1992

Sea Level Rise and Its Impact on Bangladesh

Carlos Alfredo Castro Ortiz
University of Rhode Island

Follow this and additional works at: https://digitalcommons.uri.edu/ma_etds

Part of the [Environmental Indicators and Impact Assessment Commons](#), and the [Oceanography and Atmospheric Sciences and Meteorology Commons](#)

Recommended Citation

Castro Ortiz, Carlos Alfredo, "Sea Level Rise and Its Impact on Bangladesh" (1992). *Theses and Major Papers*. Paper 237.

https://digitalcommons.uri.edu/ma_etds/237

This Thesis is brought to you for free and open access by the Marine Affairs at DigitalCommons@URI. It has been accepted for inclusion in Theses and Major Papers by an authorized administrator of DigitalCommons@URI. For more information, please contact digitalcommons-group@uri.edu.

SEA LEVEL RISE AND ITS IMPACT ON BANGLADESH

BY

CARLOS ALFREDO CASTRO ORTIZ

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
MASTER OF ARTS
IN
MARINE AFFAIRS

THE UNIVERSITY OF RHODE ISLAND

1992

February 14, 1992

Main Library
The University of Rhode Island
Kingston, Rhode Island 02881

To whom it may concern:

In presenting the thesis titled in partial fulfillment of the requirements for the Degree of Master of Arts in Marine Affairs at The University of Rhode Island, I agree that the Library shall make it freely available for inspection. I further agree that permission for copying this thesis for scholarly purposes, as provided for by the Copyright Law of the United States (Title 17, United States Code), may be granted by the Librarian. It is understood that any copying or publication of this thesis for financial gain shall not be allowed without my written permission. Citing of brief passages or statements is granted as part of scholarly writings or research if they are quoted as follows:

CASTRO ORTIZ, CARLOS A. 1992. Sea Level Rise and its Impact on Bangladesh. Unpublished thesis, Department of Marine Affairs, The University of Rhode Island, Kingston, RI.

I hereby do grant permission to the University of Rhode Island's Library to copy my thesis for scholarly purposes.

Carlos A. Castro Ortiz

P.S. Please note that when indexing this work by author, it must be done using *Castro* as the surname, and not *Ortiz*. In this case, *Castro* is the paternal surname, and *Ortiz* is the maternal surname.

MASTER OF ARTS THESIS
OF
CARLOS ALFREDO CASTRO ORTIZ

Approved:

Thesis Committee

Major Professor

DEAN OF THE GRADUATE SCHOOL

UNIVERSITY OF RHODE ISLAND

1992

ABSTRACT

Global temperatures are expected to increase as a result of the so-called "greenhouse" effect, causing concern among scientists who fear that the sea level may rise as much as three meters by 2100. Using mid-range sea-level-rise scenarios of 1.5 and 2 meters potential socioeconomic impacts on coastal Bangladesh are discussed. The geography is described to point out the spatial extent and magnitude of potential damages. Topographic and political-administrative maps are used for population distribution and economic analyses of the areas which would be affected in the sea level rise scenarios. A valuation technique is used to project the gradual GDP loss of the regions most affected from the years 2000-2100. Based on these analyses, implications for Bangladesh policies are discussed and recommendations made that intend to compromise immediate and long-term solutions. Taking into consideration the socioeconomic status of the country the implementation of a coastal zone management plan is recommended in order to preserve and protect its natural resources, but above all, to mitigate the hazards to life and property from eustatic rises in sea level and from storm surges. The results of this study indicate that, in order to avoid or mitigate the potential harm of sea level rise, the government, private organizations, and international agencies must initiate counter measures, beginning with strategic planning based on the assumption that the phenomenon will take place. Furthermore, steps to be adopted to reduce actual danger of ocean flooding will, at the same time be steps for sea level rise preparation. Major population centers that are located in high-risk areas, 1.5 or 2 m above sea level, must gradually move landward.

ACKNOWLEDGEMENTS

I thank my major professor, Gerald Krausse, for the time he spent reviewing many drafts of my thesis. I would also like to thank my committee members, Drs. Lewis Alexander and Thomas Weaver for their constructive criticism and suggestions.

I have benefitted from the help of many people. I am especially grateful to my father-in-law, John Haas, who spent many nights reading, understanding, and correcting my drafts. He knows how difficult it was for me to write in a language other than my native one. His moral support and advice at critical times were essential. I also greatly appreciated the support and friendship of my "buddy," Casey E. Bean, who helped me understand how to apply valuation techniques to environmental problems.

Throughout my graduate school years, my family has reached out across the miles from Chile to lend me the strength and support to complete my thesis. They know how difficult it is to sustain a family and be a student at the same time. *Papas ustedes me han dado el apoyo y esa formacion moral que me hace valorar lo afortunado que soy. Ustedes me han brindado su carino y apoyo a pesar de los miles de kilometros que nos separan. Gracias viejitos.* I also dedicate this work to my daughters, Nicole and Alejandra, my constant inspiration.

Finally, this thesis is dedicated to my wife, Ruth, whose love and support have brought this work to completion. Without her timely encouragement, tolerance, and clear thinking, all this work would not be done. The days and nights she spent reviewing, correcting and editing text with me and for me were invaluable. Gracias, sweetie.

PREFACE

Over the last few decades, scientists, policy makers, and society in general have become increasingly aware that human activities are profoundly changing our environment. Increasing emissions of greenhouse gases are producing a global warming on earth leading to unpredictable consequences. The most dramatic one may be an increase in the global mean sea level.

The greatest natural disaster of modern times occurred one night in November 1970 when a cyclone and tidal wave claimed an estimated 600,000 lives in the area now known as Bangladesh (Bengal nation). This small, populous nation, so vulnerable to the wrath of nature, seems a fitting focal point for a study concerning the effects of a global sea level rise.

This study presents a socioeconomic and environmental analysis of future potential effects of a predicted sea level rise on Bangladesh.

TABLE OF CONTENTS

ABSTRACT	ii
ACKNOWLEDGEMENTS	iii
PREFACE	iv
TABLE OF CONTENTS	v
LIST OF TABLES	vii
LIST OF FIGURES	viii
CHAPTER	
1. INTRODUCTION AND LITERATURE REVIEW	1
Background	1
Hypotheses	4
Methodology, data, and study area	5
Literature review	8
2. BANGLADESH: GEOGRAPHY AND ENVIRONMENT	16
Physiography	16
Climate	18
Coastal and riverine flooding	19
Potential effects of sea level rise on coastal wetlands	22
Geomorphological implications of sea level rise	24
3. DEMOGRAPHIC CONSEQUENCES OF SEA LEVEL RISE	28
Demography	28
Population distribution analysis and impact of flooding	31
4. ECONOMIC CONSEQUENCES OF SEA LEVEL RISE	40

5. POLICY IMPLICATIONS AND RECOMMENDATIONS	56
Policy implications	56
Recommendations	61
Coastal Zone Management Plan	61
Research	73
6. SUMMARY AND CONCLUSIONS	75
 BIBLIOGRAPHY	 81

LIST OF TABLES

Table	Page
1. Estimated sea level rise 2000-2100, by scenario (cm)	6
2. Case scenarios of natural subsidence: Ganges-Bahmaputra	27
3. Projection of population 1960-2010	28
4. Projection of population growth rate	30
5. Population susceptible to flooding by 1.5 and 2 meters	36
6. Projection of base year GDP	43
7. Most recent economic statistics for Bangladesh	44
8. GDP lost due to a sea level rise of 1.5 m	44

LIST OF FIGURES

Figure	Page
1. Map of Bangladesh	3
2. Areas in the world vulnerable to a rising sea level	11
3. Physiographic regions of Bangladesh	17
4. Projected growth for 1985-2010	29
5. Topographic map of Bangladesh	32
6. Political-administrative division of coastal Bangladesh	33
7. Population affected by 1.5 and 2 m scenarios	37
8. Distribution of industries and fishing centers in southern Bangladesh	49
9. Distribution of agricultural production in southern Bangladesh	51
10. Fisheries in Bangladesh	55

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Background

Bangladesh is one of the poorest and most densely populated countries in the world. With more than 113 million people in an area about the size of Wisconsin, overpopulation is a major problem, and recent estimates suggest that population growth will continue despite the government's efforts to control it. Eighty percent of the nation's area of 144,000 square kilometers is made up of the complex Bengali delta system created by the Ganges, Brahmaputra (Son of Brahma) and Meghna Rivers (Bird and Schwartz, eds., 1985). One of the most striking geomorphological features of this nation is its coastal topography, characterized by vast stretches of flood plains barely above sea level. Only a few places in the entire country rise more than 20 m above sea level.

Global warming may raise the sea level up to 2 m world wide over the next 100 years (Hoffman, Keyes, and Titus, 1983; Revelle, 1983; Barnett, 1984)). A rough estimate of the spatial distribution of the population in this country indicates that more than 13% of the total population live in the area that will be submerged. Other major problems are the exposures of the population to storm surge and strong winds. The most destructive storms, the monsoons affect the entire subcontinent of India during September and October. On average, 1.5 severe cyclonic storms attack the country each year with storm surges flooding inland as far as 160 kilometers (Broadus et

al., 1986). Scientists believe that as warming continues, it will not only cause a sea level rise, but will also intensify the pattern of cyclonic storms. Particularly affected will be areas around the city of Khulna, inhabited by about two million people (Figure 1).

Sea level rise will have an economic impact on the agricultural sector which accounts for 55% of the nation's gross domestic product and provides a livelihood for over 85% of the population (Broadus et al., 1986). Agriculture is the source of raw material for much of the small industrial sector (Zaman et al., 1983). More than 25% of the agricultural output comes from low-lying areas that are susceptible to floods.

A sea level rise will cause salt water to enter fresh groundwater reservoirs. Salt water intrusions even now extend as far as 290 km inland (World Bank, 1972). In southern Bangladesh, the Sundarbans region, regularly inundated by the sea during high tides, is one of the world's largest mangrove forests (UNEP, 1986). With 8,000 km of waterways Bangladesh is one of earth's largest delta systems. The fresh water delta fisheries are the country's most important source of animal protein. Fishing these waters provides a livelihood for about 1.5 million people and generates 4% of the Gross Domestic Product (GDP) (Broadus et al., 1986). This important food source would be diminished by salt water intrusion in the event of a gradual sea level rise of one meter or more. One can imagine other consequences for the biotic environment, especially in the coastal areas where vast stretches of mud flats, swamps and newly emerging islands are all specialized habitats of great ecological significance.

Figure 1. Map of Bangladesh
(Source: The Economist Intelligence Unit, 1989)

HYPOTHESES

The major hypotheses of this thesis are enumerated as follows:

1.- In order to prepare coastal areas for an eventual rise in sea level, the government and private agencies will have to implement a coastal defense system with a comprehensive coastal zone management plan.

2.- The government will have to implement a long-term population redistribution policy of all areas presently less than 1.5 m above sea level to avoid future consequences of unexpected flooding and a rapid rise in sea level.

3.- In order to prevent a severe impact on the economy as a consequence of a rise in sea level, the government will have to plan for eventually moving the agricultural and industrial activities in all areas presently less than two meters above sea level to the remaining inland territory.

Methodology, Data and Study Area

This study utilizes a qualitative approach to determine the impact of a steady rise in sea level taking place over a period of 100 years, based on the results of a prediction model proposed by Hoffman, Keyes, and Titus. (1983). This technique provides the data required to make predictions about the effects of the rise on the economy and the demography. Most of the literature reviewed for this project is related to global sea level changes and their large-scale effects on areas such as North America. It was difficult to obtain the basic data needed for this study and judgement has necessarily played a role in making up for the shortage of reliable data. The conclusions are based on a model that has a strong scientific basis but cannot be tested until time has been allowed for some of its predictions to be realized. Additional information utilized in this research comes from secondary data sources such as The Bangladesh Bureau of Statistics and The World Bank. Part of the difficulty in gathering the data was that only a few libraries in the U.S. have much useful material on Bangladesh and direct communication with the Bengali government was not very fruitful.

In order to be more consistent with other studies on sea level rise (Barnett, 1984; Revelle, 1983), and to give more validity to this study, the research is based on the "mid-range" scenarios described by Hoffman, Keyes, and Titus. (1983). and presented here in Table 1. This model was chosen because it is widely used by other researchers (Milliman, Broadus, and Gable, 1989; Broadus et al., 1986; Gable, 1989; Meo, 1989; Weaver and Hayes, 1989; Titus and Barth, 1984; Titus, 1988, 1987). In fact, Titus (1988) also chose the mid-low and mid-high scenarios, explaining that they "are broadly representative of the studies that have been undertaken so far."

Under the "low" mid-range scenario, the sea level rises to 144 cm by the year 2100. Under the "high" one, it rises to 217 cm. We shall refer to these as the 1.5-meter rise and the 2-meter rise, and shall assume they begin in 2000 and end in 2100.

TABLE 1. ESTIMATED SEA LEVEL RISE, 2000-2100, BY SCENARIO (cm)

YEAR	LOWEST	[MID-RANGE LOW	SCENARIOS] HIGH	HIGHEST
2000	4.8	8.8	13.2	17.1
2025	13.0	26.2	39.3	54.9
2050	23.8	52.3	78.6	116.7
2075	38.0	91.2	136.8	212.7
2100	56.2	144.4	216.6	345.0

Source: (Hoffman, Keyes, and Titus, 1983)

To help define the study area, a topographic map of Bangladesh is presented in Chapter 3 (Figure 5). The map shows the rivers and contour lines with the elevations in meters. It features shaded areas for the land which lies below the 1.5- and 2-meter flood levels. Also presented are maps and charts of demographic and economic data. These are of primary importance because they point out the spatial extent and magnitude of possible damage to the country. This information is used to calculate the economic and population losses in the areas where the land is submerged and economic resources, including large numbers of people, are dislocated.

The country's politico-administrative structure consists of divisions, regions, districts and *upzilla*, the smallest units. The source data are available by region and by district. The district is the primary geographic unit applied in the analysis. The spatial distribution of the population in districts located between 1.5 and 2 m above sea level is examined taking into consideration the present and projected growth rate up to the year 2100. Similarly, the agricultural production of southern Bangladesh including the major commodities such as jute, aus, aman and boro rice, and the industrial sector and its contribution to the national GDP are examined, as well.

In order to determine the economic impact of a given sea level rise, a valuation technique (Hufschmidt et al., 1983) is used to project the gradual GDP loss of the most affected regions over period from 2000 to 2100. The economic analysis is based on the premise that the environmental effects of a sea level rise will be reflected in the national GDP. The 1985 data from the affected regions is used for approximating the level if economic activities to be affected. The regional GDP is projected from the base year 1989 to 1999. Accordingly, a 4% national GDP growth is estimated considering the average growth of the economy of the country since 1985. In order to determine the impact of future accumulated economic losses, the GDP must be projected and discounted to determine its present value which then will represent the GDP loss attributable to the loss of land caused by sea level rise. More detail of the analysis is offered in Chapter 4.

Based on the economic and demographic analyses and on the information available on the impact of sea level rise on the environment, recommendations are made for preparing the country for flooding and eventual sea level rise.

Literature Review

A review of the literature concerning global warming and sea level rise is presented in justification of the choice of subject for this thesis. Global warming is still a controversial topic, and the literature presents different ideas about it and the need for further research.

Global warming is thought to be taking place as the result of the so-called "greenhouse effect"¹ associated with the buildup of certain gases in the atmosphere. The buildup is attributed to industrialization and the gases are referred to as "greenhouse gases." The most important greenhouse gases are carbon dioxide, methane, nitrous oxide, ozone, and chlorofluorocarbons. Clouds, ice, and snow reflect 35% of the sun's radiation, the rest being absorbed and converted into heat by the ground and the troposphere². The increased level of greenhouse gases will cause additional absorption of heat in the atmosphere. The resulting rise in surface temperature is expected to melt the snow cover on land and thereby allow the earth to absorb energy that would otherwise be deflected back into space (Titus, 1987), causing an additional warming (Hansen et al., 1983). The entire process, over 100 years, could cause a significant rise in surface temperature.

In the late 1950's, as part of the International Geophysical Year, monitoring stations for carbon dioxide were set up at Mauna Loa, Hawaii and the South Pole. Since then it has been possible to measure the increase in

¹Warming of earth by the atmospheric trapping of infrared radiation is often called the "greenhouse effect."

²The portion of the atmosphere that is below the stratosphere, extending upward about 10 miles from the earth's surface (The Merriam-Webster Dictionary, 1974).

the concentration of carbon dioxide. These measurements signify a doubling of atmospheric carbon dioxide and other greenhouse gases which could raise the earth's average surface temperature 1.5-4.5 °C (3-8 °F) in the next century (National Academy of Science, 1983). By the beginning of the last decade, the United Nations Environmental Programme (UNEP), the World Meteorological Organization, and the International Council of Scientific Unions concluded that the planet's temperature could warm a few Celsius degrees even in the next 50 years (UNEP/WMO/ICSU, 1985).

Hansen et al. (1983) and Menabi and Stouffer (1980) are two interesting studies that use climate models to analyze the greenhouse effect. Hansen et al. predict that the warming from the accumulation of carbon dioxide will be 4 °C, while Menabi and Stouffer predict 2 °C.

Menabi and Stouffer assume that the cloud patterns will not differ significantly, while Hansen et al., using a similar model, allow for important changes in the cloud patterns as a consequence of the carbon dioxide accumulations. Hansen et al. assume that oceanic currents bring heat from the tropics to the poles; Menabe and Stouffer suggest that only the atmosphere transports heat to the poles. Hansen et al. also show that their model's prediction is consistent with historical evidence. In the past century, global temperatures have increased 0.4 °C, with 0.1 °C fluctuations from decade to decade. This model explains the variation in temperatures, caused by carbon dioxide and volcanoes. For comparison, in the last two million years, the earth has never been more than 2 to 3 °C warmer than today (Flohn, 1981); since the Wisconsin Ice Age, the earth has warmed about 4 °C (Hansen, Lasis, and Rind, 1983).

One of the most immediate concerns is that global warming could cause a rise in the sea as much as 1.5 m in the next century and expand the

ocean basin from the melting or sliding into the ocean of parts of the ice sheet in West Antarctica, East Antarctica, and Greenland (Titus and Barth, 1984). Coastal areas are particularly vulnerable to a sea level rise (Figure 2).

The average concentration of carbon dioxide in the atmosphere increased from 315 parts per million (ppm) in 1958 to 346 ppm by 1980, which is equivalent to about 740 billion metric tons (Moore and Bolin, 1986). Studies of ice and tree rings have revealed that the concentration was probably between 260 and 280 ppm in the middle of the nineteenth century (Keeling, 1978). The upward trend is significant considering that the atmospheric concentration might exceed 600 ppm by volume by the end of the next century -- more than two times the pre-industrial level (Moore and Bolin, 1986). If atmospheric concentrations of carbon dioxide were to rise to 600 ppm, the temperature would rise 1.5 to 4 °C, averaged over the entire earth, and 5 to 10 °C at the polar regions, producing dramatic changes in rainfall patterns that could alter the global distribution of agriculture (Moore and Bolin, 1986). It is not possible to predict exactly how much the temperature will rise for several reasons. The initial warming will change the planet's reflectivity in an unpredictable way that will almost certainly amplify the direct warming (Hoffman, Keyes, and Titus, 1983). Generally, the predictions of temperature changes cannot completely account for the complexity of the relationships of the global climate system. The relationship between the greenhouse gases and the ocean basin is not well understood; hence, we do not know, for example, to what extent the ocean will absorb the atmospheric carbon dioxide.

Although the global climate and ocean levels have been stable for the last few centuries, man's activities are beginning to upset the balance

Figure 2. Areas in the world vulnerable to a rising sea level
(Source: Prins, 1986)

achieved through millions of years of natural evolution. The possibility of reducing the emissions of carbon dioxide seems very unlikely since much of the world's energy comes from the burning of oil, gas, wood and coal. Governmental action to curtail emissions of greenhouse gases would take decades to implement and would only lessen the increase of the world's temperature by a couple of degrees Celsius. The political feasibility of such action is very doubtful, since too many countries would have no other sources of energy. If society decided to reduce greenhouse gases emissions today, the most that could be hoped for would be equivalent to banning shale oil, synthetic fuels and coal, i. e. cutting total emissions in half, by the year 2000 (Sidel and Keyes 1983). Measures of this nature would only delay for 25 years the warming otherwise expected, still resulting in a temperature rise of over three degrees Celsius by the year 2100 (Titus, 1987b).

Most of the studies dealing with sea level rise use models that differ from one another in their methodology or the nature and validity of their input data. Nevertheless, they indicate that there will be a significant sea level rise in the next 100 years, based on the measurements of carbon dioxide accumulation in the atmosphere (Hicks, Debaugh, and Hickman, 1983).

Besides the ocean rising due to currently increasing concentrations of carbon dioxide, there have been sea level fluctuations, historically. Certain periods are marked by higher than average rates of rise. In Newport, Rhode Island, sea level rose about 3 mm/year between 1930 and 1970, although perhaps half of this was due to tectonic subsidence (Kennet, 1982). Based on measurements of weighted averages from all the tide gauges in the world, global sea level over the last century has risen 10 to 15 cm of which five can be attributed to thermal expansion of the upper layer of the ocean (Gornitz, Lebedeff and Hansen, 1982).

Addressing the impact of global warming on the sea level, Hoffman Keyes, and Titus (1983) estimate that the rise will be from about 56 to 345 cm, but more likely from 144 to 217 centimeters (Table 1). Their results are based on projections of yearly changes in the natural climatic system. In order to develop their analysis, they consider four factors: atmospheric composition, the climate, the oceans, and the cryosphere (the part of the world that is ice or snow). Not all the emissions of carbon dioxide remain in the atmosphere: some are removed by green plants and some absorbed by the oceans. The global climate-system is extremely complex and not understood well enough to predict any change in the natural carbon cycle.

Using a different approach, Revelle (1983) estimates that the rise is likely to be 70 cm, ignoring any melting of the ice in Antarctica. Barnett, (1984) uses a regional approach to predict a long-term sea level rise beginning in the early 1900's, as well as a rise of 14.3 cm per century for the total time of record.

In the small amount of literature concerning sea level rise and its impact on Bangladesh there are two interesting studies. Broadus et al. (1986) describe, in general terms, possible socioeconomic consequences, but provide no information about their method. Using scenarios of one and three meters for their estimates of sea level rise, they indicate that approximately 11.5 and 27% of the land and 9 and 27% of the population will be affected in both scenarios, respectively. The authors assume that 8 to 20% of the nation's GDP currently originates in these areas. They conclude recommending that private and public agencies begin considering possible effects of sea level rise over the next century in their long-term planning.

Edwards (1987) studies the economic impact using two extreme scenarios of 0.8 and 3.4 m in an interesting analysis, then concludes with a

confusing and misleading argument. He indicates that the total GDP originating in the affected zone is approximately \$2.92 billion corresponding to all economic activities. About 5% of the population live in the 0.8 m zone, therefore, he assumes that 5% of the GDP, about \$150 million, would be affected by a rise in sea level. The confusion begins when he realizes that sea level rise is a gradual process, in which case the effects would occur at an incremental rate. The percentage of the population to be affected the first year does not correspond to the logical sequence of the calculation. Edwards, himself, concludes that although other approaches are "conceptually superior," his GDP approach can provide a useful tool in evaluating property values.

Milliman, Broadus, and Gable (1989) expand on the previous work of Broadus et al. (1986) explaining in more detail the geomorphological implications of sea level rise for the Bengal Delta. Although this is a well documented study, it does not provide a clear indication of how the calculations were made. The authors indicate that either natural or accelerated subsidence could "surpass the most pessimistic predicted eustatic sea level rise" and greatly accentuate its effects. Countries like Bangladesh should pay considerably more attention to the impacts of river damming and the increase of groundwater extraction. Recent economic development in Asia has resulted in large scale river development projects that could affect the normal sediment deposition thereby accelerating the subsidence process. Milliman et al. conclude that the loss of land will be magnified by forcing large numbers of people farther inland "where they will increase the competition for diminished space."

The remaining literature reviewed on Bangladesh deals with the management of the waters of the Bengal delta (UNEP, 1986; Murty, 1984;

Brammer, 1987; Rogers, Lydon, and Seckler, 1989). These studies deal with the constant flooding and the strategies to confront it, important since part of the flooding comes from the sea.

The geographic descriptions and the cartography are based on Ahmad (1986), Prins (1986) and The Bangladesh Bureau of Statistics (1986). Their material helps to explain the complex delta system.

CHAPTER 2

BANGLADESH: GEOGRAPHY AND ENVIRONMENT

Physiography

Bangladesh, a country of rivers, is located on the east flank of the Indian subcontinent, at the junction of south and southeast Asia. Its 8,000 km of waterways include three great river systems: the Ganges-Padma, the Brahmaputra-Jamuna, and the Meghna. About one third of the land is under water each year after the monsoonal floods; cyclones and violent storms are also familiar hazards. Millions of people are affected by annual flooding and temporary sea level rise, but they love their land and call it "Sonar Bangla" (Golden Bengal) (Ahmad, 1976).

Physiographically, Bangladesh is characterized by five large areas (Figure 3) (Ahmad, 1968):

- (1) the tertiary hills, including the Chittagong area and the hills of southern Sylhet;
- (2) the Pleistocene terraces,
- (3) the alluvial plains, north and east of the Ganges River,
- (4) the deltaic plains that comprise nearly half of the national territory and are themselves differentiated by landscape into three areas. The first, the central section where the monsoonal rains cause seasonal flooding of the meanders of several rivers, leaving rich, sedimentary deposits, is constantly being transformed by the erosion and accretion of the riverbanks (Prins, 1986). The second area is a series of tidal plains along the Khulna and Chittagong coast. The third type of landscape

Physiographic regions of Bangladesh. Source: (Ahmad, 1968)

FIGURE 3

features turbulent estuaries of the three major rivers. The currents in these estuaries have formed many islands through the delta region that are constantly affected by intensive storm surges. Yet, the processes of deposition and erosion balance out leaving this area geomorphically stable.

- (5) the low-lying coastal plain that extends from south of Noakhali along the coast of Chittagong.

Climate

Bangladesh is strongly affected by the annual rhythms of a typical monsoonal system. The monsoonal rains cause seasonal floods which are intensified by the ongoing deforestation in the uplands. The floods cover at least 30% of the country (Prins, 1986). High temperatures and a permanently high humidity are year-round, with mild winters from the end of November to mid-February (Ahmad, 1976). Generally heavy rainfall occurs throughout the country between June and September. The weather pattern has a strong influence on agricultural productivity from one locality to another.

Between February and May Bangladesh experiences a period of climatically unstable conditions that bring devastatingly strong winds. These wind patterns are governed by warm, moist, southerly maritime air drifting over cool, dry continental air from the northwest. It is along the occlusion of these two air masses that the storms are usually generated and most intense (Ahmad, 1976). Clearly, these climatic patterns can only exacerbate the predicted conditions caused by sea level rise in the coastal environment.

Coastal and riverine flooding

Historically, Bangladesh, like China, has struggled for centuries against the devastating effects of storms and river flooding on its population and economy. Winds are an important climatic component contributing to ocean flooding, and the most destructive ones are the monsoons. The cyclones affect mostly the Bay of Bengal, bringing torrential rains followed by strong tidal waves which are particularly destructive in the coastal region (UNEP, 1986). Certain large-scale, geomorphological processes, such as subsidence and the damming of rivers, are thought to affect the magnitude and timing of floods in the river basin (Rogers, Lydon, and Seckler, 1989). The process of deforestation and the thinning of the forest cover in the hills has helped to create and intensify local flooding.

Damage from cyclones and intense flooding includes the destruction of natural storm buffers in low-lying coastal areas. These buffers, in the case of Bangladesh, are the mangrove forests of the Sundarbans (de Sylva, 1986). The loss of coastal vegetation, principally mangroves, has already reduced the protective advantage it affords beaches and water front property against normal wave-action and cyclones. Large areas of southern Bangladesh that are covered by compact mangrove forests, as the Sundarbans, including parts of the districts of Satkhira, Khulna, and Bagherhat, will be potentially inundated.

A rise in sea level will cause mangroves and other vegetation to migrate further inland, but such migration will be inhibited by manmade structures such as bulkheads and levees (Titus., 1988). The rapid population growth in the coastal zone is further stressing the protective mangrove forest. If the current practice of deforestation continues during the next decade or so

the entire forest-system will be virtually destroyed, leaving the exposed coastal areas much more vulnerable to ocean flooding (UNEP, 1986).

The extreme shallowness of the water in some near-shore areas and the absence of shore defences to protect the low-lying coastal lands is conducive to the formation of a "storm wave." Such waves are known to have travelled several kilometers inland, flooding affected areas to a depth of as much as 13 meters (Murty, 1984). About 60% of all deaths attributed to storm surges in the Bay of Bengal area have occurred in the low-lying, arable coastal areas of the nations bordering the Bay and adjoining the Andaman Sea, with Bangladesh, alone, accounting for about 40 percent (Murty, 1984).

Over the last 100 years, cyclones of extreme severity have come at intervals of 20-22 years (Ahmad, 1976). From year to year, the storms follow different tracks, and even within any one track, depending on the stage of development, different areas may receive the heaviest rain (Ahmad, 1976). The flooding has become aggravated by the silting-up of most of the rivers. Excessive destruction of the natural vegetation around all the headwaters of the rivers has led to extensive erosion and, consequently, the riverbeds have been silting up rapidly during the last decade or so.

While the immediate loss of life is often the most dramatic result of a major surge, other effects also can be very serious. The most devastating surge in this century struck Bangladesh in November of 1970. This cyclone took perhaps 600,000 lives and caused enormous economic damage which contributed to the loss of life (Ellis, 1972; Murty, Flather, and Henry, 1986). Damage due to storm surge in the Bay of Bengal region in the period 1945-75 has been estimated at seven billion U. S. dollars (Murty, 1984). In late August 1988, exceptionally heavy rains in India and northern Bangladesh swelled the three large rivers that meet in the coastal zone, inundating three

quarters of the country. About 25 million people were rendered temporarily homeless, and reports indicate at least 2,000 deaths. The damage to the economy was severe: five million acres of rice land flooded, 100,000 cattle were lost and 43,000 miles of roads damaged (U.S. Congress, House, 1988).

The most recent cyclone, of late April 1991, badly battered the coastal areas of Chittagong, taking the lives of approximately 139,000 people (McDonald, 1991). A wave of sea water, about 10 m high, surged over the Bangali islands and low-lying areas, devastating the region. The side effects of the storm were as bad as the storm itself. Following the cyclone, about 100,000 people were afflicted with gastroenteric diseases. Many of the ponds and freezing plants, used for the local shrimp fisheries, were destroyed. An estimated 520 km of embankments were also destroyed or damaged.

Human activities are making matters worse. Besides the deforestation already discussed, Bangladesh has been involved in an international conflict with its neighbor, India. During the monsoon season, the Indians tend to open the floodgates of the Farakkha Dam, complicating the flooding situation in Bangladesh. The Bengali government has presented an official protest to India bringing the case to the United Nations. Moreover, commercial timber production of paper companies directly upriver from the highlands of Bangladesh and Nepal has added to the run-off and siltation.

Coastal flooding in Bangladesh has already cost thousands of lives and caused considerable economical loss. The greenhouse effect, assuming it does occur, will change the world's climates, and, for Bangladesh, will intensify tropical storms and cyclones. If this is accompanied by a persistent sea level rise, Bangladesh is apt to suffer catastrophic consequences in a relatively short period of time.

The potential effects of sea level rise on coastal wetlands

Bangladesh is one of the largest deltaic estuaries in Asia, where vast stretches of swamps and mud flats occur along the coastal region. The Sundarbans is a complex ecological forest system that is traversed from north to south by numerous, large channels which represent former river arms in the delta. The wetlands of this coastal environment cover an area of 5,993 sq km which comprises 12.5% of the Sundarbans forest system or 4.2% of the national territory (UNEP, 1986). The diversion of waters by the historic eastward shift of the Ganges-Brahmaputra river has made a relatively modest contribution of fresh water to the Sundarbans (UNEP, 1986). The mangrove forest becomes stunted and more open as one proceeds toward the sea or westward (Ahmad, 1976).

Ecologically, mangrove swamps have been classified into three zones according to the influence of salinity (UNEP, 1986). The northeastern part of the Sundarbans has a fresh water forest. The eastern part is dominated by a moderately saline forest. And, the western part up to the Indian border has the typical saltwater mangroves. A relatively rapid increase in sea level rise would increase salinity and change the boundaries of the three zones. Furthermore, the ecological relationship between the mangroves and the biota would also change. The temperature, salinity, food, substrata, and protection found in this ecosystem is optimally balanced for a host of organisms to carry out their life cycles. This optimum balance could not be sustained in an environment of fluctuating salinity (Odum and Heald, 1975).

There are three major ways by which sea level rise can disrupt wetlands: by inundation, erosion and saltwater intrusion (Titus, 1988). With regard to inundation, if sea level rises as much as 1.5 or 2 meters in a

relatively short period of time, like 100 years, the stability of the wetlands will be dramatically affected. However, if the rise takes much longer, say, 1,000 years, then the wetlands have a chance to adapt. Bangladesh, over the centuries, has attempted to protect its wetlands by extensive levee systems along the banks of rivers and man-made waterways. Regardless of the rate of inundation, there is a present need for additional protective, engineering structures facing the coast and rivers (Park, Armentano, and Clonan, 1986).

A second way that sea level rise can disrupt wetlands is by erosion. Pramanik, Chaudhury, and Macleod (1978) believe that river bank erosion is negligible in the Sundarbans area, principally because of the coastal stabilization by the mangrove forest, particularly in the southwestern corner of the country. This area is presently a National Forest Reserve, yet a significant portion of the total population in the country depends to some extent on the mangrove environment for their livelihood (UNEP, 1986). The forests are currently supposed to be managed by a system of selective cutting and natural regeneration designed to sustain the yield of firewood (UNEP, 1986). But, widespread, illegal deforestation and over-exploitation of the forest resource continue in spite of the management system. Any erosion associated with human activity, such as forestry, could be accelerated by a sea level rise. A marked decrease in freshwater discharge and concomitant reduction in the mangrove forest cover could impose a major disruption in the fisheries and local economies of this region (UNEP, 1986).

The third way that sea level rise can disrupt wetlands is by salt water intrusion, experienced primarily in estuaries and aquifers along karstic coastlines found in many of the low-lying countries as well as in Bangladesh (Parker, 1955 and Bowen, 1982). Salt water intrusion has already taken place in the underground reserves of Bangladesh. If the population keeps

growing as it has for the last 30 years, and salt water continues to intrude further inland, there will be a serious shortage in good quality drinking water. In the western part of the country salinity levels are associated with the natural deterioration of drainage through the moribund Ganges delta (Brammer, 1987). Furthermore, during the dry season the diversion of water for irrigation from the upper reaches of the Ganges-Brahmaputra-Meghna system has allowed salt water to penetrate further inland. And finally, the damming of the former Ganges tributaries for the purpose of obtaining much-needed irrigation waters has also contributed to the problem of salt water intrusion.

Geomorphological Implications of sea level rise

The coastal zone of Bangladesh is one of the most tectonically active areas in the world. The Bengal Basin is crossed by one of the world's major subduction faults whose activity recently caused catastrophic earthquakes in the region. Moreover, this tectonic activity has caused changes in river courses (Brahmaputra to Jamuna and Atrai to Tista), bank erosion, and accretion in the Noakhali-Barisal area (Bangladesh Space Research and Remote Sensing Organization, 1986). These tectonics may be due to the presence of a major fault at depth or a subsidence along the axis of the Jamuna-Padma-Meghna river system (Rashid 1977).

Other processes that may intensify sea level changes during the next century are coastal erosion, natural and accelerated subsidence, and a probable decrease in the influx of fluvial sediments (Milliman, Broadus, and Gable, 1989). Rapid coastal inundation is predicted not only for Bangladesh

but for many low-lying areas in the world. Presently, relative sea level appears to be rising at a rate of 1 to 2 mm/yr, and in the past 100 years has risen about 10 to 15 cm (Gornitz, Lebedeff, and Hansen, 1982). The subsidence problem will be especially severe in low-lying regions where natural rates of subsidence range from 3 to 20 mm/yr, and the diversion of river sediments and the utilization of ground waters can severely aggravate the local impact of sea level rise (Gable, 1989). In low-lying deltas local subsidence can be as great as one cm/yr, 10 to 100 times the present eustatic level (Milliman, Broadus, and Gable, 1989). With regard to fluvial sediments, although the Ganges-Brahmaputra-Meghna river system transports an estimated 971 cu km of water and more than 100 million tons of sediments annually from the Himalayas to the Bay of Bengal (Milliman, Broadus, and Gable, 1989), only about eight percent of the total drainage basin of the system lies within Bangladesh (Zaman et al., 1983).

It is difficult to estimate precisely how the relationship of erosion-subsidence-deposition factors into an eventual sea level rise principally due to the lack of information concerning subsidence and river flow. Subsidence could be accelerated by an increased groundwater use in coastal areas. Both an increase in subsidence or a marked decrease in riverine sedimentation could accentuate further effects of sea level rise (Milliman, Broadus, and Gable, 1989). In particular, the possibility of groundwater depletion must be reckoned with in view of the fact that by 1985 more than 100,000 shallow tubewells and 20,000 deep tubewells, no deeper than 200m had been drilled in Bangladesh for water extraction, a six-fold increase from seven years earlier (UNEP, 1986).

Milliman, Broadus, and Gable (1989) discuss possible scenarios of geomorphological changes combined with a theoretical sea level rise for

Bangladesh for the years 2050 and 2100. Their document describes the relationship between the changes and the rise based on the effects of processes such as a eustatic sea level rise, a damming/diversion of rivers, and an accelerated subsidence as a consequence of underground water depletion. The authors utilize two theoretical situations: a conservative, "best-case" scenario of 13 cm of sea level rise by the year 2050 and 28 cm by 2100, and a "worst-case" scenario of 79 cm by 2050 and 217 cm by 2100 (Table 2). The best case assumes that the minimum rise of eustatic sea level coupled with the deposition of river-born sediment will offset natural subsidence, meaning that the delta stays approximately in equilibrium. The worst case assumes that the maximum rise of eustatic sea level coupled with the complete damming/diversion of the river draining into the delta, plus natural subsidence will produce a maximum increase in the relative sea level. In this case, the authors assume that these and many other factors, such as the removal of groundwater in the lower delta (especially in urban areas), will combine to accelerate the process. Their study implies further demographic and economical consequences, as well. However, they do not present any methodology or anything else to explain how the evaluations were made concerning the socioeconomic impact of changes in sea level.

Table 2. CASE SCENARIOS OF NATURAL SUBSIDENCE: GANGES-BRAHMAPUTRA

TABLE 2
27

	2050			2100		
	BEST CASE (NATURAL SUBSIDENCE)	WORSE CASE (NATURAL SUBSIDENCE, DAMMED RIVERS)	WORST CASE (ACCELERATED SUBSIDENCE, DAMMED RIVERS)	BEST CASE (NATURAL SUBSIDENCE, NATURAL RIVER FLOW)	WORSE CASE (NATURAL SUBSIDENCE, DAMMED RIVERS)	WORST CASE (ACCELERATED SUBSIDENCE, DAMMED RIVERS)
TOTAL SEA LEVEL RISE	13 cm	144 cm	209 cm	28 cm	332 cm	447 cm
WORLD WIDE	13 cm	(79)	(79)	(28)	(217)	(217)
LOCAL SUBSIDENCE	(0)	(65)	(130)	(0)	(115)	(230)
SHORELINE EROSION	0 km	1 km	1.5 km	0 km	2 km	3 km
% LOSS HABITABLE LAND	NA	16	18	NA	26	34
% POPULAT. DISPLACED	NA	13	15	NA	27	35

(Source: Adapted from Milliman et al., 1989)

CHAPTER 3

DEMOGRAPHIC CONSEQUENCES OF SEA LEVEL RISE

Demography

Bangladesh is among the world's most densely populated countries with about 685 inhabitants per square kilometer. Since the end of World War II there has been an explosive growth in population (Table 3 and Figure 4). The government has given a high priority to population control for many years by promoting family planning through programs aimed at reducing the growth rate. Despite the internationally aided programs the current growth rate is still 2.5%, the same as the average for the 25-year period, 1960 - 1985 (Table 4).

TABLE 3. PROJECTION OF POPULATION, 1960-2010 (Millions)

PROJECTIONS	1960	1965	1970	1975	1980	1985	1990	2000	2010
A	52.4	60.5	69.3	71.1	88.5	100.6	113.7	133.1	151.7
B	52.4	60.5	69.3	71.1	88.5	100.6	113.7	141.1	170.5
C	52.4	60.5	69.3	71.1	88.5	100.6	114.6	148.1	183.7

(World Bank, 1987)

BANGLADESH POPULATION GROWTH, 1950-1990
PROJECTED GROWTH FOR 1985-2010

(Source: World Bank, 1987)

FIGURE 4

TABLE 4. PROJECTION OF POPULATION GROWTH RATES
(Percent per annum)

PROJECTIONS	1950-60	1960-65	1965-70	1970-75	1975-80	1980-85	1985-90	1990-00	2000-10
A	2.3	2.9	2.8	0.5	4.5	2.6	2.5	1.6	1.3
B	2.3	2.9	2.8	0.5	4.5	2.6	2.5	2.2	1.9
C	2.3	2.9	2.8	0.5	4.5	2.6	2.6	2.6	2.2

(World Bank, 1987)

About 85% of the population live in rural areas, mainly due to the development of economic activities such as the extensive cultivation of jute and rice. This rural population is concentrated along the major rivers where the soil and physiographic conditions are best for growing crops. The co-cultivation of jute and rice is a unique economic-demographic development wherein vast, rural population exerts heavy pressure on the land.

This nation has long been of interest to demographers and economic development planners because of its precarious economic condition and overwhelming population density and growth. This condition represents a composite of all the extremes of poverty, inequality, famine, birth and death, typical of third world countries. Demographic conditions are so extreme that, even without considering potential changes in sea level, the next several decades look bleak. The small territory allows little room for relocating large numbers of people from areas threatened by sea level rise or other natural disasters. Per capita income is among the lowest in the world. More than 50% of the population is under 15 years of age and only 25% of the total

population are gainfully employed. Less than 15% of the adult population have five or more years of schooling (Haque, 1983).

On the positive side, the country has fertile agricultural land, and extensive waterways that provide an easy means of transport and travel. The area of productive land includes the districts of Noakhali and Barisal which are within the area that would be affected by a sea level rise.

Although population of Bangladesh is overwhelmingly rural, if the ocean rises 1.5 or 2 meters it will submerge some important urban centers such as the densely populated city of Khulna, located in the northern section of the district with the same name. This area has experienced the most significant change in the level of urbanization with a population increase greater than 500% between 1951 and 1986. About two million people live in this district with a density of 451 inhabitants per square kilometer (Bangladesh Bureau of Statistics, 1986)

Population distribution analysis and impact of flooding

The population distribution analysis considers the demographic implications of increases in the relative level of the ocean³ under the two scenarios discussed in Chapter 1. In order to carry out the analysis a cartographic spatial method is utilized to estimate the affected population. A topographic map (Figure 5) superimposed on a political-administrative chart with the same scale (Figure 6) shows where the contour lines for 1.5 and 2 m run through the southern districts.

³The effective sea level rise is the actual rise plus the subsidence due to tectonic events.

TOPOGRAPHY OF BANGLADESH - Modified from Bangladesh in Maps, University of Dhaka, 1981

FIGURE 5

(Source: modified from Bangladesh Bureau of Statistic, 1986)

FIGURE 6

Since the district is the smallest land area for which population statistics are available, it is assumed for analytical purposes that the population is evenly distributed over a given district. In reality, however, there are instances where the population of a district is locally, heavily concentrated. This is the case for each of the districts of Satkhira, Khulna and Bagherhat, where the population is concentrated in the northern part, the southern part being covered by mangrove forest. Despite this deviation from the assumed distribution, much of the population still falls within the areas flooded under the 1.5- and 2-m scenarios. Moreover, many districts such as Bagherhat, lie entirely within the area flooded under the 1.5-m scenario. The cases of Satkhira and Khulna are similar; more than 80% of the population lie under the flood level in both scenarios.

In order to determine the spatial distribution of the population affected under both scenarios, the portion of every district falling below 1.5 and 2 m are determined. The population of the affected area is given by the relationships:

$$(1a) \quad \begin{array}{l} \text{AVG. POPULATION} \\ \text{DENSITY OF } i \text{ th DISTRICT} \end{array} \times \begin{array}{l} \text{AFFECTED} \\ \text{AREA OF } i \text{ th} \\ \text{DISTRICT} \end{array} = \begin{array}{l} \text{AFFECTED} \\ \text{POPULATION OF } i \text{ th} \\ \text{DISTRICT} \end{array}$$

$$(1b) \quad \sum_{\text{DISTRICTS}} \left(\begin{array}{l} \text{AVG. POPULATION} \\ \text{DENSITY} \end{array} \right) \times \left(\text{AFFECTED AREA} \right) = \begin{array}{l} \text{AFFECTED} \\ \text{POPULATION} \\ \text{COUNTRY TOTAL} \end{array}$$

These were used to calculate the percentage of population affected by districts and on a national level. Examination of data obtained from the population distribution of southern Bangladesh indicates that 16 districts will

be affected if sea level rises 2 meters (Table 5). The magnitude of this effect will vary depending on the topography of the area. The analysis assumes that non-flood related future migrations of the population and any improvement in family planning that reduces the rate of birth will be negligible.⁴

The examination of possible effects of changes in sea level on the population also conservatively assumes that the effects of possible tectonic depressions of the country due to natural or induced subsidence from underground pumping are negligible. Otherwise, what is expected to happen in a period of 100 years may happen in a shorter period of time.

Figure 7 and Table 5 show, based on 1986 statistics, how southern Bangladesh will be affected by the two theoretical scenarios. Thirteen million people, representing 13% of the 1986 total population, will be affected if sea level rises 1.5 meters, or about 16 million people, representing 16% of the total 1986 population, if it rises 2 meters. Note that it is quite possible that temporary sea level rise may occur due to storm surge affecting even more than 16 million people.

The figures presented above correspond to the 1985 demographic statistics of Bangladesh (Bangladesh Bureau of Statistics, 1986). This situation will change drastically if we estimate annual population growth and projected population for the next 20 or more years. It is assumed that the population will continue growing steadily for the next 50 to 100 years.

Figure 4 indicates how Bengali population has been growing in the last 30 years. From 1950 to 1990 (historic region) population has more than

⁴ In 1982 the Bangladesh Contraceptive Prevalence Survey (Bangladesh Ministry of Health and Population Control, 1982) reported that 17.5% of currently married women under 50 years of age living in rural areas were not using any method of contraception. The figure for similar women living in urban areas was 29.2% (U.S. Department of Commerce, 1982).

doubled; if this trend continues, by the year 2100 the population will be over 300 million. The dimensions and implications of the population growth are staggering. Assuming no changes in sea level, if the number of live births

TABLE 5

**POPULATION OF THE SOUTHERN SECTION OF BANGLADESH
SUSCEPTIBLE TO FLOODING BY 1.5 AND 2 METERS
SCENARIOS OF SEA LEVEL RISE
(Based on 1986 statistics, unadjusted)**

DISTRICT	TOTAL POPULATION (000)	POPULATION AFFECTED BY 1.5 M SLR* (000)	DISTRICT PERCENTAGE	NATIONAL PERCENTAGE	POPULATION AFFECTED BY 2 M SLR * (000)	DISTRICT PERCENTAGE	NATIONAL PERCENTAGE
JHALAKATI	683	683	100.0	.68	683	100.0	.68
BARGUNA	824	824	100.0	.82	824	100.0	.82
PIROJPUR	1236	1236	100.0	1.20	1236	100.0	1.20
BHOLA	1346	1346	100.0	1.30	1346	100.0	1.30
PATUAKHALI	1296	1296	100.0	1.30	1296	100.0	1.30
BAGHERHAT	1417	1417	100.0	1.40	1417	100.0	1.40
BARISAL	2118	1680	79.3	1.70	2118	100.0	2.10
KHULNA	2017	1560	77.3	1.60	1883	93.2	1.90
GOPALGANJ	1135	697	61.4	.70	934	82.3	.93
SATKHIRA	1553	929	59.7	.93	1281	82.4	1.20
LAKSMIPUR	1295	733	56.6	.73	944	72.8	.94
NOAKHALI	2068	930	44.9	.93	1261	60.9	1.20
CHANDPUR	2068	146	7.0	.15	543	26.2	.54
MADARIPUR	1084	51	4.6	.05	303	27.7	.30
NARAIL	6720	29	4.2	.03	62	9.2	.06
SARIATPUR	9748	32	3.2	.03	646	6.6	.64
TOTAL		13,589		13. %	16,777		16. %

* SEA LEVEL RISE

Source: The original data; population, population density and areas was obtained from Bangladesh Bureau of Statistics (1986).

BANGLADESH POPULATION AFFECTED BY 1.5- AND 2-METER SEA LEVEL RISE SCENARIOS

POPULATION AFFECTED BY 1.5 m RISE

POPULATION AFFECTED BY 2 m RISE

FIGURE 7

remains constant at the present level and mortality rates continue as at present the population will increase from about 113 million to about 151 million by the year 2010, using the most conservative approach by the World Bank (projection A). Even if there were a successful population control program on a much greater scale than has as yet been conceived in Bangladesh, there would still be a large increase in the number of people by the beginning of the next century, partly because population planning programs take time to bear results and partly because to start with there is a very young population. The population-related problems would appear to overshadow any related to sea level rise.

Assuming that, despite governmental population control programs, the population will continue growing at a constant rate, then the question is how this nation, one of the poorest in the world, will gradually move millions of people landward into an already overcrowded space.

For economic development, to take place, the main sectors of agriculture and industry will need more land. But economic progress will be stifled if the heavy pressure of population growth continues producing an increasing demand for food, and by the first half of the next century Bangladesh will be unable to sustain its population of 151 million or so either from domestic production or from imports (Islam, 1978).

In the event of a sea level rise the possibility of starvation, famine, and rising death rates could dramatically reduce population growth in the Malthusian fashion. The availability of land for the next 50 to 100 years and the prospects for large increases in yields do not seem likely. If there is an acceleration in the rate of economic growth and a rise in the standard of living it might help to improve the Bengali attitude towards population

planning, since low birth rates are historically associated with high levels of socio-economic development (Islam, 1978).

The projections presented here are conservatively realistic considering that Bangladesh is already experiencing temporary sea level rise and flooding that not only has struck the economy of the country but also has cost the lives of thousands of people. In September of 1988 severe floods occurred in Bangladesh inundating three fourths of the nation, covering 52 out of 64 districts, affecting over 50 million people. The deaths of more than 2000 persons can be linked to the floods (U.S. Congress. House, 1988). The floods have also caused an acute shortage of pure drinking water, creating conditions conducive to epidemic levels of diseases, and has produced a serious impact on the economy, creating not only a severe supply shock but also a severe depression of income and demand. Governmental efforts to deal with annual flooding and temporary sea level rise indicate that it is beyond the resources and capabilities of the country to manage such crises effectively.

CHAPTER 4

ECONOMIC CONSEQUENCES OF SEA LEVEL RISE

The first assessment to determine the impact of a sea level rise is an inventory of all the economic resources potentially threatened by changes in sea level. Agriculture, the most important, accounts for more than 60% of the GDP and the economically active population (Bangladesh Bureau of Statistics, 1989). Within this sector, jute is the most important followed by rice. The destruction of food crops by yearly flooding already places strains on the economy. There exists a type of symbiotic relationship between agriculture and industry; flooding affecting jute cultivations will invariably affect the industrial sector, as well. Apart from producing nearly 90% of the nation's food, agriculture is the source of a number of other raw materials such as tea, tobacco, sugar and oil seeds (Farland and Parkinson, 1976).

Losses of food and cash crops are a common occurrence in the economy and precipitate unanticipated food import requirements, producing an adverse impact on industry and heavy reliance on foreign aid. External assistance finances 50 to 55% of import needs. According to the World Bank (1987) estimates, the reliance on foreign assistance will last several decades.

The regions susceptible to flooding represent a significant portion of the economy. Data available from the Bureau of the Statistics Division of the Bengali government reveals that the regions⁵, Noakhali, Barisal, Khulna and

⁵These four regions include about a dozen districts. They constitute practically the same area flooded at 1.5 m.

Patuakhali, represent approximately 15% of the total agricultural labor force. A portion of the economically active population in these regions is dedicated to other activities such as services, transportation and sales, making a small contribution to the economy, but still an important one in terms of employment. A rise in sea level would disrupt these activities dislocating millions of people and affecting the job market, nationally.

This environment is so fragile that we do not have to wait 100 or even 40 years to predict significant future losses for Bangladesh. Storm surges which raise the sea level two or three meters presently flood a large portion of the arable land not adapted to sea water. Substantial agricultural production would thus be lost in the event of permanent flooding.

An increase in sea level for the next 25, 50 or 100 years implies a gradual movement of a large number of people estimated herein earlier to be in the range of 20 or 30 million. The migration northward would inevitably result in the residential use of land that otherwise could contribute significantly to the economy. An alternative would be the gradual westward movement of the population to the Chittagong hills. This area has far less production potential and its hilly topography makes it difficult to inhabit. Thus, sea level rise would result in the loss not only of production from the flooded area but from the newly occupied areas, as well.

The problems derived from changes in sea level are not limited to the loss of living space and agricultural production, but include losses relating to the industrial and manufacturing sectors, both of which are dependent on agricultural activities. For example, several industrial centers around the city of Khulna would be affected by both scenarios of sea level rise. However, they are modest in size accounting for only 15% and 9% of the GDP under the worst- and best-case scenarios respectively (World Bank, 1987). The

approximately 70% of the nation's industrial output contributed by the manufacturing industry accounts for 8% of the total employment (Far East and Australasia, 1989). The jute industry is the backbone of the economy providing most of the foreign exchange.

On the basis of the assumptions made thus far, we shall predict how the environmental-economic relationship will evolve. Market-based techniques are commonly used to assess the impact of any hazard on the environment, specifically using actual market prices or market land values. Dwindling accuracy is a problem with any long-term projection, and would be a problem here if the attempt were made to predict market prices occurring 20, 50 or 100 years hence. The present analysis avoids this problem by using, instead, an adaptation of an economic valuation technique to project the GDP of the affected areas over the 100-year period selected.

The adaptation borrows from a technique that is commonly applied to natural systems to evaluate environmental quality (Hufschmidt et al., 1983). The idea lies in the application of a benefit-cost analysis to natural systems to determine management measures for reducing the adverse effects on the environment resulting from natural hazards. This kind of technique is used in planning and decision making processes not only on a local level but in a national context, as well.

The modified benefit-cost analysis uses the national GDP and the local GDP's from the regions affected as a basis for approximating the level of economic activities in those regions. The most recent data found for sectorial or regional GDP is from 1985 (Bangladesh Bureau of Statistics, 1986). The Economist Intelligence Unit (1990) provides macroeconomic indicators such as the GDP at current market prices and real GDP growth percentages from 1985 to 1989. These data are presented in Tables 6 and

7. In Table 6 the Base Year GDP is established for the 1.5 meter flooded areas and for the nation. Table 7 shows that the real GDP growth ranges from 2.4 to 4.7 percent. The lower values are associated with severe floods. A value of 3% is used in Table 6 to move the values from 1989 forward to the Base Year, 1999. Beyond that point the flooding from sea level rise begins according to the model already set forth, and the analysis is taken up in Table 8, where the time dependent relationship, derived shortly, between the present value of the future accumulated losses of GDP and the GDP of the base year, is used to generate the final total values.

TABLE 6
Projection of Base Year GDP

	TAKAS (000,000)		DOLLARS, U.S. (000,000)	
	1985*	1989	1989	1999
Noakhali	15150	24530	760.1	1022
Patuakhali	8096	13109	406.2	546
Barisal	17727	28703	889.5	1195
Khulna	23321	37760	1170.1	1573
National	405400	656400	20340.0	27340

*Bangladesh Bureau of Statistics, 1986

Other Notes:

- (1) 1989 regional values are computed by assuming they bear the same ratio to 1985 values as the National GDP in Table 7.
- (2) 1989 Dollars are computed using the exchange rate for 1989, Table 7.
- (3) 1999 Dollars are projected on the basis of a 3% GDP growth rate for 10 years. This is the "Base Year" for Table 8.

Table 7
Most Recent Economic Statistics for Bangladesh

	1985	1986	1987	1988	1989
Exchange rate (Takas/\$)	28.00	30.41	30.95	31.73	32.27
Nat'l GDP (10 ⁹ Takas)	405.40	465.60	538.30	594.40	656.40
Real GDP growth rate (%)	3.70	4.70	4.00	2.60	2.40
Consumer price inflation (%)	10.70	11.00	9.50	9.40	10.00

(Source: Economist Intelligence Unit , 1990)

Table 8
GDP Lost Due To Sea Level Rise of 1.5 m

YEAR BEGINNING	t	\$ (000,000)				TOTAL	
		BARISAL	KHULNA	PATUAKHALI	NOAKHALI	\$ (000,000)	% of NATIONAL
2001	1	11	15	5	10	41	0.15
2025	25	2094	2755	957	1791	7597	27.8
2050	50	4757	6262	2173	4068	17260	63.1
2075	75	6514	8576	2976	5571	23637	86.4
2100	100	7479	9846	3417	6397	27139	99.3
∞	∞	8170	10753	3733	6987	29643	108.4

The complex relationship between the environment and economic development, and, the projection of evaluation processes is the subject of the book, Environment, Natural Systems, and Development: An Economic Valuation Guide by Hufschmidt et al. (1983). This book is the basis for the present analysis which follows from the basic premise, that the environmental effects of sea level rise are reflected in the national GDP, especially in the agricultural sector. The GDP quantifies these effects in monetary terms that are time dependent. The associated reductions in physical outputs must be identified and quantified. Determining the policy implications is the final result.

In order to determine the impact of a potential sea level rise on the GDP of the affected regions (Barisal, Noakhali, Khulna and Patuakhali) the potentially affected GDP must be projected and discounted to determine its present values which then represent the GDP lost attributable to the loss of land caused by the sea level rise. The economic growth over the last ten years has taken place at the nearly constant rate, averaging about 4% per year (The Economist Intelligence Unit, 1990). Therefore, future values during the 21st century are projected based on the assumption of a constant 4% growth rate.

There are many approaches to estimating the social discount rate needed to calculate present values (Gittinger 1982; Baumol 1968; Hufschmidt et al. 1983). We assume that the rate is 8%, constant with time, based on the results of Dixon and Hufschmidt (1986). The following equations are adapted from Edwards (1987) and used to estimate the real and present values of the potential loss of gross domestic product, as a result of the projected sea level rise.

$$RV(t) = (GDP_0) \times f(t) \times (1 + g)^t \quad (1a)$$

$$PV(0, t) = RV(t) / (1+r)^t \quad (1b)$$

$$APV(0, t) = \sum_{n=0}^t PV(0, n) \quad (1c)$$

where,

$$t = \text{time in years since end of base year (1999)} \quad (1d)$$

$$GDP_0 = \text{GDP at time } t = 0 \text{ (start of 2000) of the area flooded at the end of the sea level rise at time } t = 100 \text{ (start of 2100)} \quad (1e)$$

$$g = \text{growth rate of GDP, assumed constant (4\%)} \quad (1f)$$

$$r = \text{social discount rate, assumed constant (8\%)} \quad (1g)$$

$$f(t) = \text{flood function} \\ = \begin{cases} 0 & \text{if } t \leq 0 \\ t/100 & \text{if } 0 < t \leq 100 \\ 1 & \text{if } t > 100 \end{cases} \quad (1h)$$

$$RV(t) = \text{real value of GDP at time } t \quad (1i)$$

$$PV(0, t) = \text{present value at } t = 0 \text{ of } RV(t) \quad (1j)$$

$$APV(t) = \text{accumulated value at time } t \text{ of all } PV(0, n) \text{ prior to } t \quad (1k)$$

Broadus (1989) justifies applying a discount rate to the projected GDP of the affected areas on a psychological basis, arguing that people tend to value a current payment or benefit more heavily than an equal payment at a future date. There are ethical complications when intergenerational effects are at stake (Broadus, 1989). A higher rate is justified by observing that the

low standard of living in Bangladesh probably results in strong preferences for present consumption (Edwards, 1987).

Table 8 presents the potential impact of sea level rise over periods of up to 100 years on the GDP of four regions: Barisal, Khulna, Patuakhali, and Noakhali. In order to project the regional GDP's of the affected areas the updated 1989 national GDP, 27,340 (millions of \$), was used for the base year. Each regional GDP was estimated in this period of time using the Accumulated Present Value in Equation (2),

$$\begin{aligned} \text{(Accumulated Present Value of GDP lost)} &= \begin{cases} 7.02 [1 - .963^t (1+t/27)] \text{GDP}_{\text{base year}}; & 0 \leq t \leq 100 \quad (2a) \\ 6.8367 \text{ GDP}_{\text{base year}} & ; \lim t \rightarrow \infty \quad (2b) \end{cases} \end{aligned}$$

derived as follows:

$$\text{Define: Flood function } [t/100] = \begin{cases} 0 & \text{if } (t \leq 0) \\ t/100 & \text{if } (0 \leq t \leq 100) \\ 1 & \text{if } (t > 100) \end{cases}$$

$G_0 \equiv$ GDP at time $t = 0$ of area flooded at time $t = 100$.

$G_0[t/100] =$ GDP at time $t = 0$ of area flooded at time t .

$R = G_0[t/100](1+g)^t =$ real value of $G_0[t/100]$.

$g =$ growth rate, $r =$ discount rate

$$\frac{1+g}{1+r} = \frac{1+r-(r-g)}{1+r} = 1/\gamma$$

$$\rightarrow \gamma = (1+r)/(r-g)$$

if $g = .04$ and $r = .08$ then $\gamma = 27$ years.

Present value of $R \equiv p$

$$p = G_0[t/100](1 - 1/\gamma)^t$$

Cumulative value at time t of all p prior to $t \equiv P$

$$t \quad t$$

$$P = \sum_{t=0}^t p = G_0 \sum_{0}^t [t/100](1-1/\gamma)^t$$

$$\frac{100 P}{\gamma(\gamma-1)G_0} = \begin{cases} 0 & ; t \leq 0 \\ 1 - (1 + 1/\gamma)^t (1 + t/\gamma) & ; 0 < t \leq 100 \\ 1 - (1 + 100/\gamma^2)(1 - 1/\gamma)^{100} - 100/\gamma(1 - 1/\gamma)^t & ; t > 100 \\ 1 - (1 + 100/\gamma^2)(1 - 1/\gamma)^{100} & ; \lim t \rightarrow \infty \end{cases}$$

or, with $\gamma = 27$,

$$P = \begin{cases} 7.02 [1 - .963^t (1 + t/27)] G_0 & ; 0 \leq t \leq 100 \\ 6.8367 G_0 & ; \lim t \rightarrow \infty \end{cases}$$

Since the process of sea level rise is gradual and cumulative, only a small percentage of economic activity will be affected the first year and will increase with time. The table (8) indicates that a sizeable portion of the Bengali economy could be affected if regional production gradually diminishes. While Khulna is not significant agriculturally, it is a main industrial center surrounded by many industries that are located inside the flood zone of the 2-meter sea.level rise scenario (Figure 8). Important facilities such as a large newsprint factory, several jute mills, cotton mills and chemical factories make this region one of the most important in the country. Additionally, it represents an important political and administrative center, providing an important source of income from transport and services. The Chalna-Mongla anchorage, twenty miles south of the city, makes Khulna, in reality, a seaport. Khulna is a break-of-journey point for much of the imports and exports through Chalna (Er Rashid, 1977).

(Source: Modified from Ahmad, 1976)

FIGURE 8

Rice plays an important role in Bangladesh economy, occupying approximately 80% of the cultivated areas and constituting 75% of the total produce from all field crops (Bangladesh Bureau of Statistics, 1989). The affected regions are important producers of three varieties of rice: aman, aus and boro. The rice crop is of vital importance as a staple food as well as for the economy. However, there is a constant competition with jute cultivation, especially in densely populated areas. The distribution of the main agricultural activities of southern Bangladesh (Figure 9) shows that rice cultivation will be affected the most under both scenarios. These crops will gradually disappear from those zones as the soil becomes salt ridden.

The Barisal region is important not only for rice production, but also as an economic, communication and transport center as well. This region and Noakhali posses the highest percentage of cultivated land in the country but, at the same time, the highest population densities. Aman, the major rice crop of the nation, accounts for more than 45% of the total national crop-growing areas. Aus, the next most important rice crop after aman, normally is grown for the cultivator's own consumption. However, there is an annual competition between these two crops for the use of land, the past success of a particular crop influencing the decision as to what should be planted for the next season (Ahmad,1976).

Barisal is also an important center for jute trade, although no jute is grown there. After a 1.5-meter rise only small portions of jute cultivations are lost (Figure 7) since most jute is grown in the central and northern sections further inland. After the two-meter rise a larger portion is lost. Jute, being neither aquatic nor salt-tolerant, will succumb to the invasion or intrusion of seawater.

(Source: modified from Ahmad, 1976)

FIGURE 9

General trends of the regional economic development in the last 100 years have not changed much (Ahmad, 1986). With regard to agriculture, the age-old method of ploughing with animal power, use of traditional methods, local seeds and crop-tending practices are still very common (Ahmad, 1976).

Although the international community has contributed both financially and technologically to Bangladesh, the cultural impact has been so small as to suggest that no major changes are likely to occur in the economic development for the next 100 years. Therefore, we can assume that even a gradual GDP loss at the levels we are projecting for the affected areas will still hurt the national economy. However, because this is a gradual process of change, the population will have enough time to migrate and switch to other types of economic activity. In that case, there should be little productivity lost during this rather slow process.

Making the switch depends on several factors. The relocation of so many people will be a problem because of the extensive agricultural distribution and the trends in population growth. The only area which is not under heavy cultivation is the hilly area of Chittagong; however, the topography makes habitation difficult. One of the major consequences of population growth is an increasing total demand for food. Agricultural insufficiency may threaten the economic and social development of certain regions and even cause starvation in the poorest areas. If sea level rises, this could happen where migrants move onto agricultural land and fail to increase the crop yield to meet their own needs.

The introduction of modern methods of cultivation, machinery and agricultural technology could improve the crop yield. The population could then shift to non-agricultural activities, perhaps in the area of unexploited

marine resources or clothing manufacturing, compensating for the engulfed GDP. Limited food production and runaway growth are the most important factors explaining the poverty in Bangladesh. In spite of ongoing efforts to modernize agriculture, food production is outpaced by human reproduction.

There is another industry which, although its contribution to the national economy is small, is an important source of nutrition. Bangladesh, more than any other country in South Asia, relies heavily on fish to meet its protein needs (Aguero, 1989). An estimated 70 to 80% of the total protein consumption is fish (Ministry of Fisheries and Livestock, 1986). Most of the fisheries in Bangladesh are riverine, marine fisheries contributing a much smaller percentage. Of the total fish production, 61% comes from inland open waters, 16% from inland closed waters (ponds and coastal aquaculture) and 23% from coastal marine waters (Islam, 1989) (Figure 10). The current estimated annual production of the country is approximately 815,000 tonnes of fish including marine and inland fisheries (Aguero, 1989). Potential changes in the earth's climate and consequently, in the sea level, may adversely affect fish stocks and the aquatic ecosystem in general. Fisheries dynamics are directly dependent on climatic variables. Changes in ocean or riverine surface temperatures may disrupt spawning, migration, growth rates, food supplies, and predator-prey relationships (Frye, 1983).

Fisheries in Bangladesh are important not only for nutritional values but also because they are the second largest source of foreign exchange after jute. A 1.5- or 2-meter rise in sea level would affect several fishing centers. Since the downfall of the price of jute in the world market (1987-1989), fisheries in Bangladesh has assumed a more important position in the national economy (Islam, 1989). Additionally, this sector provides full time employment to over 1.2 million people; approximately 10 million more are

estimated to be involved in fishery-related activities on a part time basis (FAO,1985).

According to the World Bank estimates, the population in Bangladesh is expected to reach over 130 million people by the year 2000. In order to maintain the current level of consumption, at least another million tons of fish will be required (Aguero, 1989). This implies an increase in fish production of approximately 30% over the present levels (Aguero, 1989). The combination of environmental change, overfishing, and unchecked population growth could seriously degrade the generally inadequate diet of the population. Limited recent data permit only speculations as to the nature and extent of possible impacts of changes in sea level on the ecology of the marine and riverine environment. A considerable amount of research is necessary to identify fisheries in the Bengal Delta area that may be most sensitive to changes in salinity and to develop a model for predicting ecosystem responses to climatic disturbances.

FISHERIES IN BANGLADESH

Source: (Islam, 1989)

FIGURE 10

CHAPTER 5

POLICY IMPLICATIONS AND RECOMMENDATIONS

Policy implications

The sea-level-rise, socioeconomic and political consequences resulting from climate change are unknown. In the absence of complete scientific understanding of the earth's biochemical systems, recommendations of actions to be taken may appear premature. However, as the earth is already experiencing some climatological changes, the "wait and see" approach could itself be a high-risk strategy.

The question of whether the people of Bangladesh should seek one or more courses of action is likely to be mediated by the institutional settings in which the technical, economic, and political feasibility of alternative defensive measures are weighed. In the short term, the problem that Bangladesh and some other Asian countries are currently facing is how to sustain economic growth against constant economic crisis due to natural catastrophes such as flooding. For instance, as has been established, jute remains by far the most profitable crop for the country, accounting for more than half of all exports. However, in recent years it has paradoxically become a major financial drain on the economy. Losses of jute mills due to flooding during 1986 totaled 0.5% of the national GDP (World Bank, 1987). The same situation occurred in 1988 and, more recently, in 1991. Since the jute price crisis, fisheries has assumed a more important role in the economy as the second largest cash

earner of the country. Further exploitation of marine or inland fishery resources could provide the nation with an alternative non-agricultural foreign exchange activity.

The cumulative effects of continued ocean flooding will be increasingly negative as the economy of affected areas becomes paralyzed for weeks and even months, taking progressively longer to return to normal. The perpetual threat of flooding affects agricultural production and probably inhibits investments to a significant degree. Therefore, estimates of loss must allow for the undisclosed effects of flood damages, including the human misery of the thousands rendered homeless.

A potential sea level rise cannot be ignored by policy makers. The concept of flooding cannot be separated from sea level rise in the planning process. By protecting the coastal areas from the effects of flooding, the country will at the same time progress toward preparedness for future rises in sea level. Even though there is currently no coastal management which could include a coordinated plan for eventual rises in sea level, there has already been some progress in coastal flood protection, described below, which will also be helpful in the event of a sea level rise.

After the 1970 storm, Bangladesh began adopting procedures to lessen the risks of further disasters. The Information Alert Warning System, a satellite system which improves the detection of cyclones, flooding and storm surges (U.S. Congress, House, 1988), was implemented (Carter, 1987). Scientists have warned that as the earth's temperature increases, the intensity and frequency of cyclones will also increase. The value of the satellite system will become greater as these consequences of sea level rise become realized.

Recently, The government of Bangladesh began extensive review and consultation in order to create a multiyear program for containing and directing the waters that enter the country (Rogers, Lydon, and Seckler, 1989). A National Water Plan has been formulated to manage the waters of the entire delta and has been partially implemented. The Plan is an assessment of all water resources that the country possesses. It addresses the problems of drought and flood, but is structured around the need and means to produce enough food to support the growing population (Ministry of Irrigation, 1986). The Plan directs various programs endorsed by the government and by some country donors. About six billion takas have been allotted for irrigation and river flooding related problems for the next 20 years (Rogers, Lydon and Seckler, 1989).

The government has also established a plan to control flooding. "Eleven Guiding Principles" have been established for the National Policy on Floods (Ministry of Irrigation). Most of the guidelines deal with short term actions that could help the population to cope with future flooding. Recent catastrophic events, such as the 1991 ocean flooding, showed that those principles have either been delayed in implementation or have been insufficient. Highlights of the guidelines are listed here:

- Implementation of a comprehensive flood plan including commercial, industrial, public utility and communication centers.
- Effective land and water management for protected and unprotected areas.
- Reinforcement of the operation infrastructure during disasters.
- Improvement of the flood forecasting system with appropriate evacuation techniques.

- The development of flood-plain zone to regulate habitation patterns and economic activities.
- Coordination of planning and construction of all rural roads, highways and railway embankments.

Some coastal defenses will be constructed, such as embankments, along some sections of the coastal zone and along the main riverbanks. The project will begin in 1993 with a cost of U.S. \$3.5 billion (McDonald, 1991). No assessment has been done on the impact that these measures will have on the environment (Rogers, Lydon and Seckler, 1989).

Bangladesh's population is approximately 115 million and growing at a rate of 2.2% annually which means that the population could reach 150 million by the year 2010. Even if population growth is reduced to a minimum, it will still have a severe impact on the quality of life. The country does not have an industry that could provide massive employment opportunities nor does it have an economic infrastructure to provide decent living conditions in high density areas such as Khulna. As a result, economic necessity drives thousands of people to work and live on a temporary, seasonal basis in areas highly susceptible to flooding (Bashirulla, Mahmood and Matin, 1989).

Bangladesh's political situation is not promising, either. The diversion of resources to disaster relief has produced a delay in the implementation of the reforms discussed above. Moreover, international donors, mainly the World Bank and the International Monetary Fund, have warned the government that unless they reform their financial institutions and there is an increase in economic growth, future allocation of funds to them will be jeopardized.

RECOMMENDATIONS

Coastal Zone Management Plan

It is recommended that Bangladesh develop and implement a Coastal Zone Management Plan (CZMP). An eventual sea level rise in the next century may have significant impacts on the coastal zone, especially along deltaic plains. The coastal zone of Bangladesh stretches 710 km from Teknaf in the southeast to Khulna in the southwest. Comprehensive management of this coastal area attempts to integrate policy and planning in a scheme that will include multiple uses of the coastal zone, economic potential, and natural resources (Klarin and Hershman, 1990). In the case of Bangladesh, the preparation for natural hazards must be a feature of the CZMP, including three areas of major attention: flood prevention, flood preparedness, and engineering measures to protect specific areas. Prevention will be economically justifiable only in valuable locations such as densely populated industrial and agricultural centers. Other areas will have to adjust to the consequences. Agricultural lands that will be affected by tides due to the rising sea may be abandoned, converted into deep water rice cultivation, resistant to high levels of salinity, or converted into brackish water ponds (Bird, 1986).

The implementation of a CZMP would help alleviate some of the problems associated with the existing complex bureaucratic system. Currently, problems of the coastal areas are split among six ministries: the Ministries of Land and Revenue; Agriculture and Forestry; Fisheries; Education; Irrigation, Water Development and Flood Control; and Planning,

authorizes any project from any minister (Bashirullah, Mahmood and Matin, 1989). The Ministry of Education is responsible for most of the present management of the coastal areas. It is not surprising that many projects directed to the management of the coastal zone do not make it through the system.

Numerous nations in the world have attempted to develop CZM programs according to their own sociopolitical and geographic reality. Attempts have been successful in the U.S., Ecuador, Sri Lanka, Costa Rica and China. Coastal management is a cooperative effort of science, policy, law, and administration and is highly dependent upon the social, economic and political status of each country and culture (Archer, 1988). The CZMP to be implemented in Bangladesh must comprehend all the problems created as a result of a rapid growing population, associated economic and development activities, the permanent threat of ocean flooding, and the potential of a gradual sea level rise.

In Bangladesh, which has a history of centralized authority, the development of a CZMP will require changes in the governmental structure. Some needed changes are underway. During the last five years there has been movement toward decentralization, concentrating resources and autonomy at the lowest administrative level, the *upzilla*, a unit with about 250,000 people (Rogers, Lydon and Seckler, 1989). Although there are general guidelines for managing particular resources, management programs cannot easily be transferred from one country to another. However, these guidelines can provide an institutional setting in which the programs can be applied. The first step in establishing an institutional framework for management is identifying the coastal problems.

The high population density of the Bangladesh is gradually forcing the "excess" population into the low-lying coastal areas. The gradual dislocation of people means the colonization of some lands presently occupied by mangrove forest. A permanent sea level rise will most likely force mangroves inland; large sections of the forests could disappear in areas where there is no available land for mangrove relocation (Paw and Thia-Eng, 1991). The occupation of these low-lying areas results in the gradual destruction of the only natural barrier against ocean flooding. Furthermore, areas located directly landward of these dynamic ecosystems are often prime agricultural lands (Leatherman, 1986). In Bangladesh those lands are commonly utilized for fish ponds and rice fields, and could potentially be colonized by migrating mangroves if local people would allow it (Bird, 1986). Increasing levels of salinity would perturb these ecosystems as well; however, overall they would threaten ground and surface water supplies.

Identifying the appropriate guidelines for mitigating these problems is the second step in establishing an institutional framework for coastal management. Management programs are usually based on several management mechanisms (Lowry, 1989). Management can be understood as the intent to influence the behavior of society whose activities contribute to the coastal problems (Lowry, 1989). Management programs tend to use direct development activities such as persuasion (education), incentives, planning and research. Development activities could mean construction of coastal defenses, coastal erosion protection, mangrove protection measures, etc. Some nations, e.g. Sri Lanka, Ecuador, and Puerto Rico, have established special area management plans for smaller areas in which development and environmental protection are in conflict. The Sunderban

mangrove forest is a good example of an area which should be subject to special management conditions.

Regulatory mechanisms are the essence of any coastal management program. Two examples of such mechanisms are coastal exclusion zones and zoning schemes. Coastal exclusion zones refer to management strategies that specifically prohibit or significantly limit activities in critical coastal areas (Lowry, 1989). In Bangladesh, although living space is limited, there are areas of low topography that are not habitable because of frequent inundation by tidal floods. The occupation of these zones will resolve the Bengali situation in a Malthusian fashion.

Zoning regulations are frequently used to manage critical areas in the coastal zone. Land zones are designated for specific categories of use such as agriculture, fish ponds or open space. The key issue in any management strategy is the assessment of the most appropriate policies for specific problems; perhaps there are different alternatives for each problem.

The development of coastal management strategies is based on a set of assumptions of cause-effect relationships. For instance, restriction of coastal development in high risk areas will presumably result in saving thousands of lives and reducing economic losses. It may also result in the protection and preservation of the environment. However, the implementation of these strategies will depend on many factors, including an understanding of the intention of the restrictions by the people and the willingness of government officials to enforce compliance (Lowry, 1989). Many of the problems faced by Bengalis relate to habitat management, e.g., loss of mangrove forest. The large number of individuals depending on this resource and the lack of economic alternatives make management of these special areas difficult.

Once management guidelines have been established, the question remaining is how to implement the regulations. First, the existing administrative system involved in the management of the coastal zone must be reorganized. As indicated above, in Bangladesh there are presently six ministries that deal with coastal issues. Once the existing management framework is defined, the administrative structure that hinders effective management must be identified. In the case at hand, that would mean determining why the Eleven Guidelines have not been fully implemented (Rogers, Lydon, and Seckler).

Lowry et al. (1988) describe two types of conflict which commonly occur in such politically complex administrative systems: jurisdiction and policy conflicts. Jurisdictional conflicts occur when more than one agency or ministry is involved in the management of one particular resource or activity. Policy conflicts result by inconsistencies in the laws or regulations regarding coastal activities. Management conflict in the coastal zone can be resolved by explicitly designating a ministry or agency to be in charge of coastal management. Perhaps, the solution could be in centralizing the authority in an existing ministry or coastal agency. When interministerial conflicts appear, several methods can be used to resolve the problems, such as inter-agency councils, mandatory plan reviews, etc. (Lowry, 1989). These types of solutions have been successfully implemented in other nations such as the Philippines, Indonesia, and Thailand. For instance, in the Philippines, twenty-two agencies make up the Coastal Zone Management Task Force; inter-agency dialogues facilitate policy conflicts in the planning stage (Tolentino, 1983).

The implementation of a CZMP in Bangladesh is a difficult but needed effort. The task of implementing a CZMP is politically difficult because the

costs are in the present, yet the potential benefits are both uncertain and distant. The risky "wait and see" policy, however seductive, could be still more harmful.

The problem of acting in spite of uncertainty is well recognized in the issues of the greenhouse effect and sea level rise (Titus, 1986). However, Titus et al. (1987) established that the degree of uncertainty about sea level rise is no worse than other uncertainties faced by policy makers, planners and engineers.

The International Institute for Environment and Development (IIED) has established that studies of environmental programs in developing countries should require a clear and broad mandate, an effective organizational structure and a high degree of professional competence within the institutions responsible for project implementation. A lack of any of these prerequisites could result in a failure to meet the project's objectives

In establishing national guidelines for a coastal management program in Bangladesh, many case studies of CZM implementation from other countries have been reviewed (Sorensen, 1991; Paw and Thia-Eng, 1991; Degong, 1989; Bashirullah, Mahmood and Matin, 1989; Lowry, 1988; IIED, 1981; Mahmood and Haron, 1989; Tolentino, 1988; U.S. Department of Commerce, Office of Coastal Zone Management, 1978). Most of these studies involve areas with a similar geographical environment, tropical climate, high population growth, and designated management areas (usually mangrove forests). All the countries are facing similar problems such as bureaucratic inertia in the implementation of management programs and the degradation of the environment affecting the economic condition and quality of life for coastal inhabitants. Some of them, such as the Philippines, Thailand and Puerto Rico, include the protection of life and property against

natural hazards, like flooding, as an important feature of their CZMP. Management strategies for identifying coastal hazards vary among nations according to the level of risk the governing agencies believe to be associated with exposure to the hazard (Lowry, 1988).

The following recommended goals do not intend to establish a CZMP for Bangladesh, but rather to give general guidelines for the establishment of a comprehensive coastal protection program which also takes into account potential changes in sea level.

1. Protect life and property in areas threatened by frequent ocean flooding and a potential rise in sea level.
2. To create and maintain the conditions under which man and nature can coexist while preserving the environment for its optimal use.
3. The development and implementation of a CZMP based on a partnership between the general public, local governments, and international and non-governmental organizations.
4. Designate the mangrove forest areas as special management areas.

These goals emphasize the major objectives in which Bangladesh could base a management program. The establishment of priorities from the government implies negotiations and extensive technical analysis with consideration given to the availability of resources. Perhaps some areas cannot be included in the program due to the lack of financial resources; however, once they are recognized, they can be included when the resources become available. For instance, Sri Lanka's CZMP recognizes

coastal erosion problems but it prioritizes other areas stating that erosion and its side effects will be addressed in subsequent developments of the plan (Lowry, 1989).

Experience has shown that decision-makers usually react only after major catastrophes; e.g., the Delta Project in the Netherlands was created only after the 1953 disaster (Goemans, 1986). The following response-strategy suggestions intend to present a management strategy in a comprehensive fashion, as it is unrealistic to consider management only for potential sea level rise consequences.

I. Minimizing Coastal Hazards

Planning for and decreasing the hazards to life and property from sudden or gradual changes in sea level is vital. Rapid evacuation plans should be a primary consideration. There are two types of evacuation, horizontal and vertical (Carter, 1987). The most common, horizontal, involves moving large numbers of people inland. The high density of people living in potentially affected areas makes it almost impossible to mobilize everyone. The other option, vertical evacuation, is more appropriate. It requires that people take shelter in high-rise (often reinforced) buildings (Carter, 1987). This method is prevalent where evacuation routes have a low capacity or are dangerous and where people cannot respond rapidly. For example, it is commonly used in Miami Beach where causeways to the mainland are narrow and where there are plenty of well-prepared high-rise buildings (Carter and Orford, 1982). The Bangladesh Red Crescent Society has developed a model shelter, a single storey building on stilts, costing U.S.\$100,000 (McDonald, 1991). Approximately 3,500 shelters will be needed for areas susceptible to flooding, which is estimated to cost U.S.\$350

million. This type of structure can be used for other functions such as schools, clinics, or village centers during non-crisis times. During the April 1991 flooding, the entire population of Sonadia Island (south of Chittagong), about 650 people, sheltered in a single building (McDonald, 1991).

A series of maps defining evacuation routes for given areas should be available in all information centers. These maps should indicate high-rise shelter locations and assembly points where people can gather to be evacuated to the shelters (ESCAP et al., 1977).

It is unlikely that buildings and other structures would be designed to withstand long-term changes in sea level (Carter, 1987). Such solutions are, for the most part, inappropriate for long-term dynamic problems. Furthermore, structures do not adjust to sea level changes (Carter and Orford, 1982). More realistic is the need to design buildings to withstand temporary rises in sea level during storms.

A third option for minimizing coastal hazards involves containing the ocean by the construction of sea defenses, structures such as embankments or dikes (Goemans, 1986). Coastal embankments have existed in Bangladesh since the early 1970's. No matter how well embankments are constructed, they cannot afford complete protection against storm surges; they weaken with time and, eventually, a storm comes along with enough power to cause breaches. However, the percentage of human fatalities is enormously decreased by the existence of such coastal defenses. If the project is planned in conjunction with other development projects, like the construction of highways or harbors, duplicated investment costs can be avoided (ESCAP et al., 1977). Presently, Bangladesh and foreign-aid donors are planning a network of embankments along the major rivers (McDonald, 1991). In small, densely settled areas where coastal defense

systems cannot provide adequate protection or, for some reason, cannot be constructed, floodwalls, structures of reinforced concrete, should be built around specific sites (UNDRO, 1976b).

II. Protecting Mangrove Wetlands

Mangrove wetlands are considered valuable not only ecologically, but also economically (Haron, 1981). Many countries, including Thailand, Sri Lanka, China, Puerto Rico, the Philippines, and Ecuador, recognize the importance of preserving this resource by designating these areas as special management areas. One of the most immediate problems of the Sunderban forest is deforestation caused by exploitation for fuel wood. Furthermore, the cutting for creating agricultural land and shrimp culture is rapidly degrading the resource (Bashirullah, Mahmood and Matin, 1989). The establishment of the Sunderbans as a special management area will protect and, at the same time, preserve the resource for its rational exploitation. As a renewable resource mangroves can be managed on a sustained-yield basis.

III. Restricting New Coastal Development

Vulnerable development should be restricted in areas of high flood risk under one meter above sea level. Substantial amounts of industrial and agricultural equipment in the coastal zone have recently been severely damaged from storm surges (Walsh, 1991). Decentralization of the population and economic activities from high risk areas will reduce the human life and economic losses from frequent flooding, and, at the same time, help prepare for an eventual sea level rise.

Land use regulations of the tidal plains need to be implemented and enforced to control and direct their use and development. The high risk

areas can be divided into zones exposed to varying degrees of hazards. Coastal areas described in detailed charts will provide the information needed for appropriate development, which can be determined by the proximity to the shoreline of the proposed project (Landry, 1990). Japan and South Korea have adopted national land-use regulations to control land use in areas subject to flooding (ESCAP et al., 1977). The Japanese have divided vulnerable coastal zones into low-hazard areas, which are subject to occasional inundation, and high-hazard areas, which experience more frequent ocean flooding. It is recommended that coastal areas in Bangladesh also be divided into zones according to levels of risk associated with development, where population settlements and economic centers are zoned, and where development is prohibited or restricted. In areas of comparatively higher risk, for instance, only buildings structurally prepared for withstanding floods would be permitted (UNDRO, 1976a).

IV. Relocation of Population Settlements

It is unrealistic to suggest that all areas threatened by flooding or sea level rise should not be occupied; the dense population makes it a necessity. However, in planning population distribution, the potential of sea level rise must be considered. It is recommended that population settlements in high-risk areas be relocated to safer locations. Any attempt to relocate people should be integrated with a comprehensive regional development plan.

High capital and social costs are inevitable for relocating people within a country or regions (ESCAP et al., 1977). However, the eventuality of sea level rise and more frequent flooding may require and even provoke migrations among regions. Small-scale movements of communities within a region may be more feasible to avoid potential socioeconomic conflicts in

other areas. The planning of such measures in a highly populated nation would indeed be a challenge.

V. Shifting Economic Activities

The potential loss of resources from sea level rise in the coastal zone could result in a severe impact on the growing population. By making changes now in economic activities, not only could stress from frequent flooding be alleviated, but it would be a beginning in preparing for an eventual sea level rise.

Increased flood levels could significantly affect the agricultural sector, especially aus and deepwater aman paddy crops (Brammer, 1987). Areas that are presently subject to moderately deep flooding will need to change over to aman paddy varieties tolerant of deeper flooding and higher salinity. The adoption of salt-tolerant crops should help farmers maintain production levels.

Aquaculture is an important economic activity which could contribute considerably to foreign currency earnings, especially by culturing shrimp (Paw and Thia-Eng, 1991). The tiger shrimp, Penaeus monodon, is economically the most important species in Bangladesh (Bashirullah, Mahmood and Matin, 1989). The construction of embankments and river dams could provide extensive socioeconomic benefits to millions of people by encouraging them to use the brackish ponds created in the process for shrimp culture. However, the development of such defenses must consider ecological impacts on the area including the potential effects on nursery grounds of fish.

Another alternative economic activity could be solar salt making, a small scale industry in many southeast Asian countries (Bardach, 1988).

Some salt manufacturing industries already exist in the Chittagong region (Bardach, 1989). The development of this type of economic activity in coastal regions could provide important socioeconomic benefits for inhabitants of those areas. Existing industrial facilities can be adapted to other types of activities such as salt making. Such adaptations can be more cost effective than relocating an entire facility.

Research

The government of Bangladesh should develop a research program in coordination with the international scientific community on the impact of sea level rise on the coastal areas. The program should include the monitoring of sea level, tides, waves, surges and all types of related climatic information in order to detect warning trends. Measured and recorded information concerning sea level should be according to guidelines from the appropriate international organizations such as the Global Observing Sea Level System (GLOSS) of the International Oceanographic Commission (Bardach, 1989). This information must then be available for those policy makers and planners in charge of determining which coastal policies are most appropriate for confronting future rises in sea level and possible associated implications.

In 1988, India and Bangladesh formed the Joint Task Force in order to set up faster responses to flooding. India is assisting Bangladesh with the necessary computer programming and flood modeling to make rapid use of the data they have begun collecting (Rogers, Lydon, and Seckler, 1989). This joint effort will help mitigate the effects of riverine and ocean flooding, and, at the same time, set a precedent of international cooperation between two nations.

Research is needed on the hydrological, geomorphological and ecological impacts of sea level rise. Much information is also lacking on the geomorphology of Bangladesh; if the delta is experiencing an accelerated subsidence, the effects of sea level rise could be dramatically amplified. The rate of tubewell installations for drinking water is rapidly increasing with population growth, and may be accelerating subsidence in the delta region. Occurrences of this nature are not unusual in areas where fluid is removed

from underground cavities. In the Wilmington Oil Field on the coast of California, subsidence created a depression of several kilometers wide and as deep as nine meters at the center (Mears, 1977). The Mississippi delta is experiencing a similar situation.

Also recommended is the development of complete, precise and detailed maps of all areas under 1.5 and 2 meters' elevations plus any other areas susceptible to ocean flooding.

The government or other organizations should perform vulnerability studies in coastal areas which will estimate potential damage from an increase in sea level and the associated storms and floods. Modifications to coastal facilities and structures to make them less vulnerable and more resilient to storms and water levels will be beneficial with or without a sea level rise (Keillor, 1990).

CHAPTER 6

SUMMARY AND CONCLUSIONS

Global warming can lead to an increase in precipitation and temperature, especially in the northern hemisphere (Malik, 1988). The United Nations Environmental Programme, the World Meteorological Organization, and the International Council of Scientific Unions have jointly concluded that the planet's temperature could warm a few degrees Celsius in the next 50 years (UNEP/WMO/ICSU, 1985). The most immediate concern is that the ocean could expand, causing a sea level rise of as much as two meters in the next century.

Studies dealing with sea level rise use models that differ from one another in their methods. However, most of them conclude that there will be an increase in the global mean sea level in the next 100 years. Estimates range from 1.5 m to 3.45 m. Even the most conservative estimates indicate that large parts of Bangladesh could go underwater. Bangladesh's low topography leaves coastal regions susceptible to ocean flooding caused by cyclones, the frequency and intensity of which could increase with global climate changes. Over the last 100 years, cyclones of extreme severity have occurred at intervals of 20 - 22 years. The most devastating surge in this century struck Bangladesh in November of 1970, taking approximately 600,000 lives. Most recently, in May of 1991, another surge killed approximately 140,000 people (Walsh, 1991). The gradual elimination of

parts of the Sundarbans combined with rapid population growth in the coastal areas heighten the problems.

Illegal deforestation and overexploitation of the forest resources could eliminate a natural barrier against ocean flooding. Any erosion associated with human activity could be accelerated by a sea level rise.

Salt water intrusion poses a serious threat to the ecosystem. Increased salinity would be harmful to not only the vegetation, but the fishing grounds, as well. Underground aquifers could be contaminated, resulting in a shortage of drinking water.

Accelerated subsidence combined with a decrease in the influx of fluvial sediments from the diversion of rivers may intensify the effects of a rise in sea level. A lack of information concerning subsidence and river flow makes it difficult to estimate with certainty future impacts on the delta region.

Bangladesh is among the world's most densely populated countries, with almost 700 inhabitants per square kilometer. Despite governmental and internationally aided programs, the current growth is just over 2%. Based on the population distribution analysis, an estimated 13% of the total national population will be affected if sea level rises 1.5 meters. A rise of 2 meters could affect approximately 16%. These figures are quite dramatic considering the country's explosive population growth rate. Furthermore, a temporary rise (storm surge) in sea level could presently affect more than 16 million people. Population growth projections for the next 25 or 50 years are alarming because the habitable land is already near capacity. Assuming no change in sea level, if the population growth rate remains as it is, the population will increase from 113 million to over 150 million by the year 2010, using the most conservative estimate of the World Bank. The

population-related problems would appear to overshadow any related to sea level rise.

A sea level rise of 1.5 or 2 meters will have an impact not only on the population distribution but also on the quality of life for the individual; there will be an impact on real income as a consequence of the loss of production and employment changes. Flood-related migration of people will change the existing economic order and produce unpredictable social disruptions. Moreover, the entire political-administrative structure of the country will change due to the disappearance of the regions flooded by the ocean.

Economic progress will be impeded if the population continues increasing, putting pressure on coastal areas. If the sea level gradually rises, covering existing productive lands, famine and death will become a grim reality. Rice crops, mostly aman, aus and boro varieties, currently occupy approximately 80% of cultivated land and constitute 75% of the total produce from all field crops. The affected regions are important to the production of rice, which will be affected more than any other agricultural activity by a sea level rise. The model used in this thesis to determine future economic losses of the affected regions during the next 100 years indicates that, unless preventive measures are undertaken, a significant part of the national GDP will be lost by the end of that period. The immediate effects will be on the food supply. Most of the affected territories such as Barisal and the industrial region of Khulna, contain extensive rice fields and important trade centers.

Bangladesh's most important source of protein is fish. Because fishery dynamics are directly dependent on climatic variables, changes in salinity and temperature in estuaries and adjacent areas may disrupt natural cycles of food supply, migration or growth rates. The depletion of the anchovy on the west coast of South America is an example of the extent to which climatic

changes can affect fishery systems. The potential disruption in the environment and, consequently, in the fishery could have severe repercussions on the already weak nutritional intake of the population.

The suggested recommendations intend to compromise immediate and long-term solutions taking into consideration the socioeconomic status of the country. Policy makers in Bangladesh are confronted with the problem of making decisions with uncertainty. The problem is whether to act now, preparing the country with an infrastructure and incurring costs that could later prove to have been unnecessary, or to wait for better information risking the possibility that the costs will be much greater upon the realization of a sea level rise.

A coastal zone management plan is essential for Bangladesh, considering not only the rapid population growth, but also the frequent occurrence of natural catastrophes and the potential sea level rise. In Bangladesh, which has a history of centralized authority, the development of a CZMP will require changes in the governmental structure, since the existing bureaucratic system responsible for coastal planning is split among six ministries.

After the catastrophic events of recent years, the government began extensive review and consultation in order to create a multi-year program for containing and directing the waters that enter the country. A National Water Plan has been formulated to manage the waters of the entire Delta. The Plan addresses the problems of drought and flood, but is structured around the need and means to produce enough food to support the growing population. The government has also established Eleven Guideline Principles the National Policy on Floods; however, the destruction by the 1991 floods

showed that the principles have either been delayed in implementation or are insufficient.

The political situation in Bangladesh suffers from the diversion of resources to disaster relief, delaying the implementation of policy reforms. Moreover, international donors have warned the government that unless they undergo economic reforms they may lose any future allocations of funds.

Most of the case studies that were reviewed in establishing national guidelines for a coastal management program in Bangladesh possess similar geographic characteristics and socioeconomic problems. The recommended response-strategy listed as follows intends to present management strategies in a comprehensive fashion considering the eventuality of a sea level rise.

1. Minimize coastal hazards by making emergency preparations such as evacuation plans, construction of high-rise, flood-resistant, wind-resistant shelters, and construction of sea defenses to protect valuable areas.
2. Protect mangrove wetlands by recognizing them as natural barriers against ocean flooding and designating them as special management areas.
3. Restrict new coastal development: vulnerable development should be restricted in areas of high flood risk under 1.5 m above sea level. Land use regulations of the high-risk areas need to be implemented and enforced to control and direct their use and development.
4. Relocate population settlements, moving people in high-risk zones to safer areas.
5. Shift economic activities by promoting inland development, undertaking new activities, and expanding existing activities such as

the exploitation of marine resources, aquaculture and solar salt producing facilities.

Research should be an important part of the strategy for preparing for an eventual sea level rise. Programs should be developed which monitor tides, waves and surges in order to detect any type of abnormal variations. Much research is also needed on the geomorphology and hydrography of the area.

Finally, Bangladesh must primarily be concerned with immediate flood problems. However, the steps to be taken now for flood preparation are also steps for sea level rise preparation. Further preparation for sea level rise can be undertaken by considering it in long-term planning. The expenses of planning for a rise have to be weighed against the expenses of the "wait and see" alternative, measured in terms of increased human poverty and damages from intensified flooding.

BIBLIOGRAPHY

- Aguero, M. 1989. Inland water fisheries in Bangladesh: Management options. In: M. Aguero, S. Huq, A. Rahman and M. Ahmed, eds. Inland Fisheries Management in Bangladesh. Department of Fisheries, Dhaka, Bangladesh; Bangladesh Center for Advanced Studies, Dhaka, Bangladesh and International Center for Living Aquatic Resources Management. Manila, Philippines.
- Ahmad, E. 1972. Coastal Geomorphology of India. Orient Longman Limited. India.
- Ahmad, N. 1968. An Economic Geography of East Pakistan. Oxford University Press. New York, NY.
- Ahmad, N. 1976. A New Economic Geography of Bangladesh. Vikas Publishing House PVT Ltd. Bombay, India.
- Archer, J. 1988. Coastal Management in the United States: a Selective Review and Summary. International Coastal Resources Management Project, Coastal Resources Center, The University of Rhode Island. Narragansett, RI.
- Bangladesh Space Research and Remote Sensing Organization. 1986. Proceedings of The Regional Seminar on the Application of Remote Sensing Techniques to Coastal Zone Management and Environmental Monitoring. Dhaka, Bangladesh.
- Bangladesh Bureau of Statistics. 1986. Statistical Pocket Book of Bangladesh. Dhaka, Bangladesh.
- Bangladesh Bureau of Statistics. 1989. Statistical Pocket Book of Bangladesh. Dhaka, Bangladesh.
- Bangladesh Bureau of Statistics. 1988. Statistical Yearbook of Bangladesh. Dhaka, Bangladesh.

- Bardach, J. 1988. Coastal zone activities and sea level rise. Working paper no. 11. Environment and Policy Institute, East-West Center. Honolulu, Hawaii.
- Bardach, J. 1989. Global warming and the coastal zone. Climatic Change 15: 117-150.
- Barnett, T. 1984. The estimation of global sea level change: A problem of uniqueness. Journal of Geophysical Research 89 (5) : 7980-7988.
- Bashirullah, A., N. Mahmood, and A. Matin. 1989. Aquaculture and coastal zone management in Bangladesh. Coastal Management. 11: 119-127.
- Baumol, W. 1968. On the social discount rate American Economic Review 58: 788-802.
- Bird, E., 1986. Potential effects of sea level rise on the coast of Australia, Africa and Asia. In Proceedings of the International Conference on Health and Environmental Effects of Ozone Modification and Climate Change. The United Nations Environment Programme and the U.S. Environmental Protection Agency. Washington, D.C. pp. 83-98.
- Bird, E., and M. SCHWARTZ, eds. 1985. The World's Coastline. Van Nostrand Reinhold. Stroudsburg, Switzerland. pp 761-765.
- Bolin, B., J. Jager and B. Doos. 1988. The greenhouse effect, climatic change and ecosystems: A synthesis of present knowledge. In: B. Bolin, R Warrick, B. Doos and J. Jager, eds. The Greenhouse Effect: Climate Change and Ecosystems. Scientific Committee on Problems of the Environment (SCOPE). pp 1-30. Chichester, New York, and Singapore.
- Bowen, R., 1982. Surface Water. John Wiley New York.

Brammer, H. 1987. The complexities of detailed impact assessment for the Ganges-Brahmaputra-Meghna delta of Bangladesh. Paper presented to the International workshop on the effects of climate change on sea level, severe tropical storms, and their associated impact. University of East Anglia, Norwich.

Broadus, J., J Milliman, S. Edwards, D. Aubrey, and F. Gable. 1986. Rising sea level and damming of rivers. Possible effects in Egypt and Bangladesh. In: Proceedings of the International Conference on Health and Environmental Effects of Ozone Modification and Climate Change.. The United Nations Environment Programme and the U.S. Environmental Protection Agency. Washington D. C. pp 165-189.

Broadus, J. 1989. Impacts of sea level rise. In: R. DeFries and T. Malone, eds. Global Change and Our Common Future. National Academy Press. Washington, D.C.

Bruun, P. 1986. Worldwide impact of sea level rise on shorelines. In: Proceedings of the International Conference on Health and Environmental Effects of Ozone Modification and Climate Change.. The United Nations Environment Programme and the U.S. Environmental Protection Agency. Washington, D.C. pp. 99-125.

Carter, R. 1987. Man's response to sea level change. In: National Research Council, Sea Surface Studies. National Academy Press, Washington, D.C. pp. 464-498.

Carter, R. and J. Orford. 1982. Miami Beach and Hurricanes. Geography Magazine 52: 442-448.

Dixon, J. and M. Hufschmidt. 1986. Economic Valuation Techniques for the Environment. The Johns Hopkins University Press. Baltimore and London.

Economic and Social Commission For Asia and The Pacific, World Meteorological Organization and The League of Red Cross Societies (ESCAP/WMO/LRSC). 1977. Guidelines For Disaster Prevention and Preparedness in Tropical Cyclone Areas. Geneva/Bangkok.

The Economist Intelligence Unit 1989. Country Report : Bangladesh. Business International. London, U.K.

The Economist Intelligence Unit. 1990. Country Report (4): Bangladesh. Business International, London, U.K.

Edwards, S. 1987. Potential economic effects of relative sea level rise on Bangladesh's economy: a case study. In An Introduction to Coastal Zone Economics: Concepts, Methods, and Case Studies. Tylor and Francis. New York, NY. pp. 87-133.

Ellis, W. 1972. Bangladesh: hope nourishes a new nation. National Geographic. 142 (3): 295-333.

Er-Rashid, H. 1977. Geography of Bangladesh. Westview Press, Boulder, Colorado.

Far East and Australasia, The. 1987. Bangladesh. Europa Publications Limited. London, England.

Farland, J. and J. Parkinson. 1976. Bangladesh: The Test Case of Development. Westview Press Colorado.

Flohn, H. 1981. Life on a Warmer Earth. International Institute for Applied Systems Analysis. Laxenburg, Austria.

Food and Agriculture Organization (FAO). 1985. Bangladesh Flood-Plain Fisheries Development Project Identification Mission. FAO/World Bank Cooperative Programme Report # 94/85, United Nations. Rome, Italy.

Frye, R. 1983. Climatic change and fisheries management. Natural Resources Journal. 23: 76-96.

Gable, F. 1989. Contemporary climate change and its related effects on global shorelines. Coastal Zone '89. 2: 1370-1383.

Gittinger, J. 1982. Economic Analysis of Agricultural Projects. Johns Hopkins University Press. Baltimore, MD.

- Goemans, T. 1986. The sea also rises: the ongoing of the Dutch with the sea. In: Proceedings of the International Conference on Health and Environmental Effects of Ozone Modification and Climate Change. The United Nations Environment Programme and the U.S. Environmental Protection Agency. Washington, D.C. pp 47-56.
- Goemans, T. and P. Velligna. 1987. Low countries and high seas. In: Proceedings of the First Northamerican Conference on Preparing for Climate Change: A Cooperative Approach. pp. 147-164.
- Gornitz, V. Levedeff, and J. Hansen. 1982. Global sea level trends in the past century. Science. 215: 1611-1614.
- Hansen, J., A. Lacis, and D. Rind. 1983. Climatic trends to increasing greenhouse gases. American Society of Civil Engineers. 2796-2810.
- Hansen, J., Russell, D. Rind, P. Stone and A. Lacis. 1983. Efficient three dimensional global models for climate studies: Models I and II. Monthly Weather Review. 111:609-662.
- Haque, C. 1983. Population versus economic activity: perspectives on temporal changes and regional disparities in Bangladesh. Asian Profile 11:2.
- Haron, H. 1981. A Working Plan for the Second 30-Year Period of the Marang Mangrove Forest Reserve, Perak: The First 10-Year Period 1980-1989. Perak State Forest Department. Perak, Malaysia.
- Hicks S, H. Debaugh Jr, and L. Hickman, Jr. 1983. Sea Level Variations for the United States, 1855-1980. U. S. Department of Commerce. Washington D.C.
- Hoffman, J, D. Keyes and J. Titus. 1983. Projecting Future Sea Level Rise to the Year 2000. US. GPO # 055-000-0236-3. Government Printing Office. Washington, D.C.
- Hoffman, J. 1984. Estimates of future sea level rise. In: M. Barth and J. Titus, eds. Greenhouse Effect and Sea Level Rise: A Challenge For This Generation. Van Nostrand Reinhold Company. New York, NY. pp 79-103.

Hufschmidt, M., E. James, A. Meister, B. Bowen, and J. Dixon. 1983. Environment, Natural Systems and Development: An Economic Valuation Guide. Johns Hopkins University Press. Baltimore, MD.

International Institute for Environment and Development (IIED). 1981. Legal, Regulatory and Natural Resource Management in Developing Countries. United States Agency for International Development and the United States National Park Service Project. Washington, D.C.

Islam, M. 1974. Tropical cyclones: coastal Bangladesh. In: G.F. White, eds., Natural Hazards: Local, National, and Global. Oxford University Press. New York, NY. pp. 19-25.

Islam, N. 1978. Development Strategy of Bangladesh. Pergamon Press. Oxford, England.

Islam, Q. 1989. Opening address. In: M. Agüero, S. Huq, A. Rahman and M. Ahmed, eds. Inland Fisheries Management in Bangladesh. Department of Fisheries, Dhaka, Bangladesh; Bangladesh Center for Advanced Studies, Dhaka, Bangladesh and International Center for Living Aquatic Resources Management. Manila, Philippines.

Keeling, C. 1978. Atmospheric carbon dioxide in the 19th century. Science 202: 1109.

Keeling, C., R. Bacastow, and T. Whorf. 1976. Atmospheric carbon dioxide variations at Mauna Loa Observatory, Hawaii. Tellus. 28:28.

Klarin, P. and M. Hershman. 1990. Response of coastal zone management programs to sea level rise in the U.S. Coastal Management. 18: 143-165.

Kennett, J. 1982. Sea level history and seismic stratigraphy. Marine Geology: 263-273.

- Landry, R. 1990. Land use implications of sea level rise. In: Long Term Implications of Sea Level Change for the Mississippi and Alabama Coastlines. Department of Information Services, Division of Agriculture, Forestry, and Veterinary Medicine, Mississippi State University. Mississippi. pp. 81-88.
- Leatherman, S. 1986. Impacts of Sea Level Rise on the coast of South America: Effects of Changes in Stratosphere Ozone and Global Climate. United Nations Environment Programme/U.S. Environmental Protection Agency Report. Washington, D.C.
- Lowry, K. 1989. Issues in designing a coastal management program. In: Coastal Area Management in Southeast Asia: Policies, Management Strategies and Case Studies. Ministry of Science, Technology and the Environment, Kuala Lumpur, and Johor State Economic Planning Unit. Johore Bahru, Malaysia. pp. 191-204.
- Lowry, K. and H. Wickremeratne. 1988. Coastal Area Management in Sri Lanka. Ocean Yearbook 7.
- Malik, M. 1988. Fear of flooding. Far Eastern Economic Review. 142 (151): 20-22.
- McDonald, H. 1991. Learning from disaster. Far Eastern Economic Review. May 30: 23-24.
- McDonald, H. and S. Kamaluddin 1991. Bitter pills. Far Eastern Economic Review. May 30: 25-26.
- Mears, B. 1977, The Changing Earth. Introduction to Geology, second edition. Van Nostrand Company. New York, NY.
- Menabi, S. and R. Stouffer. 1980. Sensitivity of a global climate model to an increase of CO² concentrations in the atmosphere. Journal of Geophysical Research 85: 5529-5554.
- Meo, M. 1989. Climate change impacts on coastal environments: implication for strategic planning. Coastal Zone '89 2: 1384-1394.

- Mercer, J. 1868. Antarctic ice and Sangamon sea level. Geological Society of America Bulletin 79: 471.
- Metz, B. and P. Velligna. 1990. The Netherlands. Environmental Protection Agency Journal 16 (2):38. Washington, D.C.
- Milliman, J., J. Broadus, and F. Gable. 1989. Environmental and economic implications of rising sea level and subsiding deltas: the Nile and Bengal examples. AMBIO 18 (6):1-24.
- Ministry of Irrigation (Bangladesh). 1986. National Water Plan, Vol III: Alternative Plans. Ministry of Irrigation. Dhaka, Bangladesh.
- Ministry of Fisheries and Livestock (Bangladesh). 1986. National Water Plan. Dhaka, Bangladesh.
- Moore, B. and B. Bolin. 1986. The oceans, carbon dioxide and global climate change. Oceanus 29 (4): 9-15.
- Murty, T., R. Flather and R. Henry. 1986. Storm surges in the Bay of Bengal. Progress In Oceanography. 16:195-233.
- Murty, T. 1984. Storm surges-meteorological ocean tides. Canadian Bulletin of Fisheries and Aquatic Science (212).
- National Academy of Science. 1983. Carbon Dioxide Assessment Committee, Changing Climate. National Academy Press. Washington, D.C.
- National Research Council (U.S.), Committee on Engineering. 1987. Implications of Changes in Relative Mean Sea Level. National Academy Press. Washington D.C.
- Odum, W. and E. Heald. 1975. Mangrove forest and aquatic productivity. In: Coupling of Land and Water Systems. Springer-Verlag. Berlin. pp. 129-136.

- Orford, J. 1987. Coastal processes: The coastal response to sea level variations. In: R.J. N. Devoy, eds. Sea Surface Studies: A Global View. New York, NY. pp. 415-463.
- Park, R., T. Armentano and C. Clonan. 1986 . Predicting the effects of sea level rise on coastal wetlands. In: Proceedings of the International Conference on Health and Environmental Effects of Ozone Modification and Climate Change. The United Nations Environmental Program and the U.S. Environmental Protection Agency. Washington, D.C. pp. 129-152.
- Paw, J. and C. Thia-Ing. 1991. Climate change and sea level rise: Implications on coastal area utilization and management in Southeast Asia. Ocean and Shoreline Management. 15: 205-232.
- Parker, G. 1955. Salt-water contamination of the aquifer from tidal canals. In: Water Resources of Southeastern Florida. Water-Supply Paper #1255. U.S. Geological Survey. pp. 682-707.
- Pramanik, M., M. Chaudhury, and N. Macleod. 1978. Sedimentation patterns and land formation studies in the Feni and Little Feni River estuaries using landsat imagery. A Bangladesh Landsat Programee Report.
- Prins J. E. 1986. Impact of sea level rise on society. Proceedings of a workshop. Delft Hydraulics Laboratory. Delft, The Netherlands.
- Rashid, H. 1977. Geography of Bangladesh. University Press Limited. London, UK.
- Revelle, R. 1983. Probable future changes in sea level resulting from increasing atmospheric carbon dioxide. In: Changing Climate. Washington, D.C. National Academy Press.
- Rogers, P., P. Lydon and D. Seckler. 1989. Eastern Waters Study: Strategies to Manage Flood and Drought in the Ganges-Brahmaputra Basin. U.S. Agency for International Development. Washington, D.C.

The Science and Technology Division, Library of Congress. 1980. Environmental Report on Bangladesh. Library of Congress. Washington, D.C.

Seidel, S. and D. Keyes. 1983. Can We Delay a Greenhouse Warming? Government Printing Office. Washington, D.C.

de Sylva, D., 1986. Increased storms and estuarine salinity and other ecological impacts of the greenhouse effect. In Proceedings of the International Conference on Health and Environmental Effects of Ozone Modification and Climate Change.. The United Nations Environment Programme and the U.S. Environmental Protection Agency. Washington, D.C. pp 153-164.

Titus, J. 1986. Greenhouse effect, sea level rise, and coastal zone management. Coastal Management. 14(3): 146-171.

Titus, J. 1987a. The greenhouse effect, rising sea level and society's response. In R.J.N. Devoy, eds. Sea Surface Studies. A global View. New York, NY. pp. 499-528.

Titus, J. 1987b. Causes and effects of sea level rise. In Proceedings of the First Northamerican Conference on Preparing for Climate Change: A Cooperative Approach. Washington, D.C. pp. 126-139.

Titus, J. 1988. Sea level rise and wetland loss: an overview. In: J, Titus, eds Greenhouse Effect, Sea level Rise, and Coastal Wetlands. U.S. Environmental Protection Agency. Washington, D.C. pp. 1-33.

Titus, J., and M. Barth. 1984. An overview of the causes and effects of sea level rise. In M. Barth and J. Titus, eds. Greenhouse Effect and Sea Level Rise: A Challenge for this Generation. Van Nostrand Reinhold Company. New York, NY. pp. 1-56.

Titus, J. R. Henderson, and M. Teal. 1984. Sea level rise and wetlands loss in the United States. National Wetland Newsletter. 6 (5): 3-6.

Tolentino, A. 1983. Philippine coastal zone management: Organizational linkages and interconnections. Working paper. East-West Center. Honolulu, Hawaii.

Tonge, P. 1990. Holding back the tides. World Monitor Magazine. May: pp. 48-52.

United Nations Environment Programme (UNEP). 1986. Environmental problems of the marine and coastal areas of Bangladesh: national report. UNEP. Regional Seas Reports and Studies. N# 75 New York, NY.

United Nations Environment Programme, World Meteorological Organization, and International Council of Scientific Unions (UNEP/WMO/ICSU). 1985. International Assessment of the Role of Carbon Dioxide and Other Greenhouse Gases in Climate variations and Associated Impacts. United Nations Environment Programme (conference statement). Geneva, Switzerland.

United Nations. 1978 . Bangladesh: a strategy for the environment. Report prepared by The Regional Office for Asia and the Pacific of the United Nations Environment Programme. Unpublish draft manuscript. Bangkok, Thailand.

United Nations Disaster Relief Co-ordination (UNDRO). 1976a. Guidelines for Disaster Prevention. Vol. 1: Pre-disaster Physical Planning of Human Settlements. United Nations. Geneva.

United Nations Disaster Relief Co-ordination (UNDRO). 1976b. Guidelines for Disaster Prevention. Vol. 2: Building Measures for Minimizing the Impact of Disasters. United Nations. Geneva.

United Nations Disaster Relief Co-ordination (UNDRO). 1976c. Guidelines for Disaster Prevention. Vol 3: Management of Settlements. United Nations. Geneva.

U.S. Congress. House. 1988. Disaster Relief for Bangladesh. 100th Cong., 2d sess., H.R. 5389 and H. Con. Res 303.

U.S. Department of Commerce. 1978. Final Environmental Impact Statement: Coastal Management for the Commonwealth of Puerto Rico. Washington, D.C.

U.S. National Committee For Man and The Biosphere. 1980. Draft Environmental Report on Bangladesh. Department of State. Washington, D.C.

Velligna, P. and S. Leatherman. 1989. Sea level rise consequences and policies. Climatic Change. 15: 175-189.

Walsh, J. 1991. Cyclone of Death. Time Magazine, May 13: 29.

Weaver, D. and D. Hayes. 1989. Proposed response to sea level rise by a local government. Coastal Zone '89 3: 2490 - 2501.

World Bank. 1972. Land and water resources. Sector Study: Bangladesh. Asia Project Department. Washington, D.C.

World Bank Country Study. 1987. Bangladesh: Promoting Higher Growth and Human Development. Washington, D.C.

Zaman, M., A. Biswas, A. Khan, and A. Nishat eds. 1983. River Basin Development. In Proceedings of the National Symposium on River Basin Development (4). United Nations Development Programme, Tycooly International. Dublin, Ireland.