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Vulnerability to Climate Change:
Adaptation Strategies and Layers of Resilience

Quantifying Vulnerability to Climate Change in Bangladesh

AKM Nazrul Islam, Uttam K Deb, Muhammad Al Amin, Nusrat Jahan, Ishita Ahmed, Shamma Tabassum, Mazbahul Golam Ahamad, Ashiqun Nabi, Naveen P Singh, Byjesh Kattarkandi and Cynthia Bantilan

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Abstract

Bangladesh is considered to be one of the countries highly vulnerable to climate change. As part of the ADB funded project, "Vulnerability to Climate Change, Adaptation Strategies and Layers of Resilience", analysis of climate change vulnerability using two popular methods was carried out for Bangladesh. A set of indicators defining the three components of vulnerability, ie, exposure, sensitivity and adaptive capacity were selected considering their functional relationship and their contribution to the vulnerability. The aim of the exercise is to characterize different regions and ecological zones (EZ) of the country in terms of vulnerability related to climate change. From the analysis, we conclude that the majority of the regions are very highly vulnerable to climate change. These regions should receive high priority for channelizing resources such as technologies, finances and developmental programs to enhance their ability to cope with the impacts. Appropriate action should be planned and carried out in advance so as to foresee the anticipated impacts of climate change and the expected vulnerability of the regions and the population.

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Contents

List of Tables

List of Figures

List of Maps

1. Introduction

The inevitable and adverse consequences associated with global climate change are no longer considered to be a threat of tomorrow. The Intergovernmental Panel on Climate Change (IPCC) has unveiled evidence that impacts of climate change are already becoming clearly visible across the world. Global response with regard to climate change has now logically turned rightly towards design and formulation of measures in the area of adaptation and remediation. In view of greater understanding about the adverse impacts and cross-cutting nature of these impacts, formulating policies and measures to cope with the impacts of climate change has become more imperative, particularly because of the fact that manifestation of the impacts of climate change could vary both temporally and spatially. As is known, the magnitude of vulnerability also varies across different countries, regions and ecological zones (EZs) as well as different socio-economic sectors.[1] On the other hand, vulnerability of a system does not only depend on the possible external impacts of climatic variability, but also depends on factors such as demography, socio-economic condition and infrastructure. These factors, defined by the term adaptive capacity[2], represent the current ability of the country or regions to respond to or cope with the impacts. This implies that formulation of adaptive measures and mainstreaming climate policies would critically hinge on characterization of vulnerability.

Developing countries, especially the least developed countries (LDCs) and small island nations, are amongst the frontline victims of climate change. Geographic characteristics, high density of poor people, lack of resources and technological limitations have combined to deepen their vulnerability. Whilst South Asia is considered to be the most vulnerable region, Bangladesh has been identified as the most vulnerable country in the world in terms of the adverse impacts of climate change.[3] In view of this, it is important that Bangladesh gets on with the task of assessing, understanding and identifying the extent of the gravity of its micro-level climatic induced vulnerability in an urgent manner. The challenges facing Bangladesh are further accentuated on account of its large population size, high dependence on agriculture and the manifold occupations that are closely linked to the agro-climatic situation that could come under serious threat from climate change impacts. In order to craft an integrated policy to cope with climatic vulnerabilities, in an environment of significant resource constraints, it is important to identify and prioritize the most vulnerable sectors and regions. From this perspective, indices based on climatic as well as geographic, demographic, agricultural and socio-economic vulnerability could serve a very useful purpose in defining the priorities for the purpose of designing and implementing appropriate adaptation policies.

In this backdrop, the present study aims to estimate climatic vulnerability of different ecological zones of Bangladesh for the period from 1970s to 2000s to better understand their respective exposures, climatic sensitivity and adaptation capacities. This can be used to design informed policy measures to address the problem of climate change effectively in the Bangladesh context.

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1 As a matter of fact, IPCC recognise that "even within regions…impacts, adaptive capacity and vulnerability will vary" (IPCC 2001; Patnaik and Narayanan 2009).

2 Adaptive capacity is defined as capacities, resources and institutions of a country or region to implement effective adaptation measures (IPCC 2007).

3 In various international fora including the 15th meeting of Conference of Parties (COP 15) of United Nations Framework Convention on Climate Change (UNFCCC) held at Copenhagen (2009), Bangladesh was identified to be the country most vulnerable to climate change impacts. The Climate Change Vulnerability Index (CCVI) 2011, released by global risks advisory firm Maplecroft, ranked Bangladesh as number one among 170 countries (http://maplecroft.com/about/news/ccvi.html).

2. Literature review

As part of the ICRISAT-led seven country (Bangladesh, China, India, Pakistan, Sri Lanka, Thailand and Vietnam) project on "Vulnerability to Climate Change, Adaptation Strategies and Layers of Resilience", ICRISAT has made an extensive review of literature on vulnerability to climate change and documented these in an unpublished training module titled "Quantitative assessment of Vulnerability to Climate Change: Computation of Vulnerability Indices". The training module was used by all the project partners to acquire required computational and interpretation skills. Project partners agreed to use similar analytical techniques to facilitate cross-country comparisons. For the benefit of the readers, the review of literature section and the methodological section of this paper have been taken mainly, albeit with minor adaptation, from the above-said training module.

A number of studies related to climate change and associated vulnerabilities have attempted to assess the negative impacts of climate change from the perspective of occurrence and outcomes of natural hazards. There is also another school, which also took into cognizance social, economic and political issues (Anderson and Woodrow 1991; Blaikie et al. 1994; Cutter et al. 2003). The issue of climate change has become more cross-cutting than ever, and issues such as adaptation strategies, prioritization of actionable measures and utilization of adaptation funds are drawing increasingly more attention (Klein 2003). Hence the need for quantitative assessment of vulnerability through a set of indicators representing all the relevant sectors is gaining importance for formulation of climate change policies. Cutter (2003) urged the need for developing measurable metrics to estimate and compare the relative vulnerability of different countries, regions, or eco-regions. Significant gaps still persist over proper understanding of climate change, its impact on particular sectors, and with regard to results of feedbacks originating from those impacts that shape vulnerability.

A survey of climate change literature reveals two distinct approaches in conceptualizing vulnerability. One approach identifies vulnerability as the 'end point' associated with potential stress on a system caused by certain climate-related stressor or event or hazard (O'Brien et al. 2004, Kelly and Adger 2000, Brooks 2003). The second approach defines vulnerability as the 'starting point', which considers prevailing state of a system before a stressor or hazard has even been countered (Sen 1981, Watts and Bohle 1993, Bohle et al. 1994, Blaikie et al. 1994, Cutter 1996). While the 'end point' approach defines the residual impacts of climate change without considering adaptation capacities, the 'start point' approach encompasses issues spanning from scientific knowledge to socio-economic conditions, access to resource and infrastructure, institutional capacity and many other issues of political economy (Adger 1996).

The term 'vulnerability' perhaps needs to be defined under a conceptual framework. Scientifically, the word "vulnerability" has originated in geography, natural hazards research, and the analysis of food insecurity and famine; however, conceptualization of vulnerability has evolved into diverse aspects across different disciplines. Liverman (1990) interpreted vulnerability within a framework of resilience, risk, marginality, adaptability, and exposure. The diversity of conceptualization has made "vulnerability" useable in different policy contexts, referring to different systems exposed to different hazards (Gbetibouo and Ringler 2009).

3. Definition of Vulnerability

The word 'vulnerability' is generally associated with natural hazards such as floods, droughts, and social hazards like poverty, etc. It is extensively used in climate change literature to denote the extent of damage by which a region is expected to be affected. There are a large number of studies on vulnerability that have been carried out in the context of climate change – the definition of vulnerability tends to vary according to the perception of the particular researcher. A brief review of various definitions is given below.

Chamber (1983) defined that vulnerability has two sides. One is an external side of risks, shocks to which can subject an individual or household to climate change; there is also an internal side, which alludes to defenselessness, meaning a lack of means to cope without damaging loss. Blaikie et al. (1994) defined vulnerability as the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist and recover from the impacts of natural hazards and states that vulnerability can be viewed along a continuum from resilience to susceptibility. According to Adger (1999) vulnerability is the extent to which a natural or social system is susceptible to sustaining damage from climate change. It is generally perceived to be a function of two components. The effect that an event may have on humans, referred to as capacity or social vulnerability and the risk that such an event may occur, is often referred to as exposure. Watson et al. (1996) defined vulnerability as the extent to which climate change may damage or harm a system, depending not only on a system's sensitivity but also on its ability to adapt to new climatic conditions. Kasperson et al. (2000) defined vulnerability as the degree to which an exposure unit is susceptible to harm due to exposure to a perturbation or stress and the ability or lack of the exposure unit to cope, recover or fundamentally adapt to become a new system or to become extinct.

O'Brien and Mileti (1992) examined vulnerability to climate change and stated that in addition to economic wellbeing and stability, which are important from the perspective of resilience of population to environmental shocks, the structure and health of the population may play a key role in determining vulnerability. Age is an important consideration as the elderly and young person's tend to be inherently more susceptible to environmental risks and hazard exposure. Generally, a population with low dependency ratio and in good health is likely to have the widest coping ranges and thus be least vulnerable in the face of hazard exposure.

Handmer et al. (1999) studied the coping mechanisms to environmental shocks or hazards brought about by biophysical vulnerability. Factors such as institutional stability and strength of public infrastructure are of crucial importance in determining the vulnerability to climate change. A well connected population with appropriate public infrastructure will be able to deal with a hazard relatively more effectively and reduce the vulnerability. Such a society could be said to have low social vulnerability. If there is an absence of institutional capacity in terms of knowledge about the event and ability to deal with it, then such high vulnerability is likely to result in biophysical risk turning into an impact on the human population.

Atkins et al. (1998) studied the methodology for measurement of vulnerability and construction of a suitable composite vulnerability index for developing countries and island states. The composite vulnerability indices were presented for a sample of 110 developing countries for which appropriate data was available. The index suggests that small states are especially prone to vulnerability when compared to large states. Among the small states, states such as Cape Verde and Trinidad and Tobago are estimated to suffer relatively low levels of vulnerability, while the majority of the states experienced relatively high vulnerability; states such as Tonga, Antigua and Barbados were more vulnerable to external economic and environmental factors.

Chris Easter (2000) constructed a vulnerability index for the commonwealth countries, which is based on two principles. First, the impact of external shocks that affected the country, and second the resilience of a country to withstand and recover from such shocks. The analysis used a sample of 111 developing countries, 37 small and 74 large, for which relevant data were available. The results indicated that among the 50 most vulnerable countries, 33 were small states of which 27 are least developed countries and 23 are islands. In the least vulnerable 50 countries, only two were small states.

Dolan and Walker (2006) discussed the concept of vulnerability and presented a multi-scaled, integrated framework for assessing vulnerabilities and adaptive capacity. Determinants of adaptive capacity included access to and distribution of wealth, technology and information, risk perception and awareness, social capital and critical institutional frameworks to address climate change hazards. These are identified at the individual and community levels and situated within larger regional, national and international settings. Local and traditional knowledge is the key to research design and implementation, and allows for locally relevant outcomes that could facilitate more effective decision making, planning and management in remote coastal regions.

Moss et al. (2001) identified ten proxies for five sectors of climate sensitivities – the sensitivities related to settlement, food security, human health, eco-system and water availability. Seven proxies were identified for three sectors of coping and adaptive capacity, economic capacity, human resources and environmental or natural resources capacity. Proxies were aggregated into sectoral indicators, sensitivity indicators and coping or adaptive capacity indicators; vulnerability resilience indicators to climate change were constructed on the basis of this. Katharine Vincent (2004) created an index to empirically assess relative levels of social vulnerability to climate change induced variations in water availability and to allow cross country comparison in Africa. An aggregated index of social vulnerability was constituted through the weighted average of five composite sub-indices, which are economic well-being and stability, demographic structure, institutional stability and strength of public infrastructure, global interconnectivity and dependence on natural resources. The results indicate that using the current data, Niger, Sierra Leone, Burundi, Madagascar and Burkina Faso are the most vulnerable countries in Africa.

For the purpose of our understanding, we follow the IPCC Third Assessment Report (2001) according to which 'vulnerability' is defined as "the degree, to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes". "Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity". Thus, as per this definition, vulnerability has three components: exposure, sensitivity and adaptive capacity. These three components are described as follows:

- *Exposure* can be interpreted as the direct danger (ie, the stressor), and the nature and extent of changes to a region's climate variables (eg, temperature, precipitation, extreme weather events).
- *Sensitivity* describes the human-environmental conditions that can worsen the hazard, ameliorate the hazard, or trigger an impact.
- *Adaptive capacity* represents the potential to implement adaptation measures that help avert potential impacts

The first two components together represent the potential impact and adaptive capacity to the extent to which these impacts can be averted. Thus vulnerability (V) is potential impact (I) minus adaptive capacity (AC). This leads to the following mathematical equation for vulnerability:

$$V = f\left(I - AC\right)$$

4. The Conceptual Framework

4.1 The Index Approach to Study Vulnerability

Quantitative assessment of vulnerability, as can be gleaned from the relevant literature, is usually done by constructing a 'vulnerability index'. This index is based on several sets of indicators that result in vulnerability of a region. It produces a single number, which can be used to compare different regions. Literature on index number construction specifies that there should be good internal correlation between these indicators. The relevance of this criterion depends on the relationship between the indicators and the construct they are supposed to measure. For this, the index is based on a reflexive or a formative measurement model. In the reflexive measurement model, the construct is thought to influence the indicators. For example, a poverty index is a good example of reflexive measurement because poverty influences indicators such as literacy and expenditure among others. All these indicators are correlated. On the other hand, in the formative model the indicators are assumed to contribute to the construct. In the case of vulnerability index, all the indicators chosen by researchers have impact on vulnerability of the region to climate change. For example, frequency of extreme events such as flood, drought, earthquakes and length of coastline all contribute to vulnerability of the region to climate change. Hence, vulnerability index is a formative measurement and the indicators chosen need not have internal correlation.

4.2 Construction of Vulnerability Index

Construction of vulnerability index involves several steps. The study area, which could include a number of regions, has to be selected first. In each region a set of indicators are identified for each component of vulnerability. Following this exercise, lists of possible indicators were selected for the purpose of the present study. The indicators were selected based on the availability of data, personal judgment or previous research. Since vulnerability is dynamic over time, it is important that all the indicators relate to the particular year chosen. If vulnerability has to be assessed over the years, then the data for each year for all the indicators in each region need to be collected. This was accordingly done for this study.

4.3 Arrangement of Data

For each component of vulnerability, the collected data were arranged in the form of a rectangular matrix with rows representing agro-ecological regions and columns representing indicators.

4.4 Normalization of Indicators using Functional Relationship

For obvious reasons, the indicators tend to be in different units and scales. The methodology used in UNDP's Human Development Index (HDI) (UNDP 2006) has been followed to normalize these. That is, in order to obtain figures that are free from the units and also to standardize their values, first they were normalized so that they all lie between 0 and 1. Before doing this, it is important to identify the functional relationship between the indicators and vulnerability. Two types of functional relationship are possible: vulnerability increases with increase (decrease) in the value of the indicator. Assume that higher the value of the indicator more is the vulnerability. For example, suppose we have collected information on change in maximum temperature or change in annual rainfall or diurnal variation in temperature. It is clear that higher the values of these indicators more will be the vulnerability of the region to climate change as variation in climate variables increase the vulnerability.

In this case we say that the variables have ↑ functional relationship with vulnerability and the normalization is done using the formula

$$x_{ij} = \frac{X_{ij} - \underset{i}{Min}\left\{X_{ij}\right\}}{\underset{i}{Max}\left\{X_{ij}\right\} - \underset{i}{Min}\left\{X_{ij}\right\}}$$

It is clear that all these scores will lie between 0 and 1. The value 1 will correspond to that region with maximum value and 0 will correspond to the region with minimum value.

On the other hand, let adult literacy rate be considered. A high value of this variable implies more literates in the region and so they will have more awareness to cope with climate change. So the vulnerability will be lower and adult literacy rate has ↓ functional relationship with vulnerability. For this case the normalized score is computed using the following formula

$$y_{ij} = \frac{\underset{i}{Max}\{X_{ij}\} - X_{ij}}{\underset{i}{Max}\{X_{ij}\} - \underset{i}{Min}\{X_{ij}\}}$$

It can be easily checked that $x_{ij} + y_{ij} = 1$ so that y_{ij} can be calculated as $y_{ij} = 1 - x_{ij}$.

This method of normalization that takes into account the functional relationship between the variable and vulnerability is important in the construction of the indices. It may be noted here that if the functional relation is ignored and if the variables are normalized simply by applying the first formula, the resulting index will be misleading.

After computing the normalized scores, the index can be constructed by giving either equal weights to all indicators/components or unequal weights. Two methods have been described below in which equal weights are given to the indicators.

5. Empirical Framework

Among the most popular methods to estimate climatic vulnerability, the methods adopted were Patnaik and Narayanan (2005) and the IPCC (2007). Both these methodologies explain how the regions are vulnerable to climate related shocks or events.

5.1 IPCC method

Using the IPCC method, indicators are grouped based on the category of three components of vulnerability – exposure, sensitivity and adaptive capacity. This analysis used long term decadal data from indicators representing the three components (Table 1).

Table 1. Indicators considered for computing vulnerability index using IPCC method.

Components	Indicators	Data Source
Exposure	Rainfall (E1) Minimum Temperature (E2) Maximum Temperature (E3)	Statistical year book of Bangladesh, Bangladesh meteorological department, Agricultural sample survey of Bangladesh
Sensitivity	Population (S1) Total food crop area (S2) Total non-food crop area (S3) Net sown area (S4)	
Adaptive Capacity	Literacy rate (A1) Cropping Intensity (A2) Irrigated area (A3)	

5.2 Patnaik and Narayanan method

In the Patnaik and Narayanan method, the possible sources of vulnerability are grouped as demographic, climatic, agricultural, occupational and geographic. Possible sub-indicators in each source are listed (Table 2). Overall vulnerability index was computed by considering each sub-indicator. In this first exercise, six agro-ecological zones are considered due to decadal data limitation and availability.

Table 2. Relationship between study regions and present administrative districts.

Regions	Administrative Districts
Barisal	Barguna, Barisal, Bhola, Jhalakati and Pirojpur
Bogra	Bogra and Joypurhat
Chittagong	Chittagong and Cox's bazaar
Chittagong H.T	Bandarban, Khagrachhari and Rangamati
Comilla	Brahmanbaria, Chandpur and Comilla
Dhaka	Dhaka, Gazipur, Manikganj, Munshiganj, Narayanganj and Narsingdi
Dinajpur	Dinajpur, Panchagarh and Thakurgaon
Faridpur	Faridpur, Rajbari, Gopalganj, Madaripur and Shariatpur
Jamalpur	Jamalpur
Jessore	Jessore, Jhenaidah, Magura and Narail
Khulna	Khulna, Bagerhat and Satkhira
Kishoreganj	Kishoreganj
Kushtia	Kushtia, Chuadanga and Meherpur
Mymensingh	Mymensingh, Netrakona and Sherpur
Noakhali	Noakhali, Feni and Lakshmipur
Pabna	Pabna and Sirajganj
Patuakhali	Patuakhali
Rajshahi	Rajshahi, Naogaon, Nator and Nawabganj
Rangpur	Rangpur, Gaibandha, Kurigram, Lalmonirhat and Nilphamari
Sylhet	Sylhet, Habiganj, Moulvi Bazar and Sunamganj
Tangail	Tangail

The different sources of vulnerability are briefly explained below:

a) Agricultural Vulnerability

For constructing agricultural vulnerability, five sub-indicators have been considered. These are: percentage of irrigated area, cropping intensity, area under food crops, area under non-food crops and forest area.

b) Climatic Vulnerability

Three sub-indicators have been used to construct the climatic vulnerability for Bangladesh. These are: annual rainfall, maximum temperature and minimum temperature.

c) Demographic Vulnerability

Two sub-indicators are taken into consideration to construct the demographic vulnerability for Bangladesh. These are density of population and literacy rate.

d) Occupational Vulnerability

To construct the occupational vulnerability index for the six ecological zones of the country, a total of four sub-indicators are considered. These are: total employed people, total labor force, self-employed and day laborer in each of the six zones. Using these four sub-indicators, the final vulnerability was then calculated.

e) Geographical Vulnerability

Two sub-indicators were taken to construct the occupational vulnerability for the six zones of Bangladesh. These are the geographic area and the total exposed area of the selected zones. Exposed area was considered on the basis of area-wise exposure to the sea for the coastal regions of the country.

f) Overall Vulnerability

Finally, to construct the overall vulnerability index for Bangladesh, all the five individual vulnerability scores, which include agricultural vulnerability, climatic vulnerability, demographic vulnerability, occupational vulnerability and geographical vulnerability, have been considered.

5.3 Study Area

Information about vulnerability situation is important at the administrative districts as well as at the eco-region level. Administrative district level information helps different government agencies to allocate their financial and other resources to address the problem. On the other hand, eco-region level information is needed for generation of agricultural technologies and project formulation to enhance farmers' adaptive capacity. In this study, we have assessed vulnerability situation at both levels.

Bangladesh has currently 64 administrative districts. However, data for 64 current administrative districts are available only for some recent years. Therefore, we have calculated vulnerability index, following IPCC (2007) method, for all 21 regions (also known as greater districts or old districts) of Bangladesh. Information gathered on indicators from 1974, 1981, 1991, 2001 and 2006 were used in the analyses. Relation between current administrative districts and regions (greater districts) are provided in Table 2.

Data at the agro ecological zones (AEZs) or ecological zones (EZs) level are not available. Deb (2005), following a rigorous method of existing AEZs and EZs based GIS maps and existing data at the region or greater district level, proposed a classification of six ecological zones (EZs). These are: Not Flood Prone, Low Flood Prone, Flood Prone, Drought Prone, Tidal Surge and the Mixed Zone. Distribution of regions to the above-said ecological zones is reported in Table 3.

Table 3. Distribution of Regions to Different Ecological Zones.

Ecological zones	Regions
Not flood prone	Chittagong HT, Dhaka
Low flood prone	Jamalpur
Flood prone	Sylhet, Tangail, Jessore, Kushtia, Pabna, Rangpur
Drought prone	Rajshahi, Dinajpur, Bogra, Faridpur
Tidal surge	Noakhali, Barisal, Khulna, Patuakhali
Mixed	Mymensingh, Comilla, Kishoregonj (Flood Prone and Not Flood Prone) and Chittagong (Not Flood Prone, Flood Prone, Tidal Surge)

Following Deb's (2005) classification of ecological zones (EZs), different regions of Bangladesh have been grouped together for computing vulnerability using Patnaik and Narayanan method. The purpose behind selecting the EZs to compute vulnerability in the context of Bangladesh was to show how climatic vulnerability over the years in various flood, drought and tidal-prone zones in the country has been changing. The study aimed to identify certain policy inputs that could be used suitably for different EZs in Bangladesh.

5.4 Sources of Data

The data on various sub-indicators were collected from sources including various issues of 'Statistical Yearbook of Bangladesh' published by BBS, Labor Force Survey Reports, Agricultural Sample Survey of Bangladesh; data from the Bangladesh Meteorological Department was also used for this purpose (Table 4).

Table 4. Data sources and time periods by sources of vulnerability.

Sources of vulnerability	Sub-indicators	Source of data	Time period
Demographic	Density of population, Literacy rate	Statistical Yearbooks of Bangladesh, BBS	1974-2006
Climatic	Annual rainfall, Maximum temperature, Minimum temperature	Bangladesh Meteorological Department	1974-2006
Agricultural	Area under food crops, Area under non-food crops, Cropping intensity, % of irrigated area, Area under forest	Statistical Yearbooks of Bangladesh, BBS Agricultural Sample Survey of Bangladesh	1974-2006
Occupational	Total employed persons Labor force Self-employed Day laborer	Statistical Yearbooks of Bangladesh, BBS	1974-2006
Geographical	Geographical area Exposed Area	Statistical Yearbooks of Bangladesh, BBS	1974-2006

Source: Authors' calculation.

5.5 Data Analysis

As is known, vulnerability is dynamic over time. Both region and EZ level data for all the sub-indicators were collected and arranged for the purpose of the study. Following this, normalization of indicators was done using functional relationship between an indicator and vulnerability (Table 5), and using Human Development Index (HDI).

Table 5. Functional relationship between an indicator and vulnerability.

Indicator	Functional relationship
Area under food crops (in acres)	↓
Area under non-food crops (in acres)	↓
Cropping intensity (in %)	↓
Forest area (in acres)	↓
Irrigation intensity (in %)	↓
Annual rainfall (mm)	↑
Maximum temperature (°c)	↑
Minimum temperature (°c)	↑
Density of population (sq. km)	↑
Literacy rate (in %)	↓
Total employed persons	↓
Total labor force	↓
Total self employed	↓
Total day laborer	↓
Exposed area (sq. km)	↑
Geographic area (sq. km)	↑

As was mentioned earlier, five possible sources of vulnerability – demographic, climatic, agricultural, occupational and geographic – were identified and corresponding indices were calculated based on an array of sub-indicators representing each of those sources. These individual indices were then deployed to develop a composite, overall index.

6. Trends in Vulnerability at the Region Level

Following the IPCC (2001) method, discussed in section 5, vulnerability index was calculated for all regions. Based on the values of estimated vulnerability index, regions can be grouped into five categories: (i) Less Vulnerable (0-0.158), (ii) Moderately vulnerable (0.158-0.173), (iii) Vulnerable (0.173-0.186), (iv) Highly vulnerable (0.186-0.198), and (vi) Very highly vulnerable (0.198-0.237).

Region-wise rankings based on vulnerability index are presented in Table 6 to 8. Jamalpur, Bogra and Kushtia were the three most vulnerable regions in 1981. During the same period, least vulnerable regions were Barisal, Sylhet and Rangpur. Two regions (Rangpur and Sylhet) were Less Vulnerable, three regions (Barisal, Comilla and Kishoreganj) were Moderately vulnerable, three (Chittagong HT , Jessore and Dhaka) were Vulnerable, five regions (Khulna, Dinajpur, Mymensingh, Rajshahi and Tangail) were Highly vulnerable and eight regions (Noakhali,Pabna, Faridpur, Patuakhali, Chittagong, Kushtia, Bogra, Jamalpur) were Very highly vulnerable.

In 1991, most vulnerable regions were Jamalpur, Kushtia and Bogra while least vulnerable regions were Sylhet, Barisal and Rangpur (Table 7). Five regions (Rangpur, Barisal, Sylhet, Jessore and Comilla) were Less Vulnerable, five regions (Rajshahi, Faridpur, Dinajpur, Chittagong H.T and Khulna) were Moderately vulnerable, five regions (Dhaka Kishoreganj, Mymensingh, Noakhali and Tangail) were Vulnerable, five regions (Patuakhali, Chittagong, Pabna, Bogra and Kushtia) were Highly vulnerable and one region (Jamalpur) was Very highly vulnerable.

In 2001, Jamalpur, Chittagong and Bogra were the three most vulnerable regions while Sylhet, Rangpur and Barisal were the least vulnerable regions (Table 8). Six regions (Rangpur, Barisal, Sylhet, Rajshahi, Dinajpur and Jessore) were Less Vulnerable, four regions (Kishoreganj, Khulna, Chittagong H.T and Faridpur) were Moderately vulnerable, five regions (Comilla, Noakhali, Mymensingh, Patuakhali and Dhaka) were Vulnerable, three regions (Pabna, Tangail and Kushtia) were Highly vulnerable and one region (Bogra, Chittagong and Jamalpur) were Very highly vulnerable.

An analysis of changes in Vulnerability level over three decades revealed three types of change: (i) Consistently decreased over time (1981, 1991 and 2001), (ii) No significant changed (change in vulnerability index between +0.01 to –0.01) over time (1981, 1991 and 2001) and (iii) Fluctuating over time (increased or decreased between two periods). A total of 14 regions (Bogra, Kushtia, Chittagong, Patuakhali, Faridpur, Pabna, Noakhali, Rajshahi, Mymensingh, Dinajpur, Khulna, Jessore, Barisal, Rangpur) experienced Consistent decrease in vulnerability over time. Six regions (Jamalpur, Tangail, Dhaka, Chittagong H.T, Kishoreganj, Sylhet) experienced no significant change over time and one region (Comilla) had Fluctuating change in vulnerability level over time.

Vulnerability index is the outcome of three different sources: Exposure, Sensitivity and adaptive capacity. With the increase in exposure level, vulnerability level increases. Increase in sensitivity also increases the level of vulnerability. On the other hand, increase in adaptive capacity reduces the level of vulnerability. Thus, vulnerability index is the combined effect of all these three sources. Decrease in vulnerability level in many regions over time indicates that Bangladesh has been successful in enhancing the adaptive capacity of many regions through various measures such as expansion of irrigation system, increased cropping intensity and improvement in education level over time. In addition, the country was able to

Table 6. Region-wise ranking based on vulnerability index in Bangladesh during 1981.

	Exposure				Sensitivity					Adaptive capacity				Vulnerability	
Districts	Total	E1	E2	E3	Total	S1	S2	S3	S4	Total	A1	A2	A3	Index	Rank
Barisal	0.08	0.03	0.00	0.06	0.25	0.06	0.05	0.10	0.04	0.18	0.07	0.11	0.00	0.169	19
Bogra	0.16	0.03	0.07	0.06	0.30	0.07	0.07	0.10	0.07	0.22	0.06	0.11	0.05	0.229	2
Chittagong	0.12	0.06	0.02	0.04	0.35	0.07	0.10	0.11	0.07	0.18	0.04	0.11	0.03	0.217	4
Chittagong H.T	0.10	0.07	0.00	0.03	0.29	0.00	0.10	0.11	0.08	0.13	0.09	0.00	0.04	0.174	16
Comilla	0.08	0.03	0.01	0.04	0.25	0.10	0.03	0.08	0.03	0.19	0.04	0.10	0.05	0.171	18
Dhaka	0.11	0.05	0.00	0.05	0.28	0.13	0.06	0.06	0.03	0.17	0.05	0.11	0.01	0.186	14
Dinajpur	0.12	0.04	0.05	0.03	0.22	0.04	0.05	0.09	0.03	0.24	0.07	0.11	0.06	0.195	12
Faridpur	0.16	0.04	0.07	0.05	0.22	0.06	0.06	0.06	0.03	0.26	0.09	0.11	0.06	0.211	6
Jamalpur	0.14	0.05	0.07	0.02	0.30	0.07	0.08	0.08	0.07	0.28	0.08	0.10	0.09	0.238	1
Jessore	0.10	0.00	0.02	0.08	0.19	0.06	0.06	0.05	0.03	0.24	0.08	0.11	0.05	0.179	15
Khulna	0.11	0.01	0.01	0.09	0.24	0.03	0.07	0.10	0.04	0.21	0.08	0.12	0.01	0.187	13
Kishoreganj	0.07	0.04	0.01	0.03	0.25	0.06	0.06	0.07	0.05	0.19	0.02	0.10	0.07	0.172	17
Kushtia	0.10	0.05	0.04	0.01	0.31	0.06	0.09	0.08	0.07	0.26	0.06	0.12	0.08	0.222	3
Mymensingh	0.07	0.04	0.01	0.03	0.26	0.06	0.07	0.07	0.06	0.25	0.08	0.10	0.07	0.196	11
Noakhali	0.11	0.07	0.01	0.03	0.29	0.07	0.07	0.10	0.06	0.22	0.07	0.11	0.03	0.205	8
Pabna	0.08	0.00	0.01	0.07	0.29	0.07	0.07	0.09	0.05	0.26	0.08	0.11	0.07	0.210	7
Patuakhali	0.12	0.05	0.01	0.05	0.30	0.04	0.08	0.11	0.07	0.23	0.10	0.12	0.02	0.216	5
Rajshahi	0.16	0.02	0.06	0.08	0.19	0.05	0.04	0.10	0.00	0.23	0.05	0.12	0.06	0.197	10
Rangpur	0.03	0.03	0.00	0.00	0.06	0.06	0.00	0.00	0.00	0.22	0.05	0.10	0.07	0.104	21
Sylhet	0.12	0.11	0.01	0.00	0.12	0.04	0.01	0.07	0.00	0.18	0.00	0.11	0.06	0.139	20
Tangail	0.06	0.01	0.02	0.03	0.30	0.07	0.08	0.08	0.07	0.23	0.08	0.09	0.06	0.199	9

Source: Author’s calculation.

Table 7. Region-wise ranking based on vulnerability index in Bangladesh during 1991.

	Exposure				Sensitivity					Adaptive capacity				Vulnerability	
Districts	Total	E1	E2	E3	Total	S1	S2	S3	S4	Total	A1	A2	A3	Index	Rank
Barisal	0.07	0.03	0.00	0.04	0.18	0.04	0.03	0.10	0.02	0.19	0.07	0.11	0.00	0.145	20
Bogra	0.14	0.05	0.06	0.03	0.28	0.06	0.06	0.10	0.06	0.17	0.03	0.09	0.05	0.194	3
Chittagong	0.11	0.04	0.02	0.04	0.29	0.06	0.06	0.11	0.06	0.18	0.06	0.10	0.02	0.191	5
Chittagong H.T	0.09	0.04	0.01	0.04	0.29	0.00	0.10	0.10	0.09	0.13	0.09	0.00	0.04	0.170	13
Comilla	0.06	0.01	0.01	0.04	0.23	0.08	0.02	0.09	0.03	0.17	0.03	0.09	0.05	0.154	17
Dhaka	0.09	0.03	0.01	0.05	0.29	0.12	0.04	0.08	0.04	0.15	0.04	0.10	0.01	0.175	11
Dinajpur	0.10	0.06	0.04	0.00	0.20	0.04	0.04	0.09	0.03	0.21	0.05	0.10	0.06	0.169	14
Faridpur	0.13	0.05	0.06	0.02	0.16	0.05	0.03	0.06	0.02	0.21	0.05	0.10	0.06	0.167	15
Jamalpur	0.17	0.03	0.09	0.04	0.29	0.06	0.07	0.09	0.07	0.24	0.06	0.09	0.09	0.231	1
Jessore	0.11	0.00	0.02	0.09	0.17	0.05	0.03	0.06	0.03	0.17	0.03	0.10	0.05	0.150	18
Khulna	0.10	0.02	0.01	0.07	0.21	0.02	0.06	0.10	0.03	0.21	0.08	0.12	0.01	0.172	12
Kishoreganj	0.06	0.02	0.01	0.03	0.25	0.05	0.06	0.09	0.04	0.23	0.04	0.12	0.07	0.176	10
Kushtia	0.09	0.05	0.04	0.01	0.27	0.05	0.07	0.08	0.07	0.23	0.06	0.10	0.07	0.195	2
Mymensingh	0.06	0.02	0.01	0.03	0.26	0.05	0.06	0.09	0.06	0.23	0.06	0.09	0.07	0.181	9
Noakhali	0.09	0.07	0.01	0.01	0.25	0.05	0.05	0.11	0.05	0.21	0.07	0.10	0.03	0.184	8
Pabna	0.09	0.00	0.01	0.07	0.27	0.06	0.07	0.09	0.06	0.22	0.05	0.10	0.07	0.193	4
Patuakhali	0.10	0.05	0.01	0.03	0.25	0.02	0.06	0.11	0.05	0.22	0.09	0.11	0.02	0.188	6
Rajshahi	0.14	0.04	0.05	0.05	0.16	0.04	0.02	0.09	0.00	0.18	0.01	0.11	0.06	0.161	16
Rangpur	0.03	0.02	0.01	0.00	0.05	0.05	0.00	0.00	0.00	0.16	0.00	0.09	0.07	0.083	21
Sylhet	0.11	0.10	0.01	0.00	0.12	0.03	0.02	0.08	0.00	0.20	0.03	0.11	0.06	0.147	19
Tangail	0.07	0.01	0.02	0.04	0.27	0.06	0.07	0.08	0.06	0.22	0.06	0.10	0.06	0.187	7

Source: Author’s calculation.

Table 8. Region-wise ranking based on vulnerability index in Bangladesh during 2001.

	Exposure				Sensitivity					Adaptive capacity				Vulnerability	
Districts	Total	E1	E2	E3	Total	S1	S2	S3	S4	Total	A1	A2	A3	Index	Rank
Barisal	0.05	0.01	0.00	0.04	0.19	0.03	0.04	0.08	0.04	0.19	0.11	0.07	0.01	0.145	20
Bogra	0.15	0.05	0.06	0.05	0.28	0.05	0.06	0.10	0.07	0.17	0.09	0.03	0.05	0.200	3
Chittagong	0.10	0.05	0.02	0.03	0.31	0.06	0.09	0.10	0.07	0.19	0.11	0.06	0.03	0.200	2
Chittagong H.T	0.09	0.07	0.01	0.02	0.28	0.00	0.08	0.10	0.09	0.15	0.00	0.09	0.06	0.172	13
Comilla	0.05	0.02	0.01	0.03	0.29	0.07	0.09	0.09	0.03	0.18	0.10	0.04	0.04	0.175	11
Dhaka	0.09	0.05	0.01	0.04	0.30	0.13	0.04	0.09	0.04	0.15	0.11	0.04	0.00	0.182	7
Dinajpur	0.11	0.05	0.04	0.02	0.19	0.03	0.03	0.09	0.03	0.17	0.10	0.02	0.04	0.156	17
Faridpur	0.15	0.05	0.06	0.03	0.16	0.04	0.04	0.04	0.04	0.21	0.10	0.05	0.05	0.172	12
Jamalpur	0.18	0.05	0.09	0.04	0.28	0.05	0.07	0.09	0.07	0.25	0.10	0.06	0.09	0.237	1
Jessore	0.11	0.01	0.02	0.09	0.20	0.04	0.05	0.07	0.04	0.16	0.10	0.03	0.03	0.157	16
Khulna	0.08	0.00	0.01	0.07	0.23	0.02	0.06	0.10	0.05	0.20	0.12	0.07	0.01	0.171	14
Kishoreganj	0.05	0.03	0.00	0.02	0.25	0.05	0.06	0.09	0.05	0.22	0.11	0.04	0.07	0.171	15
Kushtia	0.10	0.05	0.04	0.01	0.27	0.05	0.08	0.07	0.07	0.21	0.10	0.05	0.06	0.192	4
Mymensingh	0.05	0.03	0.00	0.02	0.26	0.05	0.05	0.10	0.06	0.24	0.10	0.06	0.08	0.180	9
Noakhali	0.07	0.05	0.01	0.01	0.26	0.05	0.06	0.09	0.06	0.20	0.10	0.08	0.03	0.178	10
Pabna	0.09	0.01	0.01	0.07	0.26	0.05	0.06	0.09	0.06	0.21	0.10	0.05	0.06	0.188	6
Patuakhali	0.08	0.03	0.01	0.03	0.24	0.02	0.06	0.10	0.05	0.22	0.12	0.09	0.02	0.182	8
Rajshahi	0.15	0.04	0.05	0.06	0.15	0.04	0.01	0.09	0.00	0.17	0.12	0.00	0.05	0.156	18
Rangpur	0.03	0.03	0.00	0.00	0.06	0.05	0.00	0.00	0.01	0.17	0.10	0.00	0.07	0.086	21
Sylhet	0.11	0.10	0.01	0.00	0.12	0.03	0.02	0.07	0.00	0.21	0.12	0.04	0.06	0.149	19
Tangail	0.07	0.02	0.02	0.04	0.28	0.05	0.07	0.09	0.07	0.22	0.10	0.06	0.06	0.190	5

Source: Author's calculation.

reduce the sensitivity level through continuous development in agricultural sector through improved crop varieties. Therefore, the vulnerability level has gone down though the risk has increased due to increased exposure.

Our analysis revealed that exposure level has consistently increased in Jamalpur region. It may be noted that this region is prone to river erosion. Most of the regions (Patuakhali, Faridpur, Noakhali, Khulna, Dhaka, Bogra, Rajshahi, Dinajpur, Comilla, Chittagong and Kishoreganj) had experienced fluctuation in exposure level over time. Only two regions (Mymensingh and Barisal) had experienced consistent decrease in exposure level over time. Other regions experienced no major changes in exposure level. It is important to note here that the three points of time (1981, 1991 and 2001) chosen for this analysis were normal years. Therefore, analysis presented in this section deals only with comparison of normal years. Frequency of floods and cyclones has increased in recent decades in Bangladesh. One constraint of the present analysis is that these dynamic aspects of vulnerability were not captured.

Sensitivity level has decreased over time in two regions (Patuakhali, Rajshahi) and remained unchanged in five regions (Mymensingh, Chittagong H.T, Kishoreganj, Sylhet and Rangpur). Fourteen regions (Chittagong, Khulna, Jessore, Comilla, Bogra, Kushtia, Patuakhali, Faridpur, Pabna, Noakhali, Tangail, Rajshahi, Dinajpur and Barisal) had experienced fluctuation in sensitivity.

Adaptive capacity has consistently increased over time in two regions (Kishoreganj and Sylhet). Most of the regions had fluctuations in adaptive capacity (Jamalpur, Bogra, Faridpur, Pabna, Rajshahi, Mymensingh, Dhaka, Jessore, Chittagong H.T, Comilla and Rangpur). Adpative capacity was constant or not changed significantly in six regions (Chittagong, Patuakhali, Noakhali, Tangail, Khulna and Barisal) while two regions (Kushtia and Dinajpur) experienced decrease in adaptive capacity.

We are often interested to know whether vulnerability rank of a region in a particular year or point of time has any link with its past rank condition. In other words, whether initial conditions matter for vulnerability ranking. To examine this, we have estimated rank correlation across years. Estimated results are presented in Table 9. It shows that there is high correlation of a region's vulnerability with its past. In other words, we have observed similar direction and rank in vulnerability across regions over years.

Table 9. Rank Correlation Coefficient of Vulnerability across Years.

	1981	1991	2001
1981	1		
1991	0.856**	1	
2001	0.818**	0.912**	1

Note: **Significant at 1% level

Source: Author's calculation.

7. Trends in Vulnerability at the Ecological Zone Level

7.1. Agricultural Vulnerability

Ranking of ecological zones based on agricultural vulnerability for the period of 1974 to 2006 is provided in Table 10 while Table 11 represents the changes in agricultural vulnerability of the ecological regions over the period. It may be noted that the tidal surge zone, which comprises the southern coastal region, continued to be the most vulnerable zone within the country in terms of agricultural vulnerability. Agricultural vulnerability (in terms of index value) of this zone has reduced over the period (from 0.83 in 1974 to 0.70 in 2006) though it remains to be the most vulnerable zone. Despite the fact that significant attention has been given to disaster management in the coastal areas, increasing rate of coastal hazards,

Table 10. Ecological zone-wise ranking of agricultural vulnerability.

Ecological Zones	Vulnerability index					Ranks in				
	1974	1981	1991	2001	2006	1974	1981	1991	2001	2006
Not flood prone	0.45	0.66	0.52	0.58	0.58	3	3	5	4	4
Low flood prone	0.41	0.58	0.60	0.60	0.60	4	4	2	3	3
Flood prone	0.37	0.34	0.29	0.30	0.26	5	6	6	6	6
Drought prone	0.71	0.70	0.56	0.52	0.54	2	2	4	5	5
Tidal surge	0.83	0.72	0.77	0.72	0.70	1	1	1	1	1
Mixed	0.41	0.44	0.57	0.65	0.67	4	5	3	2	2

Source: Authors' calculation.

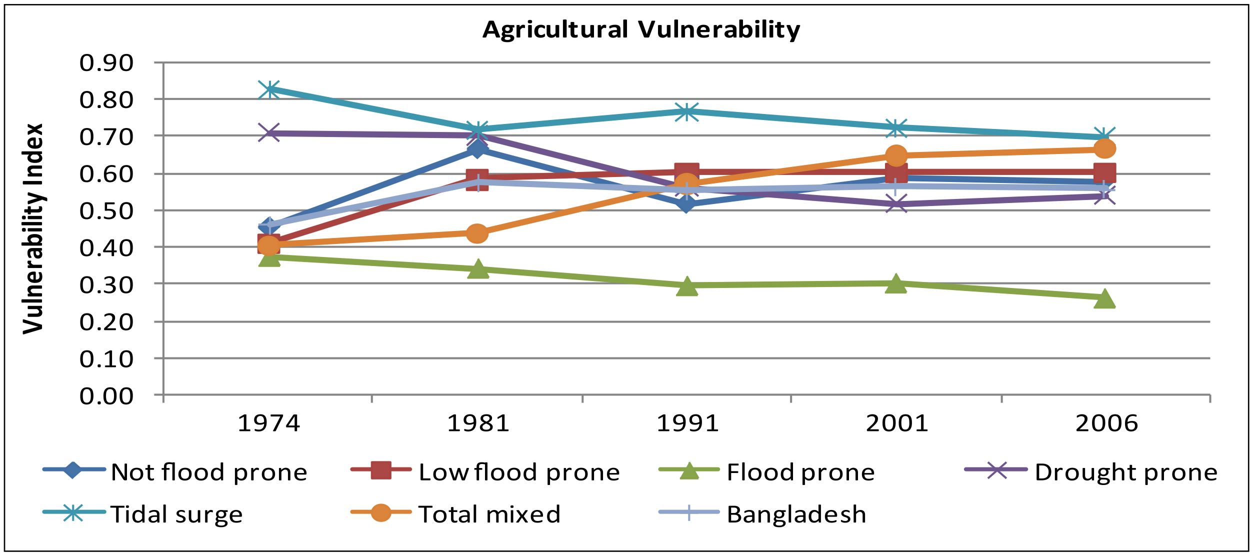
Table 11. Change of various stages of agricultural vulnerability by ecological zone in Bangladesh.

Ecological Zones	Year				
	1974	1981	1991	2001	2006
Not flood prone	Moderately vulnerable	Highly vulnerable	Moderately vulnerable	Moderately vulnerable	Moderately vulnerable
Low flood prone	Moderately vulnerable	Moderately vulnerable	Moderately vulnerable	Moderately vulnerable	Moderately vulnerable
Flood prone	Vulnerable	Vulnerable	Vulnerable	Vulnerable	Vulnerable
Drought prone	Highly vulnerable	Highly vulnerable	Moderately vulnerable	Moderately vulnerable	Moderately vulnerable
Tidal surge	Very highly vulnerable	Highly vulnerable	Highly vulnerable	Highly vulnerable	Highly vulnerable
Mixed	Moderately vulnerable	Moderately vulnerable	Moderately vulnerable	Highly vulnerable	Highly vulnerable

Source: Authors' calculation.

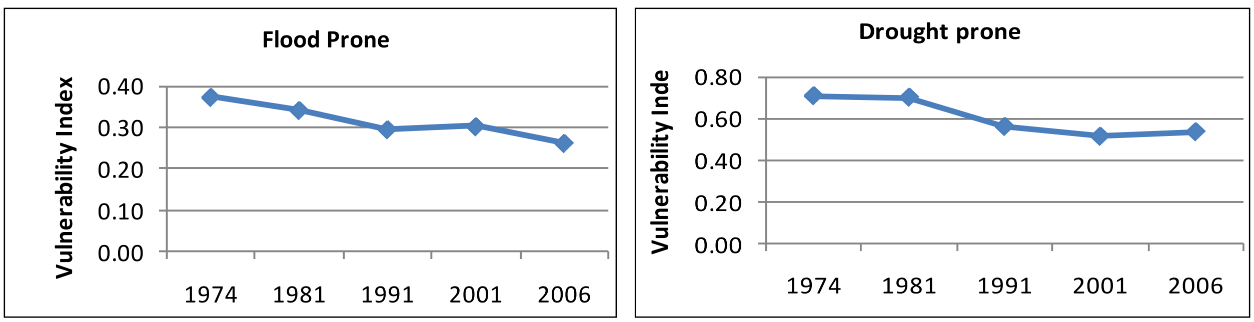
salinity intrusion and consequent loss of yield rate have made this zone relatively more vulnerable. The low flood prone zones were moderately vulnerable till 1990s. However, during 2001 and 2006 these regions were found to be highly vulnerable. Non-flood prone regions have been moderately vulnerable over the observation period while agricultural vulnerability of the mixed eco-regions has increased from 0.41 in 1974 to 0.67 in 2006. Patnaik and Narayanan (2009), while analyzing vulnerability of the Eastern coastline districts of India that are prominent for agricultural production also reported that changes in sources of agricultural vulnerability may have a direct impact on the vulnerability of peoples' livelihood.

To the contrary, drought prone zones, which were highly vulnerable over the decades of 1970s and 1980s, have become moderately vulnerable in 2006 thanks to the agricultural research in the development of drought resistant crop varieties and improvements in the irrigation system. Index of agricultural vulnerability in these regions was found to be 0.71 in 1974 (ranked 2nd), which drastically fell in 1991 to 0.56 before plateauing. Though flash floods and seasonal floods often result in severe loss in agricultural production, the flood prone areas are found to be the least vulnerable throughout the observation period. Figure 1 and Map 1 show the trends in agricultural vulnerability index for all six ecological zones while Figure 2 displays the same for the study areas.



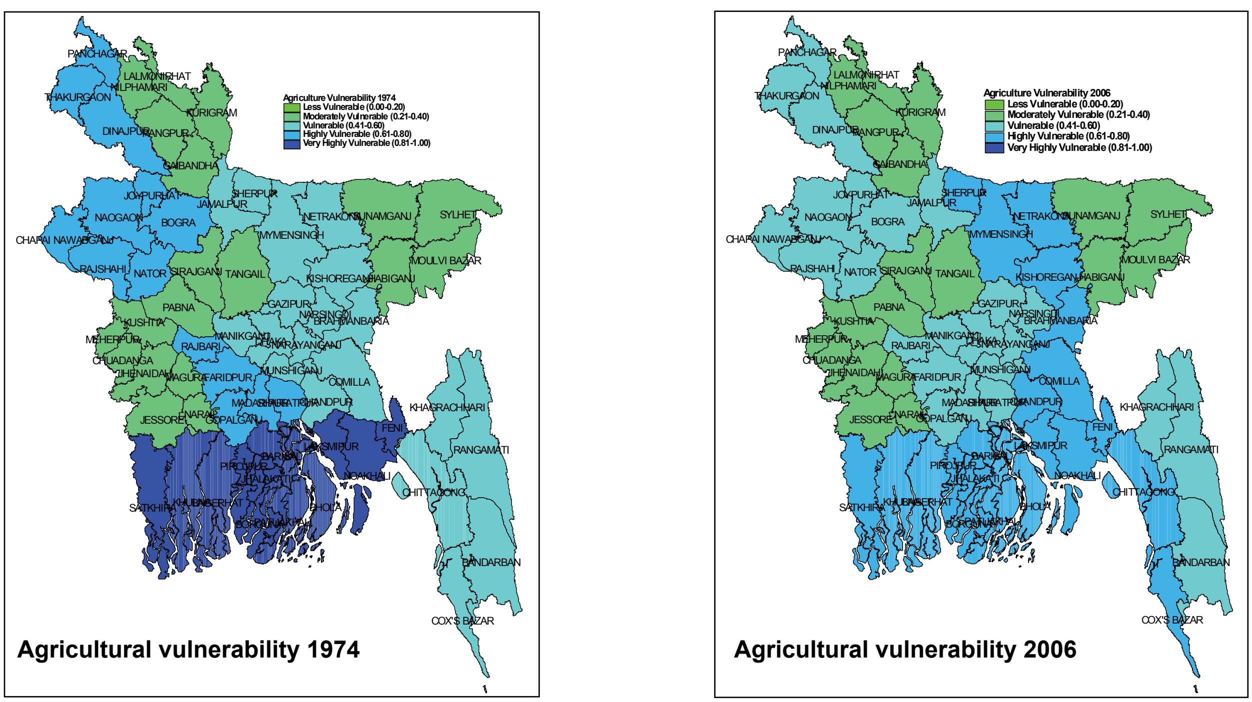
Source: Authors' calculation.

Figure 1. Ecological zone-wise agricultural vulnerability: 1974-2006.



Source: Authors' calculation.

Figure 2. Agricultural vulnerability of the study areas.



Source: Authors' calculation.

Map 1. Agricultural vulnerability in 1974 and 2006.

7.2 Climatic Vulnerability

Significant changes in climatic vulnerability were observed in different ecological zones (EZs) of Bangladesh over the last three decades. Table 12 presents the ranking of ecological zones based on climatic vulnerability for the period of 1974 to 2006 while Table 13 represents the changes in climatic vulnerability of the ecological regions over the period.

Table 12. Ecological zone-wise ranking of climatic vulnerability.

	Vulnerability index					Ranks in				
Ecological Zones	1974	1981	1991	2001	2006	1974	1981	1991	2001	2006
Not flood prone	0.67	0.59	0.71	0.72	0.91	2	3	2	2	1
Low flood prone	0.34	0.28	0.23	0.08	0.07	4	4	4	5	5
Flood prone	0.70	0.89	0.70	0.71	0.78	2	1	2	2	2
Drought prone	0.32	0.16	0.45	0.38	0.29	4	5	3	4	4
Tidal surge	0.63	0.59	0.73	0.89	0.82	2	3	2	1	1
Mixed	0.59	0.58	0.82	0.79	0.83	3	3	1	2	1

Source: Authors' calculation.

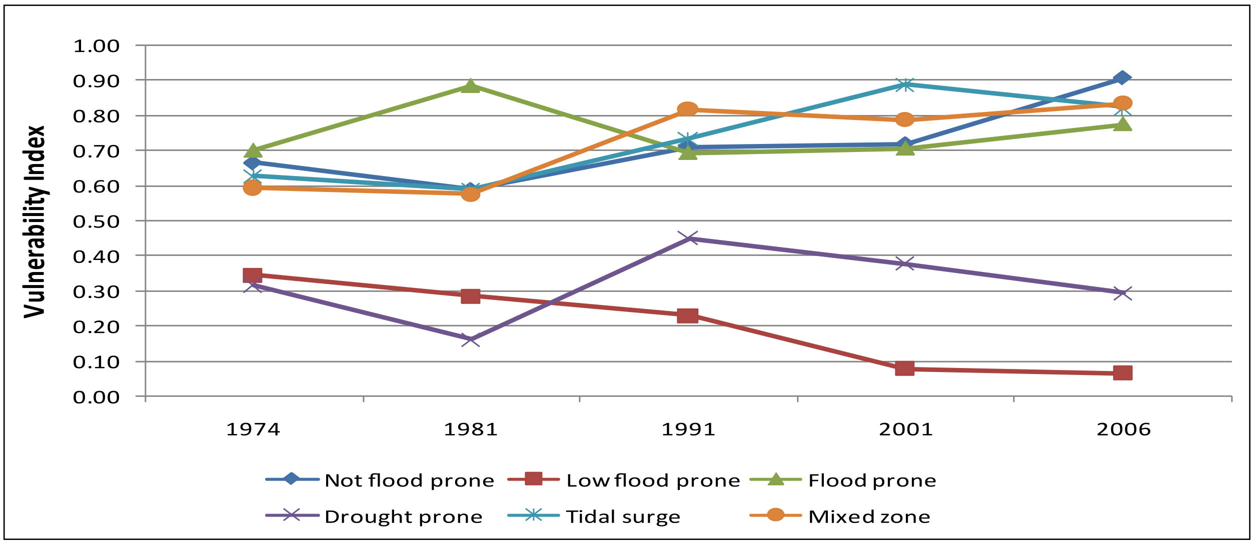
Table 13. Change of various stages of climatic vulnerability by study zones in Bangladesh.

Ecological Zone	1974	1981	1991	2001	2006
Not flood prone	Highly vulnerable	Moderately vulnerable	Highly vulnerable	Highly vulnerable	Very highly vulnerable
Low flood prone	Vulnerable	Vulnerable	Vulnerable	Less vulnerable	Less vulnerable
Flood prone	Highly vulnerable	Very highly vulnerable	Highly vulnerable	Highly vulnerable	Highly vulnerable
Drought prone	Vulnerable	Less vulnerable	Moderately vulnerable	Vulnerable	Vulnerable
Tidal surge	Highly vulnerable	Moderately vulnerable	Highly vulnerable	Very highly vulnerable	Very highly vulnerable
Mixed zone	Moderately vulnerable	Moderately vulnerable	Very highly vulnerable	Highly vulnerable	Very highly vulnerable

Source: Authors' calculation.

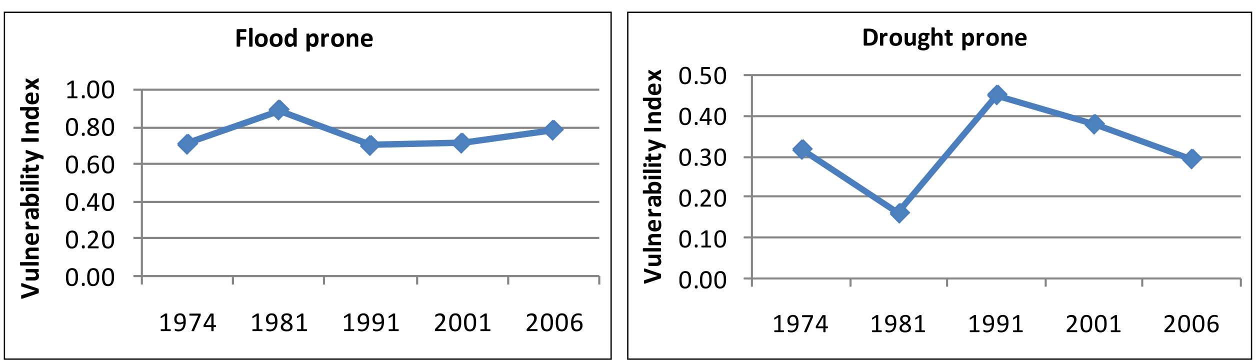
Among the zones, the mixed ecological zone has experienced remarkably significant transformation, and turned out to be very highly vulnerable in 2006 from being in a moderately vulnerable state in 1974. Tidal surge zones and non-flood prone zones also followed a similar trend of becoming more vulnerable. These observations are clear evidence of the changes in climatic patterns within the country. However, in low flood prone zones, climatic vulnerability fell sharply over the period rendering the region to less vulnerability in terms of climatic vulnerability. Yusuf and Francisco (2009) developed vulnerability mapping for Southeast Asia and revealed that the most vulnerable regions in Southeast Asia include the Mekong River Delta in Vietnam, Bangkok in Thailand and the northern part of the Philippines. Higher vulnerability of these regions was found to be associated with climatic disasters such as tropical cyclones, flooding and sea level rise.

Considering the study villages that fell within flood prone regions, climatic vulnerability has increased only insignificantly. The region continues to rank high according to the vulnerability indexing. With index value of 0.32 in 1974, climatic vulnerability increased somewhat during 1991 (index value 0.45), while reverting back to 0.29 in 2006 when it was ranked 5th among the 6 zones. Figure 3 and Map 2 show the trends in agricultural vulnerability index for all six ecological zones while Figure 4 displays the same for the study areas.



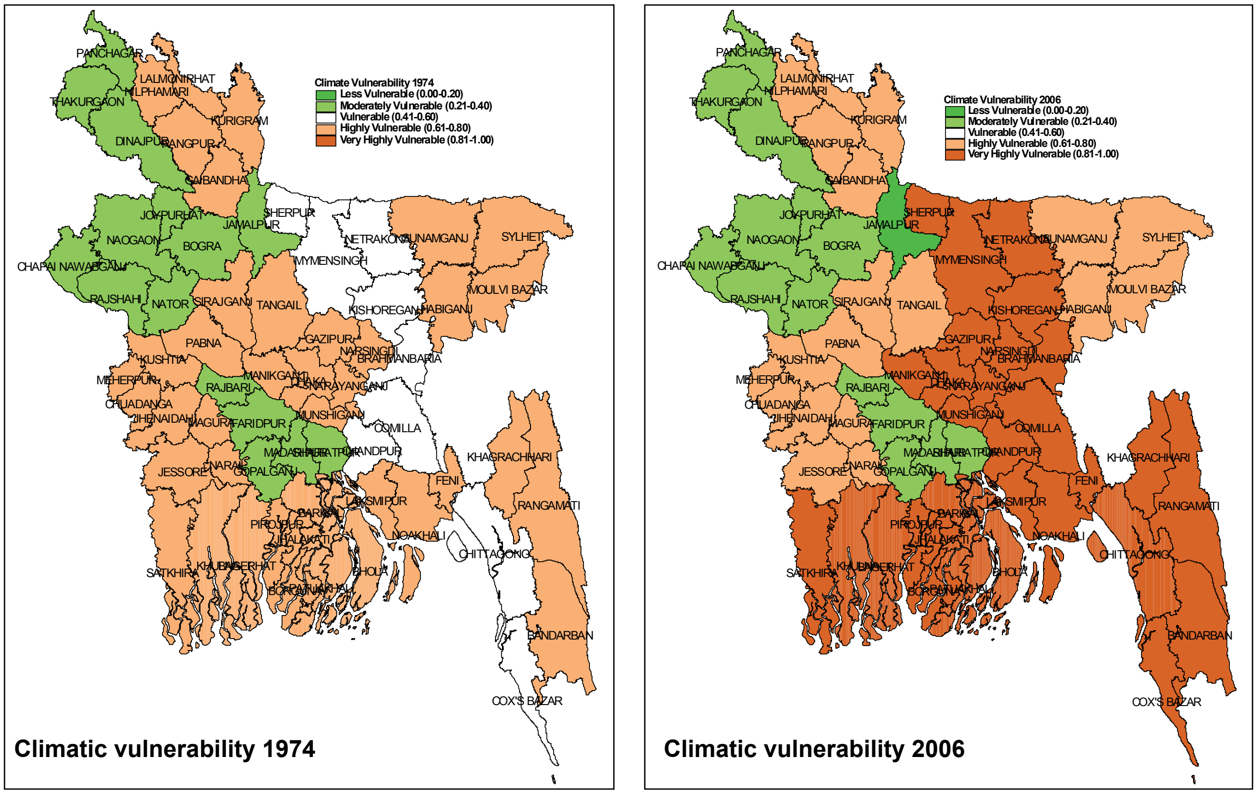
Source: Authors' calculation.

Figure 3. Ecological zone-wise climatic vulnerability: 1974-2006.



Source: Authors' calculation.

Figure 4. Climatic vulnerability of the study areas.



Source: Authors' calculation.

Map 2. Climatic vulnerability in 1974 and 2006.

7.3. Demographic Vulnerability

Bangladesh is one of the most densely populated countries in the world. The latest Population Census of 2001 estimates the total population to be 124.35 million and the density stood at 720 per sq.km.[4] According to Bangladesh Bureau of Statistics (BBS), current population of the country is about 150 million.[5] There may be some statistical discrepancies with regard to the reliability of its total population though it goes without saying that Bangladesh had one of the highest population densities anywhere in the world. It is also to be noted that about 31.5 percent of Bangladesh's total population lived under the poverty line (BBS 2011). As was noted earlier, Bangladesh is considered to be the most vulnerable country in terms of climate change impacts, in part, because of her very high density of poor population. With visible climatic changes and an increasing population size, the situation is likely to get worse in the coming days if appropriate measures are not taken.

Ecological zone-wise ranking and level of demographic vulnerability for various years are reported in Tables 14 and 15. It is clear from the tables that the low flood-prone regions are demographically most vulnerable, whereas the tidal surge region is the least vulnerable out of the six ecological zones in the country. It can be observed that except for the not flood-prone and flood-prone zones, all other ecological zones in the country maintained their respective vulnerability status over the years. This implies that the demographic patterns across the low flood-prone, drought-prone, tidal surge and mixed ecological zones has remained unchanged between 1974 and 2001. However, Patnaik and Narayanan (2009) argued that vulnerabilities associated with natural hazards have a direct relationship

4 Analysis for demographic vulnerability was carried out for 1974 to 2001 as the latest population census data were available for 2001.

5 According to the 2011 census of Bangladesh population, results of which have been released very recently (on 16 July 2011), Bangladesh's current population stands at 142.3 million.

Table 14. Ecological zone-wise ranking of demographic vulnerability.

	Vulnerability index				Ranks in			
Ecological Zones	1974	1981	1991	2001	1974	1981	1991	2001
Not flood prone	0.07	0.09	0.19	0.30	5	5	5	5
Low flood prone	0.82	0.99	1.00	0.95	1	1	1	1
Flood prone	0.62	0.60	0.56	0.55	3	3	3	3
Drought prone	0.50	0.54	0.55	0.48	4	4	4	4
Tidal surge	0.00	0.02	0.10	0.07	6	6	6	6
Mixed	0.80	0.75	0.80	0.76	2	2	2	2

Source: Authors' calculation.

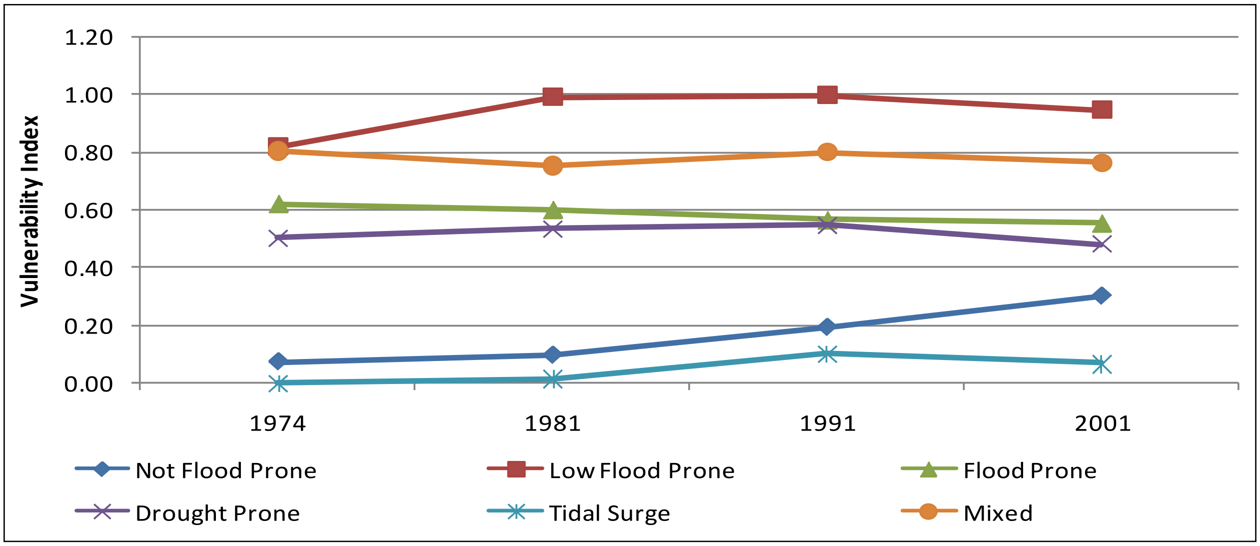
Table 15. Change of various stages of demographic vulnerability by study zones in Bangladesh.

	Year				
Ecological Zones	1974	1981	1991	2001	2006
Not flood prone	Less vulnerable	Less vulnerable	Less vulnerable	Moderately vulnerable	-
Low flood prone	Very highly vulnerable	Very highly vulnerable	Very highly vulnerable	Very highly vulnerable	-
Flood prone	Highly vulnerable	Vulnerable	Vulnerable	Vulnerable	-
Drought prone	Vulnerable	Vulnerable	Vulnerable	Vulnerable	-
Tidal surge	Less vulnerable	Less vulnerable	Less vulnerable	Less vulnerable	-
Mixed	Highly vulnerable	Highly vulnerable	Highly vulnerable	Highly vulnerable	-

Source: Authors' calculation.

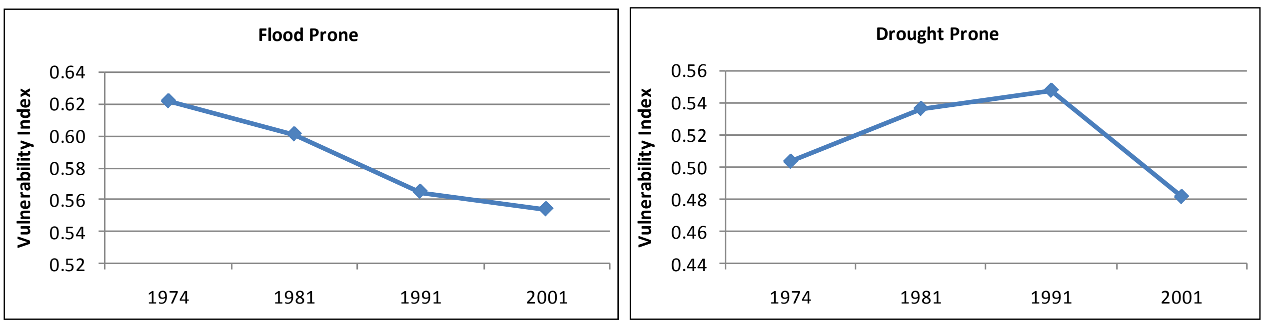
with demography as human settlements and people's livelihood in the area can be directly affected by negative shocks of disasters. They also argued that due to the high density of population in the coastal districts of India, a larger share of the population is exposed to extreme events, which in turn lead to higher vulnerability of the region.

On the other hand, vulnerability of the 'Not flood-prone zone' increased in the year 2001, whereas the demographic status of the 'flood-prone zone' improved after the year 1974. Interestingly, Bangladesh, as a country, was able to maintain her demographic vulnerability status over the years and the situation did not deteriorate thanks to a successful population policy. Figure 5 and Map 3 show the trends in demographic vulnerability index for all six ecological zones while Figure 6 displays the same for the study areas.



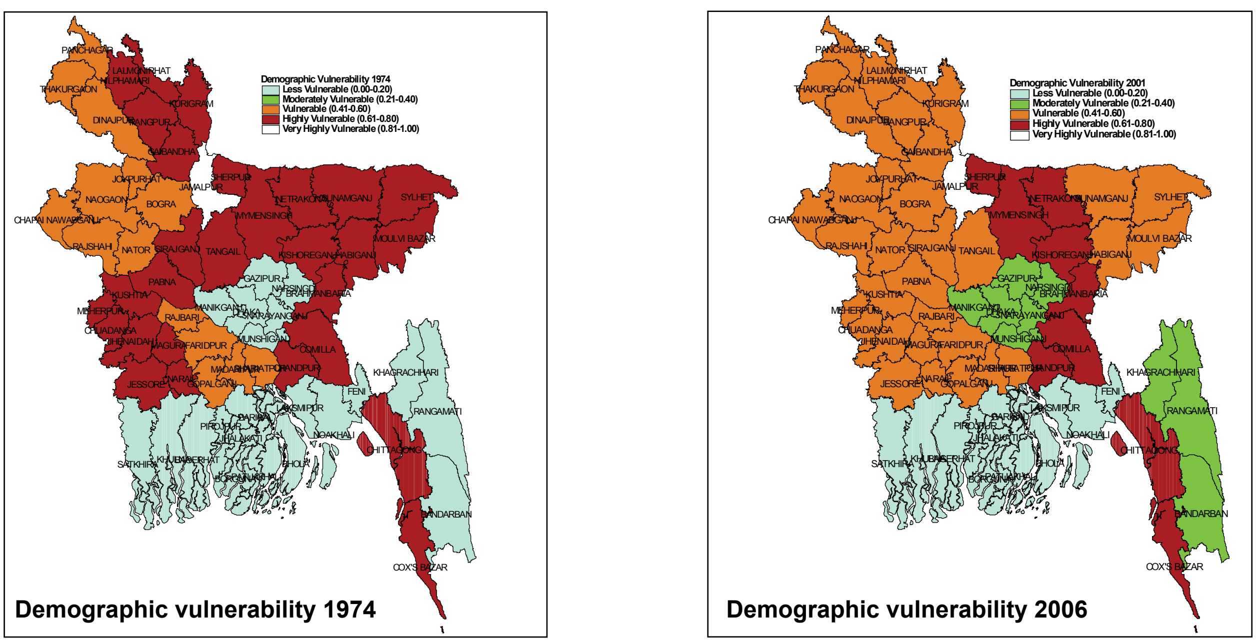
Source: Authors' calculation.

Figure 5. Ecological zone-wise demographic vulnerability: 1974-2006.



Source: Authors' calculation.

Figure 6. Demographic variability of the study areas.



Source: Authors' calculation.

Map 3. Demographic vulnerability in 1974 and 2006.

7.4. Occupational Vulnerability

Agriculture is one of the mainstays of the Bangladesh economy, and with a large share of her population associated with agriculture related employment; the overall dependence of the economy on the fluctuating fortunes of nature is very high. This dependency makes occupational vulnerability more acute in the face of climate change and global warming. In order to demonstrate the occupational vulnerability some occupational indicators such as economically active population, self-employed people (both agricultural and non-agricultural), number of day-laborers, total employed persons have been taken into account. Unfortunately, some of the indicators (self-employed, day-laborer, total employed person) could not be gleaned from the previous labor force surveys.

Ecological zone-wise ranking of occupational vulnerability reveals that the tidal surge zone occupied the position of most vulnerable zone throughout the observation period. Once again, this can be associated with the increasing natural disasters in the coastal areas where occupational hazards are common. The Bhola cyclone of 1970s hit the entire coast of Bangladesh. Severe cyclones shattered the coasts in 1971, 1973, 1974, 1975, 1977, 1983, 1985, 1997 and 1998. The devastating flood of 1988, which affected 60% area of the country, was the main reason underpinning flood prone areas to be ranked top in 1991 in terms of occupational vulnerability. Vulnerability index of this zone has shown significant decrease in terms of the value. Severe floods occurred in 1987, 1989, 1993, 1998, 2000, 2002, 2005; however, implementation of effective flood control measures, improvements in flood forecasting and rehabilitation efforts were able to minimize the potential damage. Besides investment in infrastructures to control flood, attention was also given towards invention of flood tolerant varieties of crops that have lessened the occupational vulnerability of the flood prone zone in the later periods.

The low flood prone zone has constantly been ranked the lowest occupational vulnerable zone. On the other hand, 'not flood prone zone' remains quite vulnerable to climate change, ranking second in 2001. Moreover, this zone consists of Chittagong Hill Tracts, the least developed part of the country mainly due to lack of accessibility and conflicts. The vulnerability index of the drought-prone zone showed a significant improvement, from highly vulnerable zone to vulnerable between 1991 and 2001. Changes in infrastructural development smoothened the way for business and other employment generating activities in this zone. Besides this, irrigation facilities were also expanded by utilizing surface water. Moreover, excavation and re-excavation of irrigation canal, construction and re-construction of irrigation infrastructures were developed by the government. On the other hand, the mixed zone showed quite a fighting spirit against the occupational vulnerability over the years. Although the zone was ranked highly vulnerable in 2001, it managed to become a less vulnerable zone in five years (in 2006). Table 16 presents the ranking of ecological zones based on climatic vulnerability for the period of 1974 to 2006 while Table 17 indicates the changes in climatic vulnerability of the ecological regions over the period. Figure 7 and Map 4 show the trends in occupational vulnerability index for all six ecological zones while Figure 8 displays the same for the study areas.

Table 16. Ecological zone-wise ranking of occupational vulnerability.

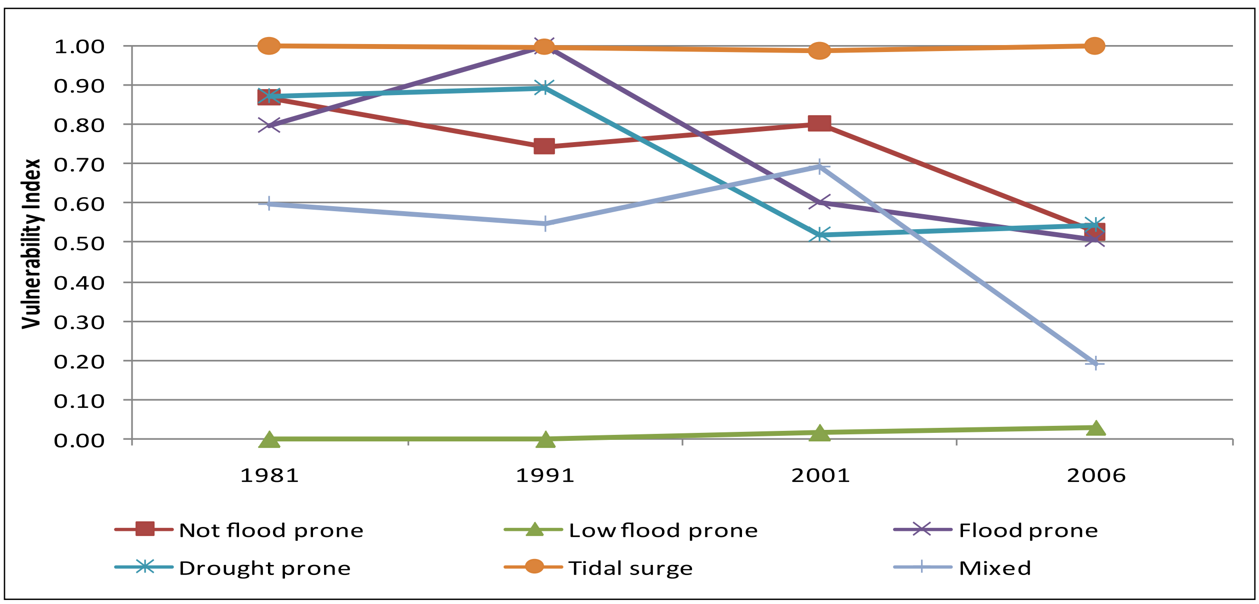
	Vulnerability Index				Ranks in			
Ecological Zones	1981	1991	2001	2006	1981	1991	2001	2006
Not flood prone	0.87	0.74	0.80	0.53	3	4	2	3
Low flood prone	0.00	0.00	0.02	0.03	6	6	6	6
Flood prone	0.80	1.00	0.60	0.51	4	1	4	4
Drought prone	0.87	0.90	0.52	0.55	2	3	5	2
Tidal surge	1.00	1.00	0.99	1.00	1	2	1	1
Mixed	0.60	0.55	0.69	0.19	5	5	3	5

Source: Authors' calculation.

Ecological Zones	1981	1991	2001	2006
Not flood prone	Very highly vulnerable	Highly vulnerable	Highly vulnerable	Vulnerable
Low flood prone	Less vulnerable	Less vulnerable	Less vulnerable	Less vulnerable
Flood prone	Highly vulnerable	Very highly vulnerable	Vulnerable	Vulnerable
Drought prone	Very highly vulnerable	Very highly vulnerable	Vulnerable	Vulnerable
Tidal surge	Very highly vulnerable	Very highly vulnerable	Very highly vulnerable	Very highly vulnerable
Mixed	Vulnerable	Vulnerable	Highly vulnerable	Less vulnerable
Bangladesh	Highly vulnerable	Highly vulnerable	Vulnerable	Vulnerable

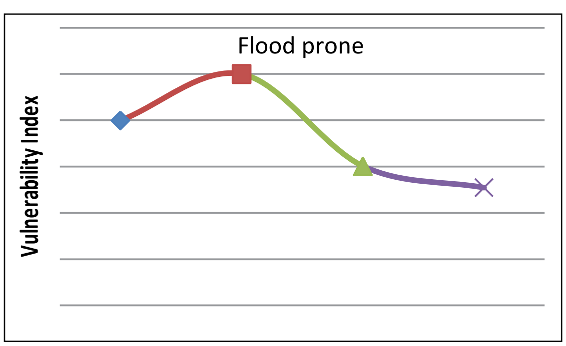
Table 17. Change of various stages of occupational vulnerability by ecological zone in Bangladesh.

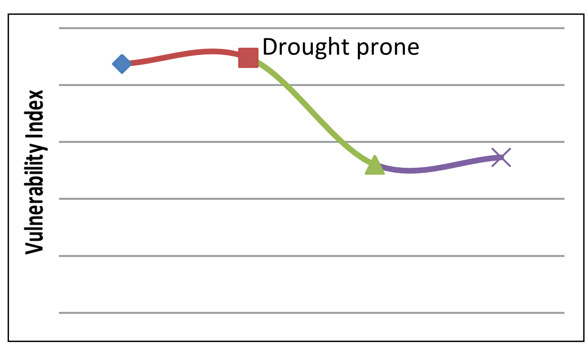
Source: Authors' calculation.



Source: Authors' calculation.

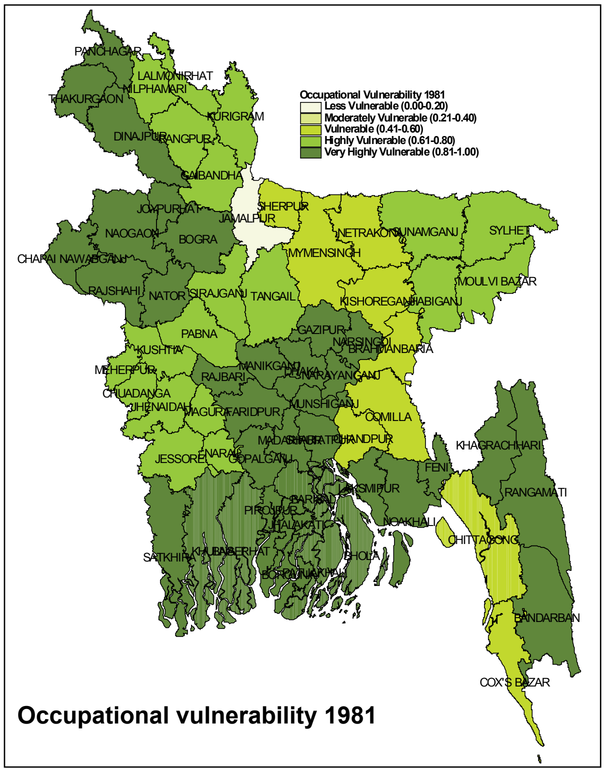
Figure 7. Ecological zone-wise occupational vulnerability: 1974-2006.

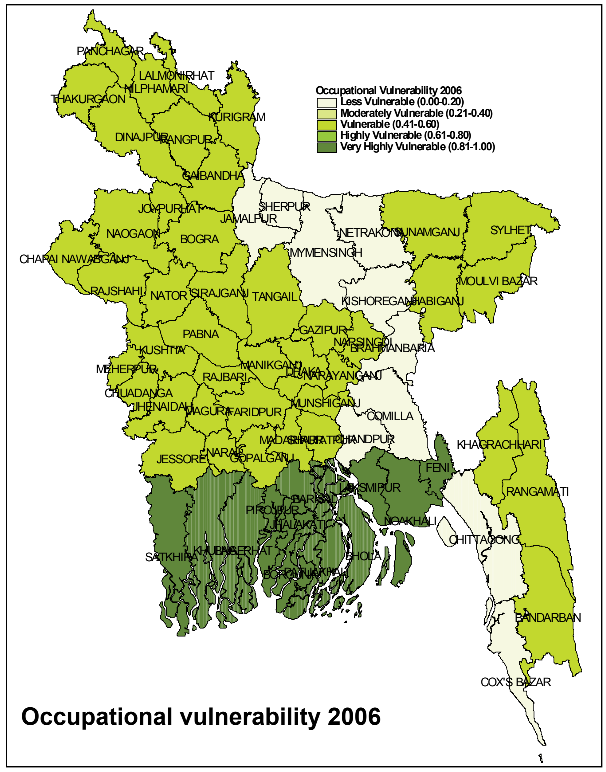




Source: Authors' calculation.

Figure 8. Occupational vulnerability of the study areas.





Source: Authors' calculation.

Map 4. Occupational vulnerability in 1981 and 2006.

7.5. Geographic Vulnerability

Geographical vulnerability is a major concern for the coastal regions of Bangladesh. As per the Population Census, 2001, about 36 million people in Bangladesh, of which 52 percent were poor and 24 percent were hardcore poor, live in the 19 coastal districts of Bangladesh. More than 50 percent people are found to be landless in these regions. Geographical vulnerability in this zone is a key threat as these areas are mostly prone to climatic shocks in the form of cyclones, storm surges and saline intrusion, which has become a matter of great concern in the recent years. Similarly the flood prone and drought prone areas are also susceptible to natural disasters.

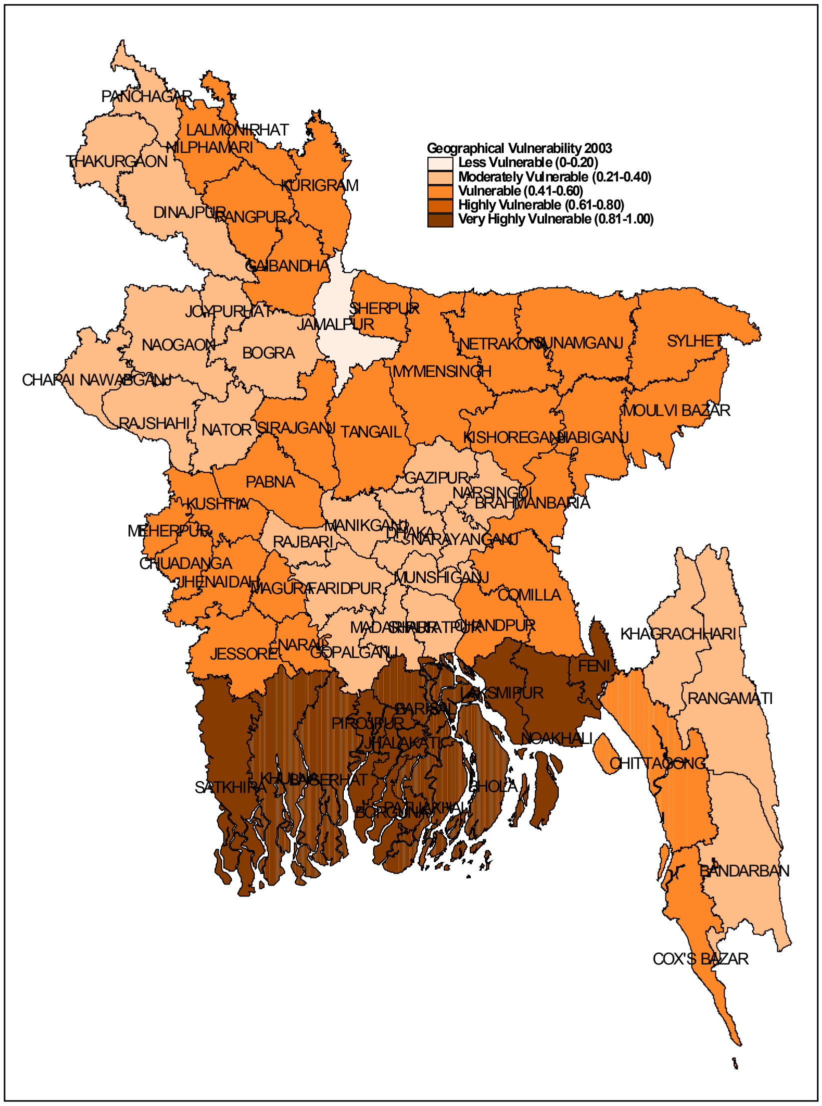
According to zone-wise ranking of geographic vulnerability, the tidal surge zone with an index value of 0.88 stands as the most vulnerable zone. With index values of 0.50 and 0.43, the flood prone and the mixed zone ranked the second and third while the drought prone zone is ranked fourth (Table 18).

Table 18. Ranking and status of geographic vulnerability, 2003.

Ecological Zones	Index	Rank	Degree of vulnerability
Not flood prone	0.24	5	Vulnerable
Low flood prone	0.00	6	Less vulnerable
Flood prone	0.50	2	Moderately vulnerable
Drought prone	0.32	4	Vulnerable
Tidal surge prone	0.88	1	Very highly vulnerable
Mixed	0.43	3	Moderately vulnerable

Source: Calculated on the basis of the Data from PDO- ICZMP 2003.

Frequent strikes of natural disasters such as cyclones, storm surges, tornados and floods made the tidal surge zone highly vulnerable. This zone also bears anthropogenic risks like soil salinity, soil erosion, water logging and also activities such as land defragmentation, ship-breaking industries and sewage dumping. A total of 12 districts out of 19 coastal districts are prone to high geographic vulnerability. However, more or less such hazards exist in all the coastal districts. There is no coastal district in the low flood-prone zone and not flood-prone zone. In the mixed zone, all three districts are highly prone to natural hazards.



Source: Authors' calculation.

Map 5. Geographical vulnerability in 2003.

7.6. Overall Vulnerability

The overall vulnerability derived from all of the five indicators, agricultural, climatic, occupational, demographic and geographical vulnerability shows some mixed but significant outcomes, which in a way are to be generally expected. It is interesting to note that, the mixed ecological zone, which was the most vulnerable in 1974, 1991 and 2001 and ranked second in 1981 was ranked 3rd in 2006. A similar trend can also be discerned for the flood-prone zone. This implies that both the mixed and the flood-prone zone, in the recent years, could significantly reduce their state of vulnerability compared to other zones in the country. These changes can be explained in terms of significant improvements in the livelihood activities across these ecological zones, which include access to better irrigation and agricultural inputs, vibrant economic activities such as fisheries and poultry. These have significantly changed much of the rural economic structure in Bangladesh. Moreover, hundreds of industrial workers, mostly working in the garments sector, are from many of these districts. In addition, flood incidences are recently on the decline in these zones.

On the other hand, the tidal surge and not flood prone zone are gradually turning more prone to vulnerability due to increasing incidences of cyclones, salt intrusion in the coastal belts and incidences of drought-like situations in the not flood prone zone where many of the river ecosystems are gradually losing their natural flows. Other zones such as low flood prone zone were also found to be less vulnerable in terms of overall vulnerability level over the same period (Table 19, Table 20, Figure 9 and Figure 10).

Table 19. Ecological zone-wise ranking of overall vulnerability.

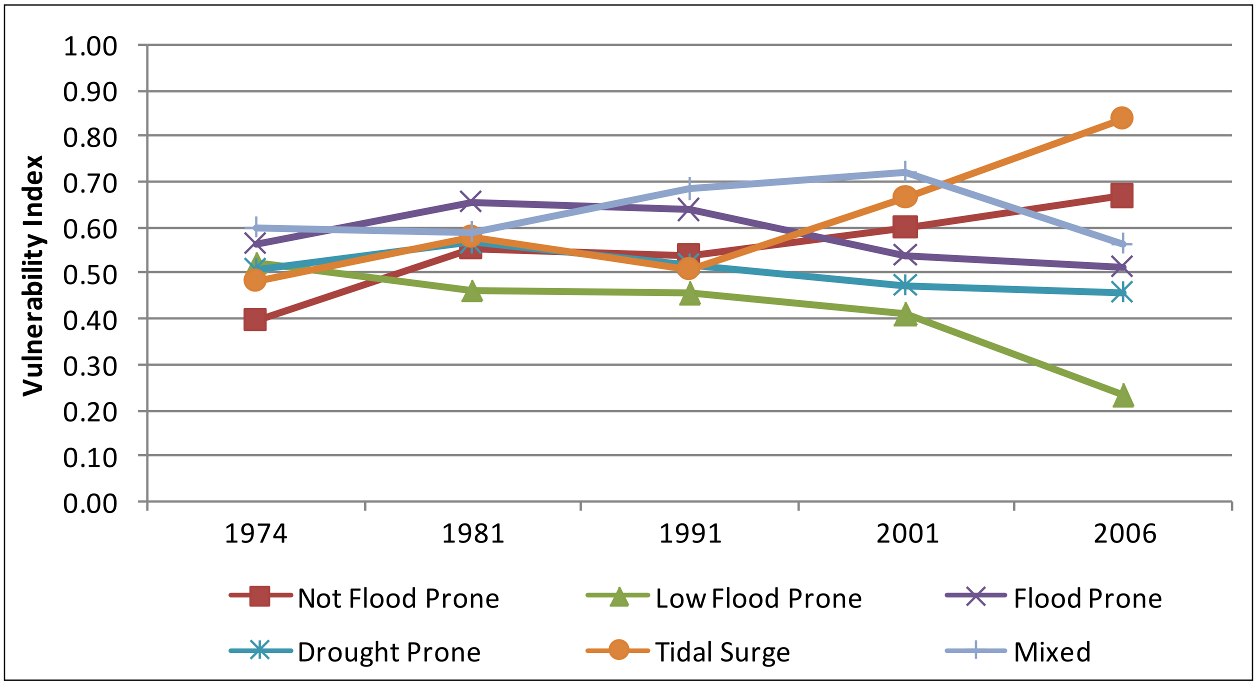
	Vulnerability Index					Ranks in				
Ecological Zones	1974	1981	1991	2001	2006	1974	1981	1991	2001	2006
Not flood prone	0.40	0.55	0.54	0.60	0.67	6	5	3	3	2
Low flood prone	0.52	0.46	0.46	0.41	0.23	3	6	6	6	6
Flood prone	0.57	0.66	0.64	0.54	0.52	2	1	2	4	4
Drought prone	0.51	0.57	0.52	0.47	0.46	4	4	4	5	5
Tidal surge	0.49	0.58	0.51	0.67	0.84	5	3	5	2	1
Mixed	0.60	0.59	0.68	0.72	0.56	1	2	1	1	3

Source: Authors' calculation.

Table 20. Change of various stages of overall vulnerability by ecological zone in Bangladesh.

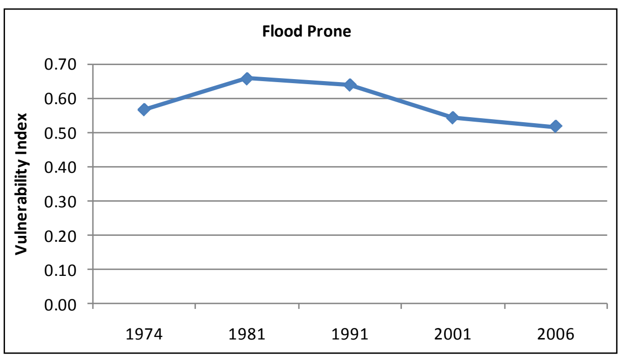
Ecological Zones	1974	1981	1991	2001	2006
Not flood prone	Moderately vulnerable	Vulnerable	Vulnerable	Vulnerable	Highly vulnerable
Low flood prone	Vulnerable	Vulnerable	Vulnerable	Vulnerable	Vulnerable
Flood prone	Vulnerable	Highly vulnerable	Highly vulnerable	Vulnerable	Vulnerable
Drought prone	Vulnerable	Vulnerable	Vulnerable	Vulnerable	Vulnerable
Tidal surge	Vulnerable	Vulnerable	Vulnerable	Highly vulnerable	Very highly vulnerable
Mixed	Vulnerable	Vulnerable	Highly vulnerable	Highly vulnerable	Vulnerable
Bangladesh	Vulnerable	Vulnerable	Vulnerable	Vulnerable	Vulnerable

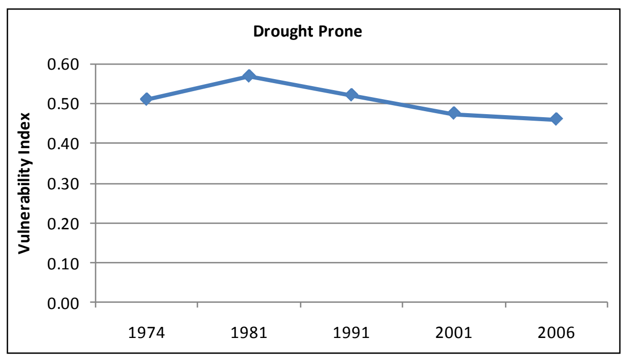
Source: Authors' calculation.



Source: Authors' calculation.

Figure 9. Ecological zone-wise overall vulnerability: 1974-2006.



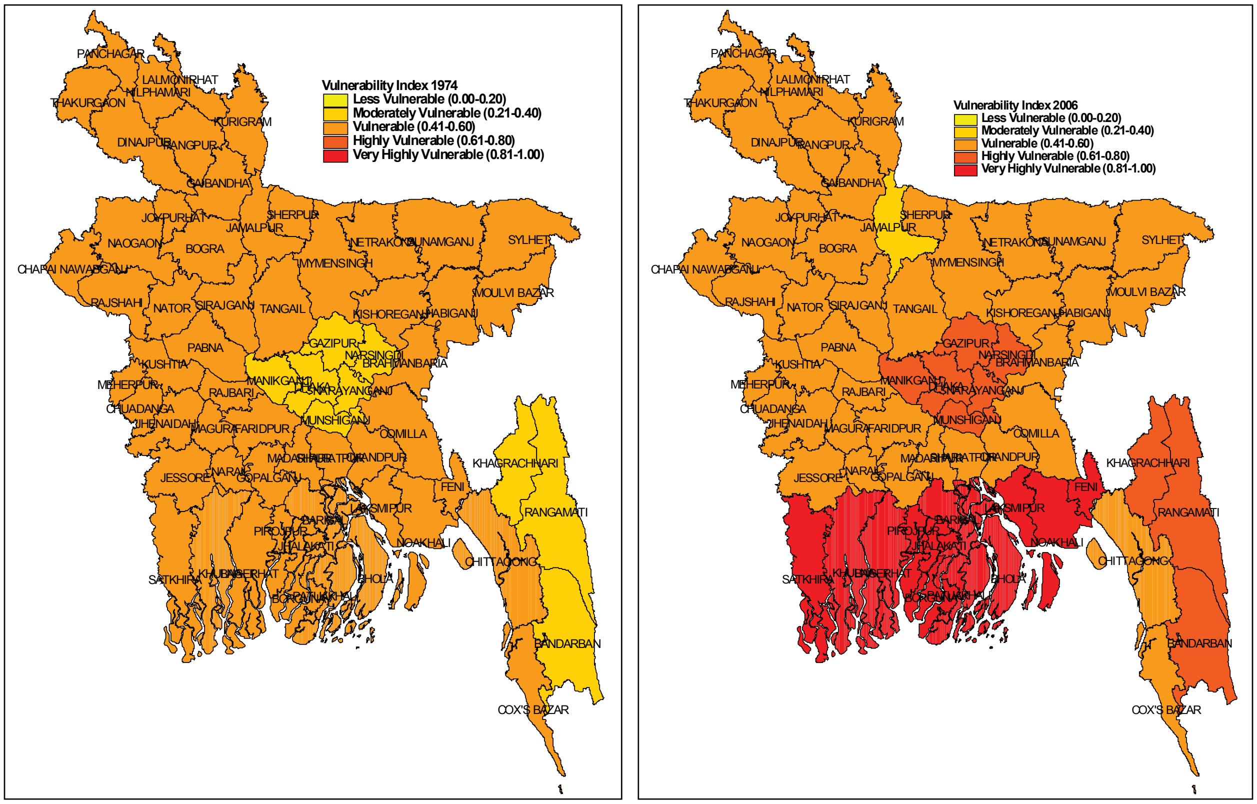


Source: Authors' calculation.

Figure 10. Overall vulnerability of the study areas.

The graphical presentation (Map 6) of the levels of overall vulnerability for all six ecological zones (EZs) in Bangladesh shows a very clear picture as to how changes have happened in terms of exposure to climatic vulnerability and their adaptive capacity over the years. It needs to be emphasized that the over dispersion of the level of vulnerability for the eco-regions in Bangladesh are getting higher with time, which is a matter of serious concern as this could widen the gaps between rich and poor and also between different ecological zones in the country.

All the regions of the Philippines, the Mekong River Delta region of Vietnam, almost all the regions of Cambodia, North and East Lao PDR, the Bangkok region of Thailand, the west and south of Sumatra, and western and eastern Java in Indonesia, were identified as the most vulnerable areas in Southeast Asia (Yusuf and Francisco 2009). The study confirmed that Philippines, unlike other countries in Southeast Asia, is not only exposed to tropical cyclones, but also to many other climate related hazards, more particularly, floods and droughts. The Philippines has an obvious similarity with conditions prevailing in



Source: Authors' calculation.

Map 6. Overall vulnerability in 1974 and 2006.

Bangladesh. Moreover, the study identifies Central Jakarta to be ranked first in the overall vulnerability assessment even though it had the highest adaptive capacity index. Severe likeliness of more than one type of disaster, frequent exposure to regular flooding and high density of population underpinned such high vulnerability. Gbetibouo and Ringler (2009) analyzed the vulnerability of South African farmers to climate change by developing a vulnerability index. While estimating exposure, sensitivity and adaptive capacity, the study shows that the regions that are most vulnerable to exposure to extreme events and climate change do not always overlap with the most vulnerable population. They showed that vulnerability to climate change is intrinsically connected to socio-economic development. The Western Cape and Gauteng provinces, with the high level of infrastructure development, high literacy rates, and low share of agricultural GDP, are lower on the vulnerability index ladder. On the other hand, the most vulnerable regions Limpopo, Kwazulu Natal and Eastern Cape, are those with high numbers of smallholder farmers, high dependency on rainfed agriculture, high land degradation, and highly populated rural areas where the majority of the population relies on agriculture for their livelihoods. They recommended that policy makers should develop region-specific policies and address climate change related challenges at the local level.

8. Concluding Remarks

Bangladesh has emerged as a highly vulnerable country in view of the impacts of climate change; the level of her vulnerability is likely to increase with time. Poor agricultural infrastructure and resource scarcity, lack of employment opportunities, geographical and demographic adversities and economic backwardness along with increasing climatic exposures and variability, have combined to make the country highly risk prone from the perspective of climate change. The aim is to provide a framework and define indicators, categories or domains that can be tailored to specific context. More importantly, climatic exposures in different ecological zones in the country are found to be quite diverse. A number of EZs and the majority of the districts are gradually becoming highly vulnerable to such changes relative to other zones. This makes the life and livelihood activities more vulnerable and risky for the people of these regions. There is thus a need to develop and pursue an agro-ecological zone-wise development strategy for Bangladesh to reduce levels of all possible sources of vulnerability. It is also important that sufficient long term information is required in realization of climate related vulnerability in prioritizing region and also an ex-post assessment of development outcome under climate change. This is needed to safeguard the interests of the people and increase their resilience in the fight against adverse impacts of climate change and to raise coping and adjusting power of the people of Bangladesh.

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