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MINISTRY OF WATER RESOURCES

BANGLADESH WATER DEVELOPMENT BOARD

MEGHNA ESTUARY STUDY

TECHNICAL NOTE MES-014

CLIMATE CHANGE AND WATER LEVEL RISE

August 1998

DHV CONSULTANTS BV

in association with

KAMPSAX INTERNATIONAL
DANISH HYDRAULIC INSTITUTE

DEVELOPMENT DESIGN CONSULTANTS
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A-45

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Technical Note on:

CLIMATE CHANGE AND WATER LEVEL RISE IN THE MEGHNA ESTUARY

Dhaka, March 1998

Project Name	:	Meghna Estuary Study (MES)
Location	:	Meghna Estuary
Key words	:	Climate change, green house effect, water level rise
		Effects sea level rise on natural resources
		Description of activities and timing
		Evaluation installation methodology

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1.0 CLIMATE CHANGE AND SEA LEVEL RISE

1.1 Introduction

Bangladesh, one of the least developed countries of the world, may also be one of the most vulnerable to climate change. The wide spread flood in 1988 which submerged about two-thirds of the country, and the storm surge of April 1991 which resulted in the deaths of 1,38,868 coastal inhabitants, are recent reminders of the degree to which the people of Bangladesh are subject to present-day variations in climate. The possibility of changes in climate and sea level rise must be considered seriously in the context of the future development of Bangladesh.

For global climate and sea level change, IPCC (Intergovernment Panel on Climate Change) is taken into account of the following (Houghton, et al., 1993):

- there is a natural greenhouse effect which already keeps the earth warmer than it would otherwise be.

- Emissions resulting from human activities are substantially increasing the atmospheric concentrations of the greenhouse gases: carbon dioxide, methane, chlorofluoro carbons (CFCs) and nitrous oxide. These increases will enhance the greenhouse effect, resulting on average in an additional warming of the earth's surface. The main greenhouse gas, water vapour, will increase in response to global warming and further enhance it.

- Under the IPCC Business-as-Usual (Scenario A) emissions of greenhouse gases, a rate of increase of global mean temperature during the next century of about 0.3°C per decade (with an uncertainly range of 0.2°C to 0.5°C per decade); this is greater than that seen over the past 10,000 years. This will result in a likely increase in global mean temperature of about 1°C above the present value by 2025 AD and 3°C before the end of the next century. The rise will not be steady because of the influence of other factors.

- Under the IPCC emission scenarios which assume progressively increasing levels of controls, rates of increase in global mean temperature of about 0.2°C per decade (Scenario B), just above 0.1°C per decade (Scenario C) and about 0.1°C per decade (Scenario D).

- That land surfaces warm more rapidly than the ocean, and high northern latitudes warm more than the global mean in winter.

- Regional climate changes differently from the global mean, although our confidence in the prediction of the detail of regional changes is low. For example, temperature increases in Southern Europe and central North America are predicted to be higher than the global mean, accompanied on average by reduced summer precipitation and soil moisture. There are less consistent predictions for the tropics and the Southern Hemisphere.

- Under the IPCC Business-as-Usual emissions scenario, an average rate of global sea level rise of about 6 cm per decade over the next century (with an uncertainty range of 3 - 10 cm per decade), is mainly due to thermal expansion of the oceans and the melting of some land ice. The predicted rise is about 20 cm in global mean sea level by 2030 AD, and 65 cm by the end of the next century. There will be significant regional variations. The increased in global temperatures are shown in figures 1.1 and 1.2.

There is a concern that human activities may be inadvertently changing the climate of the globe through the enhanced greenhouse effect by past and continuing emissions of carbon dioxide and other gases which will cause the temperature of the Earth's surface to increase - popularly termed the "global warming". If this occurs, consequent changes may have a significant impact on society.

2.0 Climate change in Bangladesh and IPCC Assessment

2.1 Climate Changes in Bangladesh

A simple definition of climate is the average weather. A description of the climate over a period (which may typically be from a few years to a few centuries) involves the averages of appropriate components of the weather over that period, together with the statistical variations of those components.

Fluctuations of climate occur on many scales as a result of natural processes; this is often referred as to natural climate variability. The climate change is that which may occur over a century as a result of human and other activities.

In order to assess the meaning of global climate changes for Bangladesh, it is first necessary to understand the present climate, and then ask how that climate could be altered through greenhouse gas forcing. Bangladesh enjoys a tropical climate, although the Tropic of Cancer (23.5^{0}N) passes through the middle of the country, dividing Bangladesh almost into two equal halves. The climate is characterised by high temperatures, heavy rainfall, often excessive humidity and fairly marked seasonal variations throughout the year. The country is well guarded by the Himalayas on the north, and is within the domain of a very active monsoon with a reversal of seasonal wind. The topography of Bangladesh is shown in figure 2.1.

The region used to be known as the "Land of Six Seasons" with regard to crop sowing and harvesting times, and cultural festivities, the notion lost some of its relevance with the initiation of various development programmes, particularly in the water resource sector during the early sixties.

The seasonal cycle is often divided into three main periods, namely, the summer (March - May), the monsoon (June - October) and the winter (November - February). Other important aspect of climate in Bangladesh include weather- related extreme events e.g. tropical cyclones, tornadoes, nor' westers and droughts. Climate may be best understood by an analysis of its elements. The most difficult aspect of the study of Bangladesh climate is the dearth of relevant data. Moreover, available data suffer drawbacks in terms of their consistency and reliability.

The global climate varies naturally on all time scales. During the Pleistocene (the last 2 million years) cold glacial epochs, associated with an expansion of continental ice sheets, were separated by relatively warmer interglacial epochs. The last glacial maximum occurred 18,000 years ago when the global temperature was 4 to 5^{0}C colder than today. Currently, the world is enjoying a warm, interglacial period.

Because of such natural cycles in global climate, the world is heading toward another cold period over the next several thousand years.

For the last 100 years, instrumental records of global climate changes are available. From these records it is evident that the world has warmed by about 0.5^{0}C although large annual and decadal variations are evident.

The current scientific consensus is that increasing atmospheric concentrations of green house gases should cause the world to warm. The rate of warming, however, is very uncertain. In 1990, the Intergovernmental Panel on Climate Change (IPCC) estimated that with a "Business- as-Usual" (i.e. with no policies to reduce emissions Scenario A) scenario of green house gas emissions, the world should be 3.3^{0}C warmer by the end of the next century, with a range of uncertainly of 2.2 to 4.9^{0}C.

In future, Bangladesh may get warmer and wetter. For the IPCC (1990) "Business-as-Usual" emissions scenario, Bangladesh is project to be 0.5 to 2.0^{0}C warmer than today by the year 2030, based on a range of global climate model results. Rainfall is more difficult to predict. However, climate models generally agree that regional monsoon rainfall should increase in a warmer world. The best estimate is a 10 to 15% increase in average monsoon rainfall by the year 2030, although the uncertainties are very large. Little can be said specifically regarding future changes in the frequency and intensity of cyclones in the Bay of Bengal.

The coastal region of Bangladesh, between 21 and 22.5°C N latitude, is located within the tropical climate and its climatological factors are strongly influenced by South- West and North- East monsoon. The South-Westerly predominates from June through September and the North-Easterly predominates from December to February.

The climate variable which are commonly used are concerned mainly with the atmosphere. But in considering the climate system we cannot look at the atmosphere alone.

Processes in the atmosphere are strongly coupled to the land surface, to the oceans and to those parts of the earth covered with ice (known as the cryosphere). There is also strong coupling to the biosphere (the vegetation and other living systems on the land and in the ocean).

2.1.1 Rainfall

Determination of the average amount of rain that falls on a watershed during a given storm is a fundamental requirement for many hydrologic studies. A number of techniques for estimating mean areal rainfall have been developed. Some of these techniques are simple, well-tried and old, as old as modern hydrology, but they tend to be employed without sufficient appreciation of their limitations.

Of practical necessity, rainfall is measured at a number of sample points. The amounts recorded at these points are utilized to form an estimate of mean areal rainfall. However, care must be exercised in employment of these rainfall records. The frequency distributions of Bangladesh monsoon rainfall is shown in figures 2.2 (a) and 2.2 (b).

In the project area (MES), the total annual rainfall varies from 2800 mm in the west near Hiron Point to 3000 mm along Chittagong Coast.

2.1.2 Temperature

The climate of Bangladesh is of the tropical monsoon type. In the Summer (March-May), the highest temperatures of the year occur at times exceeding 35^0C. In the Monsoon (June - October), the maximum temperatures are usually below 35^0C and the Winter (November - February), the lowest temperatures of the year, from 4^0C to 6^0C, are recorded in these months and daily maximum are usually below 32^0C. Skies generally remain cloud free during the Winter Season.

Temperature decreases at an average rate of about 6^0C per 1000 m increase in altitude within the troposphere, but is relatively constant in the lower part of the stratosphere.

Normal daily temperature is defined as the average daily mean temperature for a given data computed for a specific 30 year period.

Mean monthly temperature is defined as the average of the mean daily maximum and minimum temperatures. Mean annual temperature is defined as the average of the monthly means for the year.

The mean monthly temperatures do not show much variations along the region of Bangladesh coast but in Chittagong vary from 19°C in January to 29°C in June. The mean barometric pressure at Chittagong falls down from 1014 mb in January to 1000 mb in July. The mean wind speed at Chittagong vary from 1 m/s in December to 2.5 m/s in July.

The mean-annual temperature change (1870 - 1991) and the regional annual rainfall (1870 - 1990) of Bangladesh are shown in figures 2.3 and 2.4 respectively. The projections of future global warming of temperature change are shown in figure 2.5.

2.2 Greenhouse effect

Greenhouse effect is one of the most important factors for climate and sea level change. A simplified explanation of which is given as follows:

Short-wave solar radiation can pass through the clear atmosphere relatively unimpeded. But long-wave terrestrial radiation emitted by the warm surface of the earth is partially absorbed and then re-emitted by a number of trace gases in the cooler atmosphere. Since, on average, the outgoing long-wave radiation balances the incoming solar radiation, both the atmosphere and the surface will be warmer than they would be without the greenhouse gases.

The main natural greenhouse gases are not the major constituents, nitrogen and oxygen; but water vapour (the biggest contribution), carbon dioxide, methane, nitrous oxide, and ozone in the troposphere (the lowest 10-15 km of the atmosphere) and stratosphere. A simplified diagram illustrating the greenhouse effect is shown in figure 2.6.

2.3 Climate Sensitivity:

Conventionally, the climate sensitivity refers to the equilibrium change in average global surface air temperature for an "equilibrium" is important, for it denotes the eventual steady-state change that would result without reference to the time required to reach that condition. In the absence of any feed backs in the climate system, it can be readily calculated that a doubling of CO^2 should lead to a global warming of 1.2°C. However, there are feedback's in the climate system - most notably, changes in water vapour, snow/ice extent and clouds - that, on the whole, probably enhance the initial warming. The magnitude and in some cases even the direction of these feedbacks is uncertain, which gives rise to a rather broad range of estimated values for the climate sensitivity. The current range accepted by the International Panel on Climate Change is 1.5 to 4.5°C (Mitchell et al., 1990; Gates et al., 1992). In terms of estimating past and future thermal expansion effects, the value of the climate sensitivity is crucial, for it determines the amount of additional heat potentially available to be absorbed by the oceans.

2.4 The IPCC Scientific Assessment on Climate Change:

There are many uncertainties in IPCC predictions particularly with regard to the timing, magnitude and regional patterns of climate change, due to IPCC incomplete understanding of:

- Sources and sinks of greenhouse gases, which affect prediction of future concentrations.
- Clouds, which strongly influence the magnitude of climate change.
- Oceans, which influence the timing and patterns of climate change.
- Polar ice sheets which affect predictions of sea level rise.

These processes are already partially understood, and IPCC has confident that the uncertainties can be reduced by further research. However, the complexity of the system means that cannot rule out surprises.

2.4.1 The IPCC judgment

- Global-mean surface air temperature has increased by 0.3°C to 0.6°C over the last 100 years, with the five global-average warmest years being in the 1980s. Over the same period global sea level has increased by 10-20 cm. These increases have not been smooth with time, nor uniform over the globe (Houghton, 1993).
- The size of this warming is broadly consistent with predictions of climate models, but it is also of the same magnitude as natural climate variability. Thus the observed increase could be large due to this natural variability; alternatively this variability and other human factors could have offset a still larger human-induced greenhouse warming. The unequivocal detection of the

enhanced greenhouse effect from observations is not likely for a decade or more.

- There is no firm evidence that climate has become more variable over the last few decades. However, with an increase in the mean temperature, episodes of high temperatures will most likely become more frequent in the future, and cold episodes less frequent.

- Ecosystems affect climate, and will be affected by a changing climate and by increasing carbon dioxide concentrations. Rapid changes in climate will change the composition of ecosystems; some species will benefit while others will be unable to migrate or adapt fast enough and may become extinct. Enhanced levels of carbon dioxide may increase productivity and efficiency of water use of vegetation. The effect of warming on biological processes, although poorly understood, may increase the atmospheric concentrations of natural greenhouse gases.

2.4.2 IPCC predictive capability improvement

- To understand better the various climate-related processes, particularly those associated with clouds, oceans and carbon cycle.

- To improve the systematic observation of climate-related variables on a global basis, and further investigate changes which took place in the past.

- To develop improved models of the Earth's climate system.

- To increase support for national and international climate research activities, especially in developing countries.

- To facilitate international exchange of climate data.

2.4.3 The first meeting of IPCC is to provide a scientific assessment of:

- the factors which may affect climate change during the next century, especially those which are due to human activities.

- the responses of the atmosphere - ocean - land - ice systems.

- current capabilities of modelling global and regional climate changes and their predictability.

- the past climate record and presently observed climate anomalies.

On the basis of this assessment, the report presents current knowledge regarding predictions of climate change (including sea level rise and the effects on ecosystems) over the next century, the timing of changes to gather with an assessment of the uncertainties associated with these predictions.

The Policy makers of IPCC aim to bring out those elements of the main report which have the greatest relevance to policy formulation, in answering the following questions:

- What factors determine global climate ?
- What are the greenhouse gases, and how and why are they increasing?
- Which gases are the most important?
- How much do we expect the climate to change?
- How much confidence do we have in our predictions?
- Will the climate of the future be very different?
- Have human activities already begun to change global climate?
- How much will sea level rise?
- What will be the effects on ecosystems?
- What should be done to reduce uncertainties, and how long will this take?

The IPCC report is intended to respond to the practical needs of the policymaker. It is neither an academic review, nor a plan for a new research programme. Uncertainties attach to almost every aspect of the issue, yet policymakers are looking for clear guidance from scientists.

There are many factors, both natural and of human origin, that determine the climate of the earth.

Knowledge of the global mean warming and change in precipitation is of limited use in determining the impacts of climate change, for instance on agriculture. For this we need to know changes regionally and seasonally.

Models predict that surface air will warm faster over land than over oceans, and a minimum of warming will occur around Antarctica and in the northern North Atlantic region.

There are some continental-scale changes which are consistently predicted by the highest resolution models and for which we understand the physical reasons. The warming is predicted to be 50 - 100% greater than the global mean in high northern latitudes in winter, and substantially smaller than the global mean in regions of sea-ice in summer. Precipitation is predicted to increase on average in middle and high latitude continents in winter.

To carry out a climate forecast it is necessary to take into account all the complex interactions and feedbacks between the different components of the climate system. This is done through the use of a numerical model which as far as possible includes a description of all the processes and interactions. Such a model is a more elaborate version of the global models currently employed for weather forecasting.

3.0 Sea Level Rise

3.1 General

Sea level rise is primarily concerned with decade-to-century changes in global mean sea level, particularly as related to climate change. First, the evidence for sea level rise during the last 100 years is reviewed as a basis for looking for climate sea-level connections on a decade-to-century time scale. Next, the possible contributing factors-thermal expansion of the oceans and the melting of land ice - to both past and future sea level change are examined. Finally, the issue of future sea level due to global warming is addressed.

On geological time-scales, large changes in sea level have resulted from climate change especially as a consequence of glacial-interglacial cycles. At the height of the last ice age some 18,000 years ago, for example, sea level was more than 1.00 metres lower than today (Warrick et al., 1993). Over the past century, sea level has risen by 10-20 cm, most likely in response to a global warming of about 0.5°C over the same period. Thus, based on the past, there is an apparent connection between changes in global climate and sea level which should not be ignored in projecting the future.

The possibility of sea level rise is of grave concern to Bangladesh, a developing country with a vast, low-lying, densely-populated deltaic coast. Sea level rise threatens, potentially to exacerbate problems already experienced in the coastal zone of Bangladesh including erosion and inundation of land, salinisation of soil and water and especially flooding from storm surges.

There are large uncertainties involved in attempting to predict the effects of global warming on relative sea levels in the Bay of Bengal. The purpose of this work is to review the major factors involved in sea level change, both globally and regionally, and to explain the key uncertainties and knowledge gaps in making predictions for the future.

3.2. Factors Affecting Sea Level

Changes in sea level occur for many reason on different time and space scales. Tide gauges measure sea level variations in relation to a fixed benchmark and thus record "relative sea level" change due both to vertical land movements and to real changes in the ocean level. Vertical land movements result from various natural isostatic movements, sedimentation, tectonic processes and even anthropogenic activities (e.g., groundwater and oil extraction). In parts of Scandinavia, for instance, relative sea level is decreasing by as much as 1 metre per century due to isostatic "rebound" following the last major glaciation. In attempting to identify a globally-coherent, secular trend in MSL, the vertical land movements "contaminate" tide gauge records and have to be removed.

Eustatic sea level also affected by many factors. Differences in atmospheric pressure, winds, ocean currents and density of seawater all cause spatial and temporal variations in sea level in relation to the geoid (the surface of constant gravitational potential corresponding to the surface which the ocean would assume if ocean temperature and salinity were everywhere 0°C and 35 PPT, respectively, and surface air pressure was everywhere constant). Changes in the geoid itself, due to re-distribution of mass within the Earth, are irrelevant on the decadal-century time scales under consideration. Over these timescales, the most important climate-related factors are likely to be thermal expansion of the oceans and melting of land ice (but not floating ice shelves or sea ice).

It is highly likely that global-mean sea level (MSL) has been rising. This is the general conclusion of no fewer than 13 studies of MSL change over various periods during the last 100 years (Houghton, 1993). The estimates range from about 0.5 mm/yr to 3.0 mm/yr, with most lying in the range 1.0-2.0 mm/yr.

In addition, several assessments of the likely rate of past sea level rise have been made: 12±5 cm since 1900 from the SCOPE 29 assessment (Bolin et al., 1986); 10 - 25 cm since 1900 from the US. DOE assessment (MacCracken and Luther, 1985); and 10 - 20 cm over last 100 years from the PRB assessment (Polar Research Board, 1985). These assessments also include detailed reviews of the literature (Barnett, 1985; Aubrey, 1985; Robin, 1986). Rather than repeat these, we shall focus on the most recent studies and ask whether they provide any new information that would substantially alter previous assessments.

The study by Barnet (1988) is an update of previous work (Barnett, 1983, 1984) in which 155 stations are analysed over the period 1880-1986 AD. A rate of 1.15 mm/yr is obtained, in close agreement with the rates noted above. However, from a comparison of the composite global sea level curves (Figure 3.1), it is apparent that while Gornitz and Lebedeff's curve appears linear over the entire time period, Barnett's curve suggests a steeper rate of rise over about 1910-1980 approximately 1.7 mm/yr. This is more nearly in line with estimates of Peltier and Tushingham (1990) for the same period.

In future, the inherent ambiguity between land and ocean level changes in a tide gauge record will be solved by the use of advanced geodetic methods, but such data are not available for present analysis (Carter et al., 1989). In lieu of new geodetic data, one approach adopted by recent analyses has been to model explicitly the expected geology-induced MSL changes at each tide gauge site by the use of ancillary Holocene data (e.g., molluses, corals, peats, Gornitz et al., 1982; Gornitz and Lebedeff, 1987) or by the use of geodynamic models of the Earth (Peltier and Tushingham, 1989; 1990). The other approach is simply to assemble a sufficiently broad geographical spread of records such that (it is hoped) the net contribution of land movements reduces to zero (Barnet, 1983; 1984; 1988).

There are four major climate-related factors that could possibly a rise in global MSL on the 100-year time scale. These are:

a) thermal expansion of the oceans;
b) glaciers and small ice caps:
c) the Greenland ice sheet; and
d) the Antarctic ice sheet (including the special case of the West Antarctic ice sheet).

3.3. The Near Future

In making future projections of global temperature and sea level changes, it is preferable to use a single climate model (or set of linked models) in order to ensure internal consistency. Moreover, future rates of greenhouse gas emissions are extremely uncertain, so the results should be presented as scenarios, rather than actual "predictions". Let us look at some recent "best-estimate" scenarios of sea level rise for "Business-as-Usual" emission scenarios (i.e., if explicit attempts are made to reduce greenhouse gas emissions).

In 1900, the IPCC estimated that sea level could rise at an average rate about 6 mm/yr under Business-as-Usual conditions, reaching 66 cm by the year 2100 (within a large range of uncertainty: 31 to 110 cm) (Warrick and Oerlemans, 1990). The 1990 IPCC projections are shown in Figures 3.2 and 3.3. As the most recently published international scientific assessment, the IPCC projections of future sea level rise are appropriate for use as scenarios for other briefing documents in this series and are consistent with the temperature projections.

The various contributions to the IPCC projections of sea level rise are illustrated in Figures 3.2 and 3.3 . The largest contributions are derived from oceanic thermal expansion, followed by mountain glaciers and small ice caps. The contributions from the polar ice sheets are projected to be minor negative in the case of Antarctica. But, it should be noted that the uncertainties regarding the ice sheets are the largest, given to massive annual turn over of ice involved and the lack of knowledge concerning their response to climate change. Commitment to sea level rise in the year 2030 and model estimates of sea level rise from 1990 - 2100 AD due to all four emissions scenarios are shown in figures 3.4 and 3.5 respectively.

Developments since 1990 suggest that the IPCC projections of sea level rise may well be revised downwards, for several reasons (Warrick, 1993b), First, the IPCC, in its supplemental report (Houghton et at., 1993) revised its emission scenarios, inferring a lower Business-as-Usual case (Leggett et al., 1992). By itself, this implies a slower rate of global warming and, consequently, sea level rise (as indicated by the thin solid line in Figure 1.1, from Wigley and Raper, 1992). Second, there has been progress in quantifying the effects of three factors which reduce somewhat the projections of future radioactive forcing changes, namely: the terrestrial biosphere sink for carbon dioxide, the cooling effect of sulphate aerosols, and the ozone. depletion feedback - all of which tend to partially off-set greenhouse warming. Sea level rise predicted to result from Business-as-Usual emissions showing the best-estimate and range is shown in figure 3.6.

3.4 Measurements of Relative Sea Level Change from Tide Gauges, Cyclones and Storm Surges

Over shorter time-scales, tide gauges, which measure relative sea level, can provide important information for estimating the rates of vertical land movement and changes in the level of the sea surface. Bangladesh Water Development Board

(BWDB), Bangladesh Inland Water Transport Authority (BIWTA), and Chittagong Port Authority (CPA) have been operating an extensive hydrological network for several decades. A subset of BWDB tide-gauge stations that could potentially be useful for these purpose in the Bay of Bengal is shown in Figure 3.7.

Storm surges are atmospherically-forced oscillations of the water level in a coastal or inland water body, lasting for periods of a few minutes to a few days. By this definition, storm surges are distinct from wind waves and swells, which have periods in the order of a few seconds. Storm surges belong to the same class of wave as tides that is, long gravity waves.

The surges are caused by tropical cyclones that develop in the southeast part of the Bay or in the Andaman Sea during the pre-monsoon and post-monsoon seasons. The cyclones move along tracks that frequently cross the continental shelves bordering the Bay. A storm surge is generated partly by the resulting variations in atmospheric pressure, but the main contribution comes directly from the winds, often of exceptional strength, acting over shallow water (Mrty et al., 1986).

The coasts of Bangladesh and Myanmar (Burma) and the Bay of Bengal coast of India have been subjected to frequent severe cyclones and storm surges. Studies of the meteorology of the region provide a good knowledge of the origins, frequency of occurrence and behaviour of the cyclones that generate the surges. The Bay of Bengal is a breeding ground for tropical storms and depressions, the yearly average from 1880 to 1960 being 13 (Raghavendra, 1973). A warm pool of air usually forms at the 200 mb level, 3 to 4 days before the advent of cyclogenesis.

Tropical cyclones capable of generating surges usually occur during the monsoon transition periods, but rarely during the monsoon season itself. For the pre-monsoon storms (April to May) the strongest winds are usually in the south-east or eastern sector, whereas for the post-monsoon storms (September to December) the region of maximum winds is to the north of the storm centre.

On short time-scales (minutes to days), changes in sea level from cyclone-induced storm surges have devastating consequences for Bangladesh. The last major storm surge in Bangladesh, in 19 May, 1997, left more than 5,000 dead in its wake and loss of articles. Such surges are caused by the change in atmospheric pressure and the wind stress (especially in the shallower water near the coast) associated with severe tropical cyclones. Almost entire coast belt is exposed to the potential danger of cyclone. Having this reality in mind, Government of Bangladesh (GOB) have taken up a massive programme for construction of 2500 cyclone shelters in phases. During the post independence period (1972-1995), 3,931 km long coast embankments have been constructed by BWDB under 435 projects and sub-projects to protect coastal land from inundation by tidal waves and storm surges (Workshop,1995). At present, there is no firm evidence to conclude that global warming will increase either the frequency or intensity of cyclones in the Bay of Bengal. Storm surges in the Bay of Bengal affecting Bangladesh during the period 1584 to 1991 are shown in Annex I. Studies of land surface hydrology, and of impact on ecosystems, are also important which are discussed in the next section.

3.5 Hydrology

Both surface water and groundwater are important determinants of agricultural land use and potential in Bangladesh. Differences in depth and duration of seasonal flooding on different soil and land types strongly influence the kinds of crops and crop rotations which farmers can use; and surface water and groundwater are widely used for irrigation in the dry season. Accordingly, any changes in these water resources caused by climate change and sea level rise could have impacts on agriculture, they could also affect forestry, fishery and livestock, as well as domestic and industrial water supplies and water communications.

The salinity balance in the Meghna estuary and in the south-west would be affected by any major interventions made for flood control or irrigation anywhere in the Ganges-Brahmaputra-Meghna catchment during future decades. The salinity balance could also be affected by changes in river flow or sea level rise resulting from global warming.

3.6 Socio-Economic setting

Bangladesh's Socio-economic environment is characterized by high population density, widespread poverty and predominantly rural settlement with a majority of households dependent mainly on agriculture, fisheries and other forms of primary production. Here, brief attention is focused on those aspects that particularly affect land use, especially agriculture and fisheries.

3.6.1 Population

The 1991 population census gave a total population of 110 million (adjusted figure), growing at an annual rate of 2.02 percent (Bangladesh Bureau of Statistics, 1995). The urban population was 9.32 percent of the total. However, the official classification of 'urban' includes only those townships with a municipal administration. For this reason and because of definitional changes over time, the actual size and growth rate of the country's urban population are uncertain.

3.7 Land Use

Land use in Bangladesh is determined mainly by the monsoon climate and the seasonal flooding which affects the greater part of the country. These physical determinants are reinforced by high population pressure and, increasingly, by alterations to the natural environment through flood protection, drainage and irrigation interventions. Agriculture dominates both land use and the national economy.

3.8 Surface Water

This sub-section summarises the essential elements of the surface water hydrology of Bangladesh (major rivers; seasonal flooding; and flood protection) as a basis for considering how they may be affected by climate change.

3.8.1 Major rivers

Bangladesh's major rivers have their head waters outside the country. Only 9.1 percent of their total catchment area of about 1.41 million sq.km lies within country (Brammer et al., 1993; Ahmad et al., 1994). Thus, Bangladesh is exposed to the consequences of rainfall, land degradation and hydrological interventions occurring outside its boundaries. Unless a greater degree of regional cooperation is achieved than in the past, this limitation on Bangladesh's influence over external hydrological events and interventions could further aggravate adverse impacts of future climate change.

3.8.2 Seasonal flooding

Monsoon rainfall and river water both contribute to seasonal flooding of floodplan land; tidal floodplanins are subject to flooding at high tides, sometimes only in the monsoon season, where embankments do not prevent this. The extents of rain-water and river-water flooding vary from year to year, depending on local rainfall and river levels. In this respect, it is useful to distinguish between 'normal' flooding to which land use and housing are adapted, and 'floods' (Banna) which damage crops and property.

3.8.3 Flood protection

The natural flooding regime has been altered by flood protection and drainage works many areas. Embankments exist along the full length of the Brahmaputra right bank and more than half of the left bank; long stretches of both banks of the Padma and Meghna rivers, as well as along most tidal rivers in the south-west and along many small rivers inland. Submersible embankments have been built along many rivers in and around the Sylhet Basin to protect the boro paddy crop against pre-monsoon flash floods; the embankments are over-topped by monsoon floods. 3,931 km long coast embankments have been constructed by BWDB during the period 1972-1995.

3.8.4 Drainage

Increased monsoon rainfall coupled with higher river levels may increase the depth and duration of seasonal flooding on floodplain land, especially in the southern half of the delta where higher sea levels could further impede drainage from the interior. This would exacerbate existing drainage problems on low-lying land, which could only be relieved by expensive pump-drainage.

3.8.5 Salinity

The projected increase in average flood flows through the Bangladesh delta would tend to push back the salinity front in estuarine and tidal floodplains. That might apply both in the monsoon season and in the dry season. Seasonal fluctuation in the distribution of coastal soil salinity is shown in figure 3.8.

For the monsoon season, one can be reasonably confident that increased river discharges resulting from increased monsoon precipitation over upstream catchments would push back the existing salinity front. Greater uncertainty exists regarding dry-season conditions.

Whether the increased flood flows in the monsoon season and in the dry season might off-set the salinity incursion resulting from the projected 14 to 24 cm rise in sea level by the year 2030 can only be guessed at. That is because of the dynamic state of the Bangladesh delta and uncertainties regarding future dry-season flows and human interventions in the natural systems.

Four factors linked to the atmosphere or climate strongly influence plant growth. These are carbon dioxide, rainfall, light intensity and temperature. Changes in all these factors may occur with global warming. This section examines how changes in carbon dioxide concentration, light intensity, soil moisture and temperature could affect crop growth and yields. A wide range of references to research on these topics is given in Dowing, 1992 ; Parry and Jiachen, 1991 ; and Rosenzweig et al., 1993.

4.0 Effects of Climate and Sea Level Changes on the Natural Resources of Bangladesh

4.1 General

In this chapter reviews the possible impacts of global warming and sea level rise on Bangladesh's water, agricultural, forestry, fisheries and livestock resources. These resources are the mainstay of the country's economy, and will remain so far the foreseeable future. It is important, therefore, that the potential impacts of global warming on these vital resources be assessed: firstly, so as to inform decision-makers the public about the likely scale and time-frame of the kinds of impacts foreseen; secondly, so as to focus attention on mitigation measures that need to be considered in policy and research planning; and thirdly, so as to indicate subject areas where additional data need to be collected and analysesd in order to refine predictions of possible impacts and thereby improve the planning of any mitigatory measures that might be required. Historical changes in the south central coastal zone, 1779 - 1989 is shown in figure 4.1.

The review starts with a brief description of the physical and Socio-economic setting of present land-use and production. Succeeding sections give further details about the countries water, crop agriculture, forestry, fisheries and livestock resources as a basis for assessing possible impacts of climate change and sea level rise. The final section drowns conclusions from this review and identifies follow-up actions that could be taken.

4.2 The Present Resource Setting in Bangladesh

Greenhouse warming will impinge on a diverse, complex and dynamic physical environment. Significant differences in climate occur across Bangladesh, and annual variability causes periodic floods and droughts. Floodplains occupy 80% of the country, hills 12% and uplifted blocks 8%. Soils and seasonal flooding characteristics vary regionally as well as within villages, and farmers' cropping patterns are closely adapted to these heterogeneous conditions. Dynamic changes in the environment and in land use are taking place under pressure of population growth and with the spread of irrigation and the provision of flood protection works.

Bangladesh's socio-economic environment is also diverse, complex and dynamic. Over 80% of the 120 million population are rural, mainly engaged in farming, fishing and trading. Land-ownership is highly skewed. Fifty-six percent of rural house-holds are functionally landless. Poverty and malnutrition are widely prevalent. Rural population densities are high and rural-urban migration rates are accelerating. The country's population is projected to double by year 2030; by then the urban population could be one-third of the total. Therefore, greenhouse warming could then affect a different society from today's.

4.3 The Natural Resources Affected by Changing Climate and Water Regimes

About 25% land of Bangladesh is submerged by river water or rainwater during the monsoon season in most years. Housing, land use and other economic activities are well adapted to this 'normal' flooding. In years with high floods, over 60% of the land can be submerged, causing damage to crops and property, and disrupting normal economic activities. A two - pronged Government strategy is proving greater security against flood losses: promotion of irrigation, mainly from groundwater, enables farmers to increase rice production in the safer dry season and provision of flood protection works, to exclude unwanted floodwater in the monsoon season.

Climate models suggest that mean annual rainfall in and around Bangladesh could increase with global warming. By the year 2030, the best-estimate projection is for monsoon rainfall to increase by 10 to 15% and winter rainfall by 5 to 10%. Such increases would have both positive and negative effects. Increased rainfall would reduce drought frequency, increase groundwater recharge and decrease irrigation demand; by increasing river flows, it could also help to counteract salinity penetration in coastal areas associated with a rising sea level. On the other hand, increased rainfall within the catchment area of the Ganges-Brahmaputta-Meghna river systems could increase the frequency and severity of floods in Bangladesh.

Laboratory experiments show that increased carbon dioxide concentrations in the atmosphere increase photosynthesis rates by which plants absorb carbon. They also decrease transpiration rates, resulting in greater efficiency of water use by plants. Thus, if other factors are not limiting, expected increases in carbon dioxide levels could significantly increase plant growth rates and yields. Crops such as rice, wheat, jute and pules would benefit more than maize and sugarcane.

The optimum range of temperatures for plant growth varies between crops. In general, kharif, crops such as Aus and Aman paddy, and jute, would benefit from the higher temperatures, whereas dry land Rabi crops such as wheat, potatoes and pules would suffer reduced yields. Yields of Boro paddy could be reduced by higher extreme temperatures. Projected increases in rainfall should benefit crop production through increased soil moisture and irrigation supplies.

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However, increased carbon dioxide, temperature and humidity levels associated with global warming could also favour insect bacterial and fungal pests and diseases of crops. Also, crop yields and production could be reduced by a reduction in light intensity consequent upon increased cloud cover, by losses due to increased flood frequency and severity, and by increased salinity in some coastal areas. Present information is inadequate to predict whether the net effect of global warming on crop yields and production might be positive or negative.

4.3.1 Forestry

In principle, increased carbon dioxide, temperature and rainfall levels should increase tree growth rates, but such benefits could be partially or wholly off-set if warmer, wetter conditions increased pest/disease incidence, soil erosion and nutrient leaching. Potential climate benefits in mangrove forests could be off-set by sea encroachment and increased salinity due to higher sea levels. However, all forest resources seem likely to suffer more severe impacts from increasing human population pressure than from climate change in the near future.

4.3.2 Fisheries

Increased carbon dioxide and temperature levels should increase biological activity in all fish habitats. This could increase fish growth rates directly as well as indirectly through increased food supplies. Projected rainfall increases could extent the period of seasonal flooding of floodplan land which, combined with higher temperatures and increased food supplies, could extent fish breeding and growing seasons. Impacts on blackish water fish production will depend on the net balance, in different areas, between salinity reduction because of increased river flows and salinity increase due to sea level rise. Quantitative assessment of potential changes in production due to global warming is made highly uncertain because of the potentially greater impacts on fish habitats and stocks resulting from continuous increases in human population pressure and interventions in floodlpain, estuarine and tidal fish habitats.

4.3.3 Livestock

Higher summer temperatures could increase heat stress in farm animals, but higher winter temperatures could reduce cold stress. Projected increases in rainfall and consequent flooding could increase the incidence of humidity-related diseases. In principle, higher carbon dioxide and temperature levels could increase plant food availability, but this benefit would be off-set by reduced grain and fodder availability areas from sea level rise and salinization. Such negative impacts would aggravate existing problems for livestock production caused by cropping and environmental changes induced by the increasing human population pressure on the country's land and water resources.

3.9 Agriculture

Farming in Bangladesh is diverse, intensive and dynamic; and farmers are flexible, adaptable and sensitive to market prices. Although rice occupies 80% of the cropped area, more than 100 crops are grown as well as many thousands of rice varieties adapted to local micro-environments. Much land grows two or three crops a year, but average yields are low because of insecurity of production. The recent spread of irrigation has greatly increased rice production in the more secure dry season, but at the expense of pulses, oilseeds and grazing land. Flood protection works aim to increase crop security in the monsoon season. The projected doubling of food demand by year 2030 will require further intensification and security of production, but will have to be obtained from a shrinking cropped area as urban land expands.

4.5 Climate-Society Interaction

A change in climate will affect natural resources, such as water, forests, and grasslands. Changes in natural resources will have social and economic effects: some beneficial, some detrimental. For example, increased rainfall might increase the amount of water available for irrigation, but increase the rate of soil erosion and leaching (a detrimental effect on agriculture). These impacts on agricultural resources would in turn affect the social and economic circumstances of farmers and, thereby, other socio-economic sectors dependent upon their production

The socio-economic effect of climate change therefore arise from interactions between climate and society and how these in turn affect both natural and managed environments. Traditionally, in Bangladesh, climate variations have provided opportunities and imposed costs, depending on how society adapted to the environment. Thus, a bountiful floodplain rice-growing system, finely tuned to seasonal climate variations, is often disrupted by floods, droughts, and cyclones. In future, the extent to which Bangladesh will be affected or will depend on the future technological, demographic, and socio-economic trends and how they influence Bangladesh's ability to adapt in order to strike a new balance between resources and hazards.

Bangladesh is a newly developing country in transition from being a traditional rice-growing society. In the drive for modernisation, evolving technologies and economical and social structures alter existing systems and make many sectors of, and groups in, society more vulnerable to significant variations in climate and sea level. For example, large scale environmental interventions, such as flood control and irrigation, may buffer people from lesser and more frequent events thereby enhancing the resource base. On the other hand, protected areas will remain at threat from supra-design events which may be made more likely under a changing climate, even though other benefits may accrue from climate change, such as improved crop production. In the long term, Bangladesh's vulnerability may, however, depend more on the direction of technological, demographic, economic and social trends than on the rates of climate and sea level change. This is because the pace of change in society is likely to be much more rapid than for climate and sea level change.

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4.6 Population, Settlement and Climate Change

Since 1965, the population of Bangladesh has doubled to 120 million. The medium UN projection gives 235 million by 2025 AD and 305 million by over 2050 AD (Ericksen, 1993). In rural areas the population density may increase by over half by 2025 AD. The high density rural areas will continue to supply migrants to low density areas and to cities. The exposure of people to climatic extremes will persist and is likely to increase as more intense use is made of high risk areas. The urban population is projected to grow at a faster rate, about 5% per year. This increasing concentration of people in large urban areas could increase the risk of catastrophe from rare climatic events and is likely to create additional risks of climate impacts more akin to other urbanised countries, such as heat stress, urban flooding, and urban drought. Overall the trend of high population growth in Bangladesh should increase vulnerability to climate and sea level change.

Escaping adversity due to lost land and employment lies behind most migration. Permanent movements are from densely settled core to less dense periphery, and from rural to urban areas. Seasonal moves are an increasing trend. Exposure to natural disasters depreciates marginal land holdings and triggers many people to relocate. Limited opportunities mean many migrants relocate not only in areas at risk from climate extremes, but also from adverse social and environmental conditions. In general, migrants are particularly susceptible to environmental disruptions because they lack supportive infrastructure and employment. A continuation of high migration rates is likely to aggravate the potential socio-economic impact of climate and sea level changes in future.

A population that is healthy and educated is better able to avoid poverty and the adverse effects of climate variations. While recent trends in improved health care education in Bangladesh are encouraging, poverty and malnutrition remain rife, lowering the resistance of large segments of the population to disease. Even on a seasonal basis, the linkages between climate, nutrition and disease are apparent. Improvements in health care and education, as well as food production, would help buffer Bangladesh against the ill-effects of future climate change. So too will improvements in safe water supplies and waste disposal systems.

4.7 Coastal Zone of Bangladesh

The coastline of Bangladesh can be divided into three main zones - the west, central and east coastal zones (figure 4.2). Each contains distinct coastal land forms and specific geological, physical and biological characteristics (Barua, 1991 a,b). The west and central coasts are part of the Ganges-Meghna-Brahmaputra delta system, whereas the east coast is non-deltaic. In general, each of the three zones has one dominant, or controlling, factor.

The coast of Bangladesh is approximately 710 km long (Snead, 1985), as estimated by measuring the distance around the Bay of Bengal between the Indian and Myanmar (Burma) borders. If the length of the tidal-estuarine coast is considered, the total shoreline of Bangladesh may be thousands of kilometres long.

- to examine how customary behaviour is being modified in response to changing social and environmental conditions.

- to increase understanding of the various forms of migration and resettlement of the landless, in order to anticipate the likely dimensions of problems that may arise if climate extremes worsen and sea level rises.

- to develop means of empowering the landless and poor with entitlements to resources to ensure their resiliency in times of scarcity.

Fulfilling these needs requires a programme of interdisciplinary research (integrating social sciences and natural sciences) aimed at developing an optimum strategy for reducing vulnerability to climate extremes. The outcomes of this research would provide decision makers with an indication of priorities for preparing against the adverse effects of climate variation and change.

5. Review of Research Paper on Climate Change and Sea Level Rise

Review of some research papers related to climate change and sea level rise which are currently published in the International Journals are narrated below:

I. "Integrated Model Systems for National Assessments of the Effects of Climate Change: Applications in New Zealand and Bangladesh" by R.A. Warrick, G.J. Kenny, G.C. Sims, N.J. Ericksen, Q.K. Ahmed and M. Q. Mirza.

Journal of Water, Air, and Soil Pollution, Vol. 92: 53 - 62,1996.

The purpose of this paper was to presented such an alternative - an integrated model- based system for assessing the effects of climate change. The paper began by briefly described the methodology.

The methodology was than illustrated by reporting its application in a developed country, the CLIMPACTS system for New Zealand and in a developing country, the BDCLIM system for Bangladesh, finally, some judgments are offered about the prospects for the methodology's wider application in other national situations.

It was only through such a combination of quantitative and qualitative, local and national, and scientific and policy analyses that the complete picture of climate change vulnerability, and adaptive capacity would began to emerge.

For Bangladesh a prototype integrated model system (BDCLIM) was being developed. The results of which was used to scale GCM output for the region to produce time-dependent climate change scenarios for Bangladesh. These scenarios were used to perturb a baseline climatology of temperature and rainfall, developed from a 30-year (1961-1990) record of stations maintained by Bangladesh Meteorological Department (BMD). For precipitation, the spatial coverage was being extended using the records maintained by BWDB.

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II. "Climate Change Vulnerability and Adaptation in Asia and the Pacific": Workshop Summary by L. Amadore, W.C. Bolhofer, R.V. Cruz, R.B. Feir, C.A Freysinger, S. Guill, K. F. Jalal, A. Iglesias, Jose, S. Leatherman, S. Leatherman, S. Lenhart, S. Mukherjee, J.B Smith and J. Wisniewski.

Journal of Water, Air and Soil Pollution, Vol. 92: 1-12, 1996.

The Regional Workshop on Climate Change Vulnerability and Adaptation Assessment in Asia and the Pacific met to present and discuss assessments of vulnerability and adaptation to climate change in agriculture, forests, science for vulnerability and adaptation assessment, conclusions that can be drawn about the vulnerability of the region to climate change, and where future research efforts should be directed. In this workshop 100 participants were present and they actively participated discussion. There are significant vulnerabilities to climate change in the Asia and pacific region. The major conclusions of the Regional Workshop on Climate Change Vulnerability and Adaptation in Asia and the Pacific are as follows:

(a) Sea level rise is of great concern to residents of Pacific islands and coastal nations in Asia.

(b) Water resources are very sensitive to climate changes, and there are sensitivities unique to the region.

(c) Forests in many parts of Asia and the Pacific could be significantly affected by climate change.

(d) Efforts to improve general circulation models should continue.

(e) Asia and Pacific countries should cooperate on the analysis of climate vulnerability and adaptation.

(f) Asian and Pacific countries should address adaptation to climate change.

The workshop also concluded that results of vulnerability and adaptation assessments should be presented to policy makers and the public and that assessments continue to be undertaken to improve our understanding of the issue.

III. "Assessing Impacts of Climatic Variation on Foodgrain Production in Bangladesh" by Z. Karim, S. G. Hussain, and M. Ahmed.

Journal of Water, Air, and Soil Pollution, Vol. 92: 53 - 62, 1996

In this research paper a simulation study was conducted to assess the vulnerability of food grain production in Bangladesh to potential climate change.

Bangladesh is highly vulnerable to severe weather events; floods and droughts are frequent and damaging. The crop most affected by floods and droughts is rice, which contributes 93.96% of the total cereal production in the country, followed by wheat (5.81%) and other crops (0.23%).

In this study considers the possible impacts of climate change on the production of high yield varieties of rice and on wheat production. The study looks at the effects of two GCMs and eight combinations of temperature and CO_2 increases in six locations for rice, and in three locations for wheat. These locations represent the major rice and wheat growing regions of the country.

The simulation runs were made for high yield varieties of rice for Aus (March-August), Aman (July-November), and Boro (February-July), the traditional growing seasons, using the CERES-Rice model, Simulation runs were made for wheat, which is grown from November through March, using the CERES - wheat model. Three scenarios (baseline, Canadian Climate Centre Model, and Geophysical Fluid Dynamics Laboratory) and sensitivity analysis for temperature increases of 2 and 4°C at three levels of CO_2 (330,580 and 660 ppm) were used. In the simulation, increased CO_2 levels increased rice yields over baseline, and considerable spatial and temporal variations were noted. Higher temperatures reduced the yields in almost all study locations and in all seasons, and it was particularly pronounced with a 4°C increase. The detrimental effect of temperature rise was observed even with increase CO_2 levels. Wheat yields increased with increased CO_2 level in all three locations. The adverse effects of increased temperature were more pronounced for what than for rice at all levels of increased CO_2.

In the scenarios of the Canadian Climate Centre Model and Geophysical Fluid Dynamics Laboratory, both rice and wheat yields were decreased 35% and 31% respectively) over baseline in all seasons, especially in the Aus season, and in all season locations. The adverse effects of the climate under the Geophysical Fluid Dynamics Laboratory scenario were more pronounced for wheat than for rice.

The greatest reductions in aggregated production for both crops were noted at 330 ppm CO_2 with a 4°C temperature rise. The greatest increases in aggregated production for rice and wheat were observed at a 660 ppm CO_2 with no temperature increase.

Public awareness of the impact of climate change on the agricultural production systems deserves priority consideration, and mitigating technologies must be developed, which will require increased public and private investment.

IV. "Tropical Cyclones and Coastal Inundation under Enhanced Greenhouse Conditions" by A. B. Pittock, K. Walsa and K. Mcinnes, Journal of Water, Air, and Soil Pollution, Vol. 92: 159 -169, 1996.

In this paper the behaviour of tropical cyclones under enhanced greenhouse conditions has been the subject of considerable speculation. Tropical cyclones are destructive. Typical spatial scales of these cyclones are on the order of tens to hundreds of kilometers. The effect of the enhanced green house effect on the climatology of tropical cyclones is currently unknown. Current climate models lack the resolution to simulate tropical cyclones accurately, but the development of fine resolution global and limited area climate models holds the promise of increased knowledge of future tropical cyclone behaviour. This paper provides an overview of current research efforts on tropical cyclones under enchance greenhouse conditions and detailed discussion of a study on tropical cyclone- like vortices in a limited area model.

V. "Vulnerability of Bangladesh to Climate Change and Sea Level Rise through Tropical Cyclones and Storm Surges" by A. Ali (SPARRSO) Journal of Water, Air, and Soil Pollution, Vol. 92:171-179, 1996.

This paper discusses the vulnerability of Bangladesh to climate change and sea level rise, concentrating on the effects on tropical cyclones and storm surges.

Climate change and sea level rise are likely to worsen the effects of the naturally occurring disasters in Bangladesh. Bangladesh is frequently visited natural disasters such as tropical cyclones, storm surges, floods, droughts, tornatoes and "norwesters". Of these topical cyclones originating in the Bay of Bengal and associated storm surges are the most disastrous. There are various reasons for the disastrous effects of cyclone and storm surges in Bangladesh. Superimposed on these disastrous effects, climate change and any consequent sea level rise are likely to add fuel to the fire. Arise in temperature is likely to change cyclone activity: cyclone intensity, if not cyclone frequency, may increase. As a result, storm surges may also increase substantially. This paper examines the climatology of cyclones in the Bay of Bengal for the last 110 years and trends in cyclone frequency and intensity.

This paper also discusses both qualitatively and quantitatively the impacts of rises in temperature on topical cyclone intensity in Bangladesh.

A brief examination of the frequency of tropical cyclones that formed in the Bay of Bengal during 1881-1990 was made. A 30-40 years period of oscillation was observed in the cyclone frequency, but no trend as far as the relationship to global warming was observed.

The wind speeds of the April 1991 cyclone that hit Bangladesh under two sea surface temperature scenarios of 2 and 4°C have been estimated. These wind speeds were used to generate storm surge scenarios in Bangladesh for a sea surface temperature rise of 2 and 4°C, and sea level rise of 30 and 100 cm.

An analysis of all the cyclones that formed in the Bay of Bengal between 1881 and 1990 (110 years) shows that about 14% of them hit Bangladesh and about 66% hit in India. If the bay's share is 10% of the world cyclones, the percentage of the world total hitting Bangladesh is 1.4% and the percentage hitting India is about 6.6%. This percentage is lower if the above mentioned 6% for the Bay is considered. About 49% of the world total of deaths due to these cyclones occurred in Bangladesh alone, and about 22% occurred in India (Ali, 1980).

The monthly distribution of cyclone frequency in the Bay of Bengal shows a maximum in about August. This maximum is dominated by the depressions that form in the north Bay of Bengal during the south west monsoon. During the south west monsoon, strong winds blow over the land in the north Indian

Ocean from the Southwest direction toward land in the north, and bring huge amounts of moisture that turn into heavy precipitation. The south west monsoon period extends from June to September.

The cyclonic storms and severe cyclonic storm show two maxima, one in April-May and the other in October- November, i.e., during the pre-monsoon (before the southwest monsoon) and post-monsoon periods, which correspond to two sea surface temperature maxima (Choudhury, 1995). This shows that the monthly distribution of cyclones in the Bay is strong related to sea surface temperature.

Finally, concluded that more detailed and in-depth research on vulnerability and adaptation processes needs to be done so that better adaptation and protective measures may be undertaken against possible climate change and sea level rise.

VI. "Physical Impacts of Climate Change on Deltaic Coastal Systems (I): An Approach" by Sanchez-Arcilla, A. and Jimenez, J.A., Journal of Cilmate Change, Vol. 35: 71 - 93,1997.

In this paper the evaluation of the impact of climate change on deltaic systems implies studying a multi-component system in which the complexity of links is high enough to present doing it as a whole. The main objective of this paper was to introduce a methodology to evaluate the physical impact of climate change on a deltaic coastal fringe which will be presented in two companion papers (Jimenez and Sanchez-Arcilla, 1997 ; Sanchez-Arilla and Jimenez, in preparation). The two components papers, the way to deal with and characterise driving- terms (Jimenez and Sanchez, 1997) and coastal responses (Sanchez-Aarcilla and Jimenez, in preparation) to define a dynamical 'reference' situation will be presented .

The established methodology considers the field data normally available in European Mediterranean deltas, and makes reference to the MEDDELT research project, whose aim is to evaluate the climate impact on three Mediterranean delta: Ebro, Po and Rhone.

VII. " Physical Impacts of Climatic Change on Deltaic coastal Systems (II): Driving Terms " by Jimenez, J.A. and Sanchez-Arcilla, A., Climate Change, Vol.35: 95 - 118,1997.

The main objective of this paper was to present the first part of a methodology to evaluate the physical impact of climate change on a deltaic coastal fringe, already introduced in Sanchez-Arcilla and Jimenez(1997). The evaluation of the impact of climatic change on deltaic coastal systems requires establishing a 'reference situation'. As deltaic coastal zones are highly dynamic areas, it is necessary to define the reference situation as a function of their present evaluative stage. This implies characterising coastal processes as a complex system defined by the links between driving or forcing terms and the coastal response at different temporal and spatial scales('long/large', 'medium' and 'episodic' scales). Starting from classical previous works on deltaic systems and including all available field and conceptual knowledge to properly consider present conditions (largely regulated rivers, subsidence, etc.) a detailed methodology to analyze forcing or driving agents at the three mentioned scales is presented. This methodology which developed the general approach presented in a companion paper, will be followed by a future paper focusing on the analysis of the coastal response.

VIII. "Sea Level Rise and Bangladesh: A Preliminary Analysis" by Saleemul Huq, Syed Iqbal Ali, and A. Atiq Rahman, Journal of Coastal Research, SI No. 14, 44-53. Fort Lauderdale (Florida). ISSN 0749-0208, 1995.

In this paper a preliminary analysis of sea level rise of Bangladesh coast has been presented. This study also re-examined the effects of a one metre scenario of relative sea level rise. They also utilized updated information and data including topographical maps, tidal tables, satellite images, aerial photos and hydrographic maps. Thematic maps were then used to estimate the effect of a one metre sea level rise on agriculture, population and infrastructure. The time frame for the rise in sea level is nominally 2100, but this rise is superimposed on the existing situation and is only important when considering the impacts on mangroves and other wetlands.

The coastal area of Bangladesh experiences significant, but poorly quantified subsidence due to its deltatic nature. The cause of subsidence is due mainly to the compaction of unconsolidated sediments. Therefore, the selected scenario, a relative rise in sea level of one metre by the year 2100, will occur due to a smaller rise in global sea level. Such information is vital for the most effective long - term management of the coastal zone in Bangladesh.

The location and orientation of the co-tidal range line with respect to the one metre contour (above mean sea level) has been studied in this paper to assess the tidal fluctuation that would occur along this contour. They found that out of the major districts in Bangladesh six would be affected by inundation due to a one metre rise in sea level. These districts are: Barisal, Patuakhali, Kulna, Noakhali, Comilla and Faridpur. The area predicted to be inundated covers an estimated area of 25,150 Km^2, which is about 17.5% of the total area of Bangladesh. Districtwise inundation with percentage, land area is shown in Table 1. Impact of a one metre rise in sea level on infrastructure, and habits and agriculture are shown in Table 2 and Table 3 respectively.

Table 1: Districts, land area, and existing population vulnerable to inundation given a one - metre rise in sea level

District	Area (%)	Area (Km^2)	Population (millions)
Barisal	90	6600	4.5
Patuakhali	100	4100	2.0
Khulna	80	9750	3.0
Noakhali	50	2750	1.5
Comilla	15	1000	0.5
Faridpur	15	1000	1.5
Total		**25200**	**13.0**

Source: Huq et al., 1995

Table 2: Impact of a one-metre rise in sea level on infrastructure and habitats

		Affect
A.	Type of infrastructure	
	Roads	800 Km
	Railways	28 Km
	Cities and towns	85
	Port	1 (Mongla)
	Coastal embankments	4187 Km
	Coastal aquaculture	64000 ha
	Poldered area	7640 Km^2
B.	Type of Habitat	
	Coastal island	3500 Km^2
	Forest area (including Sundarbans)	5770 Km^2
	Flooded area (increase)	5500 Km^2

Source: Huq et al., 1995

Table 3: Effect of a one metre rise in sea level on agriculture (major crops).

Crop	Area Affect (ha)	Total for Bangladesh (%)
Aman (Monsoon) rice	1280000	21
Aus (Summer) rice	40000	12
Boro (Winter) rice	102000	8
Jute	13800	2

Source: Huq et al., 1995

In this paper, a rise in sea level will also include the enhanced flooding, salinity intrusion and storm surges effects. Bangladesh undergoes annual river flooding due to both snowmelt waters from the Himalayan mountains through the three major rivers; the Ganges, the Brahmaputtra and the Meghna. Any rise in sea level will enhance the height and duration of such river floods and will increase the flood hazard zone. Salinization of the surface water systems will occur and cause serious problems in the south western region particularly the Sundarbans areas of Bangladesh. The major port city of Khulna, are facing problems due to salinization of the ground water aquifer. Any increase in sea level will also increase the height and land ward penetration of storm surges. Near Cox's Bazar, one of the longest beaches in the world (over 100 Km long) may also occur erosion due to a rise in sea level.

From their analysis, it is seen that to provide minimum protection against a one metre rise (protection against a 20-year flood), Bangladesh will have to upgrade 4,800 km of existing embankments and build 4,000 km of new embankments. This costs over one billion U.S. dollars at 1989 prices. Natural sedimentation and the resulting vertical accretion it process is not considered. Further, research on the long term coasts and benefits of different response strategies is essential.

Sea level rise will also interact with river flow and cyclones to increase the already severe problems of flooding in Bangladesh. Therefore, sea level rise, in specific and global climate change in general, is of great concern to Bangladesh. Bangladesh required the assistance of the world community in order to face this new challenge. The developed counties have a responsibly to help Bangladesh cope with the consequent global sea level rise.

6 Conclusions

Global mean temperature has increased by 0.3 - 0.6°C over the past 100 years. Magnitude of this warming is broadly consistent with the theoretical predictions of climate models, but it remains to be established that the observed warming can be attributed to the enhanced greenhouse effect.

To determine the magnitude of the natural and anthropogenic sources, sinks and fluxes of greenhouse gases in Bangladesh. For Bangladesh, it may be particularly important to resolve the uncertainties regarding methane.

To develop integrated impact models for Bangladesh that link existing climate, environmental and socio-economic models and data. For Bangladesh there is a need to develop methods for integrating existing models and data at different scales - global, regional, national, and local - in away that allows analyses which are relevant to policy development and strategy implementation.

Climate change is a global problem. It requires global solutions involving cooperative actions by all nations.

The average rate of sea level rise over the 100 years has been 1.0 - 2.0 mm/yr.

There is no firm evidence of accelerations in sea level rise during this century (although there is some evidence that sea level rose faster in the century compared to the previous two centuries).

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Future changes in sea level were estimated for each of the IPCC forcing scenarios. For each scenarios, three projections - best estimate, high and low were made corresponding to the estimated range of uncertainty in each of the potential contributing factors.

For the IPCC Business-as-Usual scenario at year 2030, global-mean sea level is 8 - 29 cm higher than today, with a best-estimate of 18 cm. At the year 2070, the rise is 21 - 71 cm with a best-estimate of 44 cm.

The present assessment does not force a sea level rise of greater and equal to 1.0 metre during the next century. Nonetheless, the implied rate of rise for the best-estimate projection corresponding to the IPCC Business-as-Usual scenario is about 3 - 6 times faster than over the last 100 years. The prospect of such an increase in the rate of sea level rise should be of major concern to many low-lying coasts subject to permanent and temporary inundation, salt intrusion and beach erosion, and other deleterious effects.

Different researchers have made different models for the predictions of climate change and sea level rise (Manabe and Wetherald,1987; Meehl and Washington, 1988,1989; Mitchell and Warrilow, 1987; Vinnikov and Yeserkepova. 1989; Manabe et al.,1990; Charlson et al.,1992; Wigley, 1989; Wigley and Raper, 1991, 1992, 1993 ; Isaksen et al., 1992; Ali, 1996; Summary Report, 1995; Jimenez and Sanchez-Archilla, 1997). All models show substantial changes in climate when carbon dioxide concentrations are doubled, even though the changes vary from model to model on a sub-continental scale.

The future impact of climate change and sea level rise on the coastal zone of Bangladesh will depend on the vulnerability and resilience of its physical, biological, social and economic systems. Previous studies have estimated future coastal impacts by calculating the areas of low-lying land and assuming that these areas will be permanently lost under rising the sea levels. Such studies have failed to address the considerable natural resilience of the Bangladesh coastal zone. For example, the supply of river sediments to the coastal zone may well provide a buffer against sea level rise. Furthermore, there is considerable human resilience to environmental change ; adapting to constantly shifting lands, floods and cyclones is part of the way of life of coastal people.

The impacts of projected changes in climate and sea level will impinge on environments already changing under pressure of population growth. Planning, research and environmental monitoring studies need to consider both these factors together.

Hydrological modeling studies should take into account the possible increased river discharge and internal flooding which could result from increased precipitation in and around Bangladesh so as to indicate the implications for flood frequency and extent, and for the design of flood mitigation measures.

There are several general areas in Bangladesh in which research could improve the base of knowledge required to enhance adaptation and to guide policy, including studies:

- relationship between climate change, runoff and stream flow, erosion and accretion process, and freshwater and sediment supply to the coast ;

- the vulnerability of coastal people and the possible adaptive strategies in the face of climate change and sea level rise ;

- the sensitivity of coastal areas to potential changes in sediment supply and sea level rise ;

- the sensitivity of Sundarban mangrove species to changing salinity and other environmental conditions so as to improve predictions of probable changes with sea level rise.

In the short term, the coordination and integration of existing coastal zone research programmes is needed in order to efficiently guide and carry out research. Agricultural and biological research studies are also needed to measure plant, animal and fish responses to higher carbon dioxide and temperature levels, and to select biotype tolerant of expected conditions.

Bangladesh, like other coastal countries of the world, must begin planning for Integrated Coastal Zone Management (ICZM) as stipulated in the UN Frame work Convention on Climate Change, to which Bangladesh is a signatory.

Policies and plans for ICZM must be based on a comprehensive understanding of the biophysical systems and their modification and use by human inhabitants. Such knowledge is vital to the development of policies to manage coastal resources sustainable and to avoid the adverse effects of future climate change and sea level rise.

Rough estimates of economic loss were made for Bangladesh (Broadus, 1993). The analysis suggests that, in the absence of mitigating adjustments, a relative sea level rise of 1.0 metre by year 2050 could result in a cumulative loss (in present terms) equivalent to 1-2% of the nation's current GDP (Gross Domestic Product). However, human adjustments such as defensive measures, recombinations of productive factors, and institutional and technological adaptation would tend to reduce this loss. So, it is best seen as a 'worst case' estimate. Even so, the potential scale of economic impact in Bangladesh suggests that further detailed investigations are warranted.

The effect of sea level rise should be taken into account by MES for making long term master plan and development plan but more reserach also need for the analysis of sea level rise and its effect in the near future.

Finally, it can be concluded that more detailed and in-depth research on vulnerability and adaptation processes etc. need to be done so that better adaptation and protective measures may be undertaken against possible climate change and sea level rise.

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FIGURES

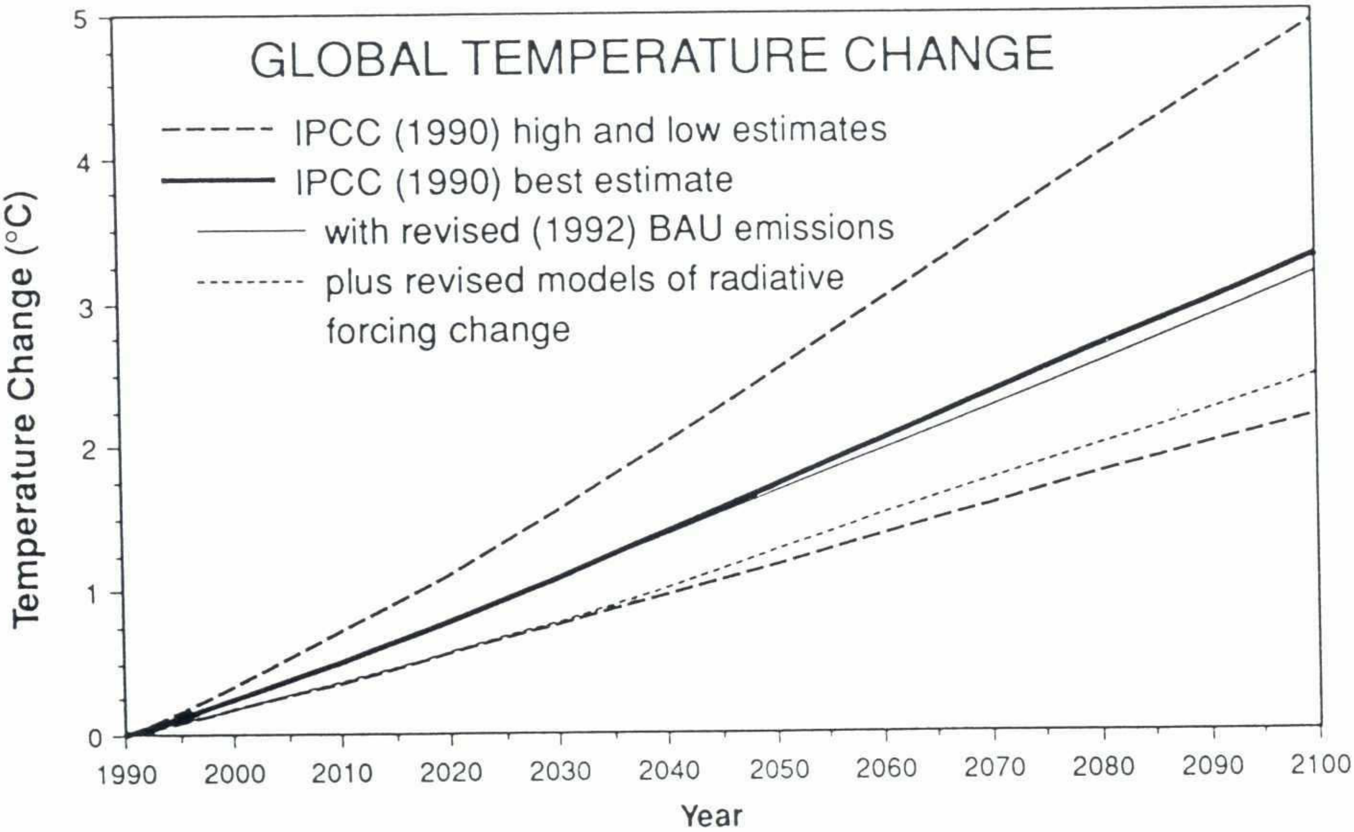

Figure 1.1: Projections of future global warming. (Source: the IPCC projections are from Bretherton et al., 1990; the revised curves are from Wigley and Raper, 1992).

The definition of the coast zone used in this document is the area of the "Greater coastal districts" which is the most commonly used definition in Bangladesh. The coastal districts are the five Greater districts which adjoin the coast, namely: Chittagong, Noakhali, Patuakhali, Barisal and Khulna. The coastal districts, and hence the coastal zone as defined here, cover 23% of the area of Bangladesh.

The transition between land and sea in Bangladesh is so gradual that small changes to the definition of coastal zone can produce very large changes in the extent and location of 'Coast" land.

Waves, tides, river flow, sediment movement, plants and animals interacts to shape coastlines. This shaping occurs each minute, each day of each year from decade to decade, century to century. The coastline of Bangladesh varies because the relative importance of these processes is not uniform around the Bay of Bengal.

Humans have traditionally altered the natural character of the Bangladesh coastal zone through their exploitation of its natural resources. The type and scale of human modifications have changed dramatically during the past 40 years as traditional Bengali practices have given way to modern technologies. These traditional and modern human modifications may have a profound effect on the vulnerability and resilience of the coastal zone to climate change and sea level rise.

The natural shape of the Bangladesh coastline is controlled by the forces of erosion and accretion involving tides, rivers and waves. Where wave forces are strong, straight coastlines of beaches and dunes are formed, as in the south-east. Where tidal forces dominate, complex patterns of tidal cracks result, as on the coast. If the forces of rivers and the sediments that they carry dominate over tides or waves, the chars and estuaries of the central coast result.

Approximately 24 million people, or 22% of the total population of Bangladesh, live in the coastal zone (figure 4.3). The coastal population is closely tied to the resources that land and water provide, either directly through fishing, agriculture and forestry, or indirectly through the processing of coastal fish, shrimp and timber. The two main urban centres in the coastal zone are Khulna and Chittagong, where most of the coastal industry is located. The people work within the seasonal moods of the coast: monsoon floods and rains, dry season salinity and the seasonal threat of cyclones. Rapid population growth has pushed many people to the margin of survival in the coast zone, where there may be many as 45 to 50 million people by the year 2050. Such population growth could put further stain on coastal systems and resources, and climate change and sea level rise could then be a threat to a much higher number of people. Cyclones and their associated storm surges are the major natural threat in the coastal zone, especially in the east and central coast. Over 6,00,000 people have been killed in Bangladesh by cyclones and storm surges since 1960. The massive loss of life from cyclones is due to poorly constructed houses. lack of an adequate cyclone warming system and the extremely low-lying nature of much of the coastal zone. The worst cyclone since 1970 crossed the coast on 29 April, 1991. claiming 1,38,868 lives (Kausher et al.,1993). The surge generated by cyclones can be very high, a surge of 4 to 5 metres on top of the normal tide were reported in the present year 1997 (19 May) hitting the eastern coast near and around Chittagong.

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Accurate predictions of future climate change for the coastal zone of Bangladesh are not yet possible. However, scenarios of change (that is , what could happen) based on climate models suggest a warmer, wetter future. Monsoon rainfall in particular may increase, perhaps by about 20% by the middle of the next century, resulting in higher river flows and discharge. Sea level may rise by about 30 cm. It is not clear whether the frequency and intensity of severe tropical storms in the Bay of Bengal would increase in a warmer world, but the possibility is of major concern since cyclones are the paramount threat to the region.

Being a low-lying country, the prospect of sea level rise is cause for alarm. However, sea level rise will not necessarily cause a permanent inundation of the present coastal zone of Bangladesh. The coastal zone exists in a dynamic balance between forces of erosion and accretion. Land subsidence and sea level rise favour the loss of land to the sea, whereas supplies of freshwater and sediment to the coast promote the accretion of land. Whether climate change and sea level rise will drown the coast depends critically on how the dynamic balance is maintained in the future. How the coast will respond to the cumulative effects of the changes in sea level, waves, storms, river flow and sediment supply in the future is not clear.

It can be stated with greater certainty that the stresses currently being induced by population growth, over exploitation of resources, and re-current natural disasters are likely to be exacerbated by climate change and sea level rise. One natural system at risk from such stresses is the mangrove forest.

The mangrove forests of the Sundarban, in their natural condition, are extremely resilient to fluctuations in mean sea level. However, over-exploitation of forest resources is decreasing their natural resilience, leaving the forests increasingly susceptible to possible climate and sea level changes. Superimposed on these climate-induced changes will be modifications to the forest from human use. The pressure on forest resources will increase as the coastal population expands and if unsustainable forest use continuous. The future of the forest under such multiple threats is uncertain. Sustainable management is vital to protect the forest resource now and to buffer the affects of climate change and sea level rise in the future.

In the south-west, salinity levels are likely to change in the polders due to sea level rise and increased rainfall. However, Because sea level rise will act to increase salinity, whereas increased rainfall will act as to decrease salinity, the net effect on polders and other agricultural areas is uncertain.

4.8 Socio-Economic Effects

In some areas there is a lack of fundamental knowledge concerning the relationship between climate variations and socio-economic effects. There is uncertainty regarding the range of adaptive measures that are available for coping with environmental adversity. Research is needed to fill these gaps in knowledge. Specifically, studies need to be carried out with the following aims:

- to determine the extent to which traditional technologies are being adapted to changing socio-economic conditions.

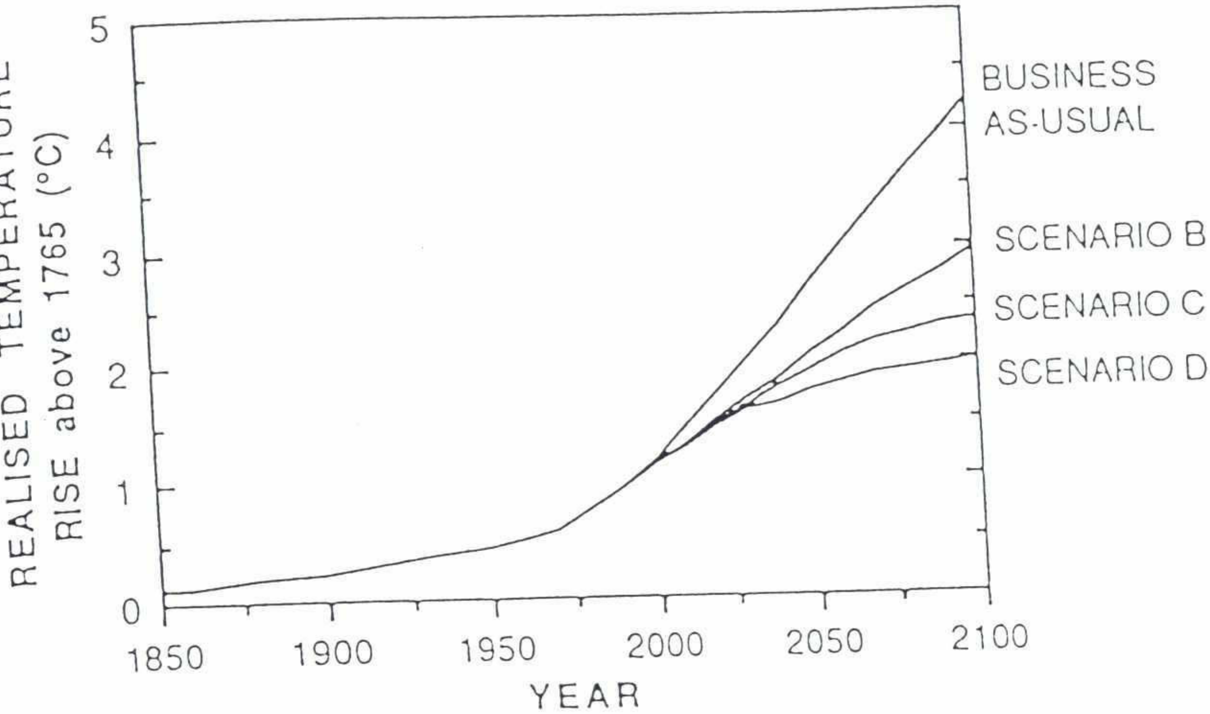


Figure 1.2: Simulations of the increase in global mean temperature from 1850-1990 due to observed increases in greenhouse gases, and predictions of the rise between 1990 and 2100 resulting from the IPCC Scenario B.C and D emissions, with the Business-as-Usual for comparison (Source: IPCC)

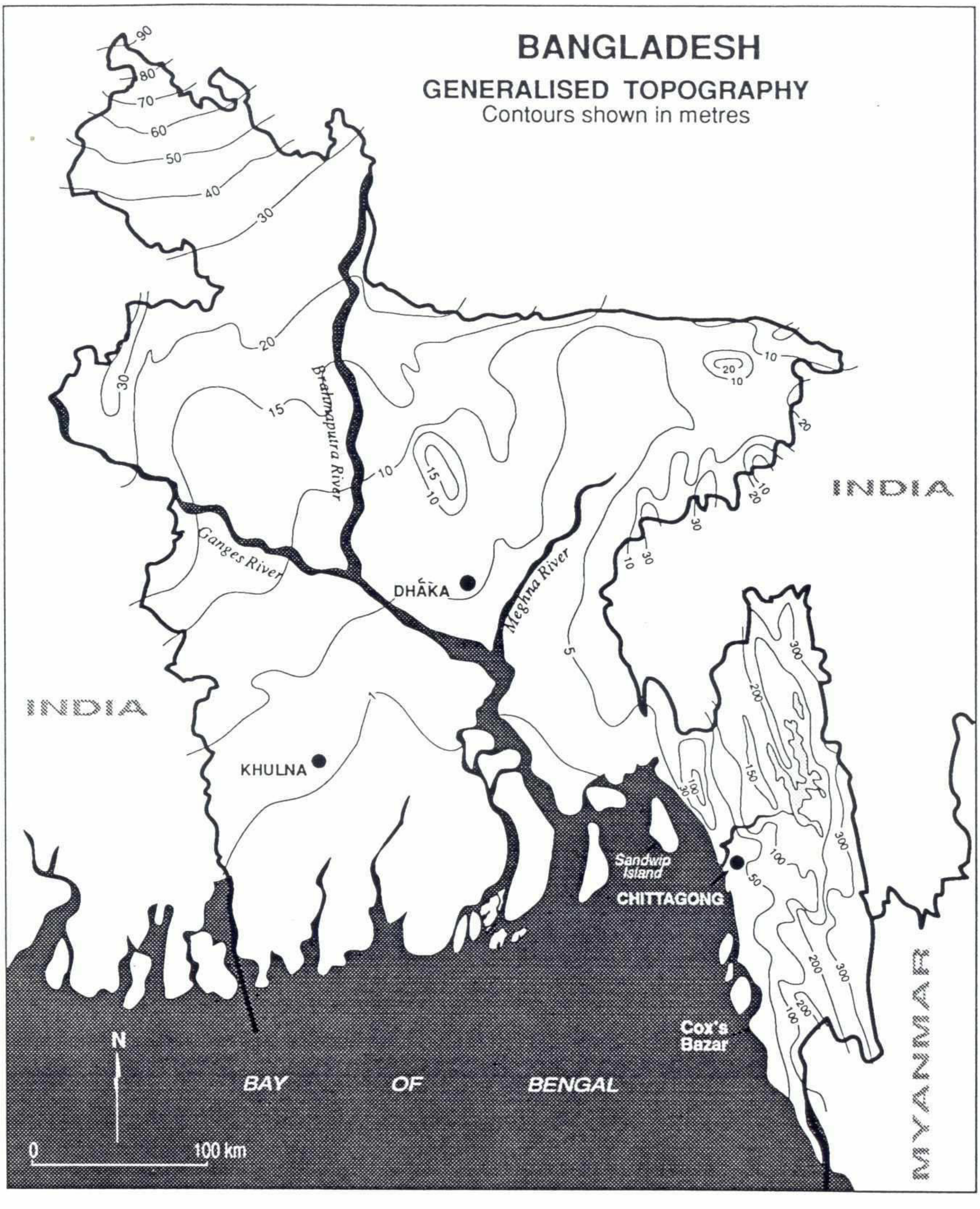


Figure 2.1: Bangladesh topography (Source: Adapted from the Master Plan Organisation [MPO], 1985)

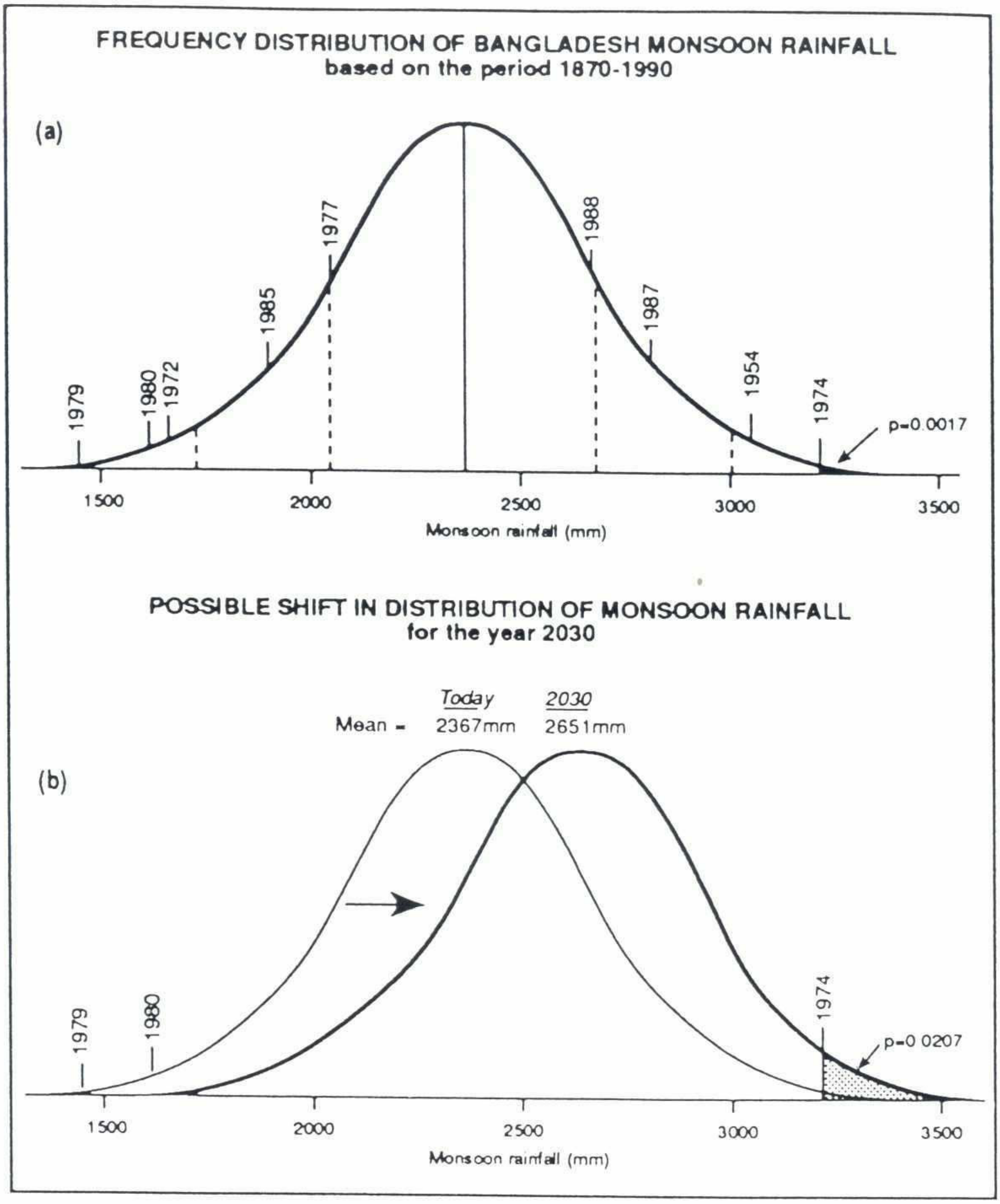


Figure 2.2: Frequency distribution of Bangladesh monsoon rainfall (June-Oct.). (a) Present distribution based on the period 1870-1990, with selected extreme wet and dry seasons noted. The shaded area denotes the probability of the extremely wet monsoon of 1974 being equaled (or exceeded) in any given year. (b) The shift in distribution for a 12% increase in mean rainfall projected for the year 2030, assuming no change in variability. The stippled area under the curve indicates the increase in probability of occurrence of an extremely wet monsoon like 1974. (Source: data courtesy of Climatic Research Unit.)

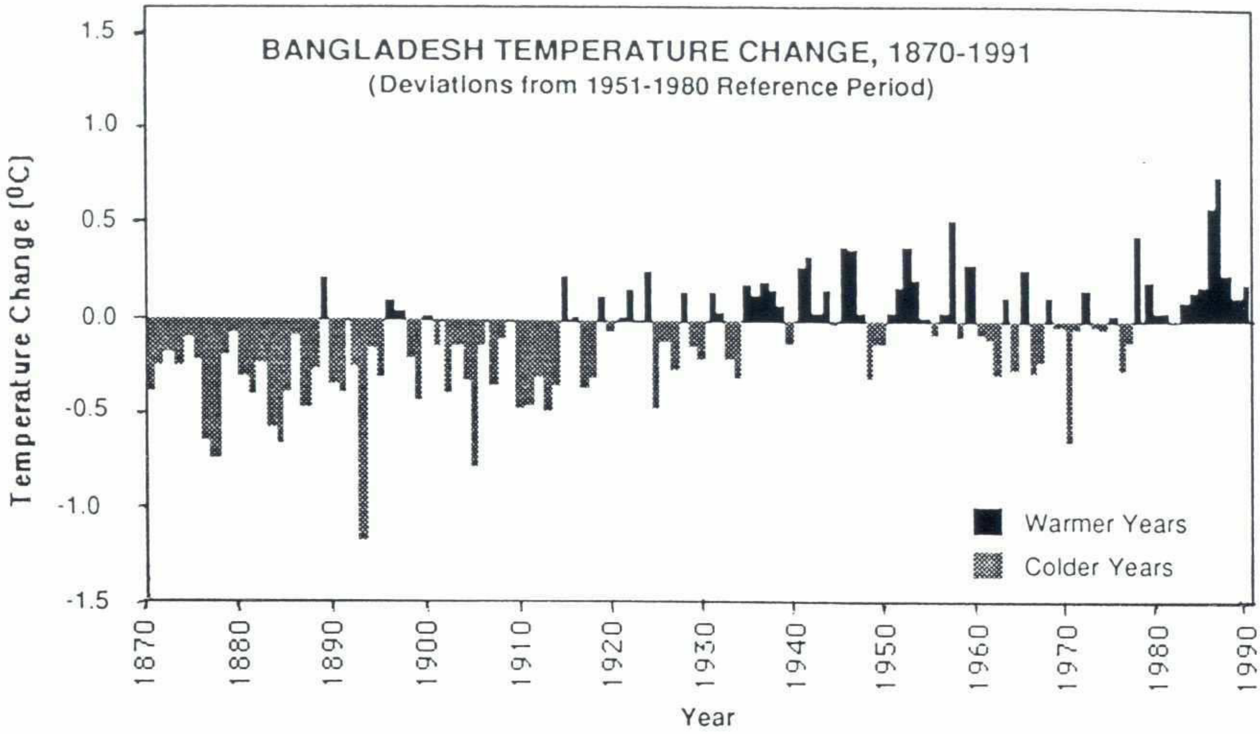


Figure 2.3: Bangladesh mean-annual temperature change. 1870-1991. The values are departures from the 1951-80 reference period (data provided by the Climatic Research Unit). (Source: BUP).

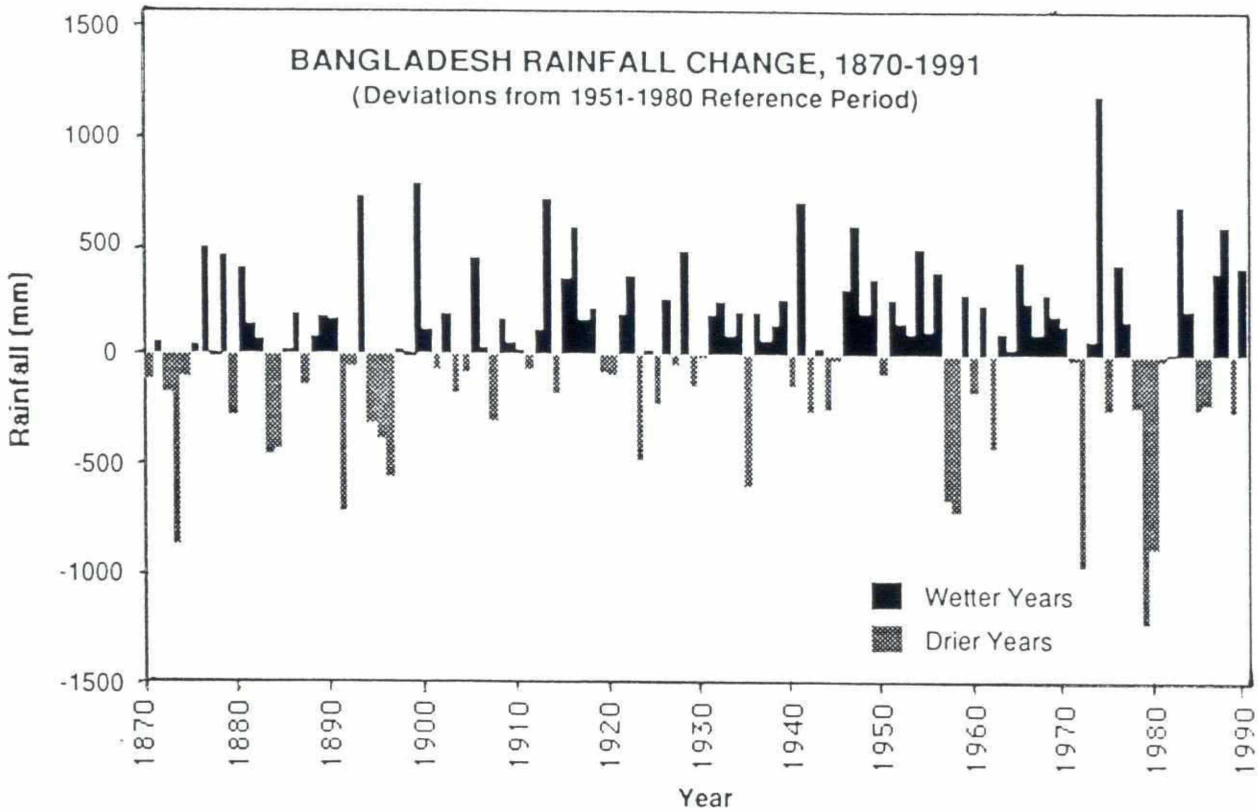


Figure 2.4: Bangladesh regional annual rainfall. 1870-1990. The values are departures from the 1951-80 reference period (data provided by the Climatic Research Unit (Source: BUP)

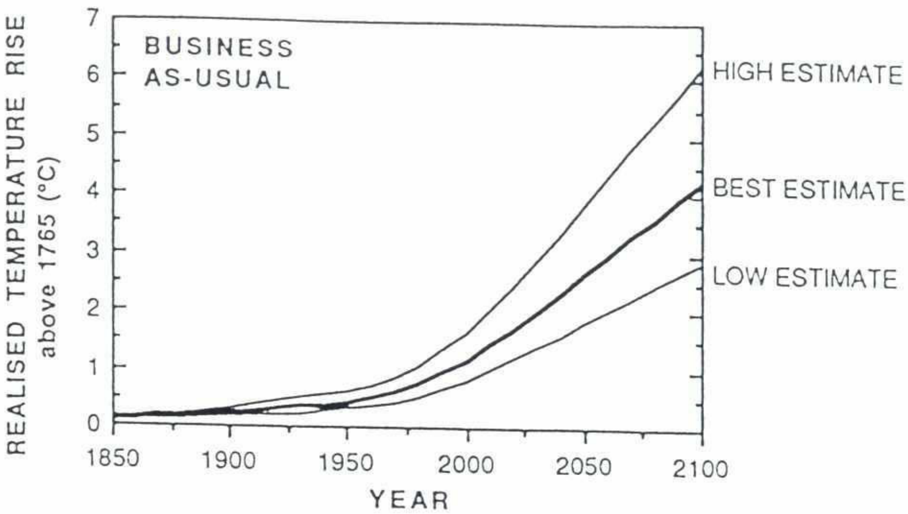


Figure 2.5: Simulation of the increase in global mean temperature from 1850-1990 due to observed increase in greenhouse gases. and predictions of the rise between 1990 and 2100 resulting from the Business-as-Usual emissions. (Source: IPCC).

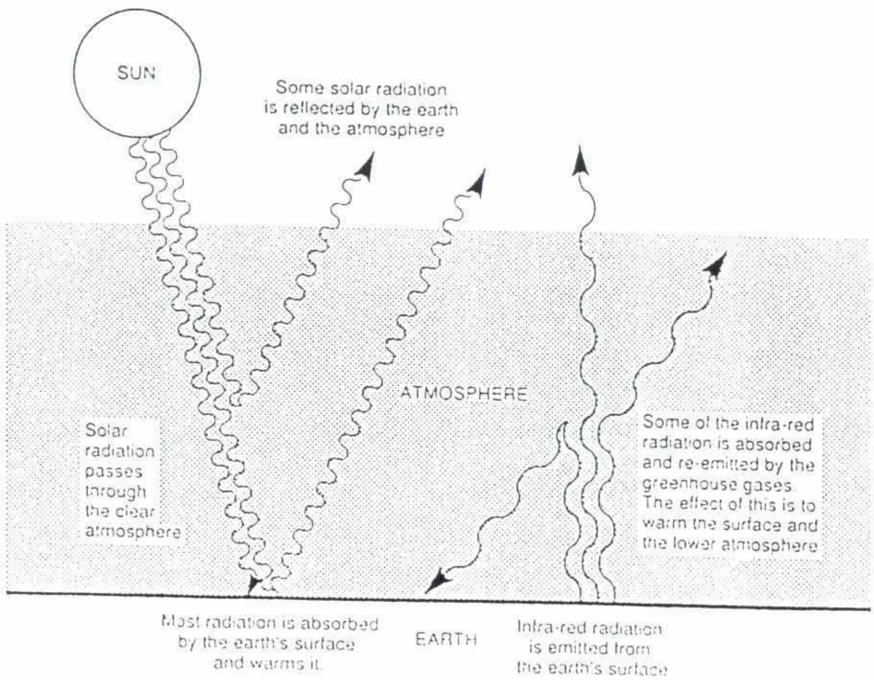
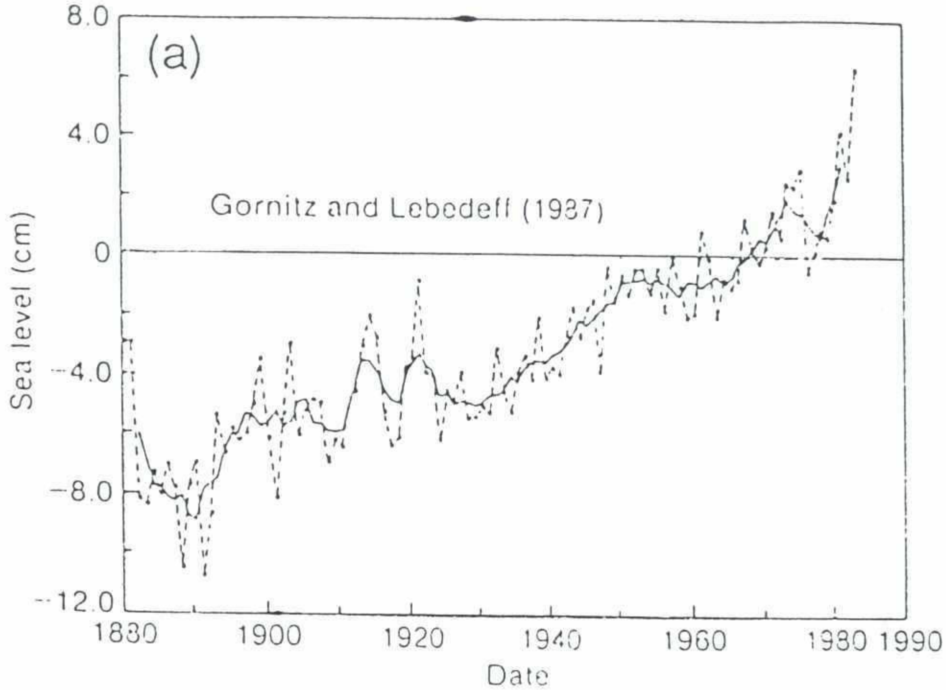


Figure 2.6: A simplified diagram illustrating the greenhouse effect (Source: IPCC).



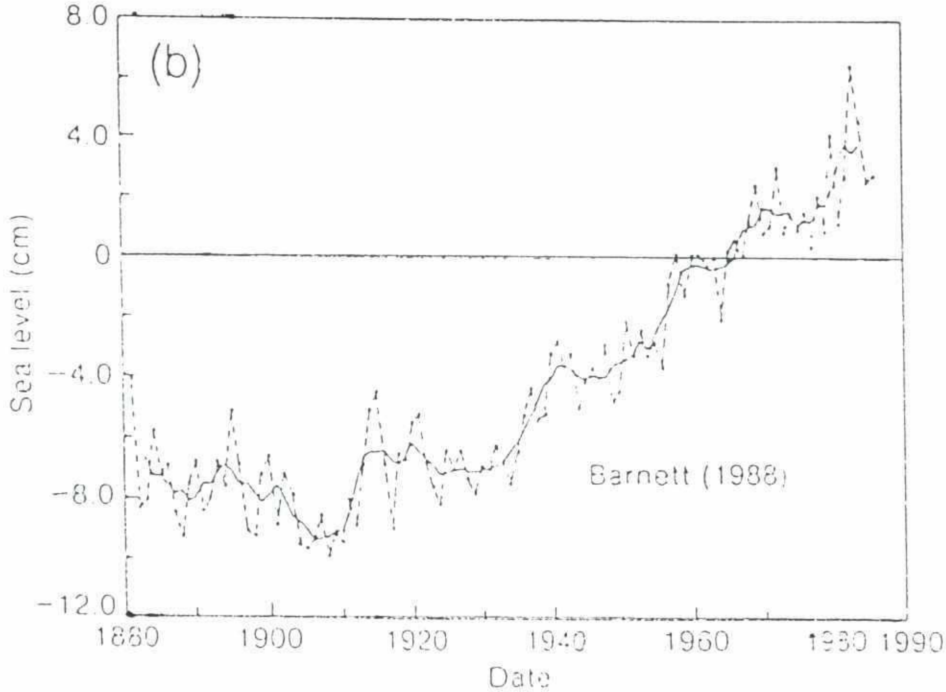


Figure 3.1: Global-mean sea level rise over the last century. The baseline is obtained by setting the average for the period 1951-1970 to zero. The dashed line represents the annual mean and the solid line the 5-year running mean. (a) Gornitz and lebedeff (1987). Barnett (1988).

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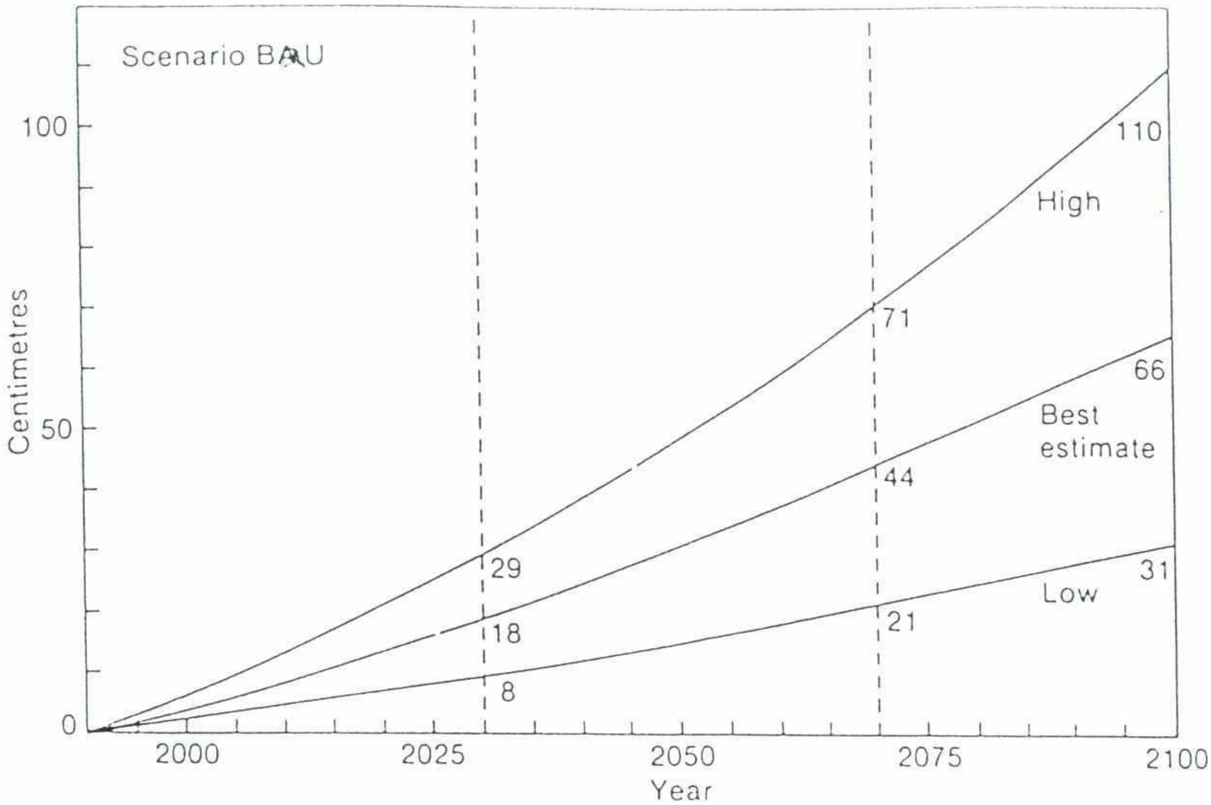

Figure 3.2: Global sea-level rise, 1990-2100, for Policy Scenario Business-as-Usual (Source: IPCC).

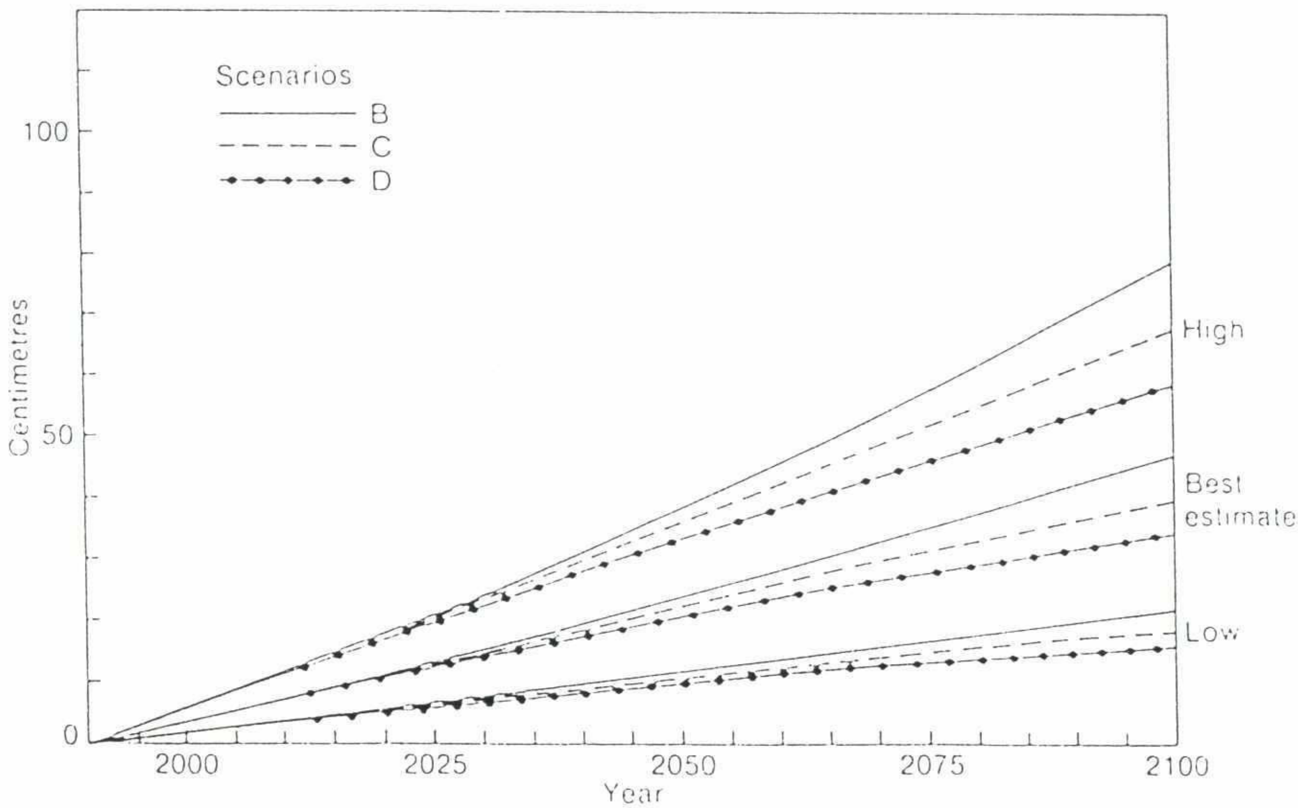

Figure 3.3: Global sea-level rise. 1990-2100, for Policy Scenarios B.C.D. (Source: IPCC).

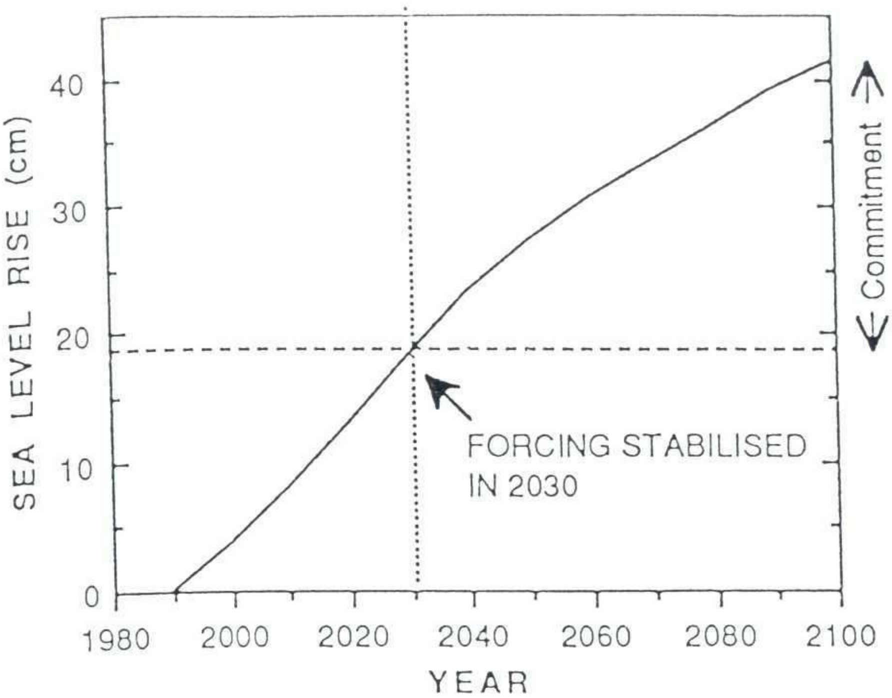

Figure 3.4: Commitment to sea level in the year 2030. The curve shows the sea level rise due to Business-as-Usual emissions to 2030, with the additional rise that would occur in the remainder of the century even if climate forcing was stabilised in 2030. (Source: IPCC).

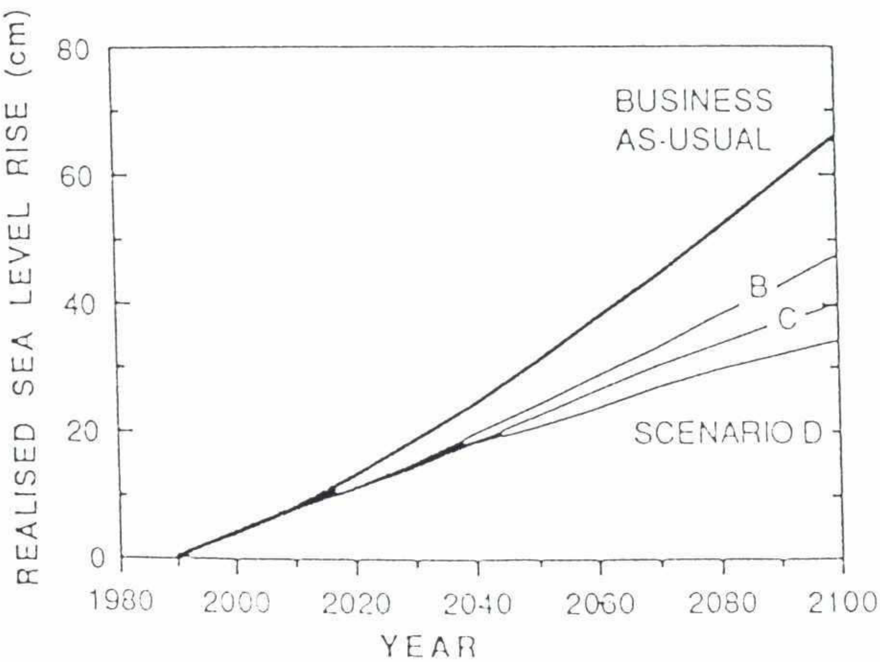

Figure 3.5: Model estimates of sea-level rise from 1990-2100 due to all four emissions scenarios. (Source: IPCC).

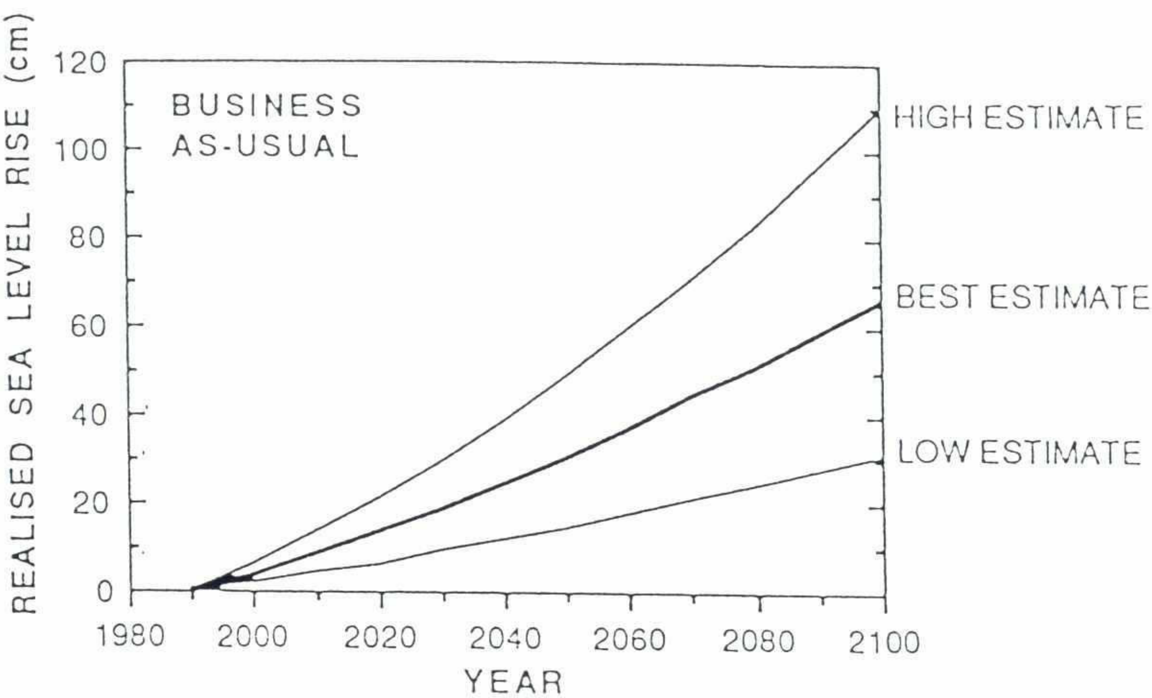

Figure 3.6: Sea level rise predicted to result from Business-as-Usual emissions, showing the best-estimate and range. (Source: IPCC).

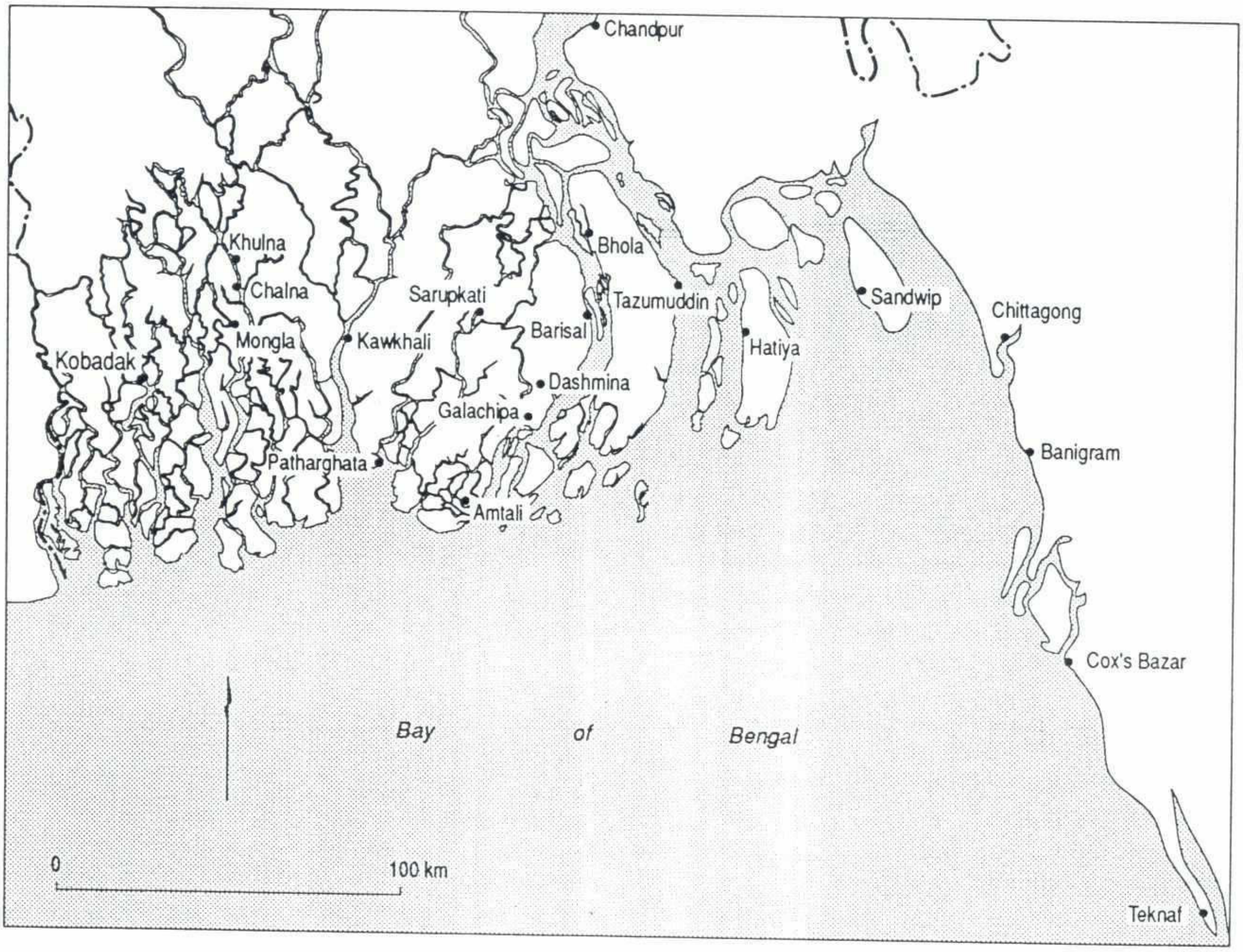

Figure 3.7: The location of selected water level gauges in the Bay of Bengal that are potentially useful for examining trends in sea level (Source: Bangladesh Water Development Board hydrological network.)

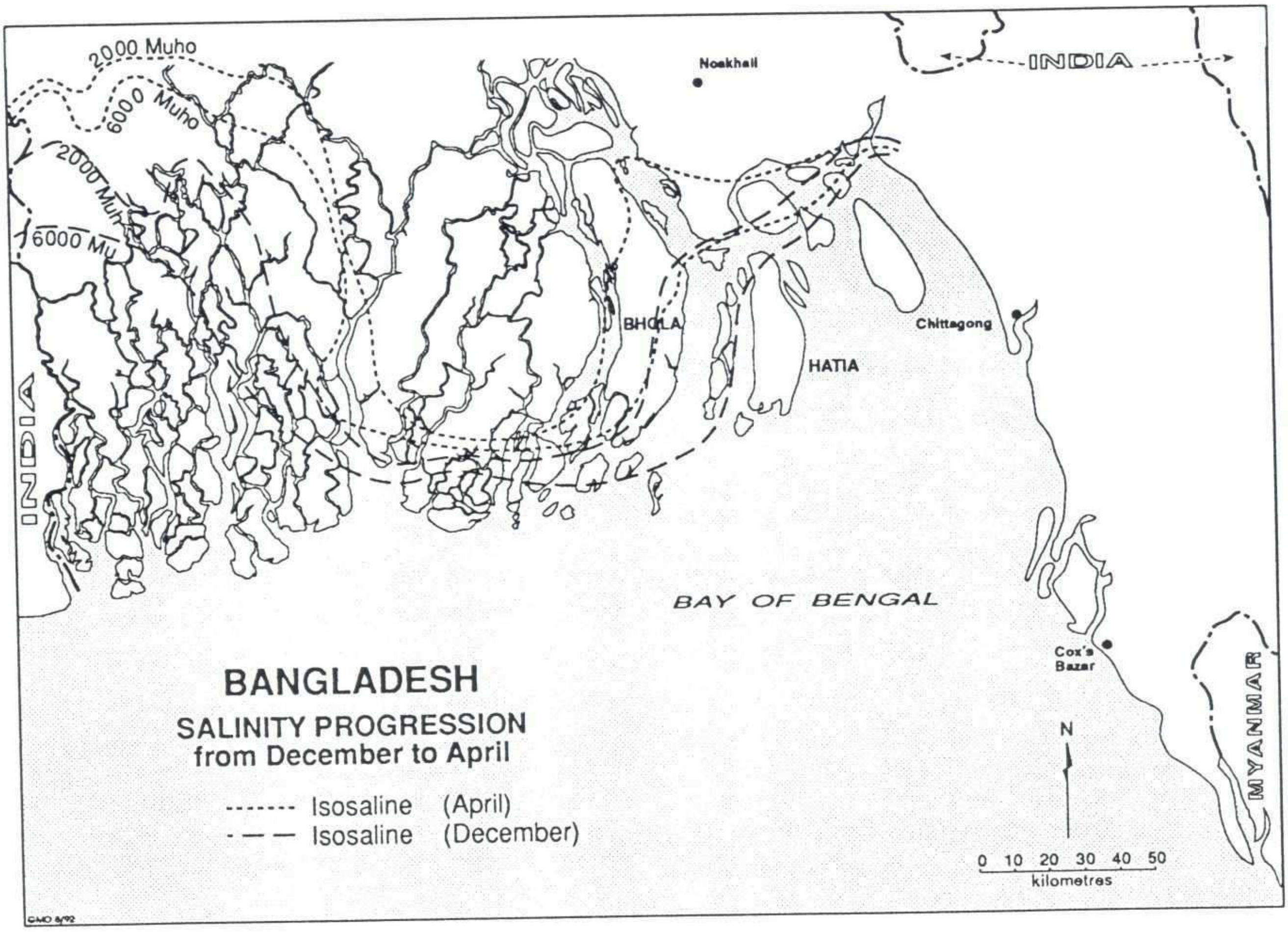

Figure 3.8: Seasonal Fluctuation in the distribution of coastal soil salinity (Source: MPO. 1986).

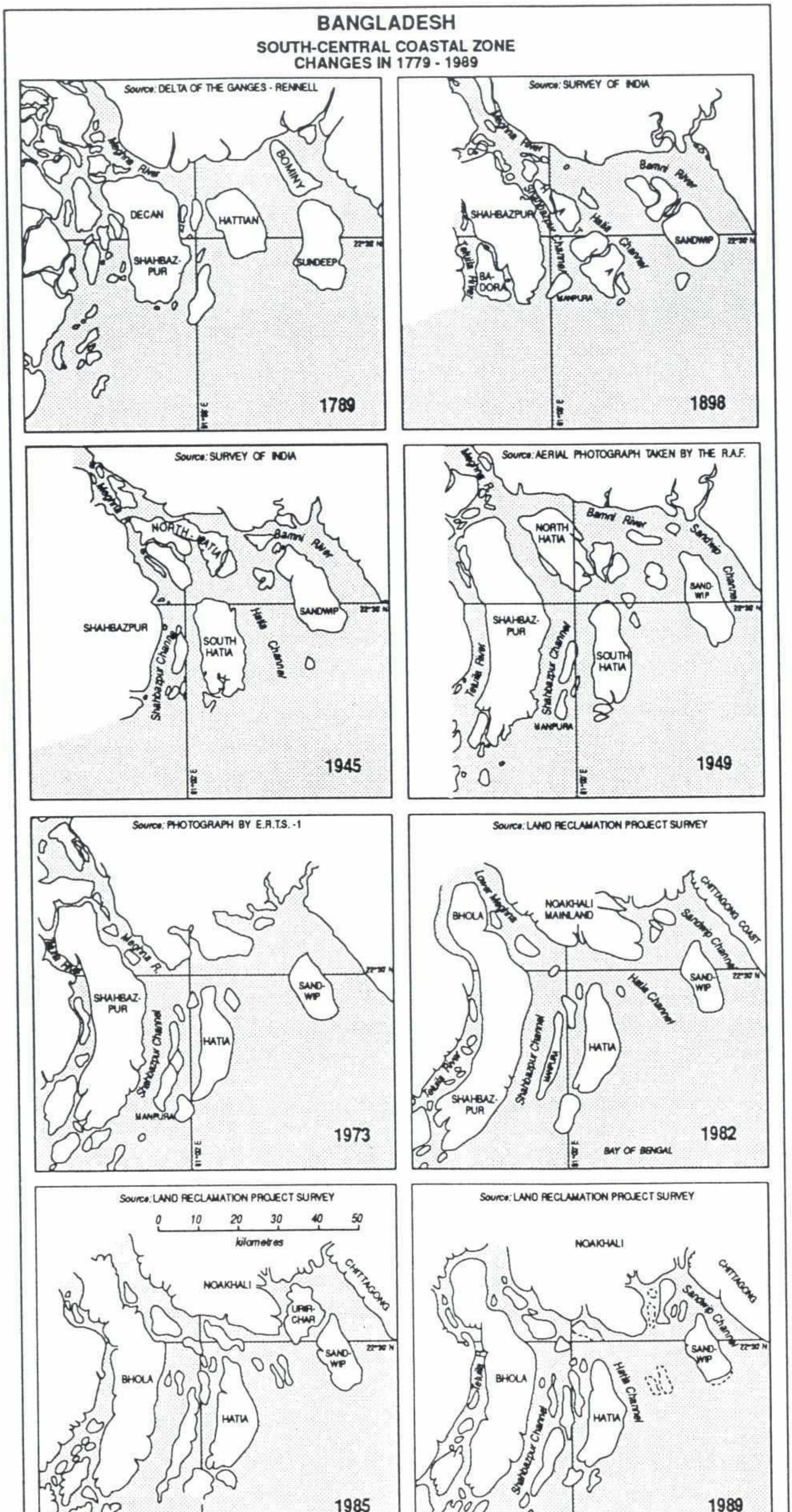

Figure 4.1: Historical Changes in the South-central coastal zone, 1779 -1989 (Source: LRP, 1990 and BUP, 1993).

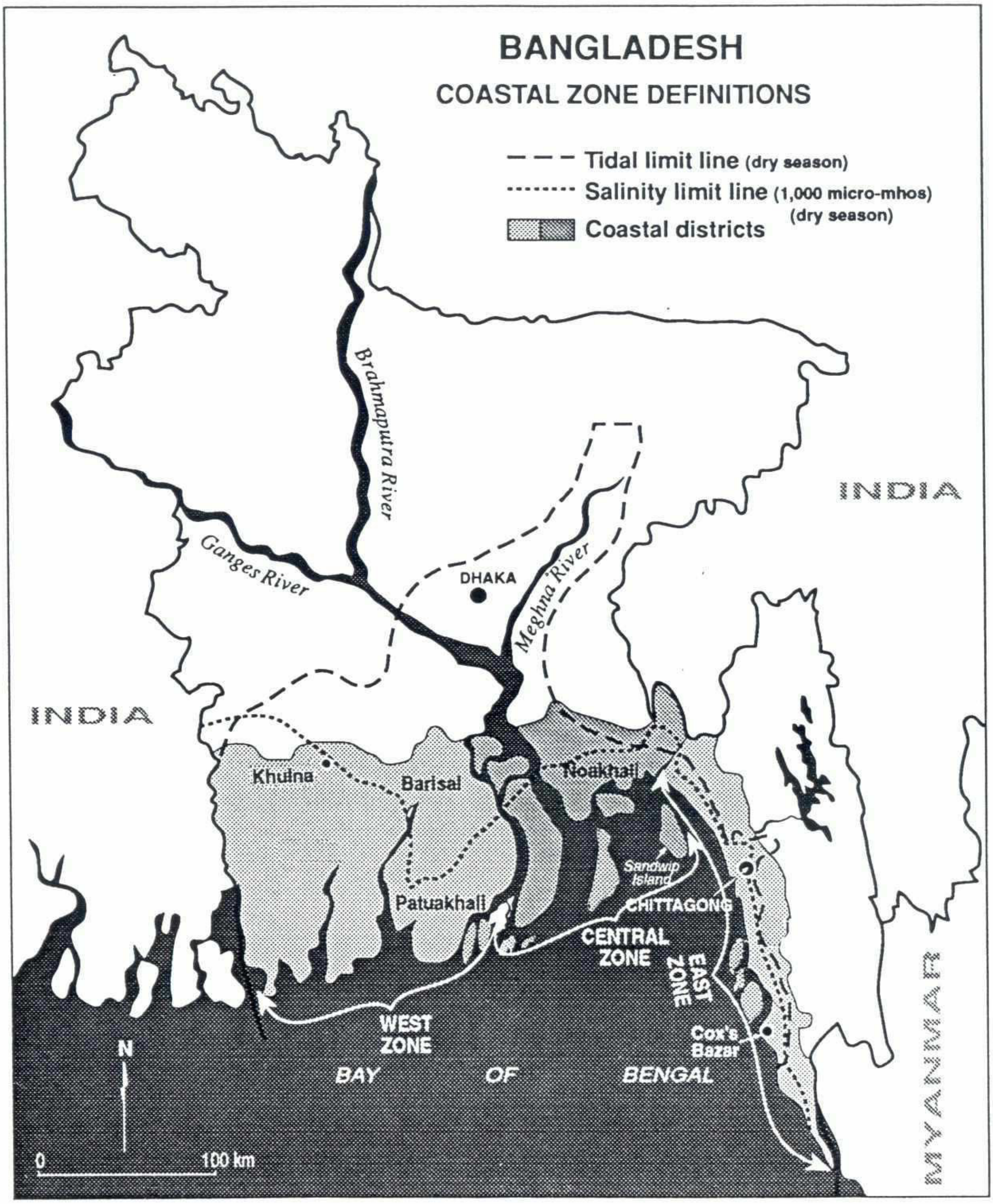

Figure 4.2: The coastal zone of Bangladesh. (Source: BUP).

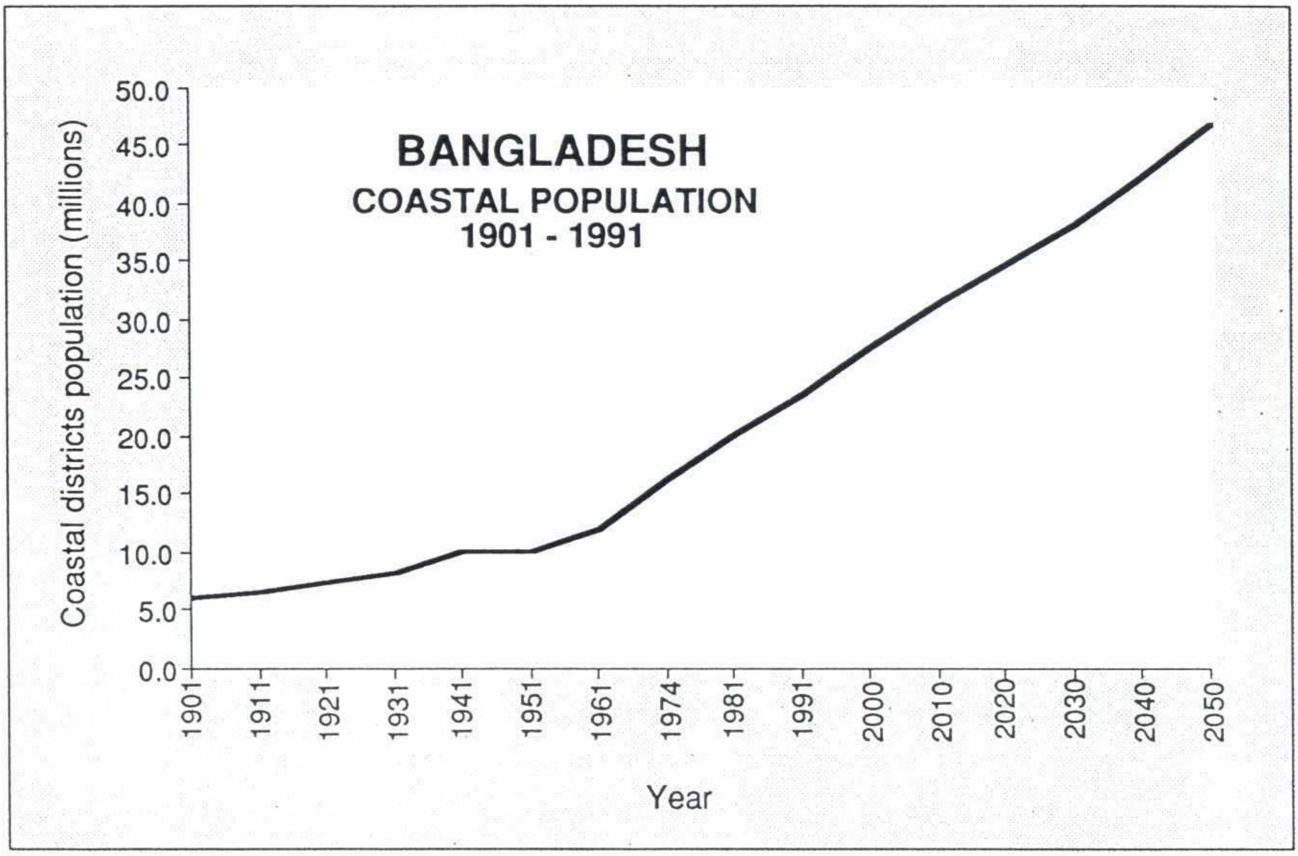

Figure 4.3: Coastal population growth 1901-1991, with a projection to the year 2050. (Source: BBS, 1991 [1901-1991 data]).