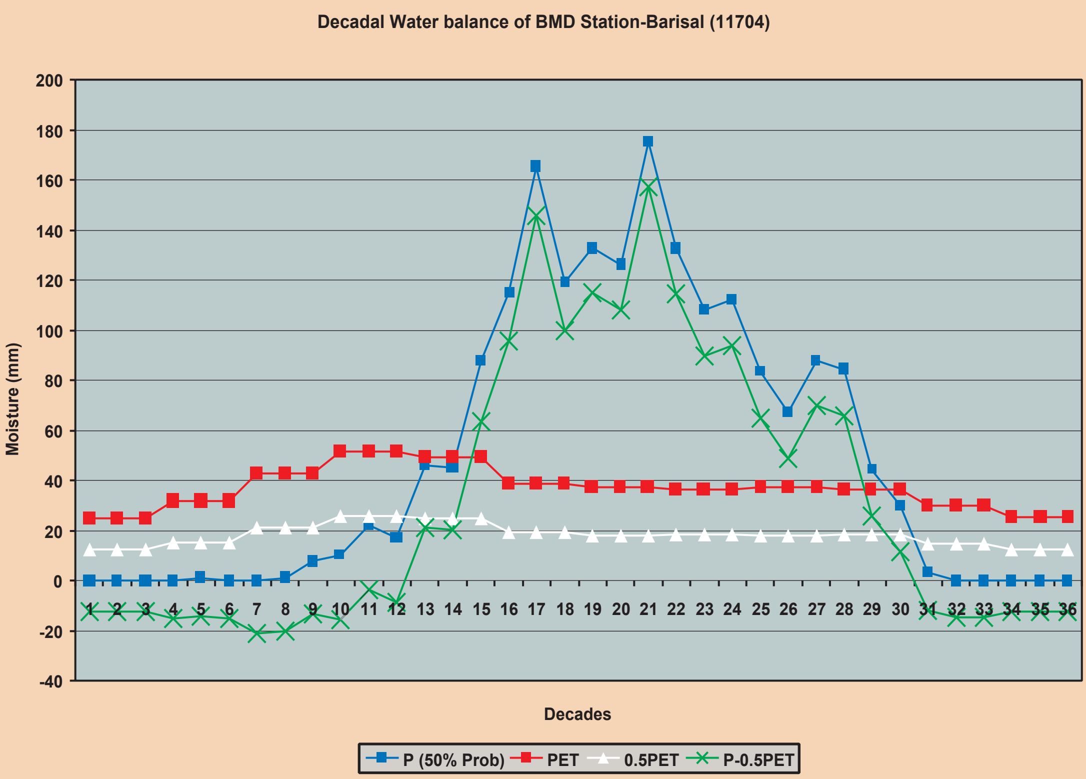
EO End of Humid Period

PET Potential Evapo-transpiration

B Beginning of Kharif Growing Period

EHO End of Humid Period

## Decadal Water Balance



### Assign weight to individual factors

| Factor | Values of different factors | | | | |
|---|---|---|---|---|---|
| Weight | 1 | 2 | 3 | 4 | 5 |
| Soil Moisture | <100 mm | 100-200 mm | 200-300 mm | 300-400 mm | >400 mm |
| Soil Percolation rate | Very High | High | Moderate | Low | Very Low |
| Pre-Kharif Transition period | >60 days | 50-60 days | 40-50 days | 30-40 days | < 30 days |
| Kharif LGP | < 200 days | 200-220 days | 220-240 days | 240-260 days | > 260 days |
| Rabi LGP | <90 days | 90-100 days | 100-110 days | 110-120 days | > 120 days |
| Total LGP | 240-255 days | 255-270 days | 270-285 days | 285-300 days | > 300 days |
| Pre-Kharif Dry Decades | >71 % | 63-71 % | 46-63% | 29-46% | <40% |
| Pre-Kharif Dry Sub-humid | >90% | 80-90% | 60-80% | 40-60% | <40% |
| Kharif Dry Decades | >18% | 15-18% | 12-15% | 9-12% | <9% |
| Kharif Dry Sub-humid | 22-30% | 19-22% | 15-19% | 12-15% | <12% |

Weights implies (1-Very High, 2-High, 3-Moderate, 4-Slight 5-None) prone to drought for the specific factor

### Percent importance weight to the factors to get combined drought index

| Drought season | MHC | Percolation | Correspond-ing LGP | Correspond-ing Dry Sub-humid | Correspond-ing Dry Decades | Irrigation |
|---|---|---|---|---|---|---|
| Kharif | 40 | 20 | 20 | 20 | - | - |
| Rabi | 60 | - | 40 | - | - | Yes |
| Pre-Kharif | 40 | - | 25 | 25 | 10 | - |

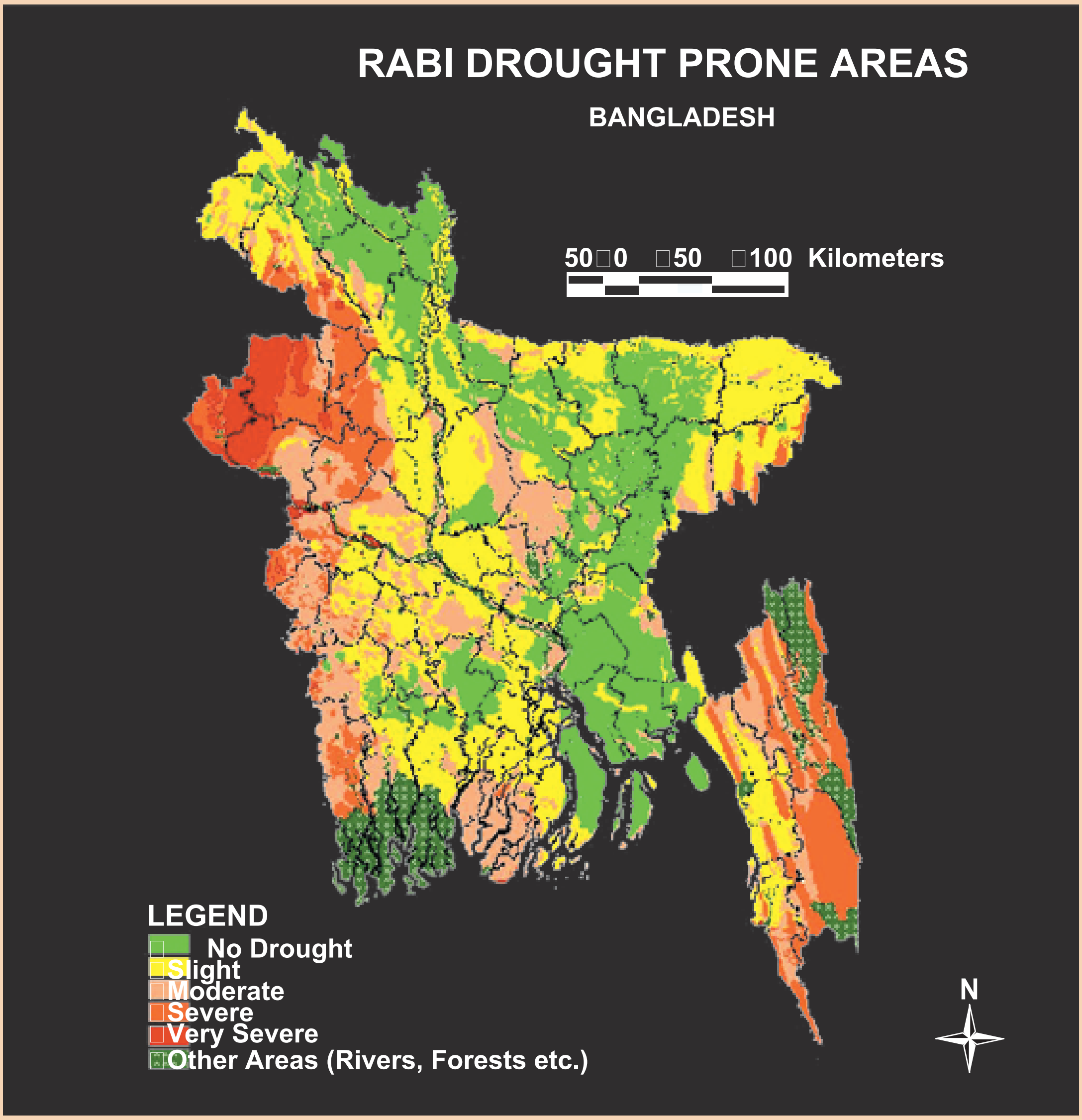
- Example of calculating overall index combining factors (using grid manipulation)
- $$\text{PKHDrIndex} = \frac{(\text{MHCWt} \times 40) + (\text{KHLGPWt} \times 25) + (\text{DSHWt} \times 25) + (\text{DDWt} \times 10)}{10}$$

Where

MHCWt => Moisture holding capacity weight,
KHLGPWt=> Kharif LGP Weight
DSHWt=> Dry Sub-humid weight
DDWt=> Dry Decad weight

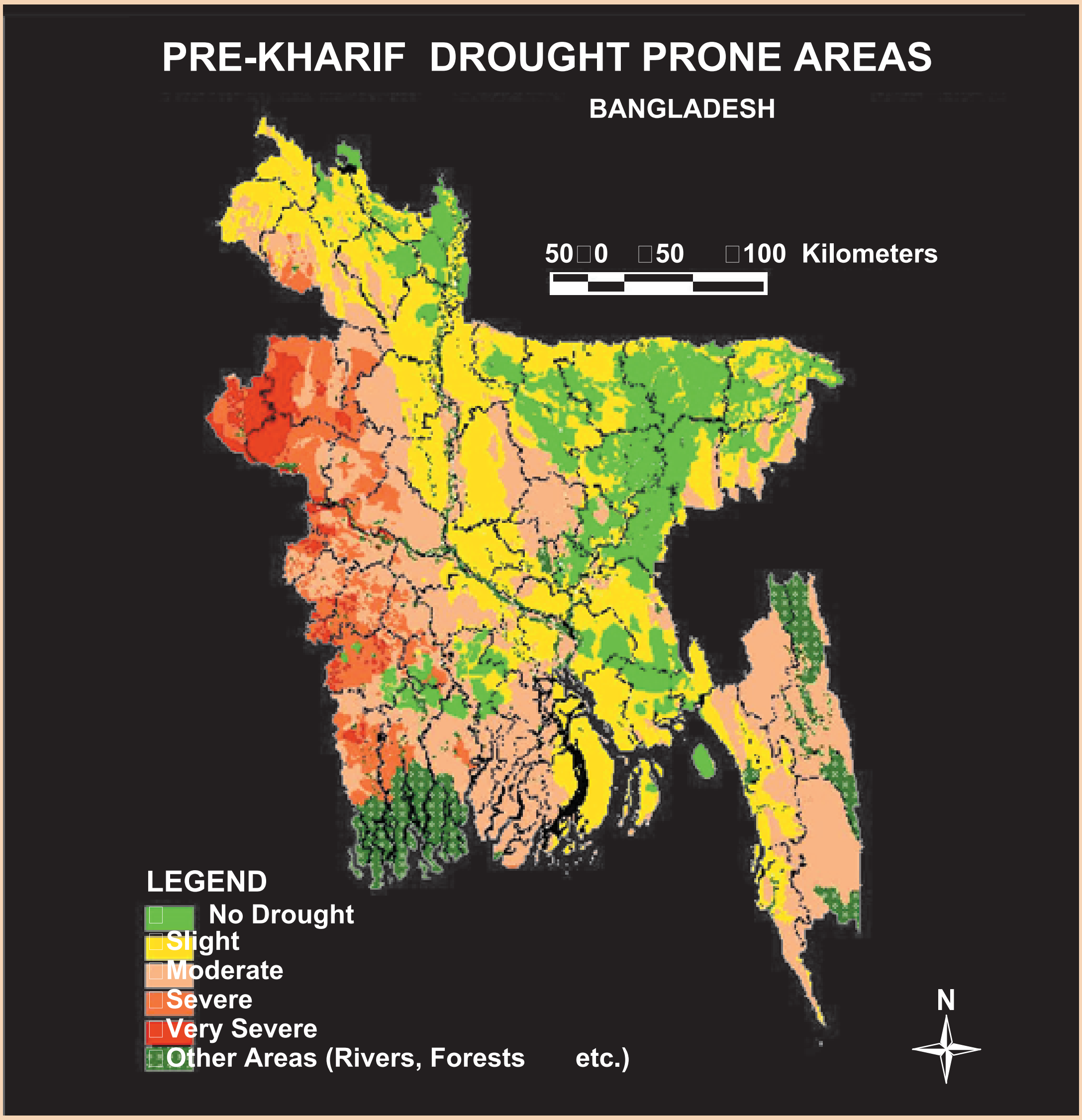
- An overall pre-kharif drought index is obtained starting values from 15 to 50, where a severity is assigned in terms of 5 different classes of the above indices. 15-20-Very severe, 21-26 Severe class, 26-31-Moderate Class, 32-40 Slight class and 41-50 is no drought class.

## Rabi Drought Map



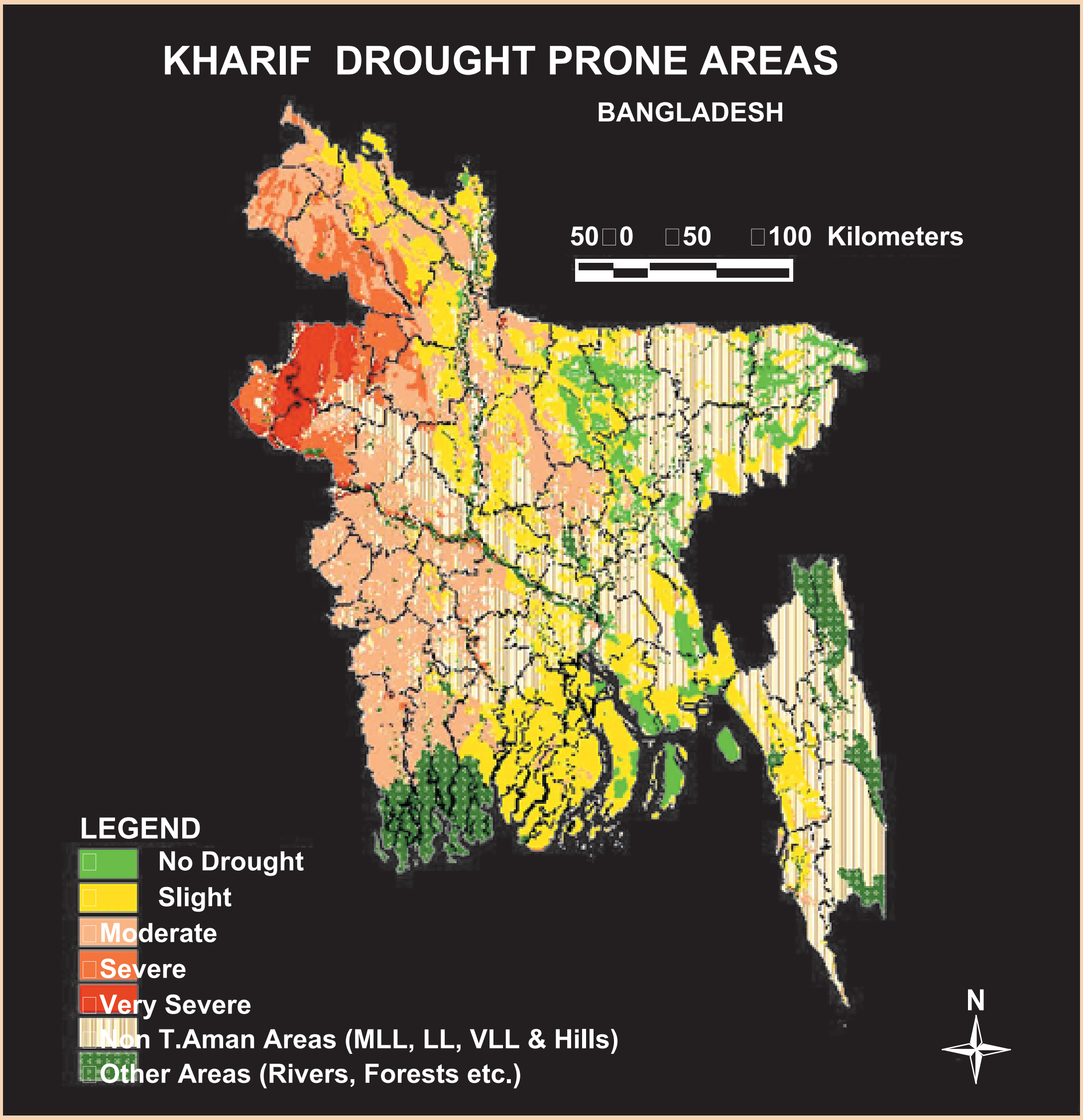

*Source: BARC GIS*

## Pre-Kharif Drought Map




*Source: BARC GIS*

## Kharif Drought Map




*Source: BARC GIS*

## Adaptation

**Droughts**

- Drought related vulnerability can be minimized by supplemental irrigation
- Develop drought resistant varieties of crops for drought prone areas of the country
- Drought tolerant crops and varieties - maize, sorghum, millet, kharif pulses and oilseeds - matching with the land and climatic requirements
- Effective use of minimum tillage as a management practice under rainfed conditions - wheat, cowpea, field pea, chickpea, lentil, grasspea and water melon
- Minimum tillage utilized for many years with such practices as over-seeding mustard and pulses immediately after harvesting of transplanted Aman rice crop
- Mulching with straw or water-hyacinth
- Use of deep-rooted crops and low-water consuming crops
- Increase water use efficiency thru varietal and irrigation management

## Conclusions

There are many more aspects of natural and human systems, which would be vulnerable to climate change; some of them would be directly impacted while the others indirectly.

Only drought and its modeling aspects have been considered in this article giving more emphasis on the impact of climate change agriculture because it would be the most vulnerable sector. On the other hand, this sector has the most potential to counteract the impacts.

# Use Of High Resolution RegCM for Modelling of Climate Variabiity and Change in Bangladesh

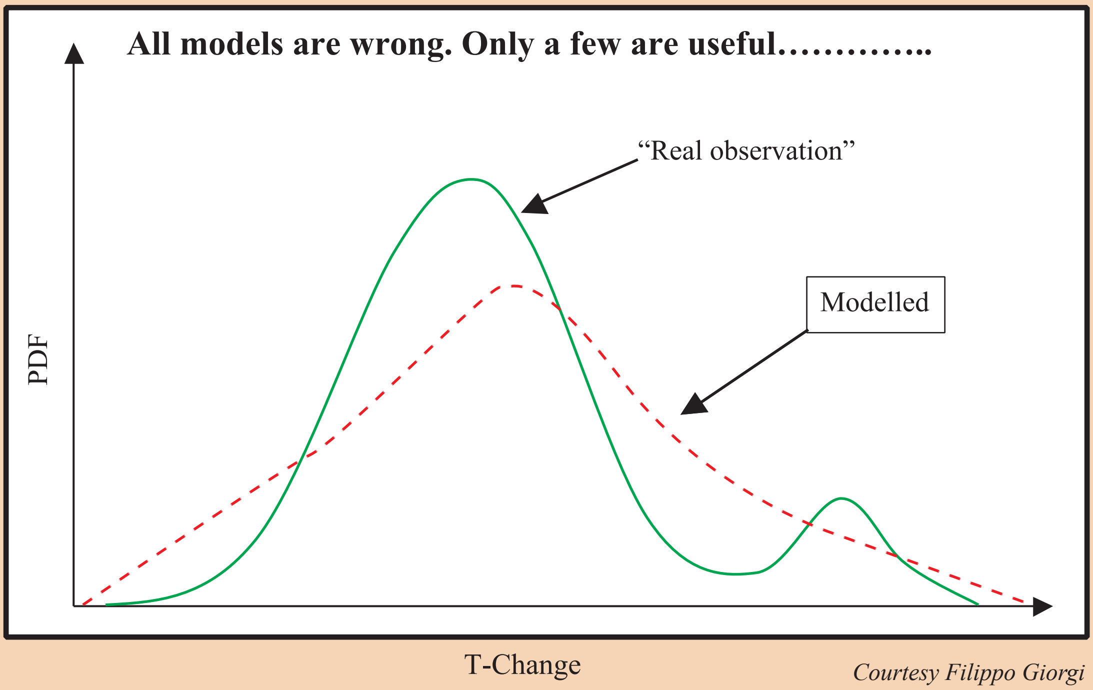
Dr. Ahsan Uddin Ahmed
*Executive Director*
*Bangladesh Unnayan Parishad (BUP)*

## Abstract

Climate variablity and change may be modelled by the use of mathematical models. In recent times, there have been tremendous advancements in the field of climate modeliling, primarily due to increased levels of understanding regarding physical processes and also due to increased access to higher end computers. General circulation models (GCM) have been used for modelling of large-scale climate variability and change. Advanced GCMs could estimate physical processes which can define climate system for large areas based on atmosphere-ocean interaction and feedbacks. However, researchers have taken relentless strides to improve the physics behind the AOGCMs, incorporated feedbacks of meso-scale physical processes into the AOGCM equations which have culminated into the development of meso-scale Regional Climate Models (RCM). A number of RCMs actually are nested in GCM, and resolve equations at much finer levels which provide climatic information up to 25Km X 25Km resolution, at even three hourly time-steps. RegCm is one of many such regional climate models, which is now being tested for reproducing the monsoon system over South Asia, and more specifically, over Bangladesh.

From initial results, RegCM provides appreciable results in tearms of capturing basic climate singals such as rainfall as well temperature variability, both in spatial and temporal scales. Over South Asia, the model successfully captures large rainfall around the Western Ghat as well as the northern Bay of Bengal and north-eastern Bangladesh. The diurnal behaviour of rainfall over Bangladesh is also captured well. The seasonal progression and department of monsoon fronts are also well captured over the South Asia domain. The temporal temperaure variability is well captured, while there exists about $2^{o}$C could bias systematically over the entire Bangladesh. Similar cold bias is also observed over the whole of South Asia. It is found that Grell convention scheme performs muvh better for the regional rainfall patterns. Grell convention scheme in conjunction with Arakawa-Schubert closure assumption reduces cold bias only slightly, while the combination of Grell CS with Fritsch-Chappel closure assumption resolves the rainfall variability better than the former cobination. Despite such improvement in model option, the pre-monsoon seasonal rainfall appears higher than observed total rainfall, while the monsoon rainfall appears lower than the observed total rainfall. The Model can oick up extreme climatic events such as cyclone. Examining the model outputs, it may be inferred that RegCM may be used primarily as a diagnostic toll to understand climate change for Bangladesh. It may also be used, with appropariate correlation with observed data sets, to generate future climate scenarious at much higher resolution than the GCMs.

***Acknowledgements:*** The author acknowledges the kind support forwarded by the APN (Japan) through CAPaBLE Programme. Acknowledgement is also due to Dr. M. N. Islam, Mr. M.M. Rahman and Mrs. R. Afroze for their collabaration and collective effort. The Author also acknowledges F. Giorgi at ICTP, Dr. J. Pal (ICTP), Mr. F. S. Syed (GCISC-Pakistan) and Mr. J. Karmacharya for their collaboration and support.




*Courtesy Filippo Giorgi*

## Historical Evolution of Regional Climate Models (RCM)

General Circulation Models (GCM) have been used to understand large-scale climatic processes.

Atmosphere-Ocean couple models (AOGCM) have been used for simulating climatology of a large area (500 Km X 500 Km) based on atmospheric and oceanic energy balance, feedbacks, and interactions between A-O circulations.

Dickinson et al. (1989) and Giorgi (1990) proposed that Limited Area Models (LAMs) could be used for regional studies.

Concept: One way nesting within a driving GCM, in which large scale meteorological fields from GCM runs provide initial and time-dependent meteorological lateral boundary conditions (LBC).

Advantage: High resolution.

Disadvantages: Computationally (highly) demanding. No feedback from RCM to the driving GCM.

## First Generation RegCM

NCAR-PSU Mesoscale Model version MM4 (Dickinson et al., 1989; Giorgi, 1989)

Dynamical core of RegCM is similar to that of the hydrostatic version of MM5 (Grell et al., 1994).

The first generation RegCM included the Biosphere-Atmosphere Transfer Scheme (BATS) (Dickinson et al., 1986) to represent surface processes;

The radiative transfer scheme of the NCAR Community Climate Model (CCM, V 1);

A medium resolution local planetary boundary layer scheme;

The Kuo-type cumulus convection scheme (Anthes, 1977); and

The moisture scheme (Hsie et al., 1984)

## Second Generation RegCM (Giorgi et al., 1993a,b)

Based on the climatology (physics) of CCM2 (Hack et al., 1993) and the mesoscale model MM5 (Grell et al., 1994)

CCM2 considered the effects of H2O, O3, O2, CO2 and clouds in its radiative transfer package.

Solar radiative transfer was treated.

Cloud radiation: (a) cloud fractional cover; (b) cloud liquid water content; and c) effective droplet radius.

Radiation calculation: radiative transfer package by Briegleb, 1992

Introduction of a non-local boundary layer scheme provided by Holtslag et al., 1990 (replacing local scheme)

Introduction of a mass flux cumulus cloud scheme provided by Grell (1993) as an option

BATS equations have been updated (as provided by Dickinson et al., 1993)

## The RegCM3

It is based on the physics provided by CCM3

CCM3 retains most of the physics provided in CCM2, however enriched it with incorporation of radiative effect of other GHGs such as NO2, CH4, and CFCs.

Aerosols are also incorporated in the radiative budget analysis.

Cloud ice has also been factored in.

Original moisture scheme has been updated and simplified.

Cloud water equation: accounts for cloud water formation; advection and mixing by turbulence; re-evaporation in sub-saturated conditions; and conversion into rain.

## Inclusion of

- A stretched grid model configuration.
- A new subgrid-scale variability of cloud and precipitation scheme (Pal et al., 2000)
- New parameterizations for ocean surface fluxes (Zeng et al., 1998)
- A cumulus convection scheme (Emanuel, 1991)
- Subgrid-scale heterogeneity in topography and land use (Giorgi et al., 2003)

## Dataset

NCEP and ECMWF global reanalysis datasets are generally used for the initial and boundary conditions. Huge data sets.

Surface terrain data:
USGS Global Land Cover Characterization data
Global 30 Arc-Second Elevation datasets

## Computational requirements

Minimum: HT PC with 3.0MHz processor (takes few days of continuous and uninterrupted running for 1 year model run)
Relatively better performance: 64 bits dual processor with SATA HD, configured in LINUX NOT ENOUGH!

Cannot be run in Windows environment

Projection: Rotated Mercator/ Lambert Conformal / Polar Stereographic Proj.

Software for projection: Grads

## Regionalization Techniques

'Downscaling' From a large region to a smaller area.

- Dynamical Downscaling
  - High Resolution "Time-Slice" AGCM Experiments
  - Variable Resolution AGCM
  - Nested Regional Climate Model

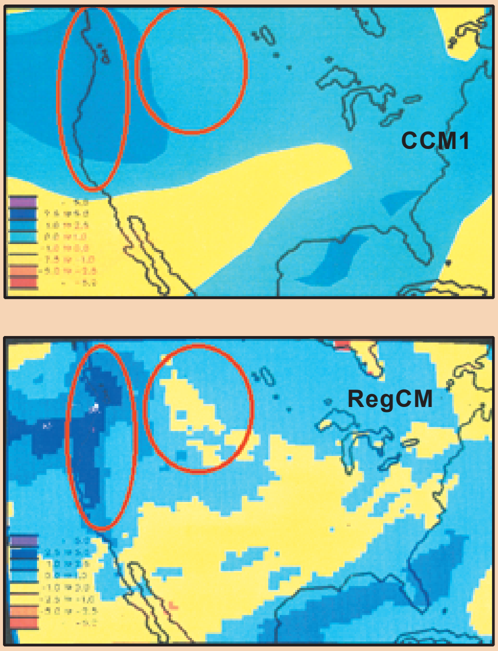
- Statistical Downscaling
  - Relationships are derived from large-scale variables (predictors) and local/regional variables (predictands)
  - Large-scale model output is then fed into the derived statistical relationship to determine the local/regional variables

Combined use of different techniques

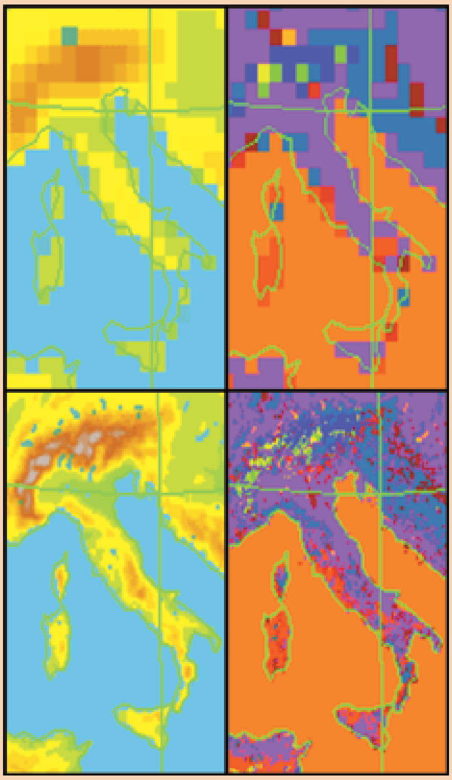
## Rationale for Using a RCM

- Improved resolution of coastlines and topography
- Improved simulation of mesoscale climatic systems
- Improved simulation of extreme events
  - e.g. floods, wind storms, heat waves, cyclones
- Can include additional processes not included by the GCM simulations
  - e.g. land cover changes, aerosols, lake effects, glacial melting
- Improved resolution for Impacts Models
  - e.g. agriculture, hydrology, air quality, storm surge
- Process studies to understand mechanisms
  - e.g. land-surface, sea surface temperatures, glacial/snow albedo

## 2xCO2 Simulated Differences




*Courtesy: J. Pal*

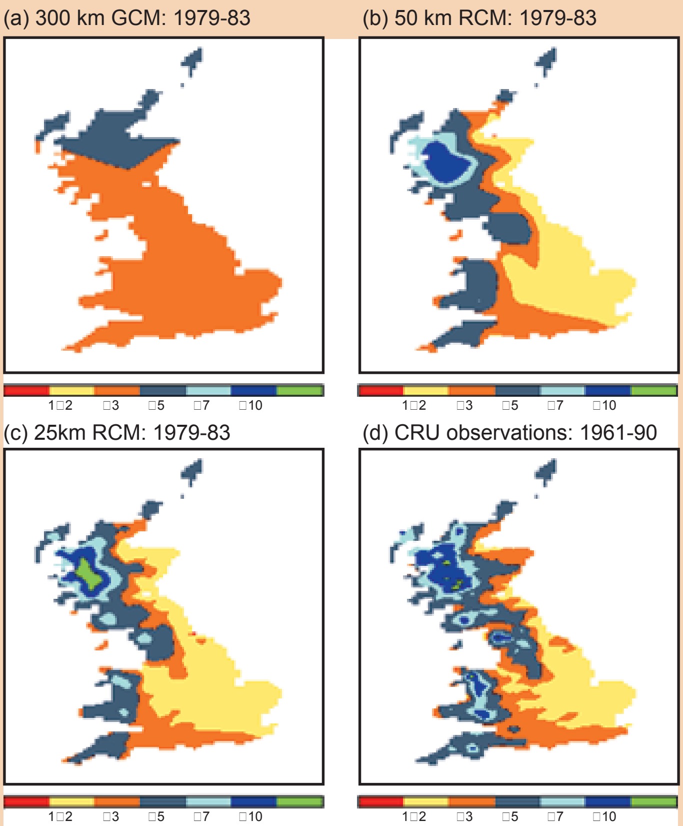


*Courtesy: J. Pal*

## Resolution Factor: Winter Precipitation Over Britain

300km GCM

25km RCM

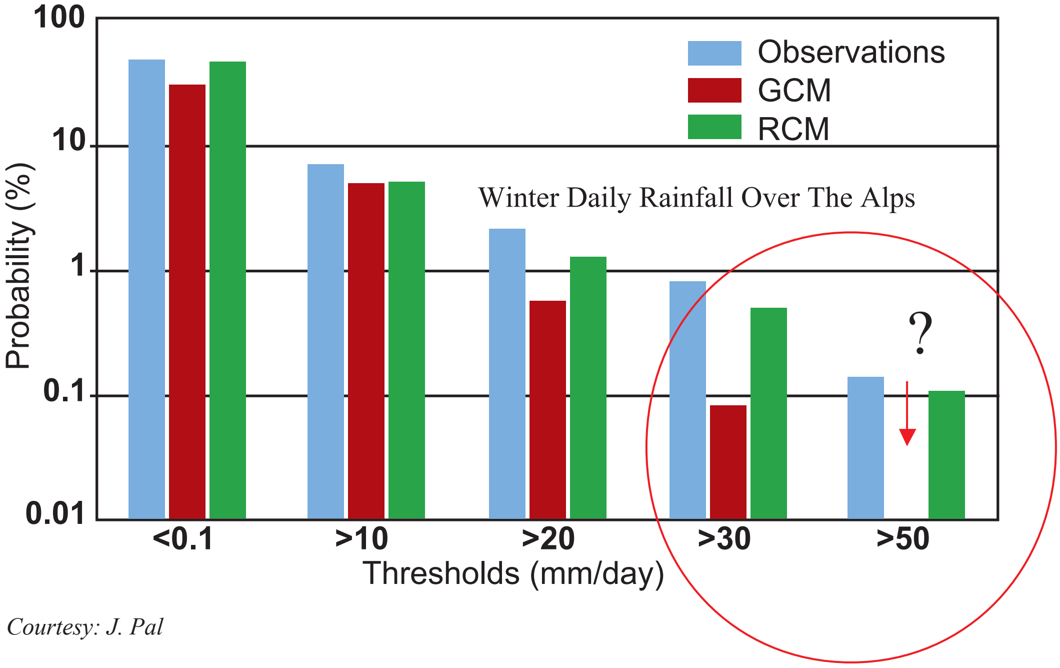



50km RCM

Observed

*Courtesy: J. Pal*

**RegCM simulates extreme rainfall much better than GCMs**




*Courtesy: J. Pal*

## RCM Limitations

▶ One-way nesting

- No regional-to-global feedbacks

▶ Technical issues in the nesting technique

- Domain, boundary condition procedure, physics, etc.

▶ Not intended for correcting systematic errors in the large-scale forcing fields

- It is always necessary to analyse first the forcing fields

▶ Computationally extremely demanding

## Strategy for Regionalize Climate Change Projections

### 1. "Perfect Boundary" Condition RCM Experiments

- It is necessary to make sure that the RCM performs well.
- Model optimization (or customization) may be necessary
- Selection of convection scheme. (Emmaluel or Grell?)

### 2. IMPORTANT: reanalysis products have problems

- Analysis of GCM present-day simulations
- "Garbage" in, "garbage" out
- Selection of best available GCMs

### 3. "Non-perfect" boundary condition RCM experiments

- May require further customizations to match driving model
- Necessary to assess "added-values" of the RCM simulations
- It is necessary to decide what additional processes to include (e.g. aerosols, land cover changes)

## 4. GCM driven present-day and future simulations

Important to decide which Scenario to consider (extent of forcing)

## Summary of RegCM3 Core

▶ **Dynamics:**
MM5 Hydrostatic (Grell et al 1994)

▶ **Radiation:**
CCM3 (Kiehl 1996)

▶ **Large-Scale Clouds & Precipitaion:**
SUBEX (Pal et al 2000)

▶ **Cumulus convection:**
Grell (1993)
Anthes-Kuo (1977)
Emanuel (1991)

▶ **Boundary Layer:**
Holtslag (1990)

*(Pal et al 2005; Giorgi et al 1993ab)*

▶ **Tracers/Aerosols:**
Qian et al (2001); Solmon & Zakey

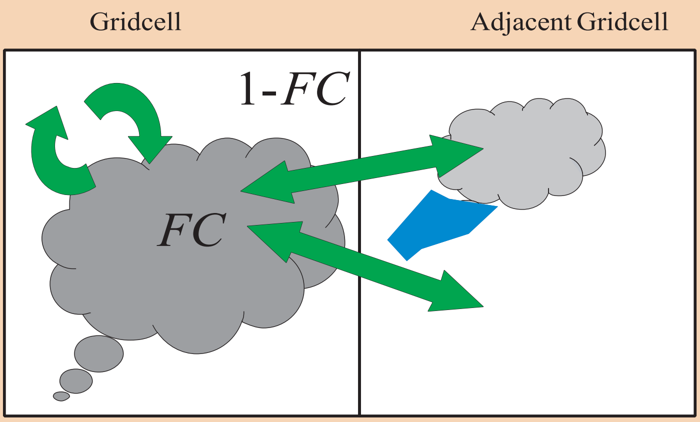
▶ **Land Surface:**
BATS (Dickinson et al 1993)
SUB-BATS (Giorgi et al 2003)
CLM (Dai et al 2003, In progress)
IBIS (Foley; In progress)

▶ **Ocean Fluxes**
BATS (Dickinson et al 1993)
Zeng et al (1998)

▶ **Computations**
Parallel Code (Yeh, Gao)
Multiple Platforms
More User-Friendlier Code

**SUBEX: Large-scale Clouds and Precipitation Estimation**

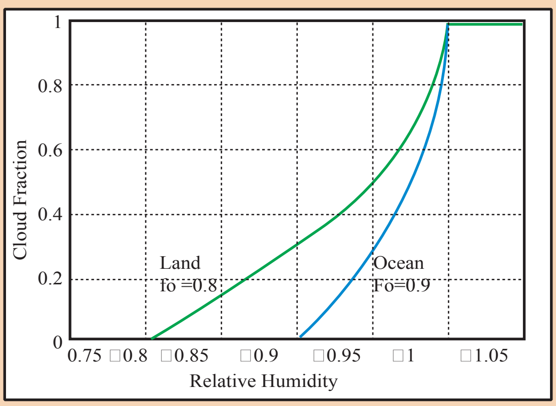
▶ Each gridcell is divided into cloud and cloud-free fraction
(Sundqvist et al, 1989)
- Cloud fraction is based on 'gridcell averaged relative humidity'
- In-cloud values are used as opposed to gridcell average values.




▶ Cloud liquid water threshold at which precipitation forms is based on Observations (Gulteppe 1997).

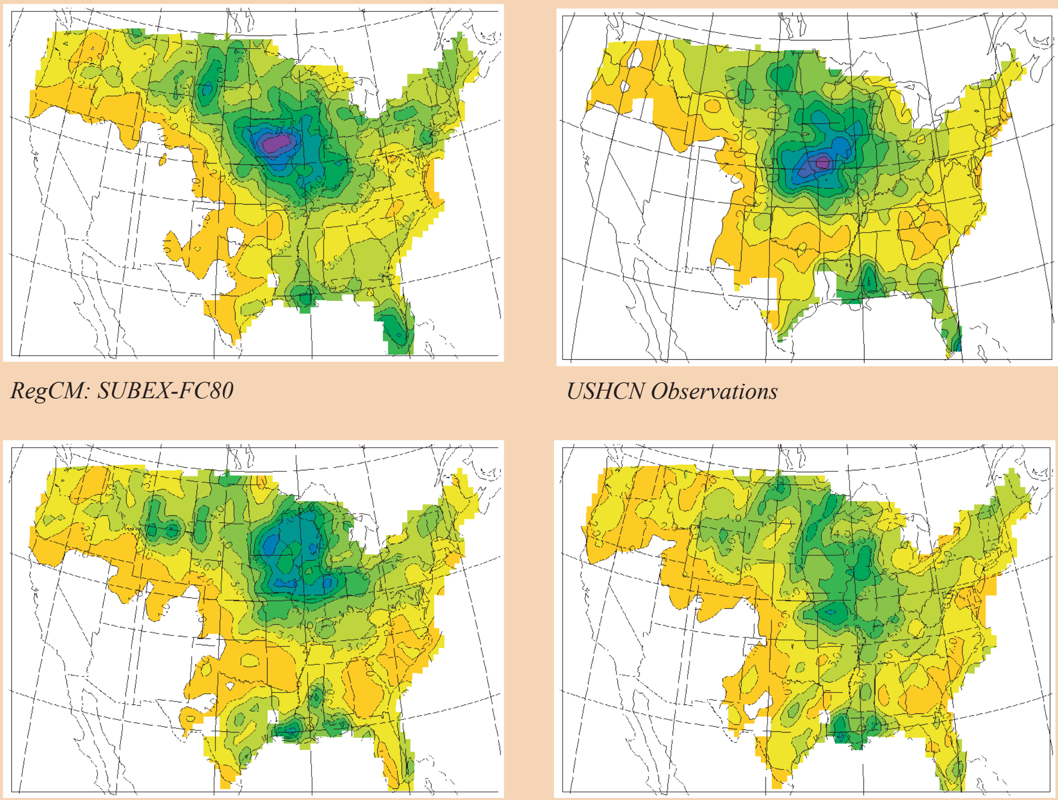
▶ Accretion of cloud droplets by precipitation (Beheng 1994).

▶ Precipitation evaporation is also considered (Sundqvist et al 1989).



## Convective Processes

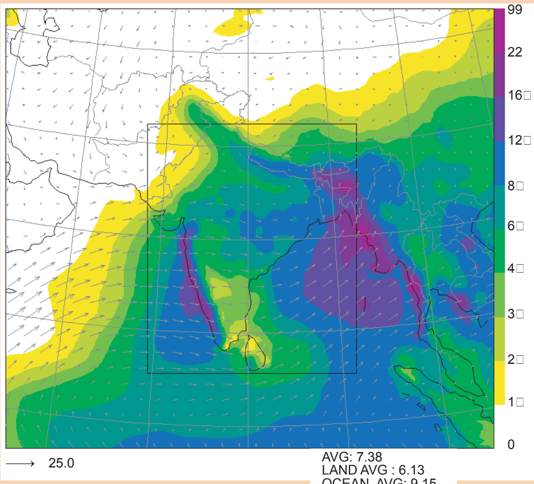
- Convective processes occur at horizontal scales on the order of 1-km.
  - Convection is parameterized assuming that its statistical properties can be deduced from the large-scale (resolved) variables.
- In models, an inadequate representation of convection can significantly increase the uncertainty of the model predictions.



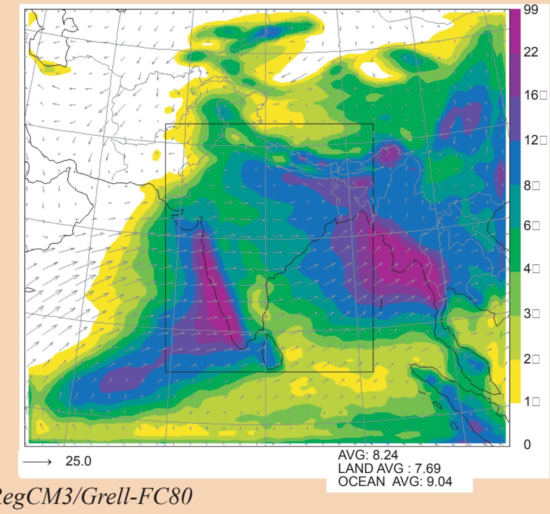
*RegCM: SUBEX-FC80* *USHCN Observations*

*RegCM: SUBEX-AS74* *RegCM: SIMEX-AS74* *Courtesy: J. Pal*

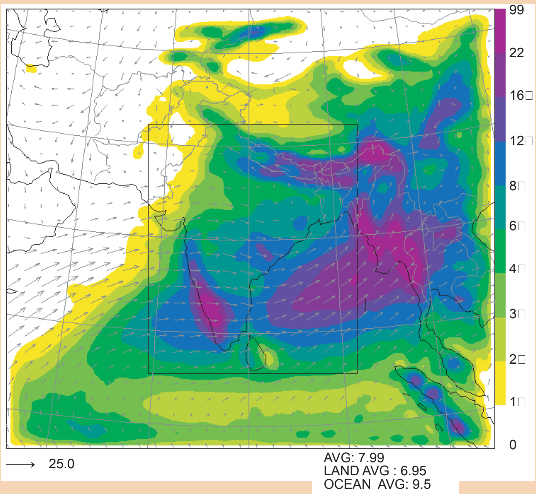
## Precipitation & Winds 1987-2000 JJAS Climatology




*CRU/CMAP/ERA40*




*RegCM3/Grell-FC80*

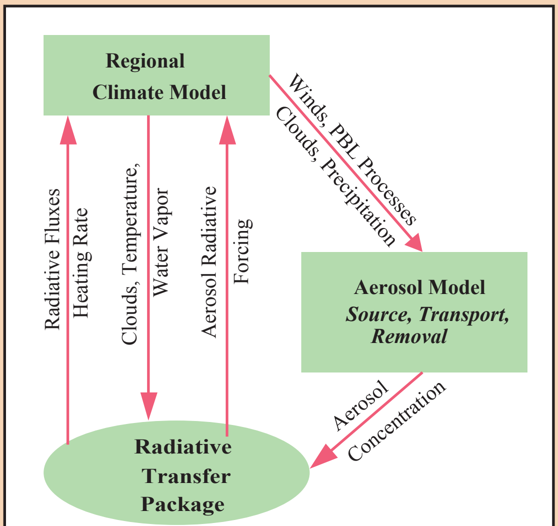



*RegCM3/MIT-Emanuel Scheme*

*Courtesy: J. Pal*

## Tracer/Aerosol Scheme

- Transport
  - Advection/Diffusion
  - Convection
- Emissions
- Removal processes
  - Precipitation (large-scale and convective)
  - Dry deposition
- Chemistry scheme for Sulfates
- Direct and indirect radiative effects
- Dusts




Adapted from Qian et al, 2001; Solmon et al, 2005

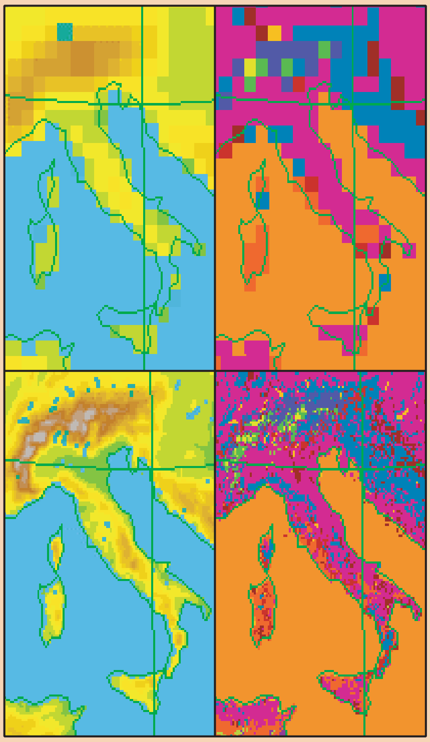
*Courtesy: J. Pal*

## SUB-BATS: General Methodology

- Define a regular fine scale sub-grid for each coarse scale model grid-box.
  - Landuse, topography, and soil texture are characterized on the fine grid.

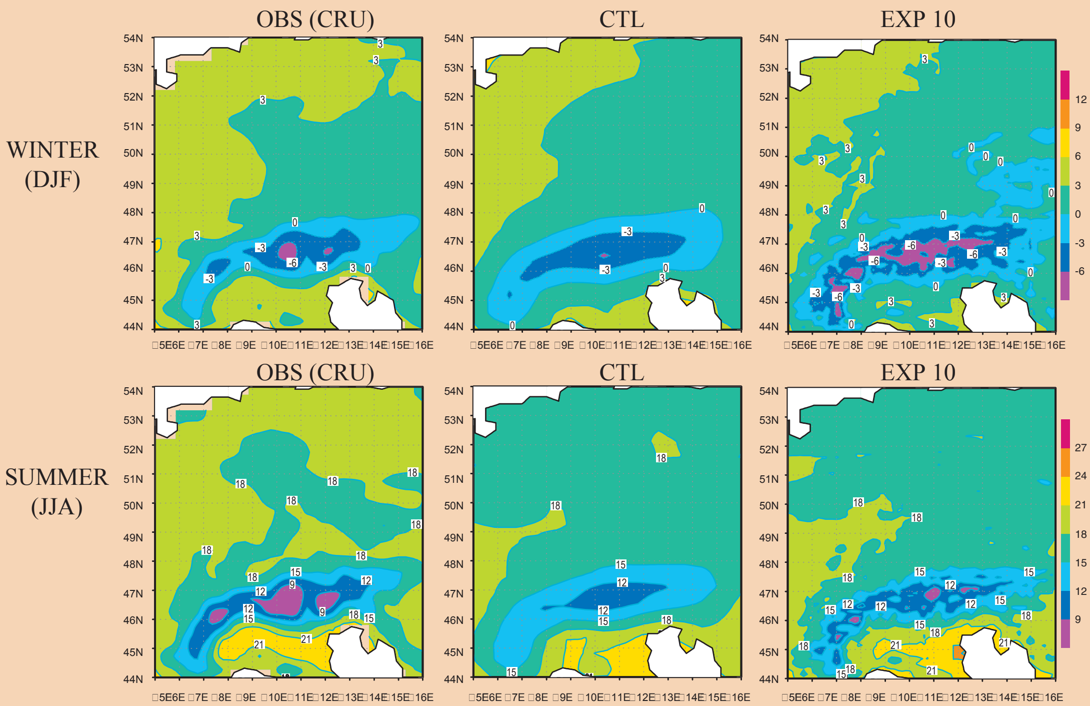
- Disaggregate climatic fields from coarse grid to fine grid.
  - Based on the elevation differences between the coarse grid and the fine grid.
  - Perform BATS surface physics computations on the fine grid.

- Reaggregate from the fine grid to the coarse grid.



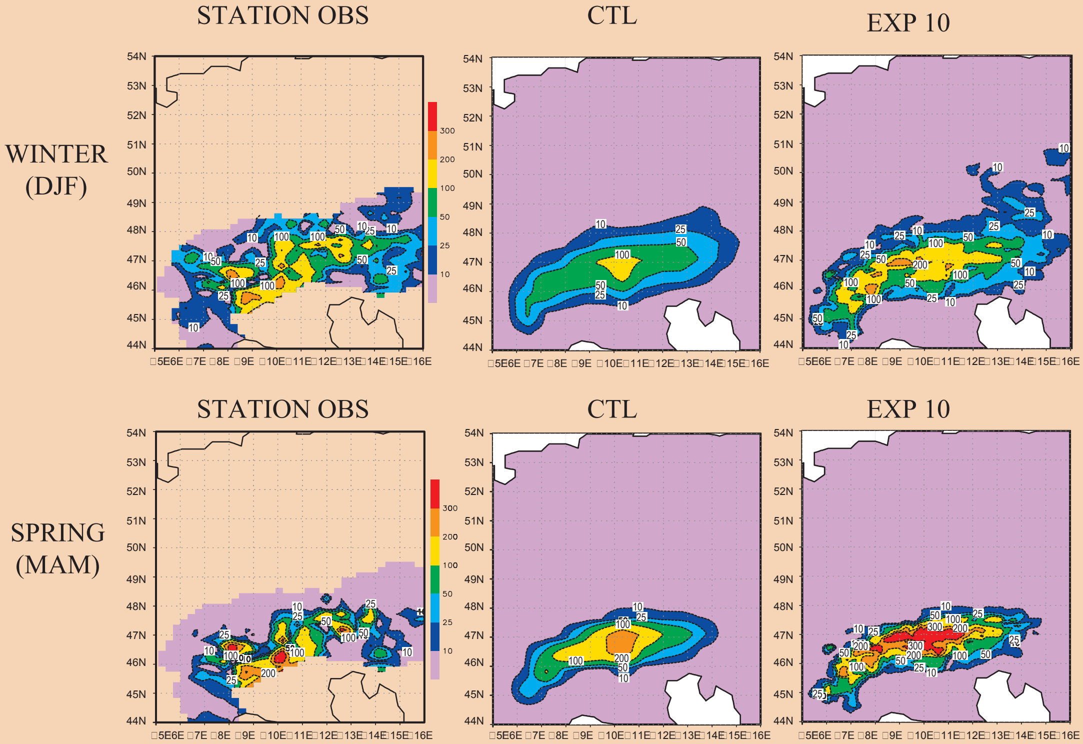
*Courtesy: J. Pal*

## SUB-BATS Results: Land-Surface Effects on Temperature




*Courtesy: J. Pal*

## SUB-BATS Results: Land-Surface Effects on Snow



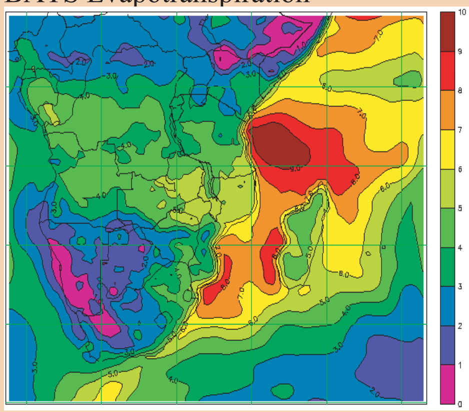

*Courtesy: J. Pal*

## Ocean Flux Scheme

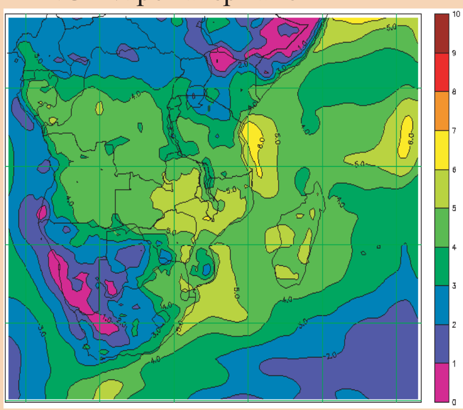
- BATS Ocean Flux
- (Dickinson et al 1993)
  - Overestimates latent heat in both weak and strong wind conditions
  - No special treatments of convective or very stable conditions.

- Zeng Ocean Flux
  - Describes all stability conditions
  - Takes into account the additional flux induced by boundary layer scale variability

BATS Evapotranspiration



ZENG Evapotranspiration



*Courtesy: J. Pal*

## Model Run

Used LBC: NCEP re-analysis data (NNRP2) OI_SST

Projection: Rotated Mercator

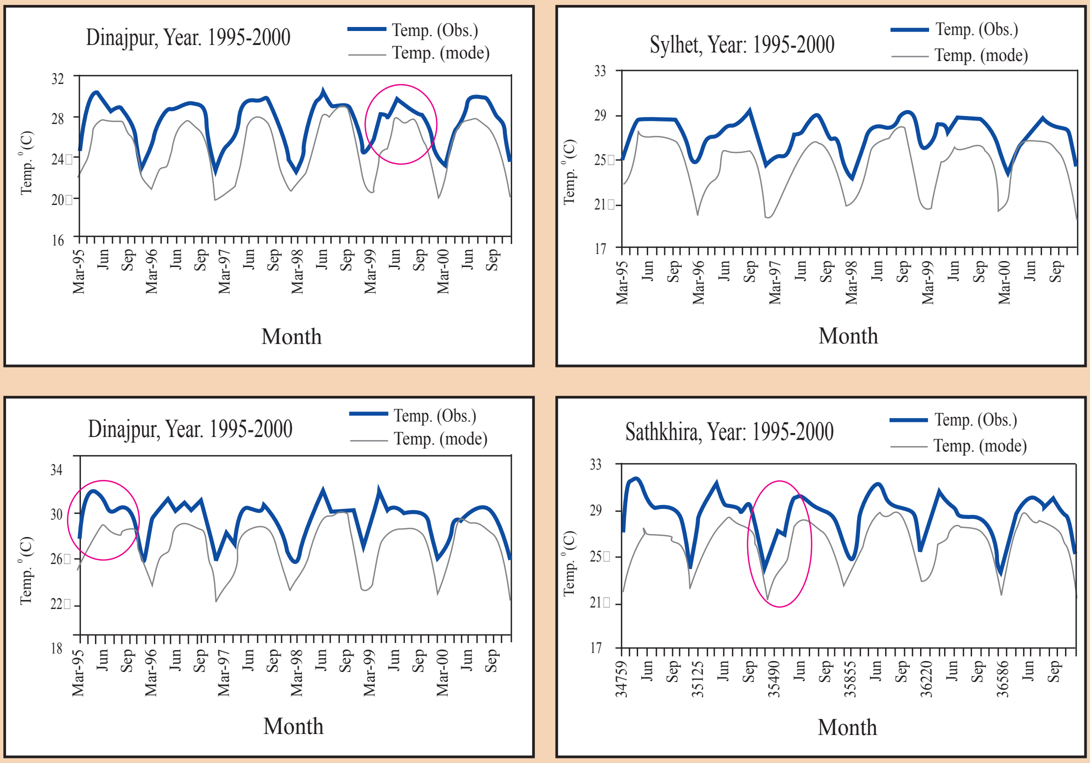
Analysis Period: 1982-1990

Analysis domain: South Asia region (65E-117E, 5N-35N)

Grid resolution: dx = 60 km horizontal grid mesh with
time step dt = 200 sec

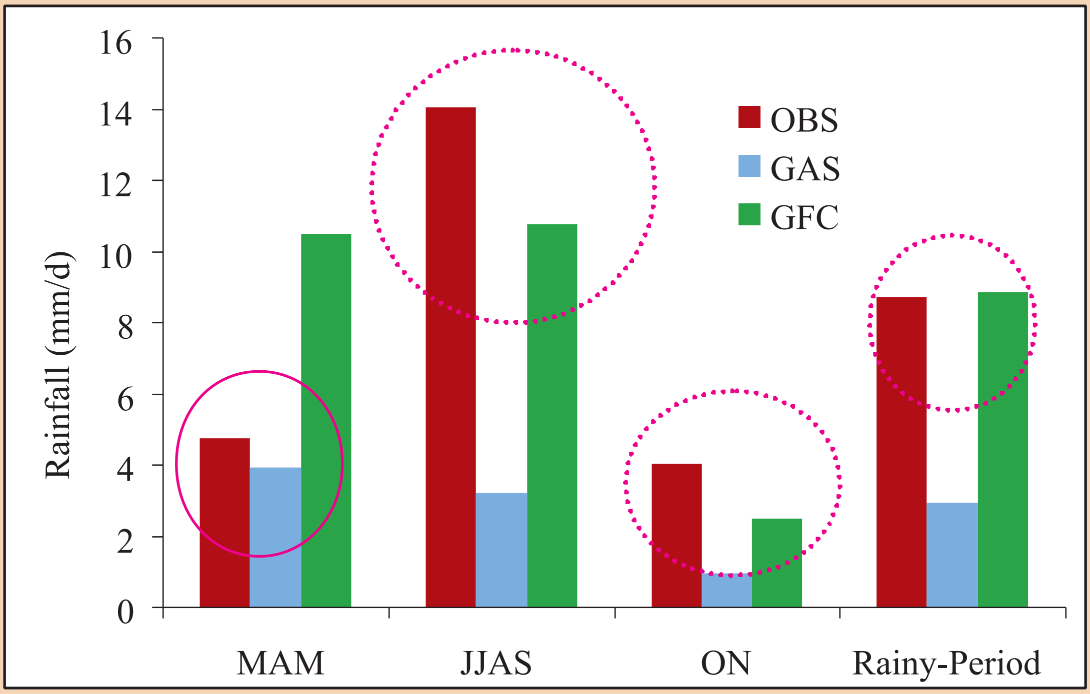
Model physics: Grell convective scheme with Arakawa Schubert and Fritsch Chappell assumptions

## Comparison of Temperature Variability (Observed VS Model Output)



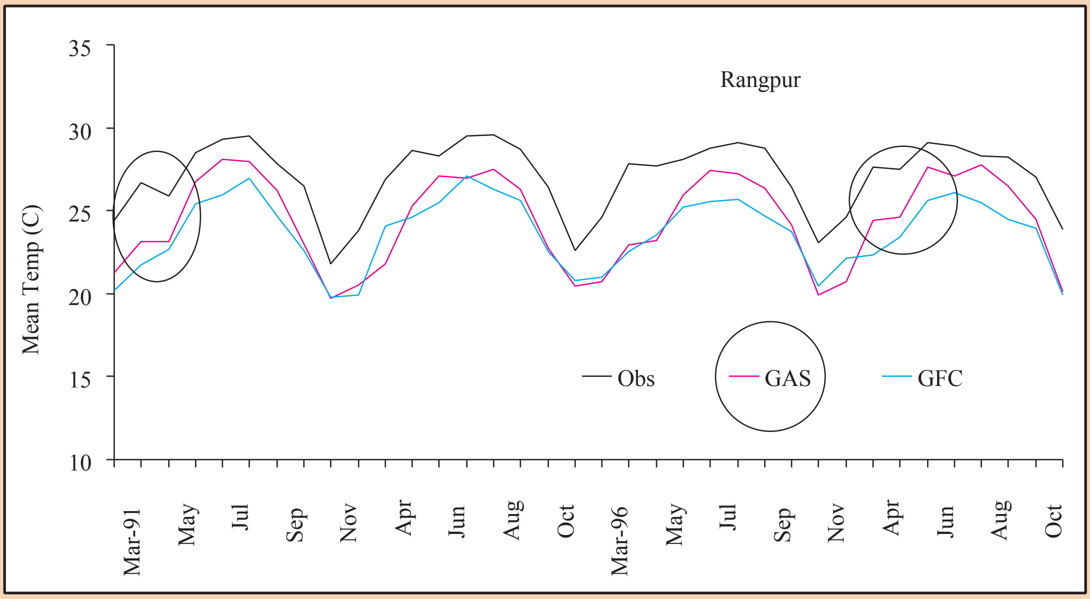

*Courtesy: Islam et al., 2006*

**Season-wise performance of RegCM as against observed data**




*Courtesy: Islam et al.,2006*

**Comparison of RegCM outputs with different closure assumptions**




*Courtesy: Islam et al.,2006*

# Modelling Approach of Water Availability Assessment in CLASIC Project

Arpana Rani Datta[1] and Jahir Uddin Chowdhury[2]
*[on behalf of project team members from*
*Centre for Ecology & Hydrology (CEH), UK,*
*Hadley Centre, Meteorological Office, UK,*
*Institute of Water & Flood Management (IWFM), BUET, Dhaka and*
*Center for Environmental & Geographic Information Services (CEGIS), Dhaka.]*

## Introduction

A research project entitled 'Impact of **CL**imate **A**nd **S**ea level change in part of the **I**ndian sub-**C**ontinent (CLASIC)' was initiated at the end of August 2003. It is expected to be completed by March 2006. The lead agency is the CEH, UK. The project is funded by DFID, UK under its Knowledge & Research (KAR) Programme. The purpose of the project is to investigate the implications of climate change on water resources availability from Ganges, Brahmaputra and Meghna basins in the Indian subcontinent with particular reference to Bangladesh. For this part of the study, Hadley Centre, IWFM and CEGIS are collaborating with CEH. The water resources model that is being used to assess the water availability, is the subject of this paper. Although the project purpose focuses on water availability, the project is also examining the possible impacts of climate change upon cyclonic storm surges in the Bay of Bengal, which affect low-lying coastal regions particularly Bangladesh.

## GWAVA Model

A model called '**G**lobal **W**ater **AV**ailability **A**ssessment (GWAVA )' is being used in the CLASIC. The implications of climate change on water availability will be assessed by GWAVA using the climate predictions from the PRECIS (**P**roviding **RE**gional **C**limates for **I**mpact **S**tudies) model of the Hadley Centre. The GWAVA was developed by the CEH and the British Geological Survey. Details can be seen in the user notes (CEH, 2002) and Meigh et al. (1999). The GWAVA is a global scale water resources modelling approach and it uses a grid cell approach to represent the spatial variation of physical characteristics, water availability and water demands. Important features of the analysis include:

- A rainfall-runoff model to generate river flows for each grid cell.
- Links between the grid cells to represent the river network of the drainage basins, and allow consideration of water transfers between the basins.
- Accounting for water demands due to domestic use, irrigation, livestock and industry.
- Representation of effects of reservoirs, wetlands, water abstractions, irrigation, return flows and water transfers in the surface water availability assessment.
- Inclusion of groundwater availability for total water availability assessment.
- Display of results using a Geographical Information System (GIS).

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## Glacier and Snow Model

A significantr proportion of the flow arriving in Bangladesh is from glacial and snowmelt originating in the Himalayas. In order to capture these aspects of the hydrological cycle, the glacier model is designed for the Himalayas by Rees and Collins (2004) and the snow-pack model by Bell and Moore (1999).

## Representation of Ganges-Brahmaputra-Meghna Basins

The whole of the Ganges-Brahmaputra-Meghna basins is represented by a coarse scale model at $0.5^0$x$0.5^0$ resolution as shown in Fig. 1(a). The drainage network was based on Doll and Lehner (2002) who based their work on Hydro1k drainage maps produced by USGS (2001). These drainage directions were checked using Jet Navigation and Pilot Charts and altered accordingly, particularly around the Himalayan region. The drainage directions are also updated in the Bangladesh part. The drainage network is shown in Fig. 1(b). The flows generated by the coarse-scale model at trans-boundary borders on the Ganges and the Brahmaputra, are used as boundary conditions for a fine-scale model discussed below.

## Representation of Bangladesh

Bangladesh is represented by a fine scale model at $0.1^0$x$0.1^0$ resolution (approx. 11km x 11km). Grided representation of Bangladesh and adjacent areas is shown in Fig. 2(a) while the drainage network in Fig. 2(b). The grid network is extended outside Bangladesh to capture the catchments of transboundary rivers other than two large rivers, the Ganges and the Brahmaputra. This has minimized the number of points at which coarse-scale model generated flows would enter the fine-scale model. The topographic information on the area outside of Bangladesh was obtained from Tactical Pilotage Charts by the Defence Mapping Agency Aerospace Center, USA.

## Input Data

GWAVA model requires climate data and a variety of physiological data and human data to simulate the hydrological processes as well as to assess the availability of water. The data for the coarse-scale model has been retrieved from publicly available sources. Local data sources have been used for the fine-scale grid. Sources of data are discussed below.

***Climate***: The climate data include rainfall, temperature and potential evaporation. Climate data of Climate Research Unit (CRU) of the University of East Anglia, UK have been used in the grid cells outside Bangladesh. For the fine-scale grid cells in Bangladesh, the daily rainfall data of the Bangladesh Meteorological Department (BMD) have been used. The temperature and potential evaporation data have been extracted from the CRU data. The potential evaporation is calculated using the Penman-Montieth equation.

***Physical characteristics***: Physical parameter data include the drainage direction, soil type, land use types and topography. Land use and soil texture data were combined to calculate field and saturated capacities. Dominant soil texture for areas outside Bangladesh was obtained from the FAO soil map of the world (FAO, 1997), and from the Soil Resources Development Institute (SRDI) for the areas in Bangladesh. The land use data outside of Bangladesh were extracted from the Global Land Cover Characteristics Data base (USGS, 2005). For the fine-scale region within Bangladesh, land use data were from the National Water Resources Database (NWRD).

***Water management interventions***: Data on river water withdrawal/diversion by hydraulic structures (e.g. pump station and barrage) at a cell are required. Existing water management interventions and that are proposed by National Water Management Plan (NWMP) of Bangladesh will be incorporated to predict the impact of climate change. The details of Kaptai reservoir at Chittagong has been considered in the fine-scale grid model. Provision has been made to incorporate water sharing at Farakka as per the Ganges Water Treaty (GWT).

***Water demand***: The demand data include domestic consumption, industrial consumption and irrigation abstractions including cropping pattern to calculate evapotranspiration. BBS population data was used to estimate domestic demand. Demand data from global data sources were used in the coarse-scale model. For water use data within Bangladesh, the minor irrigation survey data of BADC and the NWRD database of WARPO were used. Global Map of Irrigated Areas (GMIA) along with FAO (2005) and DES (2004) was used to extract irrigation data outside Bangladesh. Future population and demand within Bangladesh would be extracted from NWMP of Bangladesh.

## Assessment of Water Availability

GWAVA produces water availability indices by comparing the 90% reliable runoff and demand at each grid cell. The positive values of the index indicate an excess of supply over demand and negative values a shortfall. It is expressed as a ratio ranging from -1 (negligible water available to meet demand), through zero (available water meets demand), to 1 (available water exceeds demand).

## Calibration of the Model

Whilst many of the model parameters are linked to physical attributes, some model calibration is still necessary. The calibration parameters are soil storage parameters and flow routing parameters. A time step of one day has been used in the simulation for the base-line period of 1961-1990. Calibration of fine-scale grid model has been performed based on observed discharge data of the base line period from gage stations covering 8 catchments. A comparison of fine-scale model generated discharge and observed discharge is given in Fig. 3 for two locations, one at the north-west region while the other at the north-east region of Bangladesh. The comparisons are shown for decad average discharges by selecting a high flood year, an average flood year and a low flood year from the baseline period. The Nash and Sutcliffe coefficient of efficiency is greater than 0.68 for 50 % of the years.

## Concluding Remarks

The GWAVA model has been used in climate change impact studies in many regions of the world, including eastern and southern Africa, West Africa, and the Volga River Basin. Present study involves application of GWAVA to Bangladesh where hydrology is quite different. Bangladesh is a floodplain country where the hydrologic cycle and the runoff process have many unique characteristics. An important output of CLASIC project would be the assessment of the impacts of climate change on flooding and water availability in the complex hydrologic setting of floodplain environment in Bangladesh. Results of this study are expected to be helpful to the updating of the NWMP. The results will be presented in the final workshop of the project.

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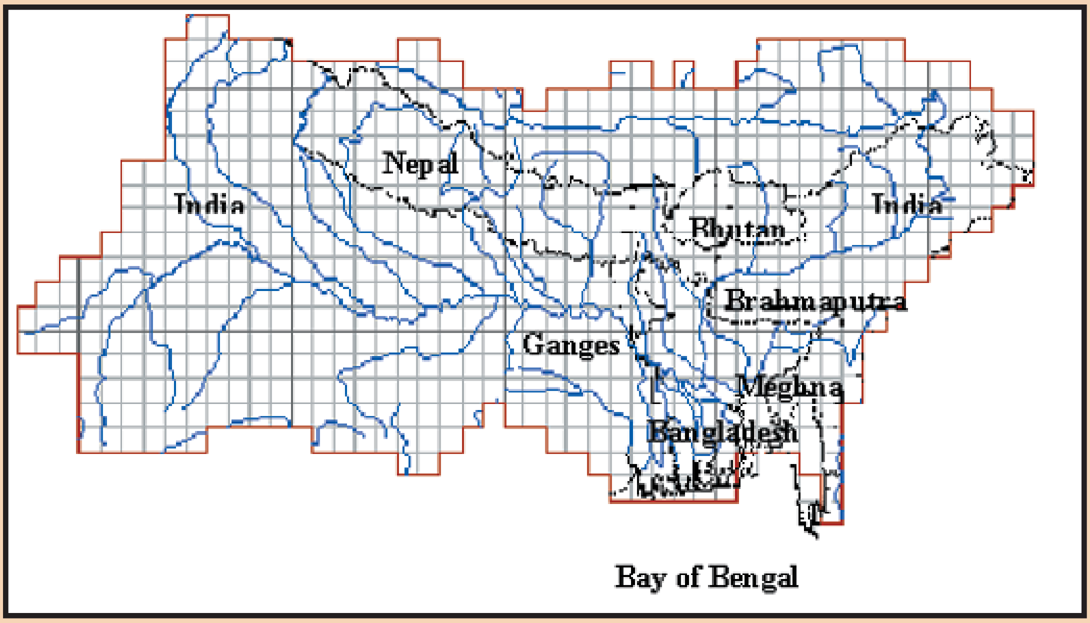


*Fig. 1(a) Representation of Ganges-Brahmaputra Meghna basins*

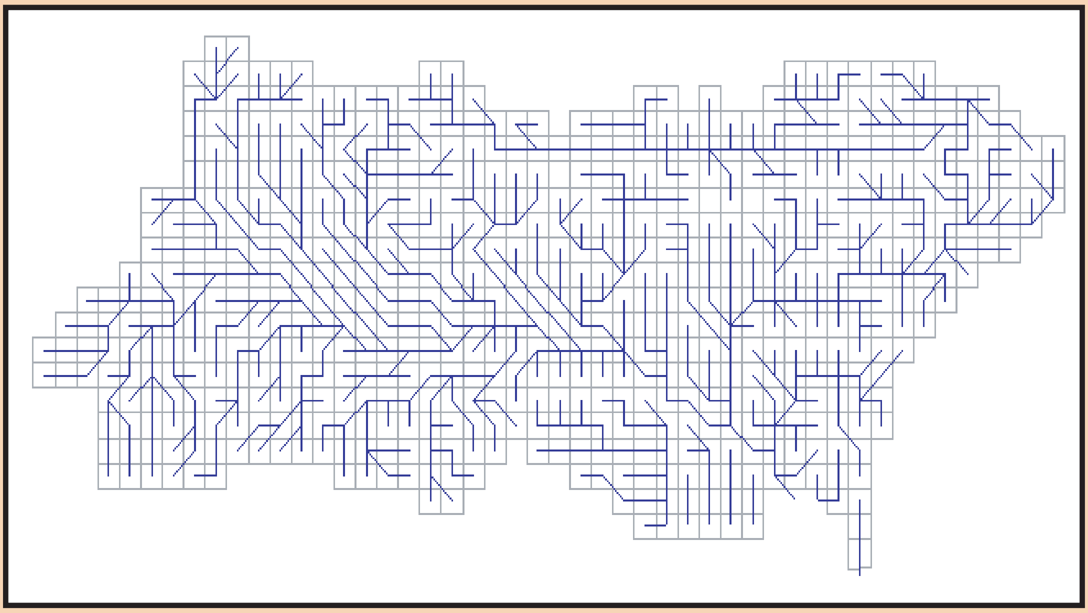

*Fig. 1 (b) Drainage network of the coarse-scale model covering GBM basins*

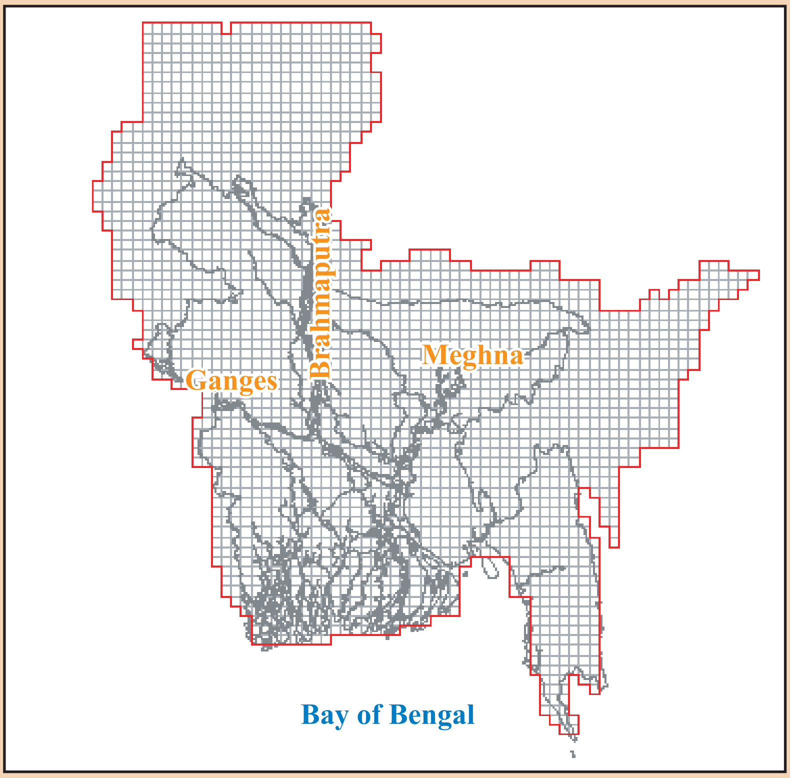


*Fig. 2(a) Representation of Bangladesh and adjacent areas*

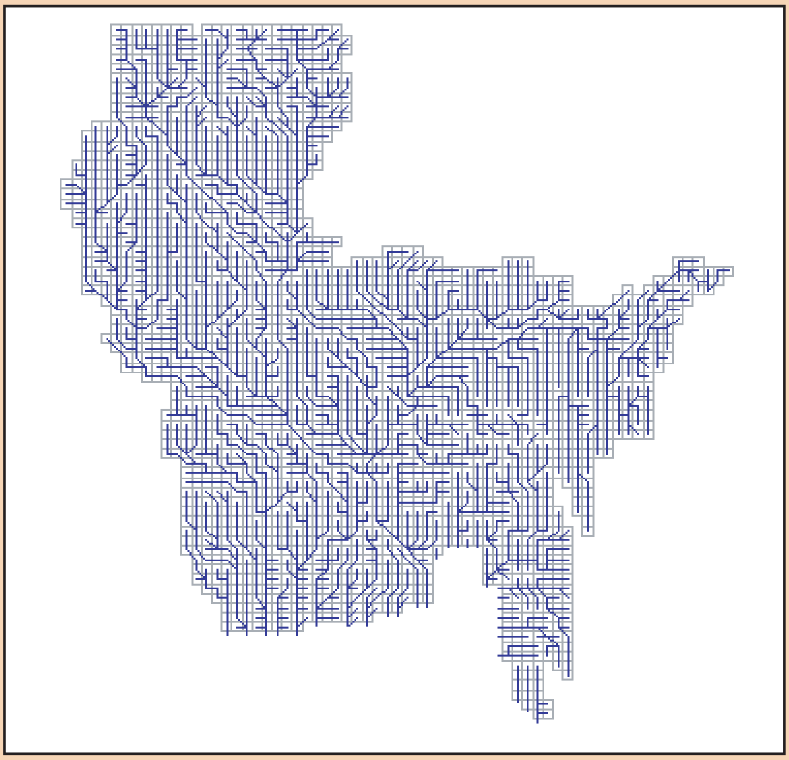

*Fig. 2 (b) Drainage network of fine-scale model covering Bangladesh and adjacent areas*


*Fig. 3 Comparison of modelled and observed discharge for two sub-catchments*
*(a) Atrai sub-catchment Area (b) Manu sub-catchment*

# Impact of Sea Level Rise on Suitability of Agriculture and Fisheries: A Case Study on Southwest Region of Bangladesh

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## Abstract

Sea Level Rise is one of the most vital issues of global climate change. It will have multiple effects on agriculture, fisheries, forest and livelihoods especially in coastal zones. To reduce vulnerability, proper landuse planning is required, which is primarily depends on the landuse suitability mapping of the possible affected areas. Considering the issues, CEGIS conducted a comprehensive research on impact of sea level rise on landuse suitability in southwest region of Bangladesh under the Ministry of Environment and Forests, Government of Bangladesh, financed by United Nation Development Programme (UNDP). Following the study, this paper presents the approach of landuse suitability mapping under different sea level rise scenarios, especially showing the impacts on agriculture (T. Aman and Boro rice) and fisheries (*Golda* and *Bagda*). Good ranges of deflections were observed regarding suitability of crops and shrimps with changing sea level rise scenarios. This study will show future pathway of sustainable landuse planning in environmentally vulnerable regions.

*Key Words: Sea Level Rise, Crop and Shrimp Suitability, Adaptation Options*

## Introduction

The issue of global climate change has come to global attention since last century. The Intergovernmental Panel on Climate Change (IPCC) was established by the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP) in 1988. This panel aims to assess all aspects of climate change. Impact assessment of climate change is continuing all over the world. Among the frightening issues of climate change, sea level rise (SLR) is a vital issue, to which livelihood of millions of people are related. A sea level rise of 0.09 to 0.88 m is projected by IPCC for 1990 to 2100, primarily from thermal expansion and loss of mass from glaciers and ice caps. It was predicted that the maximum rise of sea level would be 14 cm by the year 2025, 32 cm by the year 2050 and 88 cm by the year 2100 all over the world (IPCC, 2001). According to Nicholls and Leatherman (1995), a 1 m sea-level rise would affect 6 million people in Egypt, with 12% to 15% of agricultural land lost, 13 million in Bangladesh, with 16% of national rice production lost, and 72 million in China and "tens of thousands" of hectares of agricultural land. More than direct land loss due to seas rising, indirect factors are generally listed as the main difficulties associated with sea-level rise. These include changing erosion patterns and damage to coastal infrastructure, salinization of wells, sub-optimal functioning of the sewerage systems of coastal cities with resulting health impacts, loss of littoral ecosystems and loss of biotic resources (Gommes *et. al.*, 1998). But the agriculture sector is considered as most vulnerable to sea level rise because of multiple effect of surface water, groundwater and soil quality change.

Considering this issue, a study was carried out by Center for Environmental and Geographic Information Services (CEGIS) in the southwest region of Bangladesh to assess the impacts of sea level rise on agricultural, fisheries and forest. This study was taken under the project "Impacts of Sea Level Rise on Landuse Suitability and Adaptation Options in Southwest region of Bangladesh' financed by UNDP under the Ministry of Environment and Forests, Government of Bangladesh. Basically the suitable areas for agriculture, fisheries and forest were assessed in terms of different sea level rise scenarios. In addition, the impacts of four possible adaptation options were assessed. The major observations of the study are presented in this paper.

## Study Area and Methodology

Three districts, Khulna, Satkhira and Bagerhat, of Southwest region of Bangladesh were selected as study area for this study (Fig.1). The Sundarbans comprises parts of these districts. This part of coastal area of Bangladesh is considered as most vulnerable to sea level rise due to its unique resources such as largest mangrove forest, fisheries (*Golda i.e. freshwater shrimp* and *Bagda i.e. brackish water shrimp* farming) and agricultural lands. Hence, this area was selected for this study.

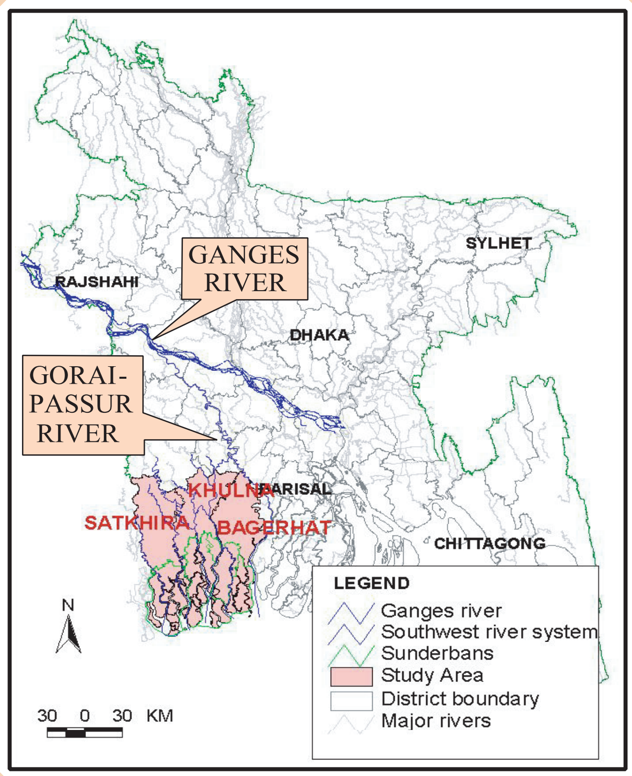



*Figure 1: Southwest Region of Bangladesh*

The sea level rise scenarios used for this study are 32 cm (by the year 2050) and 88 cm (by the year 2100) accepted for Bangladesh context (WARPO, 2005), which are also predicted by IPCC (IPCC, 2001). The impact of different sea level rise on agriculture and fisheries were assessed in terms of change in suitable land under the sea level rise scenarios. Different satellite images of 1992, 2001 and 2005 were used to delineate the existing landuse for agriculture (mainly *Boro, T. Aman* rice and *Pulses*) and fisheries (mainly *Bagda* and *Golda* shrimp) and also to know the trends of change. Field investigations were conducted to estimate the production range for crops and shrimps under different salinity and flood regimes.

An analytical tool, developed by CEGIS, named "CROPSUIT" was used to estimate the physical suitability of land for different agricultural crops and shrimps. CROPSUIT determines the physical suitability of crops and shrimps based on land characteristics and land use requirement suitability matrix. CROPSUIT model has similar computational algorithm as in Automated Land Evaluation System (ALES), developed by Cornell University. CROPSUIT computational engine uses Grid based GIS analysis and data environment. The flow diagram of CROPSUIT is shown in Figure 2.

All land characteristics (LC) data were regenerated from the soil map produced by SRDI and converted into GIS Grid format. For example, the tabular information about the land type available with the soil maps was mapped using DEM as the basis for distribution. Similarly, the soil drainage information in SRDI maps was mapped using both land type map and groundwater depth contours as a basis for distribution over the area, in GIS grid format. Also the physical changes, such as, water level (flood depth), drainage, salinity and sedimentation was analyzed under different SLR using Mike11 mathematical hydrodynamic model. The physical suitability of land use under different changed condition of flood and salinity was also computed.

The CROPSUIT generated the suitability maps and tables using the LC and land use requirement (LUR) tables as inputs. The four different categories or classes of suitability that were derived for each crop and shrimp are: S1 - highly suitable; S2 – suitable; S3 - moderately suitable; and S4 - not suitable. The criteria for each crop and shrimp that defines the suitability classes are given in Tables 1, 2, 3, 4 and 5.

Also, the four adaptation options were examined with reference to three strategies under different SLR scenarios.

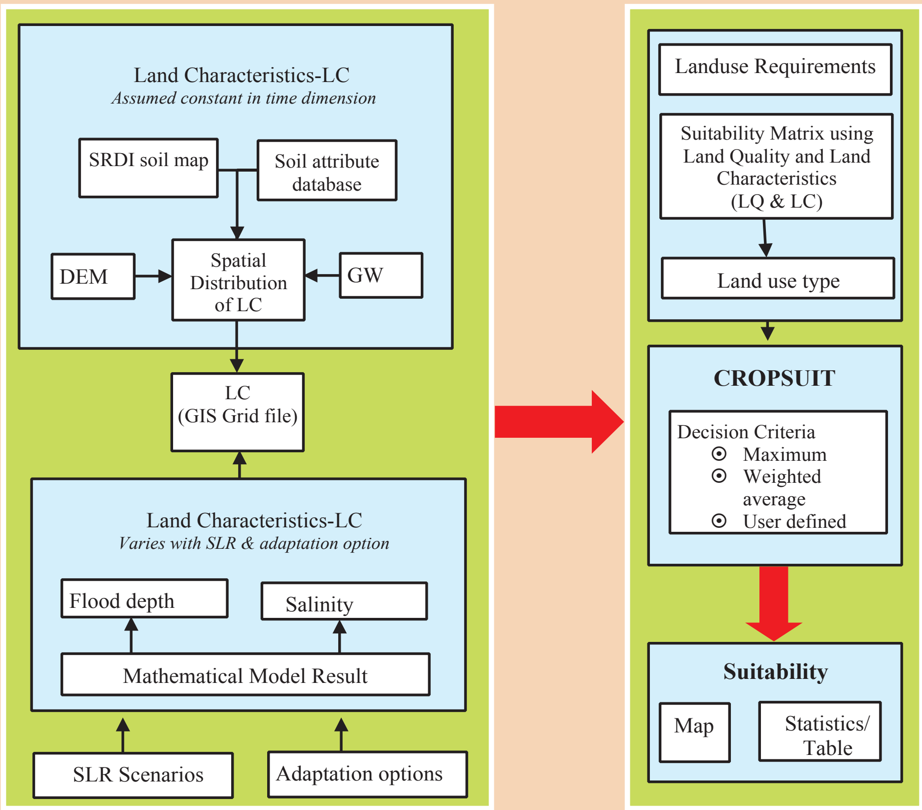



*Figure 2: Flow diagram of CROPSUIT model*

**Table 1: Criteria of Suitability for Land Use type – T Aman rice.**

| Land Characteristics | Unit | Factor rating | | | |
|---|---|---|---|---|---|
| | | S1 | S2 | S3 | S4 |
| Topsoil texture | Class | Clay, Clay loam, Silty Clay | Loam | Silt loam, Silt | , |
| Depth of inundation | Inundation depth | 1-30 | 30-90 | 90-180 | >180 |
| Drainage condition | Class | Pd | Impd | Mwd | Wd |
| Soil salinity in wet season | Ds/m | <2 | 2-4 | 4-8 | >8 |
| Moisture holding capacity | mm/m | >300 | 200-300 | 100-200 | <100 |
| Soil reaction | pH | 5.6-8.4 | 4.5-5.5 & 8.5-9.0 | <4.5 | - |

**Table 2: Criteria of Suitability for Land Use type –Boro rice.**

| Land Characteristics | Unit | Factor rating | | | |
|---|---|---|---|---|---|
| | | S1 | S2 | S3 | S4 |
| T op soil texture | Class | C, Sic, | Sicl, Cl | Sil, L | S, Sl, Ls |
| Drainage condition | Class | Pd | Impd | Mwd, | Vpd Wd |
| Depth of inundation | Inundation depth | 30-180 | <30 & >180-300 | - | >300 |
| Salts in ground water | ppt | <1.0 | 1.0-1.5 | 1.5-2.5 | >2.5 |
| Salts in surface water | ppt | <1.0 | 1.0-1.5 | 1.5-2.5 | >2.5 |
| Salinity | Ds/m | <2 | 2-4 | 4-8 | >8 |
| Soil reaction | PH | 5.6-8-4 8.5-9.0 | 4.5-5.5 & | <4.5 | - |

**Table 3: Criteria of Suitability for Land Use type –Pulses.**

| Land Characteristics | Unit | Factor rating S1 | S2 | S3 | S4 |
|---|---|---|---|---|---|
| Drainage condition | Class | Impd | pd | Wd, Mwd | Vpd |
| Depth of inundation | Inundation depth | 0-90 | 90-180 | 180-300 | >300 |
| Moisture holding capacity | mm/m | >300 | 300-200 | 200-100 | <100 |
| Soil salinity | Ds/m | <2 | 2-4 | - | >4 |
| Soil reaction | pH | 6.6-8-4 | 5.5-6.5 & 8.5-9.0 | 4.5-5.6 | <4.5 |

**Table 4: Criteria of Suitability for Landuse type - Golda.**

| Land Characteristics | Unit | Factor rating S1 | S2 | S3 | S4 |
|---|---|---|---|---|---|
| Salinity of surface water | ppt | 15-25 | 10-15 | 5-10 | 0-5 |
| Soil reaction | pH | 6.6-7.4 | 5.5-6.4 & 7.5-8.0 | 5.0-5.4 & 8.0-8.5 | >5.0 & >8.0 |
| Land type/inundation depth | Class | F2 | F1 | F3 | F0, F4 |

**Table 5: Criteria of Suitability for Landuse type - Bagda.**

| Land Characteristics | Unit | Factor rating S1 | S2 | S3 | S4 |
|---|---|---|---|---|---|
| Surface water salinity | ppt | <5 | 5-7 | 7-12 | <12 |
| Soil reaction | pH | 6.5-7.4 | 5.5-6.5 & 7.5-8.0 | 5.0-5.5 & 8.0- 8.5 | <5.0 & >8.5 |
| Depth of inundation | Inundation depth (cm) | 90-180 | 30-90 | 0-30 & >180 | Permanent water |

## Existing Landuse for Agriculture and Fisheries

Different types of satellite images were acquired to derive landuse/landcover maps of the study area such as Landsat 5 TM (April, 1992) for dry season landuses (Boro rice and Bagda shrimp), Landsat5 TM and Landsat7 ETM+ (January, 2001) for Pulses (dry season), IRS 1D – LISS III (April, 2001) for dry season landuses (Boro and Bagda), RADARSAT Standard Beam (August, September, October, 2001) for Aman rice, RADARSAT Fine Beam (August, October, November 2000) for Golda shrimp and IRS P6 LISS III (February, 2005) for Boro rice and Bagda shrimp. Existing crop and shrimp landuse is presented in the following sections.

## *Bagda shrimp*

The Bagda shrimp is mostly cultured in the southern parts of the study area (Fig. 3). It is observed from satellite image analysis that there was about 80,000 hectares of Bagda shrimp area in 1992. It was highly practiced in Rampal and Paikgachha, which are about 15658 ha and 14,195 ha respectively. After 1992, the practice of Bagda shrimp cultivation was increased dramatically. A big amount of fallow land, which is about 95,017 hectares, was converted to Bagda shrimp areas. A total of 175,330 ha Bagda shrimp areas were found in 2001 whereas in 2005, the total area was about 187,640 ha. Since 2001 to 2005 the Bagda shrimp cultivation was also increased but the rate was low.

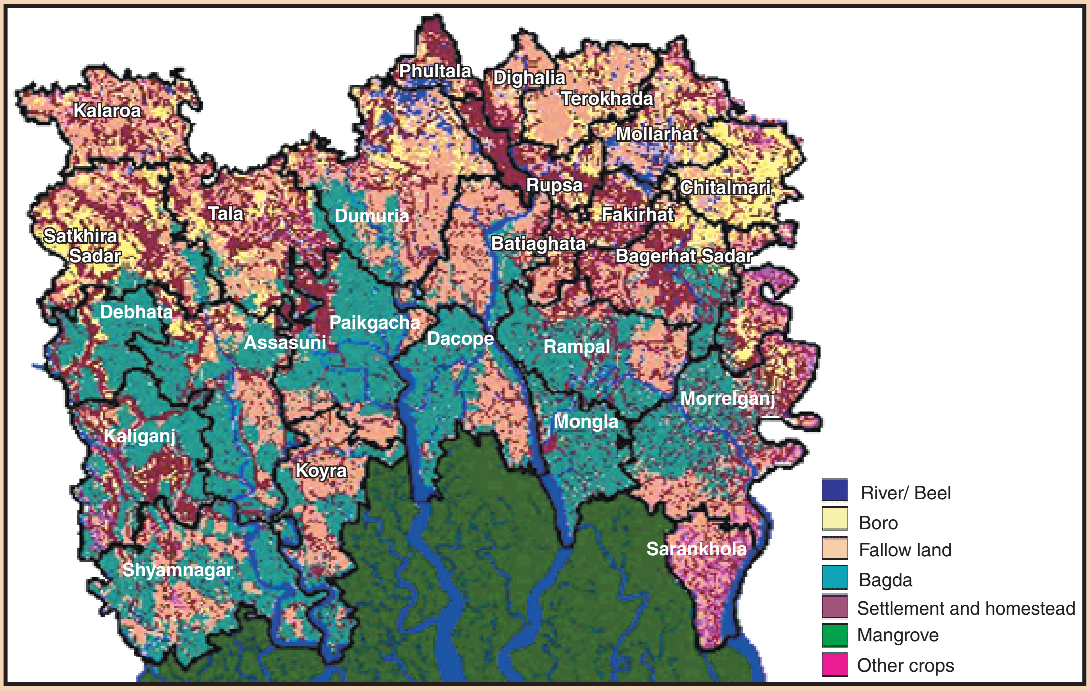



*Figure 3: Boro and Bagda area, 2005*

## *Boro rice*

It was found that there was about 53,685 hectares of boro rice area in 1992. It was commonly practiced in Satkhira Sadar and Kalaroa Upazila. After 1992 the Boro rice increased to about 94,546 hectare in 2001. From analysis it was found that a big amount of fallow land about 41, 681 hectare including a little potion of other landuses / landcovers were converted to boro rice areas. It was highly increased in Mollarhat, Terokhada, Dumuria, Tala and Chitalmari Upazila. As the boro rice areas of 2005 do not represent the whole study area it was not compared with the boro areas of 1992 and 2001.

***Aman rice***

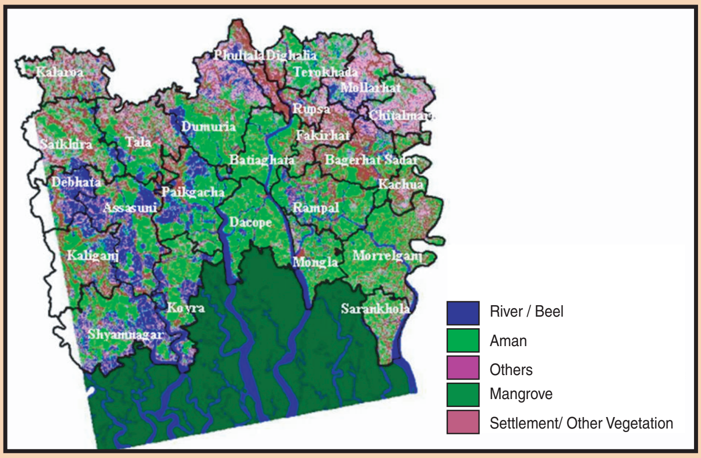



*Figure 4: Aman area, 2001*

A total of 2,39,196 hectare of land (39% of the total study area excluding rivers and the Sundarbans) was found under Aman rice cultivation during the wet season in 2001 (Fig. 4). It should be noted that this figure does not represent the total Aman area in the study area as the western part of Satkhira Sadar, Debhata, Kaliganj and Shyamnagar Upazila was not covered by the RADARSAT image. From aimage analysis it was found that this rainfed crop is quite dominant in Morrelganj, Dacope, Rampal, Paikgacha and Dumuria. Some farmers take up Aman cultivation in the southern part of the study area after harvesting Bagda. In the northern part, Aman is cultivated relatively less, especially in Mollarhat, Chitalmari, Kalaroa, Fakirhat and Rupsa upazila.

## *Golda shrimp*

It was found that golda is mainly cultivated in the northeast part of the study area. Fine Beam images show that the Golda area is about 27,476 hectare in 2000, which is 5% of the study area excluding rivers and the Sundarbans. Most extensive cultivation is found in Dumuria (23% of the total Golda area) and Mollarhat (20% of the total Golda area).

## *Pulses*

About 5% of the total area excluding rivers and the Sundarbans was under Pulses (2001). From image analysis it was found that Pulses are cultivated relatively more in Tala, Kalaroa and Shyamnagar Upazila. On the other hand, very little practice of pulses was found in Dacope, Debhata, Paikgacha, Koyra and Terokhada Upazila. Besides, about 6% of the total area excluding rivers and the Sundarbans was under other winter crops. About 14% of "Other Winter Crops" was found in Tala Upazila.

## Impact of SLR on Suitability of Crops and Shrimps

Crop suitability model, CROPSUIT, was run under different SLR scenarios and produce suitability maps for land use types – T Aman, Boro, Pulses, Bagda and Golda. The change in suitability under different SLR scenarios from base condition was analyzed. The results of the model are presented in the following sections.

## *T. Aman*

The T Aman suitability map has been generated for different SLR scenarios using CROPSUIT model as shown in Figure 5. In the base condition, the suitable area was about 84% and it is reduced to only 12 percent under 88 cm SLR scenario. Consequently, 'not suitable' areas are increased gradually with the increase of sea level. It suggests that production of T.Aman will be reduced significantly due to sea level rise. It can be noted that there is no highly suitable area for this crop in the study area.

| Scenarios | Highly Suitable (S1) Area | Suitable (S2) Area | Moderately Suitable (S3) Area | Not Suitable (S4) Area |
|---|---|---|---|---|
| Base | 0 % | 84 % | 14 % | 2 % |
| 32 cm SLR | 0 % | 60 % | 24 % | 16 % |
| 88 cm SLR | 0 % | 12 % | 57 % | 31 % |

***Suitability for 32 cm SLR*** ***Suitability for 88 cm SLR***

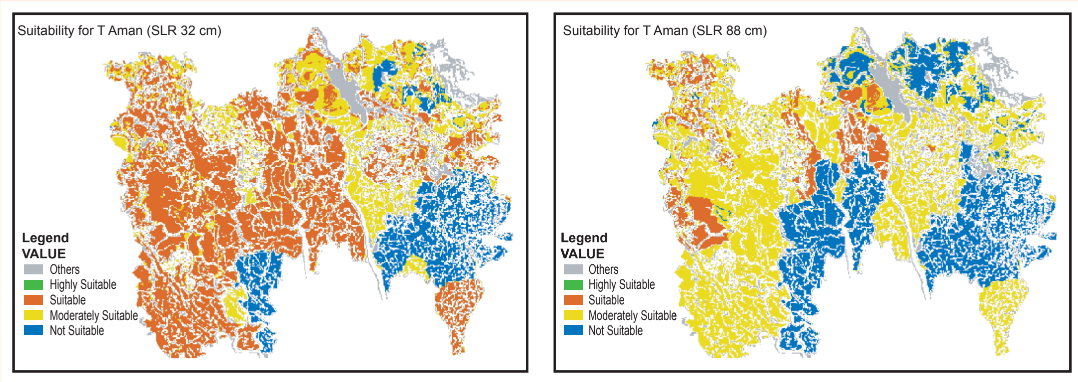



*Figure 5: T Aman - Suitability under different SLR scenarios*

## Boro

For different SLR scenarios, the Boro rice suitability map has been generated using CROSUIT model, which is shown in Figure 6. The data shows that the 'not suitable' area will be increased from 11% to 61% from base condition to 88 cm SLR. But the moderately suitable area will not reduce significantly.

| Scenarios | Highly Suitable (S1) Area | Suitable (S2) Area | Moderately Suitable (S3) Area | Not Suitable (S4) Area |
|---|---|---|---|---|
| Base | 10 % | 36 % | 43 % | 11 % |
| 32 cm SLR | 0 % | 6 % | 37 % | 57 % |
| 88 cm SLR | 0 % | 6 % | 33 % | 61 % |

***Suitability for 32 cm SLR*** ***Suitability for 88 cm SLR***

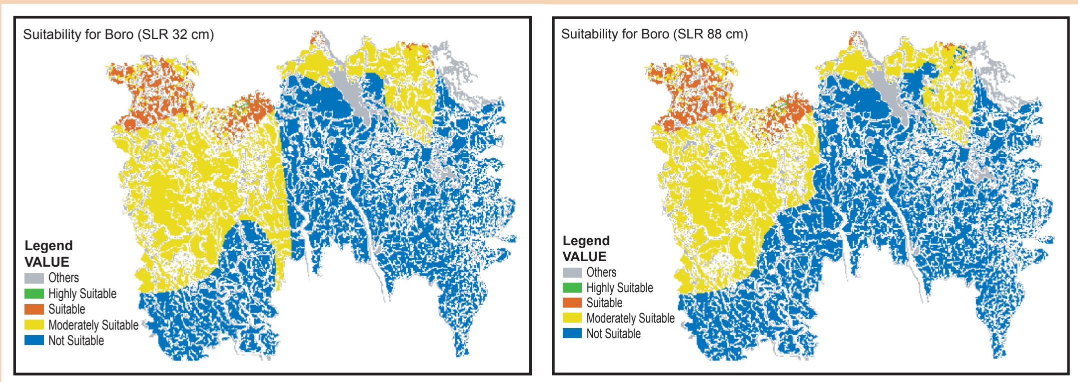



*Figure 6: Boro - Suitability under different SLR scenarios*

## Pulse

The suitability map for Pulses (Fig. 7) shows that the suitable area for pulse will be reduced to 8% at 88 cm SLR from the base i.e. from 14 % to 8 %. However, the moderately suitable will not be reduced significantly.

| *Scenarios* | *Highly Suitable (S1) Area* | *Suitable (S2) Area* | *Moderately Suitable (S3) Area* | *Not Suitable (S4) Area* |
|---|---|---|---|---|
| Base | 3 % | 14 % | 37 % | 47 % |
| 32 cm SLR | 2 % | 9 % | 35 % | 54 % |
| 88 cm SLR | 1 % | 8 % | 27 % | 64 % |

***Suitability for 32 cm SLR*** ***Suitability for 88 cm SLR***

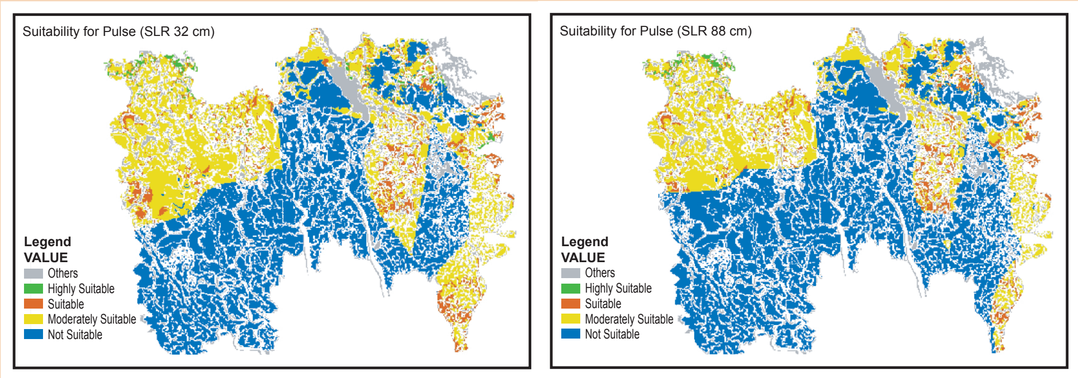



*Figure 7: Pulses - Suitability under different SLR scenarios*

## Bagda

CROPSUIT model used three land characteristic data i.e. inundation, surface water salinity and pH, of which pH assumed constant in the time dimension for evaluating the suitability for Bagda cultivation under SLR scenarios period. The Bagda suitability maps for different SLR scenarios are shown in Figure 8. It is found that the suitable area will increase up to 37 % with 32 cm sea level rise but it will reduce from 32 cm SLR to 88 cm SLR due to increase of flood depth and salinity. So it can predicted that Bagda production will increase due to sea level rise up to 32 cm.

| *Scenarios*□*Highly Suitable (S1) Area* | □*Suitable (S2) Area* | □*Moderately Suitable (S3) Area* | □*Not Suitable (S4) Area* | |
|---|---|---|---|---|
| Base□0 % | □25 % | □35 % | □40 % | |
| 32 cm SLR□1 % | □37 % | □42 % | □20 % | |
| 88 cm SLR□9 % | □29 % | □29 % | □33 % | |

***Suitability for 32 cm SLR*** ***Suitability for 88 cm SLR***

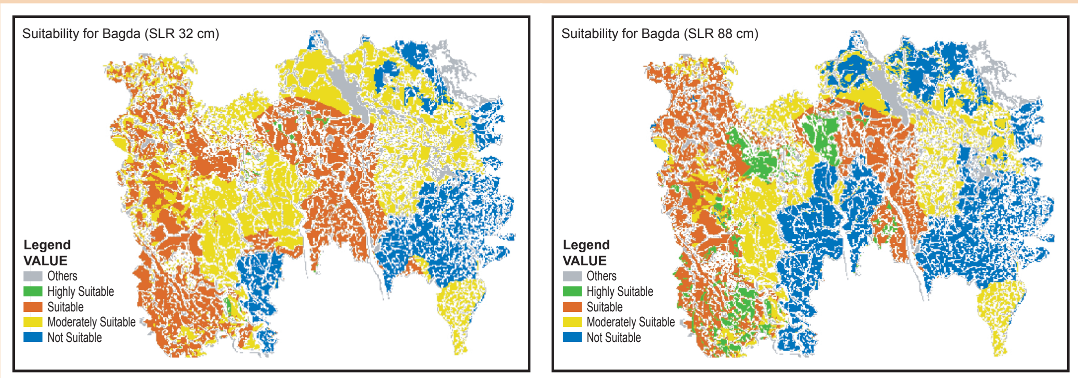



*Figure 8: Bagda - Suitability under different SLR scenarios*

## Golda

The Golda suitability maps (Fig. 9) show that the 'not suitable' area will increase from 30% to 57% from base condition to 88 cm SLR. In contrary, the suitable area will reduce from 38% (under 32 cm SLR) to 17% (under 88 cm SLR).

| *Scenarios* | *Highly Suitable (S1) Area* | *Suitable (S2) Area* | *Moderately Suitable (S3) Area* | *Not Suitable (S4) Area* |
|---|---|---|---|---|
| Base | 2 % | 38 % | 30 % | 30 % |
| 32 cm SLR | 3 % | 27 % | 25 % | 45 % |
| 88 cm SLR | 6 % | 17 % | 19 % | 57 % |

***Suitability for 32 cm SLR*** ***Suitability for 88 cm SLR***

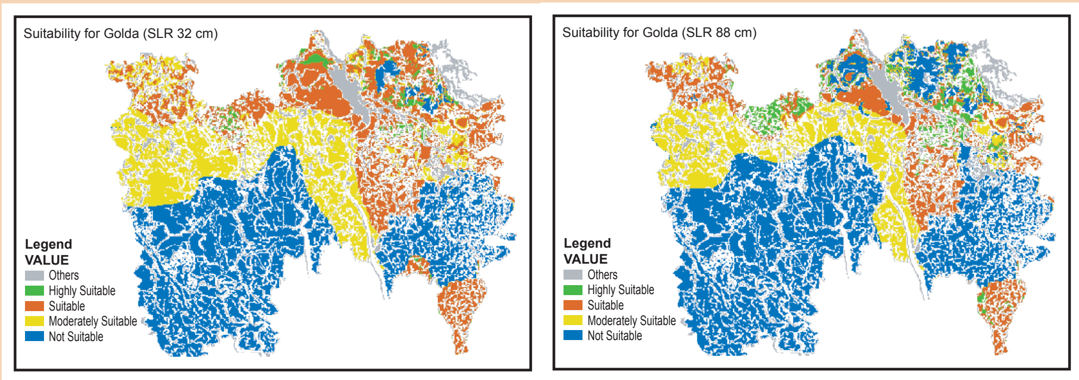



*Figure 9: Golda - Suitability under different SLR scenarios.*

## Possible Adaptation Options and their Effect

Several physical measures could be taken to reduce the effects of sea level rise. In this study, the effects of possible physical interventions under different SLR on crops and shrimps (categorized by cropping patterns) were analyzed. The major observations are presented in the following sections.

## *Physical adaptation measures*

To assess the improvement of the change in crop suitability under different scenarios, four physical measures were tested, such as:

- Long term measures – Ganges barrage
- Mid term measure – Augmentation of Gorai flow
- Construction of closures on main river systems (Pussur, Shibsha and Kobadak rivers)
- Raising embankments to prevent overtopping

These physical measures were considered to protect the effect of 88 cm SLR. To evaluate the impact of these measures on crop suitability, three strategies have been considered. The strategies are:

- **Environmental:** to ensure crop suitability as per landuse zone based on physical suitability
- **Social:** to maximize the social preferences, for example maximizing paddy cultivation.
- **Economic:** to maximize economic return through credit facilities and other financial incentives to the farmer to grow most economically profitable crops-shrimp.

## *Cropping patterns*

Eight different types of cropping patterns were considered for the impact analysis with and without the physical measures. The cropping patterns along with the decision tree are shown in Table 6.

**Table 6: Cropping pattern in the area.**

| Sl. No. Sub- zones | Cropping pattern Name/ | Decision Tree (Paddy preference) | Decision Tree (Shrimp preference) |
|---|---|---|---|
| 1 | Fallow-Fallow-Boro | 3 | 7 |
| 2 | Fallow-T Aman-Boro | 1 | 5 |
| 3 | Fallow-T Aman – Fallow | 4 | 8 |
| 4 | Fallow-T Aman-Pulses | 2 | 6 |
| 5 | Bagda-T Aman-Bagada | 6 | 1 |
| 6 | Bagda-Fallow-Bagda | 8 | 2 |
| 7 | Golda-Golda-Boro | 5 | 4 |
| 8 | Golda-Golda-Golda | 7 | 3 |

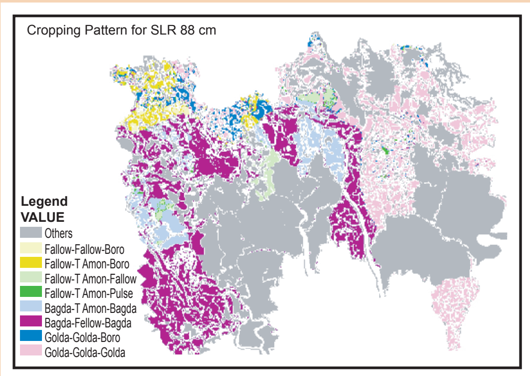
## *Impact of environmental strategy*

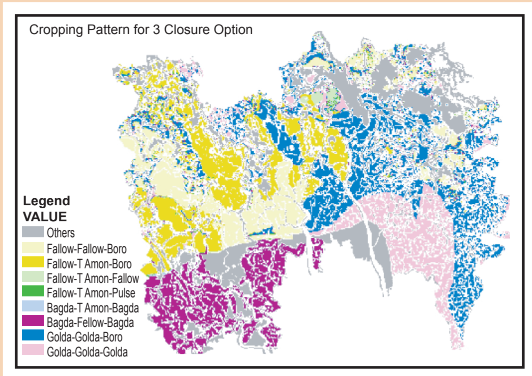
It was assumed that the physically suitable land is less adverse to the environment. On this assumption landuse zoning was delineated for the respective crops. The share of land for each cropping patterns under different scenarios and options are shown Table 7 and Figure 10. It is observed that, under *do-nothing* option Fallow-T.Aman-Boro areas will reduce from 45% to 5% with 88 cm SLR in year 2100, whereas the area suitable for Bagda cultivation will increase from 20% to 55% in year 2100.

**Table 7: Distribution of Landuse Zones for Environmental Strategy**

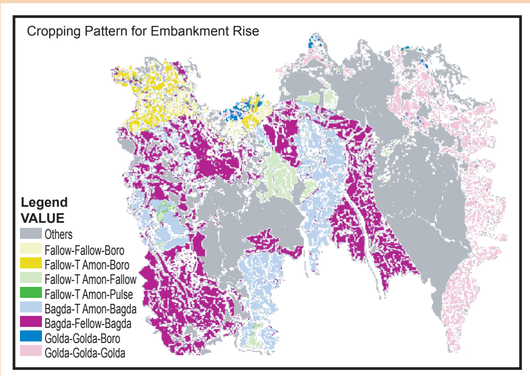
| SLR/Adaptation Options | | Percent of Land for Different Cropping pattern | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Fallow-Fallow-Boro | Fallow-T Aman-Boro | Fallow-T Aman-Fallow | Fallow-T Aman-Pulse | Bagda-T Aman-Bagda | Bagda-Fallow-Bagda | Golda-Golda-Boro | Golda-Golda-Golda | Total |
| Do nothing | SLR 0 cm (base) | 0 | 45 | 25 | 0 | 20 | 0 | 5 | 5 | 100 |
| | SLR 32 cm (Y2050) | 0 | 5 | 30 | 5 | 35 | 5 | 0 | 20 | 100 |
| | SLR 88 cm (Y2100) | 0 | 5 | 5 | 0 | 10 | 45 | 5 | 30 | 100 |
| With physical measures considering SLR 88 cm | Closures | 15 | 20 | 0 | 0 | 0 | 15 | 35 | 15 | 100 |
| | Embankment raise | 5 | 5 | 5 | 0 | 20 | 45 | 0 | 20 | 100 |
| | Augmentation of Gorai flow | 15 | 10 | 0 | 0 | 0 | 20 | 35 | 20 | 100 |
| | Ganges barrage | 15 | 15 | 0 | 0 | 0 | 15 | 35 | 20 | 100 |

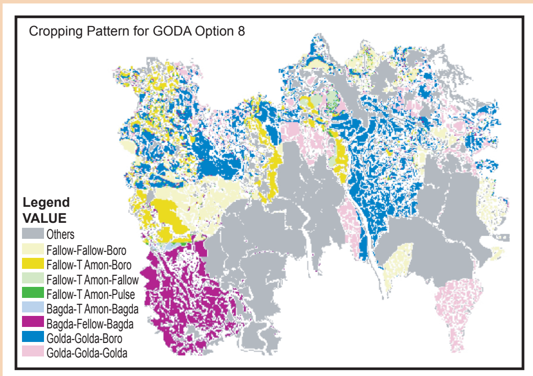
With the physical measures, with closure option, the Fallow-T.Aman-Boro suitable zone can be restored upto 20% from 5%, and Bagda zone will reduce to 15%. But with Ganges barrage, more fresh water flow which pushes the salinity front down, will shift Bagda dominant zone towards Golda-Boro dominant zone which is more environment friendly. On the other hand embankment raising option will increase the Bagda dominant zone inside the polders.




*Do-nothing with 88 cm SLR in year 2100 Closures with 88 cm SLR in year 2100*




*Raising embankments with 88 cm SLR in year 2100 Ganges barrage with 88 cm SLR in year 2100*

*Figure 10: Change in Landuse (crops) for Environmental Strategy*

## *Impact of Social strategy*

The objective of this strategy was to attain maximum paddy cultivation, which will contribute to food-security and social well-being. In this regard paddy cultivation generates job opportunities for low-income groups (day laborers). The assumption for this strategy was that the farmer would grow paddy (Aman or Boro), even if the physical suitability of land were rated as S3 (moderate suitable) for paddy cultivation. Accordingly, crop landuse zones were delineated under different scenarios and options, which are shown in Table 8 and Figure 11.

It is observed that, under do-nothing option fallow-T.Aman-Boro will reduce from 90% to 50% with 88 cm SLR in year 2100. Where as the zone suitable for Bagda-T.Aman-Bagda cultivation will increase from 5% to 25% in year 2100.

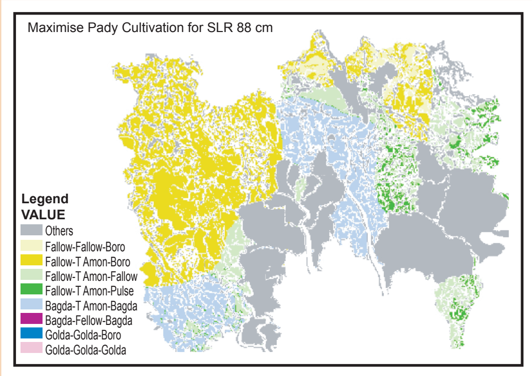
With the physical measures, with closure option, 95% of the land might be brought under paddy cultivation, and Golda zone will increase to 5%. But with Ganges barrage, the total land (100%) will come under paddy cultivation.

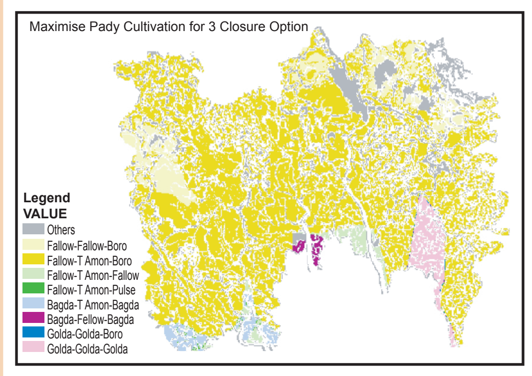
## *Impact of Economic strategy*

The objective of this strategy was to achieve maximum economic return through increased income from shrimp cultivation. The assumption for this strategy was that the farmer would cultivate shrimp, even if the production were as low as 100 kg/ha. Accordingly, landuse zones were delineated under different scenarios and options and they are shown in Table 9 and Figure 12.

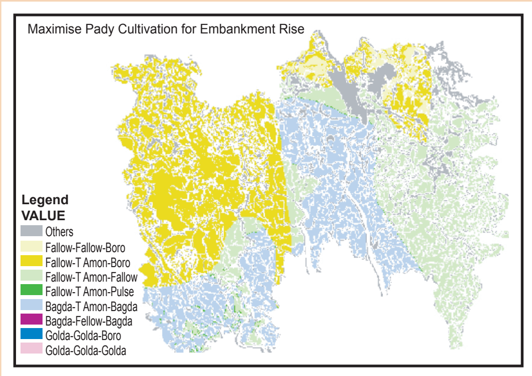
**Table 8: Distribution of Landuse Zones for Social Strategy.**

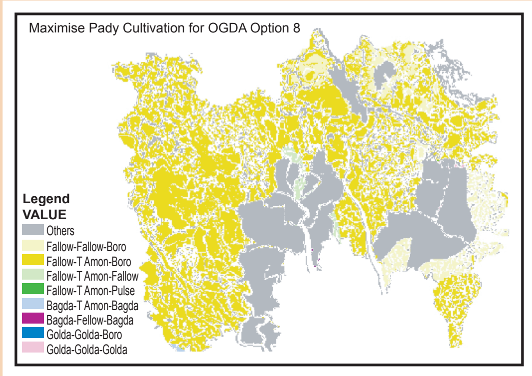
| SLR/Adaptation Options | | Percent of Land for Different Cropping pattern | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Fallow-Fallow-Boro | Fallow-T Aman-Boro | Fallow-T Aman-Fallow | Fallow-T Aman-Pulse | Bagda-T Aman-Bagda | Bagda-Fallow-Bagda | Golda-Golda-Boro | Golda-Golda-Golda | Total |
| Do nothing | SLR 0 cm (base) | 0 | 90 | 5 | 0 | 5 | 0 | 0 | 0 | 100 |
| | SLR 32 cm (Y2050) | 0 | 50 | 20 | 5 | 25 | 0 | 0 | 0 | 100 |
| | SLR 88 cm (Y2100) | 5 | 50 | 15 | 5 | 25 | 0 | 0 | 0 | 100 |
| With physical measures considering with SLR 88 cm | Closures | 10 | 85 | 0 | 0 | 0 | 0 | 0 | 5 | 100 |
| | Embankment raise | 5 | 40 | 30 | 0 | 25 | 0 | 0 | 0 | 100 |
| | Augmentation of Gorai flow | 15 | 75 | 5 | 0 | 5 | 0 | 0 | 0 | 100 |
| | Ganges barrage | 15 | 85 | 0 | 0 | 0 | 0 | 0 | 0 | 100 |




*Do-nothing with 88 cm SLR in year 2100 Closures with 88 cm SLR in year 2100*



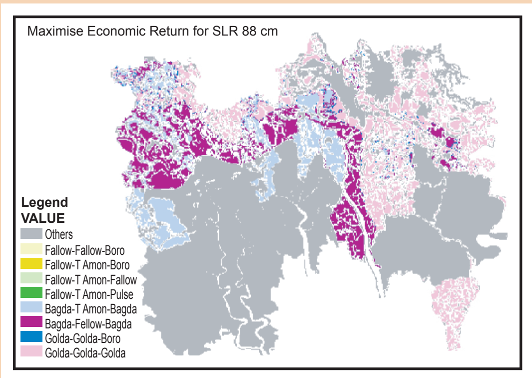

*Raising embankments with 88 cm SLR Ganges barrage with 88 cm SLR*
*in year 2100 in year 2100*

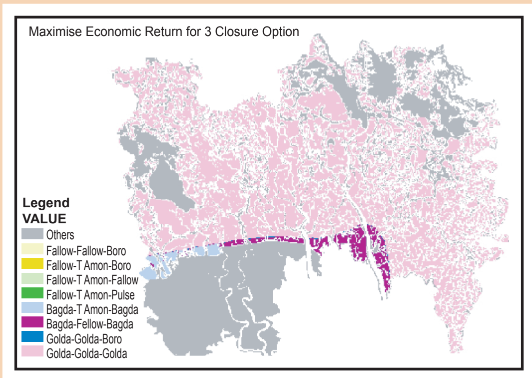
*Figure 11: Change in Landuse (crops) for Social Strategy*

It is seen that, under do-nothing option, 75% of the land will be suitable for shrimp production and the remaining 25% will be suitable for Bagda-T.Aman-Bagda. The closure, Ganges barrage and Gorai augmentation will make the land more suitable for Golda cultivation than Bagda. With the physical measures, raising embankments, maximum area will be suitable for Bagda cultivation.

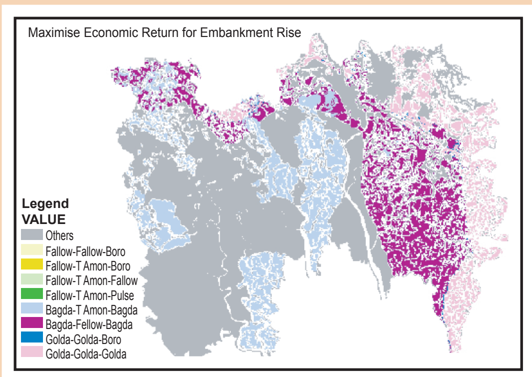
**Table 9: Distribution of landuse zones for Economic strategy.**

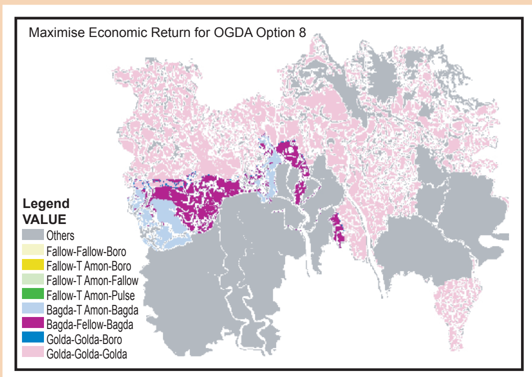
| SLR/Adaptation Options | | Percent of Land for Different Cropping pattern | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Fallow-Fallow-Boro | Fallow-T Aman-Boro | Fallow-T Aman-Fallow | Fallow-T Aman-Pulse | Bagda-T Aman-Bagda | Bagda-Fallow-Bagda | Golda-Golda-Boro | Golda-Golda-Golda | Total |
| Do nothing | SLR 0 cm (base) | 0 | 0 | 0 | 0 | 55 | 5 | 0 | 40 | 100 |
| | SLR 32 cm (Y2050) | 0 | 0 | 0 | 0 | 75 | 5 | 0 | 20 | 100 |
| | SLR 88 cm (Y2100) | 0 | 0 | 0 | 0 | 25 | 30 | 0 | 45 | 100 |
| With physical measures considering with SLR 88 cm | Closures | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 95 | 100 |
| | Embankment raise | 0 | 0 | 0 | 0 | 35 | 40 | 0 | 25 | 100 |
| | Augmentation of Gorai flow | 0 | 0 | 0 | 0 | 5 | 15 | 0 | 80 | 100 |
| | Ganges barrage | 0 | 0 | 0 | 0 | 5 | 10 | 0 | 85 | 100 |




*Do-nothing with 88 cm SLR in year 2100 Closures with 88 cm SLR in year 2100*




*Raising embankments with 88 cm SLR in year 2100 Ganges barrage with 88 cm SLR in year 2100*

*Figure 12: Change in Landuse (crops) for Economic Strategy*

## Impact of Adaptation options on Production of Paddy and Shrimp

*Paddy production*

Under different SLR scenarios the paddy production has been estimated and shown in Table 10 by districts. In base condition the production is over 200 kg/ca/yr, which will reduce to 96 and 30 kg/ca/yr in year 2050 and 2100 respectively. Among the three districts, Bagerhat is the worst affected district.

**Table 10: Paddy production (kg/capita/year) under different SLR scenarios.**

| District Yr | Paddy production (kg/capita/year) under different SLR scenarios | | |
|---|---|---|---|
| | Base 2005 | SLR 32 cm Yr 2050 | SLR 88 cm Yr 2100 |
| Bagerhat | 287 | 77 | 5 |
| Khulna | 123 | 52 | 14 |
| Sathkira | 298 | 161 | 70 |
| **Average** | **236** | **96** | **30** |

This study also estimated the paddy production under different adaptation options. The comparison is done against the 88 cm SLR (year 2100) as shown in Table 11. It is seen that with Ganges barrage the per capita production increased from 30 to 133 kg/ca/yr, where as the closure option will give maximum production increase, 30 to 180 kg/ca/yr.

**Table 11: Paddy production (kg/capita/year) in year 2100 under different adaptation options.**

| Districts | Paddy production (kg/capita/year) under different SLR scenarios | | | | |
|---|---|---|---|---|---|
| | SLR 88 | Closure | Augmentation of Gorai flow | Ganges barrage | Embankment raising |
| Bagerhat | 5 | 132 | 69 | 106 | 2 |
| Khulna | 14 | 136 | 60 | 81 | 30 |
| Sathkira | 70 | 272 | 165 | 212 | 69 |
| **Average** | **30** | **180** | **98** | **133** | **33** |

*Shrimp production*

From field investigation and secondary data the shrimp productions (kg/ha) were collected and used in estimation of shrimp production as shown in Table 12. Under different SLR scenarios the shrimp production was estimated and shown in Table 13 by districts. In base condition the production is about 40,000 tons in three districts. This will increase to double in year 2050 and over three times in the year 2100 under different SLR scenarios.

**Table 12: Present Shrimp production (kg/ha) by landuse zones.**

| Land use zone | Shrimp production (kg/ha) | |
|---|---|---|
| | **Bagda** | **Golda** |
| Bagda-T.Aman-Bagda | 185 | |
| Bagda-Fallow-Bagda | 275 | |
| Golda-Golda-Boro | | 570 |
| Golda-Golda-Golda | | 570 |

**Table 13: Shrimp production (Ton/Yr) under different SLR scenarios.**

| **District** | **Shrimp production (Ton/Yr)** | | |
|---|---|---|---|
| | **Base** | **SLR 32 cm** | **SLR 88 cm** |
| Bagerhat | 10,740 | 27,265 | 50,502 |
| Khulna | 21,032 | 34,290 | 33,649 |
| Sathkira | 7,414 | 17,245 | 45,946 |
| **Total** | **39,186** | **78,800** | **130,097** |

## Conclusions

Since the natural resources of the world are vulnerable to climate change induced sea level rise, we should proper attention to this issue and develop efficient technologies for adaptation. Landuse suitability mapping will assist in reducing vulnerability and will guide proper landuse planning in the possible affected coastal zones. Further studies should be taken to improve this method of landuse suitability analysis and implementing it in landuse planning.

### *Acknowledgement*

*We highly appreciate the assistance of the research project ‘Impacts of Sea Level Rise on Landuse Suitability and Adaptation Options in Southwest region of Bangladesh’ conducted by Center for Environmental and Geographic Information Services (CEGIS) and the team members: Iffat Huq, M.M. Awlad Hossain, Someswar Das, Atiq Kainan Ahmed, Mohammad Ragib Ahsan, Mohammad Razu Ahmed, Md. Shahidul Islam, S. M. Shazzadul Haq, S H M Fakruddin, Dr. Munir Ahmed, Mohammad Hossain Mollah, Syed Ahsanul Haque, Md. Atikul Islam, Ruknul Ferdous, Md. Mahadiur Rahman. We are also thankful to Giasuddin Ahmed Choudhury, the Executive Director of CEGIS for kind cooperation.*

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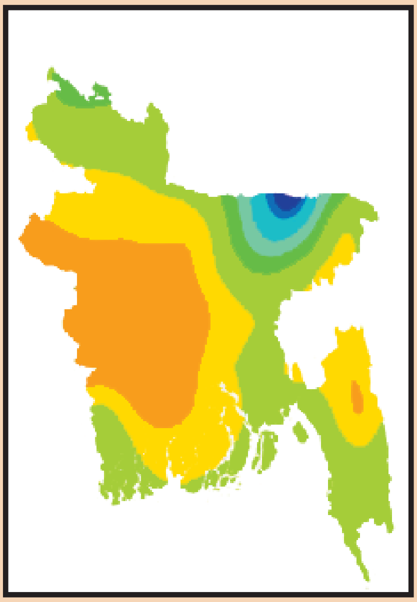

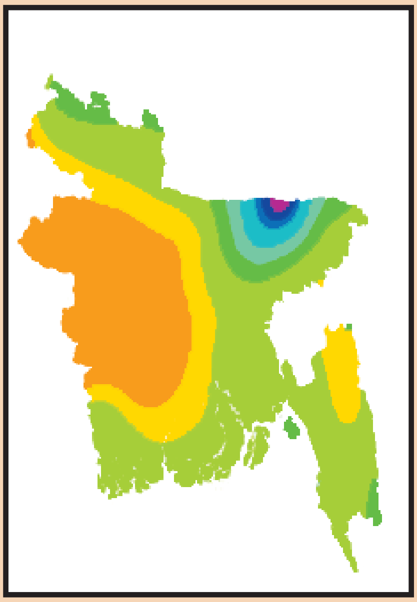

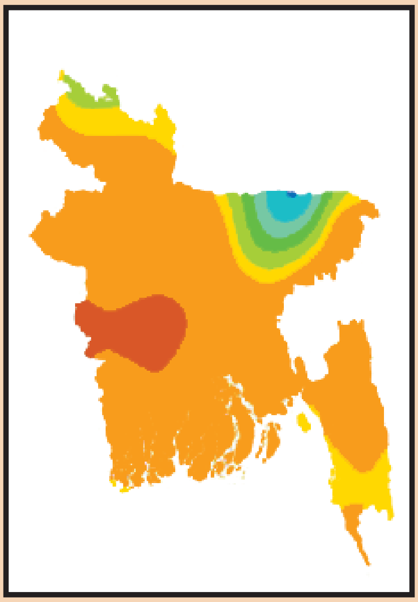

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