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Indicator Based Spatial Climate Change Vulnerability of South West Coastal Bangladesh

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Authors' contributions

This work was carried out in collaboration between both authors. Author MAR designed the study, performed the statistical analysis, wrote the protocol, managed the literature searches and wrote the first draft of the manuscript. Author MA managed the analyses of the study. Both authors read and approved the final manuscript.

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ABSTRACT

Aims: The aim of the study was to assess the indicator based climate change vulnerability of south west coastal Bangladesh and its future.
Place of Study: Four districts form south west coastal Bangladesh, having a total of 50 upazilas, have been selected as the study area. They are Satkhira, Khulna, Bagerhat, Pirojpur, Barguna and Patuakhali districts.
Methodology: This study has been conducted, using multivariate statistical techniques, to assess the vulnerabilities of the coastal region of Bangladesh by considering the IPCC framework of vulnerability studies. A total of 31 indicators have been selected of which 23 are socio-economic and 8 are biophysical which have been retrieved from the secondary sources. Principal Component Analysis (PCA) has been applied to derive unbiased weights of all indicators considering both present (2011) and the future (2050) climate change scenarios.
Results: This study has identified 7 principal components through PCA which has been grouped as PC1 (Demographic Vulnerability), PC2 (Economic Vulnerability), PC3 (Climatic Vulnerability), PC4 (Health Vulnerability), PC5 (Agricultural Vulnerability), PC6 (Infrastructural Vulnerability) and

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PC7 (Water Vulnerability). For all 7 PCA groups (termed as vulnerability profile), the number of high and medium vulnerable coastal Upazilas will be significantly changed in the future. No of highly vulnerable Upazila will increase from 0 to 1 for PC1, unchanged for PC2, increase from 0 to 1 for PC3, from 32 to 33 for PC4, from 47 to 68 for PC5, decrease from 48 to 46 for PC6, and an increase from 14 to 21 for PC7, respectively.

Conclusion: Discrete spatial maps of each profile have been generated to assess the regional variation of all vulnerability profiles across the southwest coastal region of Bangladesh. The findings of this study might be useful for policy makers and planners.

Keywords: South west coastal Bangladesh; climate change; principal component analysis (PCA); k-mean cluster; vulnerability mapping.

1. INTRODUCTION

Bangladesh is among the most vulnerable countries in the world in the context of climate change and climate variability. Extreme climatic events became distinctive of Bangladesh [1-2]. with an area of 147,570 km^2 [3] and a fast-growing population currently stands at over 160 million [4,2] and anticipated to be added by another 20 million by 2025 [5]. The population density of the country is very high which is 1015 per sq. km. with an annual growth rate of 1.37 percent [5]. By 2025, population density could be over 1200 per km^2 [5]. Coastal districts adjacent to Bay of Bengal were considered highly vulnerable to extreme climate condition, including changes of uneven disasters such as cyclone-induced storm surge, coastal floods, river bank erosion, and increasing trend of sea level rise, saline water intrusion and many more natural calamities [6].

Vulnerability is the factor for risk level assessment as well as building resilience [7]. It is also the degree to which a system either susceptible or incapable to cope with the adverse effects of climate change, including climate variability and extremes [8-9]. Though vulnerability assessment is not a new concept, still it emerged in the climate science and climate policy application [10] which is the primary step in lessening the impact of the future extreme climate on socio-ecological system [11-12]. Assessing vulnerability to climate change is important for characterizing the risks posed by climate change and made the base for recognizing measures in order to adapt to the adverse impacts of climate change. This assessment of vulnerability facilitated stakeholders and decision-makers to mark the most vulnerable areas, the most vulnerable social groups and the most vulnerable sectors. On the other hand, sensitivity is the degree to which a system is experienced with positive and negative by directly or indirectly of all elements of climate changes [13]. The ability of a system to cope with extreme climate variability and to moderate the potential damages is termed as adaptive capacity [9,11,13-18]. The vulnerability of a system is the function of these three components: i) the presence of people, livelihoods, species or ecosystems, environmental functions, services, resources, infrastructure, or economic, social or cultural assets in places and settings that could be adversely affected (exposure), ii) the degree to which the system is affected (sensitivity) and iii) the ability of the system to adjust to potential damage (adaptive capacity) [19].

Typically, coastal regions were recognized as vulnerable to climate change and extremes due to the impacts on water quantity and quality from various activities such as continuing high density of socio-economic and development activities, rising of sea level, saltwater intrusion [20]. Another reason of coastal region being more vulnerable is the rising of temperature and changing of both cyclone and precipitation patterns [21]. From Global Climate Model results it was found that agricultural sector is highly impacted by climate extreme events [20,22] sea level rise, storm surge [23] and coastal erosion [24]. The southern part in Bangladesh was found to be severely affected by extreme climate under the higher emission scenarios [25]. The assessment of vulnerability due to coastal inundation, which is very essential in the context of climate change, in present and the future scenarios from sea level rise would be useful for assessing adaptation options [26-27]. Vulnerability assessment should be done integrating natural processes, socio-economic conditions, and the mechanisms of responses of the integrated ecological and economic system [28].

2. MATERIALS AND METHODS

2.1 Study Area

For the present study, four districts form south west coastal Bangladesh, having a total of 50 upazilas (sub districts), have been selected as the study area. They are Satkhira, Khulna, Bagerhat, Pirojpur, Barguna and Patuakhali districts. The first three districts are adjacent to the Sundarbans and the rest are adjacent to the Bay of Bengal. Most of the coastal Upazilas in the 6 districts have elevations about 1.2–4.5 m above mean sea level. These districts are directly or indirectly affected by various natural or manmade events. In subtropical climate, summer extends from March to May followed by monsoon from June to September and winter months from November to February. Agriculture is the primary source of economy and major land is used in the agricultural sector. Most of the coastal region is covered with high population density, notably Khulna city occupied with more than 20,000 populations per sq. km.

2.2 Indicator Based Vulnerabilities Assessment

Six districts of the coastal belt of Bangladesh has been selected as the study area. The vulnerability profile has been developed for baseline scenarios and forth future scenarios considering climate change. Year 2011 has been considered as baseline due to the availability of various social and economic data of the study area. Year 2050 has been considered as the future scenarios.

2.3 Socio-economic Indicators

A total of 23 socio-economic indicators has been considered for this study which has been obtained from the Bangladesh Bureau of Statistical Yearbook [3], while 8 biophysical indicators are collected from various reports, journals, articles, and maps. These collected data have been checked and normalized before conducting a multivariate statistical analysis. A brief description of the selected indicators is given in Table 1.

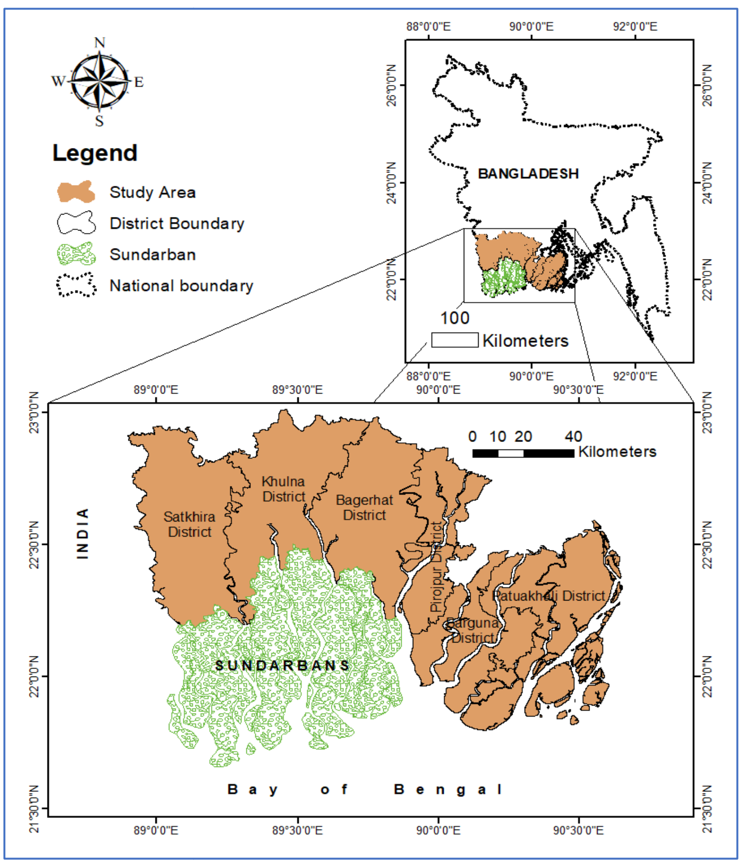

Fig. 1. Study area in the context of Bangladesh

Table 1. Identified indicators from socio - economic and bio-there tegory along withphysical ca sources

Dimension	Sl.	Indicators	Index	Unit
Socio-economic	1	Density of population	Sensitivity	people/sq.km
	2	Sex ratio		male/100 female
	3	Gender gap in literacy		percentage
	4	Disability percentage		percentage
	5	Poverty headcount		percentage
	6	Literacy rate	Adaptive capacity	percentage
	7	Source of drinking water		number/1000 of population
	8	Electricity connection		number/1000 of population
	9	Access to transport		number/1000 of population
	10	Medical institutes		number/1000 of population
	11	Govt. primary school		number/1000 of population
	12	Water way		km/1000 of population
	13	Embankment roads		km/1000 of population
	14	Cyclone shelter		number/1000 of population
	15	Flood camp/ shelter		number/1000 of population
	16	Unmetalled road		km/1000 of population
	17	Cooperative societies		number/1000 of population
	18	Growth center		number/1000 of population
	19	Irrigation by power pump		number/1000 of population
	20	Production of Rice		Metric ton
	21	National & private bank		number/1000 of population
	22	Insurance company		number/1000 of population
	23	Bank loan borrower		number/1000 of population
Biophysical	24	Storm surge inundation	Exposure	m
	25	Inundation due to flood		m
	26	Shoreline erosion		m/year
	27	Shoreline accretion		m/year
	28	Coastal elevation		m
	29	Rainfall		coefficient
	30	Temperature		coefficient
	31	Salinity Intrusion		ppt

Source: BBS, 2011; and published reports and journals

2.4 Biophysical Indicators

The 8 biophysical system indicators for the present base scenario have also been classified based on the collected information from different sources and literature. A brief description of the biophysical indicators is provided in Table 1. For most of the cases, the data were collected from maps of different study reports and research articles. The maps were digitized and overlaid with the coastal Upazila map using a GIS tool to determine the values of the respective indicator. Then the data were classified according to vulnerability range from 1 to 5. Inundation due to storm surge in the coastal Upazilas has been derived from an inundation risk map developed by IWM [29]. The flood risk exposure map for the 24-h inundation of Bangladesh was obtained by a study of World Bank [30]. Shoreline erosion and accretion have been obtained from the study conducted by Sarwar and Woodroffe [31]. Salinity intrusion due to sea level rise for the present scenario has been obtained from a study conducted by Centre for Environmental Geographic Information Service [32]. The rainfall and temperature data collected from Bangladesh Meteorological Department (BMD) for 4 stations of the duration 1985 – 2015. The map of the digital elevation model (DEM) of the coastal region at a 50 m resolution has been collected from IWM [33]. Future changes in salinity intrusion, maximum 1-day precipitation, flood inundation considering climate change have been developed based on the climate projections in 2050 and secondary information. Inundation map due to storm surges considering climate change projections in 2050 was generated from World Bank [34]. Flood risk exposure map for climate change scenario in 2050 was developed considering changes in temperature and precipitation levels and increases in the sea level [30]. Salinity intrusion for different sea level rise projection map was used for possible future changes of salinity [32].

2.5 Normalization of the Indicators

Normalization is important for multivariate statistical analysis as some variables have large range of variance and some of them have a small range of variance. Normalization technique that implies the transforming dataset to a specific range (0–1) is thus essential. Normalization technique has been applied to create a stronger relationship amongst the dataset and imply to normalize residuals using the methods of transformation [35]. To avoid the influence of one variable to other variables, the dataset has been normalized. A similar approach has been followed in developing human development index and life expectancy index [36-38]. Data normalization has been done using the following equation (Eq. (1)).

Index,

$$X_d = \frac{X_d - X_{min}}{X_{max} - X_{min}} \qquad (1)$$

Where, X_d is an observed value in an array of observed values for a given variable; X_{max} is the highest value in the same array; X_{min} is the lowest value in the same array.

2.6 Principal Component Analysis (PCA)

The principal component analysis is used by many scientific disciplines. PCA is a statistical procedure that applies an orthogonal transformation in order to convert a set of observations which might be possibly correlated variables into linearly uncorrelated variables called principal components. This transformation is conducted in such a way that the first principal component has the largest possible variance, and each of the next principal components has the highest variance possible following the constraint that it is orthogonal to the preceding components. Finally, the resulting vectors produced by PCA are an uncorrelated orthogonal basis set.

Mathematically, the PCA depends on the Eigenvector based multivariate analysis [39]. The principal component analysis can be done by eigenvalue decomposition of a data covariance (or correlation) matrix or singular value decomposition of a data matrix. The results of a PCA are usually presented in terms of component scores, which is often known as factor scores (the transformed values of variable related to a particular data point), and loadings (the weight used to multiply each standardized original variable in order to get the component score) [40].

2.7 Cluster Analysis

The cluster analysis encompasses a number of algorithms and methods to identify structures within the data as a homogeneous group of cases. Cluster analysis has been applied to a wide range of research problems [41-43]. In this study, the k-mean clustering method has been applied to produce much more stable cluster boundaries. In order to identify a reasonable optimal number of ‘k’ clusters, the sum of square errors (SSE) metric [44] has been determined in conjunction with the elbow method [45-46]. A good clustering with smaller ‘k’ can have a lower SSE than a poor clustering with higher ‘k’ [47]. It has been found that 3 number of clusters having a SSE value of 2.68. These three clusters are named as the low, medium and high scale with the range between 0.00 and 0.33, 0.34–0.67 and 0.68–1.00, respectively for both present and future cases. All the 50 coastal Upazilas have been expressed in terms of the three clusters: high, medium and low. Based on these optimal 3 clusters, the vulnerability scale maps have been generated.

3. RESULTS AND DISCUSSION

In this study, principal component analysis has been conducted to reduce variables quantities into a smaller number of variables-called principal components (PCs) as well as provides the useful information of original dataset [48-49]. A pairwise correlation matrix has been used in the PCA process visualizing the relations between respective variables to reduce the initial matrix to a subset of non-highly correlated metrics [50]. Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy test value has found about 0.587 for present set and 0.609 for the future dataset. The Kaiser’ criterion with an eigenvalue greater than one [51] and Cattell scree test have performed to extract the number of principal components (PCs) [52]. In both cases, 7 principal components have been retained in present study that tabulated below in which Table 2 for present scenario as well as Table 3 for the future scenario. Tables 2 and 3 demonstrate the cumulative percentage of variance of 79 percent under present and 80 percent under future scenarios for 7 principal component (PCs) that having an Eigenvalue greater than one, respectively.

Unbiased weights have been found for each individual indicator after carrying out PCA for the present period and shown in Table 2 in which 7 vulnerable groups as Principal Component 1 (PC1) to 7 (PC7) are tabulated with the loadings. In Tables 2 and 3, the heaviest loadings have been marked as bold shaded. The 7 groups are titled with heavily loaded and termed them into vulnerability profiles: PC1 as Demographic Vulnerability, PC2 as Economic Vulnerability, PC3 as Climatic Vulnerability, PC4 as Health Vulnerability, PC5 as Agricultural Vulnerability, PC6 as Infrastructural Vulnerability, and PC7 as Water Vulnerability.

Indicators of these groups are selected based on their heaviest loadings and marked by a bold shade in both Tables 2 and 3. The PC1 (Demographic Vulnerability) has been highly loaded by 5 indicators: population density, literacy rate, male-female ratio, govt. primary school, and the gender gap in literacy rate. The PC2 (Economic Vulnerability) has been loaded for 3 indicators which are nationalized and private bank, insurance company and bank loan. The PC3 (Climatic Vulnerability) has been loaded for 6 indicators: medical institution, inundation due to flood, storm surge inundation, coastal elevation, rainfall, and salinity intrusion. The PC4 (Health Vulnerability) has been loaded for 3 indicators which are disable, poverty and medical institution. The PC5 (Agricultural Vulnerability) has been loaded for 2 indicators which are rice production and irrigation by power pump. The

Table 2. List of retained principal component weights of all indicators for present scenario

Indicators	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Density of population	0.55	0.25	-0.05	0.34	0.01	0.52	-0.10
Sex ratio	0.58	0.33	0.28	0.21	0.38	0.05	-0.20
Gender gap in literacy	0.78	0.45	-0.07	-0.15	-0.02	0.15	0.07
Disability percentage	-0.19	-0.10	-0.56	0.33	-0.15	0.01	-0.28
Poverty	0.03	-0.34	-0.04	0.61	-0.16	-0.33	-0.42
Literacy rate	0.71	-0.28	-0.17	-0.06	0.24	0.39	-0.25
Source of drinking water	0.27	-0.40	-0.21	0.25	-0.38	-0.44	0.31
Electricity connection	-0.11	-0.12	0.08	-0.05	0.40	0.86	0.22
Access to transport	0.05	-0.49	-0.45	-0.14	-0.24	0.29	0.18
Medical institutes	-0.02	-0.10	0.06	0.84	0.44	-0.11	0.25
Govt. primary school	0.54	-0.55	-0.05	-0.43	0.19	-0.28	-0.03
Water way	-0.35	-0.30	0.12	-0.04	0.01	-0.03	0.44
Embankment roads	-0.32	0.32	0.25	-0.46	0.16	0.36	0.24
Cyclone shelter	-0.50	-0.38	0.14	0.08	0.05	0.39	-0.32
Flood camp/ shelter	-0.29	-0.14	-0.09	0.31	0.08	0.34	0.31
Unmetalled road	-0.49	-0.34	0.15	-0.49	-0.19	0.33	0.22
Cooperative societies	0.06	-0.29	-0.01	-0.62	-0.03	0.08	-0.18
Growth center	-0.10	-0.28	0.08	-0.37	-0.24	0.30	0.06
Irrigation by power pump	0.03	-0.03	0.32	0.05	0.60	-0.27	-0.22
Production of Rice	-0.01	0.10	0.32	0.20	0.62	-0.14	-0.04
Nationalized & private bank	-0.11	0.84	0.08	-0.03	0.45	-0.11	0.23
Insurance company	-0.18	0.82	0.09	-0.10	0.44	-0.12	0.21
Bank loan	-0.18	0.19	-0.08	0.14	-0.12	0.09	-0.52
Storm surg inundation	-0.49	-0.45	0.47	0.09	0.39	-0.04	0.06
Inundation due to flood	-0.79	-0.15	0.33	-0.22	-0.12	0.03	-0.03
Shoreline erosion	-0.63	0.18	0.48	0.06	-0.08	-0.18	0.13
Shoreline accretion	-0.60	-0.07	0.32	0.28	-0.25	-0.37	0.03
Coastal elevation	0.03	-0.18	0.67	0.13	-0.56	-0.05	0.07
Coefficient rainfall	0.33	-0.20	0.83	-0.11	-0.07	-0.21	0.13
Coefficient temperature	0.27	-0.12	0.29	-0.18	0.19	0.12	-0.65
Salinity	-0.60	0.40	0.49	-0.13	0.09	-0.04	0.15
Eigenvalue	4.23	2.86	2.19	1.99	1.72	1.62	1.03
Cumulative variability %	0.25	0.41	0.54	0.64	0.71	0.76	0.79

Table 3. List of retained principal component weights of all indicators for future scenario

Indicators	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Density of population	0.87	0.02	-0.31	0.10	-0.12	-0.01	0.12
Sex ratio	0.61	0.24	-0.36	-0.27	-0.19	0.28	0.19
Gender gap in literacy	0.68	0.49	-0.24	0.06	0.23	-0.15	0.12
Disability percentage	-0.14	-0.23	-0.23	0.29	-0.39	-0.41	0.11
Poverty	0.01	-0.48	0.20	0.60	0.35	0.11	-0.24
Literacy rate	0.76	-0.39	-0.02	-0.21	0.10	-0.19	0.25
Source of drinking water	0.25	-0.39	-0.02	-0.21	0.10	-0.19	0.76
Electricity connection	0.12	-0.12	-0.30	0.18	0.04	0.90	-0.11
Access to transport	0.03	-0.41	0.30	0.26	0.12	0.31	0.18
Medical institutes	0.20	-0.11	-0.35	0.88	0.02	0.09	-0.13
Govt. primary school	0.56	-0.52	0.09	0.01	0.36	0.13	-0.27
Water way	-0.35	-0.27	0.00	0.20	-0.04	0.16	0.45
Embankment roads	-0.29	0.24	-0.25	0.31	0.23	0.50	0.45
Cyclone shelter	-0.45	-0.51	-0.28	-0.31	-0.08	0.21	0.17
Flood camp/ shelter	-0.29	-0.09	-0.17	0.25	-0.30	0.32	-0.32
Unmetalled road	-0.49	-0.30	0.22	0.15	0.44	0.46	0.19
Cooperative societies	0.06	-0.27	0.24	-0.12	0.23	0.58	-0.35
Growth center	-0.12	-0.23	0.33	0.23	0.22	0.39	-0.07
Irrigation by power pump	-0.02	0.11	-0.24	-0.10	0.38	0.34	0.05
Production of Rice	-0.07	0.21	0.21	0.00	0.54	0.29	0.13
Nationalized & private bank	-0.13	0.88	-0.35	0.18	0.03	0.12	-0.13
Insurance company	-0.20	0.86	-0.30	0.18	0.09	0.14	-0.17
Bank loan	-0.18	0.29	0.16	-0.46	-0.21	-0.19	-0.21
Storm surge inundation	-0.42	-0.49	0.09	0.06	-0.43	0.01	-0.42
Inundation due to flood	-0.62	-0.48	0.26	-0.07	-0.15	-0.04	-0.15
Shoreline erosion	-0.58	0.06	0.10	-0.07	-0.61	-0.01	-0.11
Shoreline accretion	-0.56	-0.12	0.18	-0.15	-0.11	-0.15	-0.35
Coastal elevation	0.56	0.04	0.59	0.21	-0.26	-0.01	0.01
Coefficient rainfall	0.30	-0.09	0.86	-0.03	0.20	-0.16	-0.12
Coefficient temperature	0.31	-0.23	0.36	-0.58	0.12	0.10	0.18
Salinity	-0.49	-0.63	0.18	0.03	0.18	0.15	0.11
Eigenvalue	4.42	3.59	1.77	1.75	1.58	1.21	1.12
Cumulative variability %	0.27	0.45	0.58	0.67	0.72	0.76	0.80

PC6 (Infrastructural Vulnerability) was loaded for 9 indicators: cyclone shelter, flood shelter, cooperative society, electrified village, growth centers, transport facility, non-metallic road, length of embankment road, and motor vehicle. The PC7 (Water Vulnerability) has been loaded for 2 indicators which are the length of water ways and water source. These 7 PC groups of vulnerabilities for both present (2011) and future scenario (2050) have been used to generate GIS maps to investigate their spatial distribution across the coastal region of Bangladesh. Fig. 2 and 3 demonstrate the present and future vulnerability scenario for the coastal region of Bangladesh based on PCA.

With a large and growing population, coastal region of Bangladesh is highly vulnerable to extreme climatic events. The coastal region of Bangladesh has already experienced a major threat of socio-demographic vulnerability (PC1). However, the spatial discrete map provides an indication that the coastal region or Upazilas will be relatively less vulnerable considering the demographic changes in the future (Fig. 2 (a) and 3 (a)). The number of high and medium vulnerable coastal Upazilas has been changed from 0 to 1 and from 43 to 39 respectively from present to the future the under changing climate and growing adaptive capacity. However, the number of low vulnerable Upazilas increased from 7 to 10 Upazilas from present to the future scenario (Table 4).

The economic vulnerability has been defined as greater economic distress in dealing with economic resource and losses, arising out of economic openness. In this study, the term economic vulnerability (PC2) has been defined as the lack of financial capital availability in the Banking and risks arising from lack of insurance coverages. Nonetheless, the future vulnerability in the coastal region of Bangladesh will not be significantly changed from present condition (Figs. 2 (b) and 3 (b)).

Based on the findings from recent studies on this region, natural disasters such as cyclone, storm surge, floods, and drought will be more frequent and intense in the future. The climate vulnerability (PC3) will be enhanced in the coastal region of Bangladesh due to geographic settings, dense population, and poverty. The number of highly vulnerable of coastal Upazilas will be increased from 0 to 1 while the medium vulnerable Upazilas will be increased from 30 to 41 reducing low vulnerable upazilas from 20 to 8 (Table 4).

The potential human health impacts of climate change are needed to inform the development of adaptation strategies, policies, and measures to lessen projected adverse impacts. Recent evidence suggests that the associated changes in temperature and precipitation are already adversely affecting public health. About 28 percent of the total population has lived in the coastal region of Bangladesh and highly vulnerable to health and wellbeing (PC4) due to the negative impact of climate variability and sea level rise. The spatial maps clearly show that most of the coastal regions are highly vulnerable to health issues (Figs. 2 (d) and 3 (d)). Considering climate change, the number of highly vulnerable coastal Upazilas will be increased from 33 to 32 while the low vulnerable Upazilas will remain the same (Table 4).

Table 4. Clusters of relative vulnerability scale of 50 upazilas of the study area

PCs	Vulnerability profile	Present scenario			Future scenario		
		High	Medium	Low	High	Medium	Low
PC1	Demographic	0	43	7	1	39	10
PC2	Economic	45	3	2	45	3	2
PC3	Climatic	0	30	20	1	41	8
PC4	Health	32	16	2	33	15	2
PC5	Agricultural	47	3	0	48	2	0
PC6	Infrastructure	48	2	0	46	4	0
PC7	Water	14	33	3	21	29	0

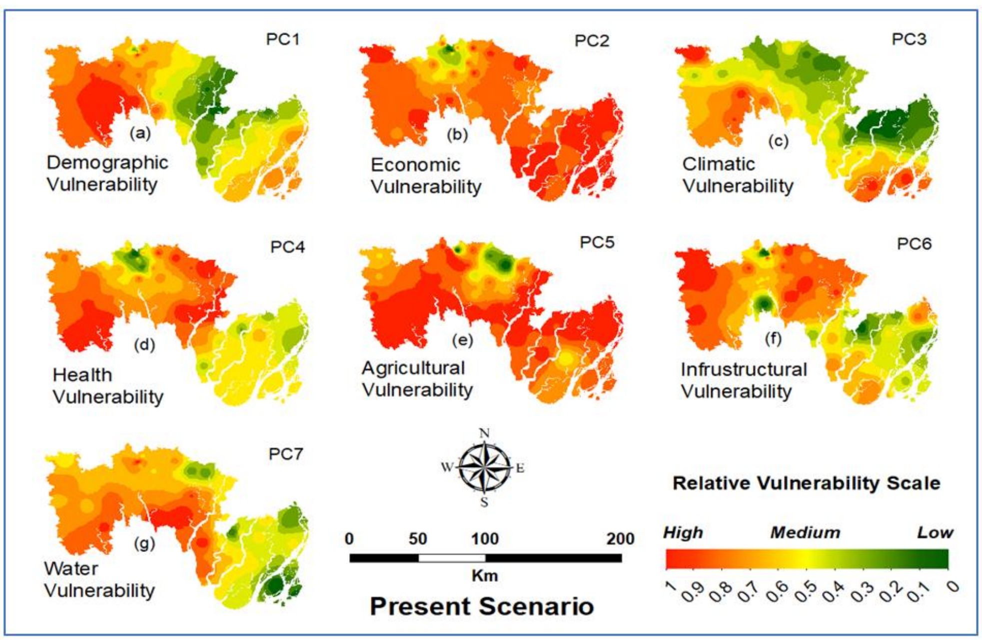

Fig. 2. Present vulnerability scenario for the south west coastal region of Bangladesh

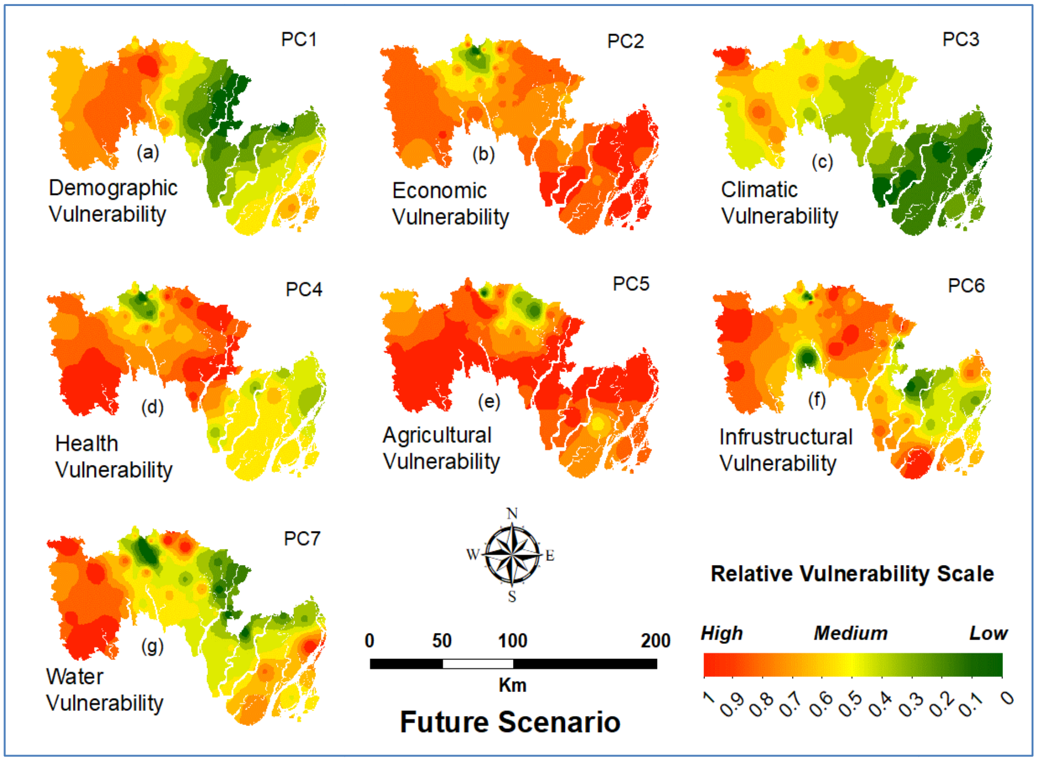

Fig. 3. Future vulnerability scenario for the south west coastal region of Bangladesh

Climate change will create an additional stress and have direct a negative consequence on food security across the coastal belt. The crop production undergoes a change in most of the coastal Upazilas are aggravated by the extreme climate in the future. Extreme climate poses a significant threat to agricultural development. The high level of agricultural vulnerability (PC5) has been found in the study area as shown in spatial maps (Figs. 2 (e) and 3 (e)). Highly vulnerable coastal Upazilas will be increased from 47 to 48 whereas the low vulnerability region will be 0 for each scenario (Table 4).

Infrastructure related vulnerability (PC6) will be lower in the future due to climate change. Though climate-proof infrastructure will be required to combat climate change in the coastal region of Bangladesh. The number of highly vulnerable coastal Upazilas will be decreased from 48 to 46 while medium vulnerable Upazila will be increased from 2 to 4.

A large proportion of the population has already been experienced water vulnerability and raised the demand of water availability in most of the part of the world. The coastal region of Bangladesh has already experienced an increasing demand of drinking water and freshwater requirements to maintain a healthy ecosystem. In the future, the number of highly vulnerable coastal Upazilas will be increased from 14 to 21 due to sea level rise and consequent saline water intrusion (Table 4). The spatial aggregation maps also depicted an increasing trend of water vulnerability of the study area (Figs. 2(g) and 3(g)).

The use of PCA to derive multiple independent components of vulnerability from 31 indicators of sensitivity, exposure and adaptive capacity considering in the broad scale mapping is able to assess different components of the vulnerability. For present and the future scenarios under the changing climate, the pattern of the vulnerability of coastal Upazilas will also be changed. Composed by a combination of social, economic, physical and environmental factors, the assessment implies combining different domains and makes it therefore a challenge to identify a metric for vulnerability. Here, vulnerability has been defined in the context of climate change and developed spatial aggregation map of the multi-sectoral vulnerability profile in the coastal region of Bangladesh, which is largely prone to extreme climatic events. The high vulnerability and low adaptive capacity are a major concern in coastal regions of Bangladesh. People of coastal region lived exacerbate with health diseases and access to inadequate drinking water, infrastructure, and technology, degradation of natural resources and its ecosystem. It is needed to address the potential challenges of climate variability and extreme.

4. CONCLUSION

This study has identified 7 principal components through PCA which has been grouped as PC1 (Demographic Vulnerability), PC2 (Economic Vulnerability), PC3 (Climatic Vulnerability), PC4 (Health Vulnerability), PC5 (Agricultural Vulnerability), PC6 (Infrastructural Vulnerability) and PC7 (Water Vulnerability). For all 7 PCA groups (termed as vulnerability profile), the number of high and medium vulnerable coastal Upazilas will be significantly changed in the future. No of highly vulnerable Upazila will increase from 0 to 1 for PC1, unchanged for PC2, increase from 0 to 1 for PC3, from 32 to 33 for PC4, from 47 to 68 for PC5, decrease from 48 to 46 for PC6, and increase from 14 to 21 for PC7, respectively. PCA based assessment of the vulnerability of the coastal region of Bangladesh demonstrates that different aspects of vulnerability are spatially discrete, with different areas characterized by different types of vulnerability. PCA technique for vulnerability assessment is found a very useful tool to identify vulnerable areas in the coastal region of Bangladesh considering both present and the future scenarios of climate change. The findings of this study might be useful for the policymakers as well as the planners of the country to combat the challenges posed by climate change.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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