Mapping of Vulnerability Paths for Coastal Bangladesh Applying Principal Component Analysis (PCA)

M. N. Uddin, S. K. Bala, AKM S. Islam, GM T. Islam, S. Adhikary, L. C. Sutradhar

Institute of Water and Flood Management, Bangladesh University of Engineering and Technology
ahamedn00@gmail.com

Abstract: Climate change is likely to increase the frequency and magnitude of some extreme climate events and disasters in Bangladesh especially in the coastal belt. It is being already affected by climate change due to various natural and human induced vulnerabilities. The aim of this paper is to assess these vulnerabilities using multivariate vulnerability analysis considering IPCC framework. A total of 30 indicators were used of which 23 are socio-economic and 7 are natural indicators. Unbiased weights were estimated using Principal Component Analysis (PCA) to find out different types of coastal vulnerabilities in accordance with the 30 indicators. Afterwards, 7 vulnerability groups (Principal Component - PC) were generated as a result of clustering the indicators which co-varied across the indicators throughout the coastal belt. The groups are Literacy and Population Pressure Vulnerability (PC1), Economic Vulnerability (PC2), Agricultural Vulnerability (PC3), Drinking Water Vulnerability (PC4), Poverty and Health Vulnerability (PC5), Climate and Natural Vulnerability (PC6) and Infrastructural Vulnerability (PC7). These groups of vulnerabilities were tasted for both present and future (2050) scenario. These groups of vulnerability were used to generate GIS maps for the coastal Bangladesh to see the influence of spatial distribution of 7 types of vulnerabilities across the coastal area. The findings of this study might be useful for policy makers as well as planners to consider the climate vulnerability in the development of Bangladesh.

Keywords: Coast, Vulnerability, Climate, Principal Component Analysis, GIS

Introduction: Bangladesh is one of the most vulnerable countries to climate change because of its geographical location, low deltaic flood plain, and hydro-meteorological influence of erratic monsoon rainfall and other extreme climate events. We conceptualize composite vulnerability as a function of exposure, sensitivity and adaptive capacity (Eakin & Luers, 2006; Gallopin, 2006; Yohe & Tol, 2002). Exposure is defined as the degree to which a system experiences internal or external system perturbations. Sensitivity is defined as the degree to which a system is affected by those system perturbations (McCarthy et al., 2001). Adaptive capacity is defined as the ability of a system to adjust its behaviour and characteristics in order to enhance its ability to cope with external stress (Brooks, 2003). Vulnerability is a highly complex phenomenon with different social, economic and environmental factors affecting exposure and sensitivity (Adger, 2006). Spatially vulnerability assessments are increasingly important instruments in environmental policy formulation and in informing environmental and development debates (Metzger & Schröter, 2006; Stelzenmüller, Ellis, & Rogers, 2010), as vulnerability maps can act as powerful visual tools. Such maps can help identify those groups and areas most susceptible to harm at a particular point in time, allowing more targeted policy and investments that both mitigate current challenges and reduce future risks (Davies & Midgley, 2010; Ericksen et al., 2011). A Principal Component Analysis (PCA) approach provides several potential advantages. When the original variables are correlated then the higher orders Principal Components (PCs) capture more of the total variability in the original data than any individual original variable. The present study used the principal component analysis to see the socio, economic and environmental based vulnerabilities through GIS mapping in the coastal region of Bangladesh.

Materials and Methods:

Study area -The coast of Bangladesh is about 710 km long and most of the coastal upazilas in the 20 districts have elevations about 1.2-4.5 m above mean sea level. These districts are directly or indirectly being affected by various natural or man-made events. These 20 districts have 140 upazilas which have been considered as the study area. The total coastal area is about 47,201 km2 (WARPO, 2006) which lies within the tropical zone between 21◦23” N and 89◦93” E.

Indicators - 23 socio-economic and 7 natural indicators are selected for the study. Data for socio-economic indicators are obtained from Bangladesh Bureau of Statistical Yearbook (BBS, 2013), while natural indicators are collected from various reports, journals, articles and maps. The maps were digitized and overlaid with the coastal upazila maps using GIS tool to determine the values of the respective indicator. A brief description of the selected indicators is given in Table1.

Table1: Indicators used for the study

Indicators	Description	Unit	Data source
Socio-economic			
Density of Population	Sensitive	persons/sq.km	
Male-Female Ratio	Sensitive	males/100 females	
Literacy Rate	Adaptive Capacity	percentage	Bangladesh
Gender gap in literacy rate (GGLR)	Sensitive	percentage	Bureau of
Percentage of Disable	Sensitive	percentage	Statistics, BBS
Source of Drinking Water	Adaptive Capacity	number/1000 of population	(2011)
Electricity Connection	Adaptive Capacity	number /1000 of population	
Poverty	Sensitive	percentage	
Access to Transport Facilities	Adaptive Capacity	number /1000 of population	
Medical Institution	Adaptive Capacity	number /1000 of population	
Govt. Primary Schools	Adaptive Capacity	number 1000 of population	
Motor vehicles	Adaptive Capacity	number /1000 of population	
Railway and water way	Adaptive Capacity	km/1000 of population	
Embankment Road	Adaptive Capacity	km/1000 of population	
Cyclone Shelter	Adaptive Capacity	number/1000 of population	
Flood Shelter	Adaptive Capacity	number/1000 of population	
Un-metaled road	Adaptive Capacity	km/1000 of population	
Co-operative Society	Adaptive Capacity	number/1000 of population	
Growth Centre	Adaptive Capacity	number/1000 of population	
Irrigation by Power Pump	Adaptive Capacity	number/1000 of population	
Production of Rice	Adaptive Capacity	metric ton	
Nationalized and Private Bank	Adaptive Capacity	number/1000 of population	
Insurance Company	Adaptive Capacity	number/1000 of population	
Bank Loan	Adaptive Capacity	number/1000 of population	
Natural			
Storm sure inundation	Natural	m	Various
Inundation due to flood	Natural	m	Reports,
Shoreline erosion	Natural	m/year	Journal articles
Shoreline accretion	Natural	m/year	and maps
Coastal elevation	Natural	cm	
1 day maximum rainfall	Natural	mm	
Salinity intrusion due to SLR	Natural	Percentage (%)	

Normalization of the indicators -The 30 variables are normalized to a scale of 0-1. Each of the indicators is measured in different unit. The following equation was used to convert these indicators and was adopted from the Human Development Index (UNDP, 2007).

$$Index_{X_d} = (X_d - X_{min})/(X_{max} - X_{min}) \quad (1)$$

Where,

X_d is an observed value in an array of 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.

Principal Component Analysis (PCA) - Principal Component Analysis (PCA) is a data exploration tool that converts a number of potentially correlated variables into a set of uncorrelated variables that capture the variability in the underlying data. As such, PCA can be used to highlight patterns within multivariable data. PCA uses orthogonal linear transformation to identify a vector in N-dimensional space that accounts for as much of the total variability in a set of N variables as possible the first principal component (PC) where the total variability within the data is the sum of the variances of the observed variables, when each variable has been transformed so that it has a mean of zero and a variance of one. A second vector (second PC), orthogonal to the first, is then sought that accounts for as much of the remaining variability as possible in the original variables. Each succeeding PC is linearly uncorrelated to the others and accounts for as much of the remaining variability as possible (Jolliffe, 2002). The ranking of the PCs in order of their significance (based on how much of the variability in the data they capture) is denoted by the Eigen values associated with the vector for each PC. All PCAs were undertaken using the R statistical program. Pair wise correlation tests were applied in an attempt to reduce the initial set of metrics to a smaller subset of non-highly correlated metrics (Schindler, et al., 2008). The Kaisere-Mayere-Olkin (KMO) sampling adequacy test value was taken >0.5 and Bartlett's sphericity test returned p as <0.05 for all PCA analyses, considered as the variables suitable for PCA analysis (Hair, et al 2006). A correlation matrix was used for the PCA analyses to make the data standardized and to avoid potential bias resulting from the inclusion of data with different scales and ranges.

Result and Discussion:

Data for 30 indicators were normalized as per UNDP (2007) report applying HDI method. Unbiased weights were found for each individual indicator after carrying out Principal Component Analysis (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. Table 2 shows different types of coastal vulnerabilities as per 30 indicators arranged according to the highest value of PCA loadings. These 7 PCs represent 79.5% variability of 30 indicators demonstrating vulnerability of the coastal belt under study. The Eigen value has been considered 1 and greater than 1 for the 7 PCs which co-varied across the indicators throughout the coastal belt. The 7 groups are titled as PC1 as Literacy and Population Pressure Vulnerability; PC2 as Economic Vulnerability; PC3 as Agricultural Vulnerability; PC4 as Drinking Water Vulnerability; PC5 as Poverty and Health Vulnerability; PC6 as Climate and Natural Vulnerability and PC7 as Infrastructural Vulnerability.

The PC1 (Literacy and Population Pressure Vulnerability) was highly loaded for 5 indicators like population density, literacy rate, male female ratio, govt. primary school and gender gap in literacy rate. The PC2 (Economic Vulnerability) was loaded for 3 indicators as nationalized and private bank, insurance company and borrowing money from bank. The PC3 (Agricultural Vulnerability) was loaded for 2 indicators like rice production and irrigation by power pump. The PC4 (Drinking Water Vulnerability) was loaded for 2 indicators as length of water way year and water source. The PC5 (Poverty and Health Vulnerability) was loaded for 3 indicators as disable people, poverty and medical institution. The PC6 (Climate and Natural Vulnerability) was loaded for 6 indicators like medical institution, inundation due to flood, storm surge inundation, coastal elevation, rainfall and salinity intrusion. The PC7 (Infrastructural Vulnerability) was loaded for 9 indicators as cyclone shelter, flood shelter, cooperative society, electrified village, growth centers, transport facility, non-metallic road, length of embankment road and motor vehicle.

These 7 PC groups of vulnerabilities were found for both present and future (2050) scenario and used to generate GIS maps for the coastal Bangladesh to see the influence of spatial distribution of 7 PC types of vulnerabilities across the coastal area. Figure 1 and Figure 2 demonstrate the present and future vulnerability scenario for the coastal Bangladesh respectively, where normalized vulnerability index for all 30 indicators as well as seven PC vulnerabilities of higher values are spatially represented. They show different scale of vulnerabilities across the coastal belt.

The Figure 1 demonstrates that for present scenario, the coastal Bangladesh does not bear any major threat of vulnerability except some minor vulnerability for PC1 in the field of population density, literacy rate, male female ratio, govt. primary school and gender gap in literacy rate.

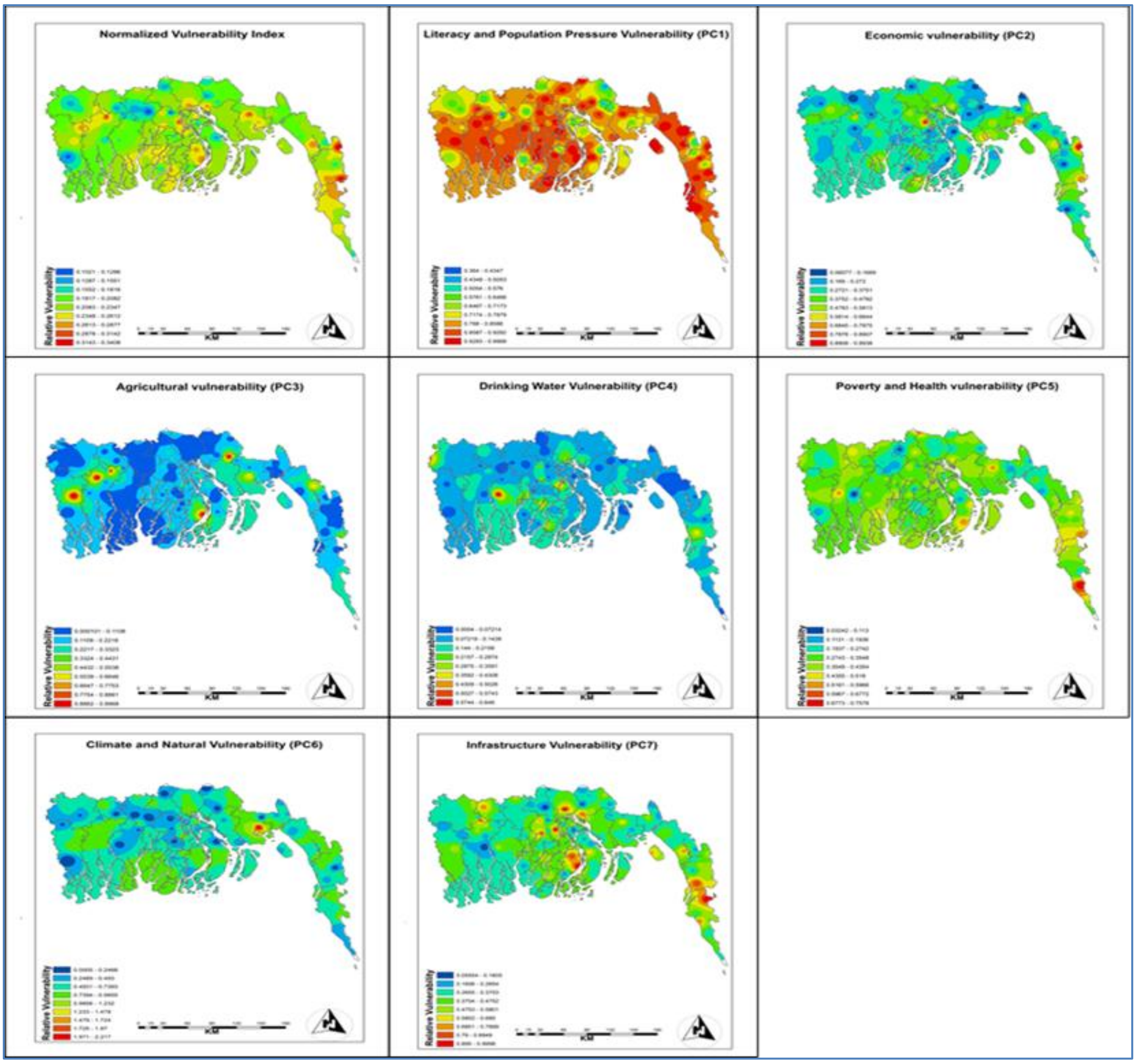

Figure 1: PCA based maps of relative vulnerability in present time for the study area.

In the future scenarios the 7 retained components represent the 83% of the variability in the original 30 variables included in the analysis. Vulnerability is a dynamic concept and spatial mapping provides clear visible description of increasing vulnerability at a particular time in future (2050). The Figure 2 shows clear increasing trend of all vulnerabilities. The results presented here do suggest that the use of PCA to derive multiple independent component of vulnerability from 30 indicators of sensitivity, exposure and adaptive capacity considering in the broad scale mapping provides assessing broad scale different component vulnerability.

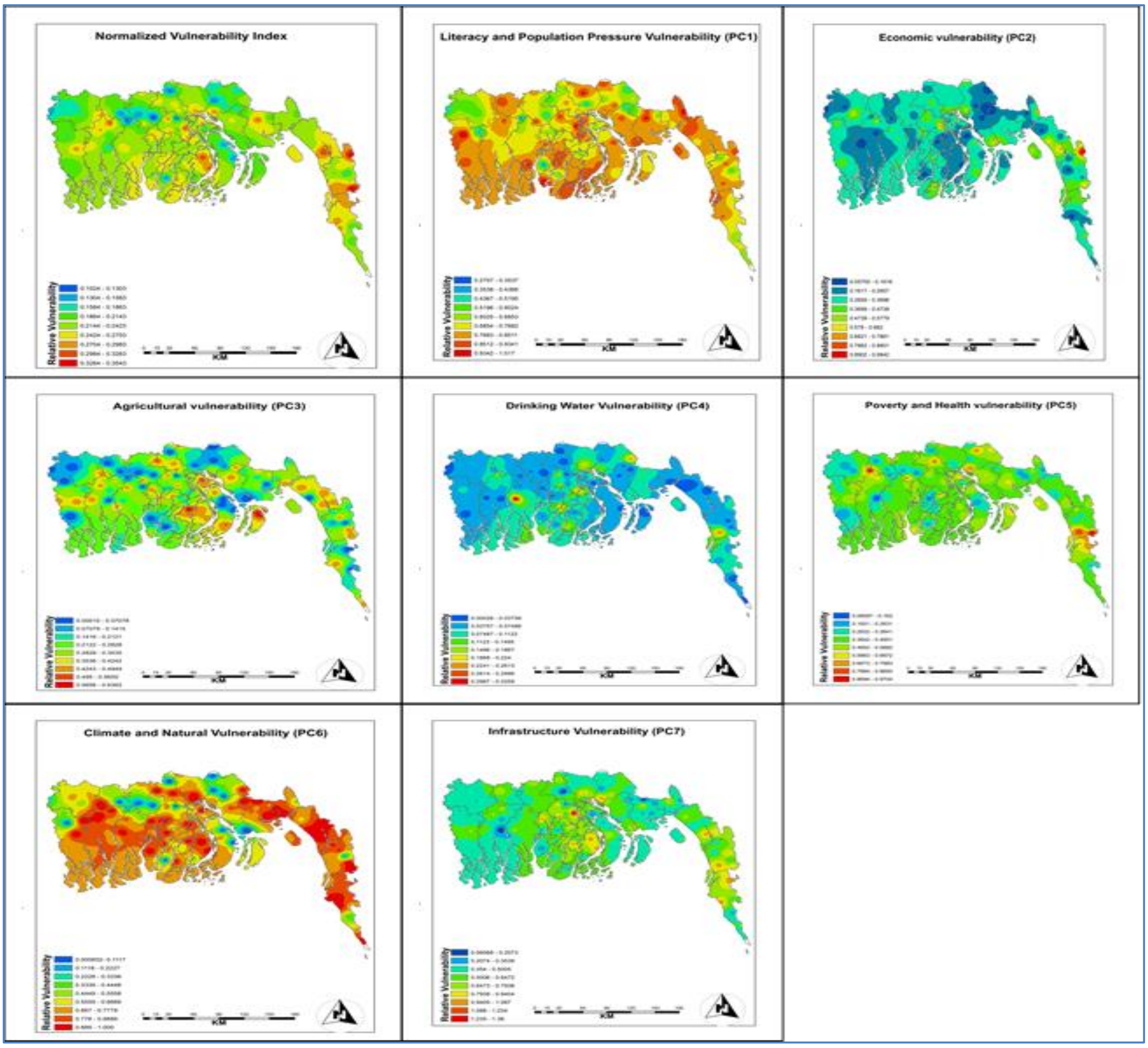

Figure 2: PCA based maps of relative vulnerability for future (2050) scenarios in coastal region.

Conclusion:

It may be concluded PCA technique for vulnerability assessment is a very useful tool to identify vulnerable areas to be affected for both present and future coastal Bangladesh. This study clearly shows that significant imprints for future vulnerabilities will be around PC1 (Literacy and Population Pressure Vulnerability) and PC6 (Climate and Natural Vulnerability). This PCA based assessment of the vulnerability of coastal region demonstrates that different aspects of vulnerability are spatially discrete, with different regions characterized by different types of vulnerability. The findings of this study might be useful for policy makers as well as planners to consider the climate vulnerability in the development of Bangladesh.

References

Adger, W. N. , 2006, "*Vulnerability. Global Environmental Change"*, VOL. 16, NO. 3, 268-281

BBS, 2013, "*Bangladesh Bureau of Statistics"*, Government of the People Republic of Bangladesh

Brooks, N., 2003, *Vulnerability, risk and adaptation: A conceptual framework*. Working paper 38. Norwich: Tyndall Centre for Climate Change Research, University of East Anglia.

Davies, R. A. G., &Midgley, S. J. E. ,2010, "*Risk and vulnerability mapping in Southern Africa: a hotspot analysis, OneWorld Sustainable Investments"*.

Eakin, H., &Luers, A. L. ,2006, *"Assessing the vulnerability of social-environmental systems*". Annual Review of Environment and Resources, 31, 365-394

Ericksen, P., Thornton, P., Notenbaert, A., Cramer, L., Jones, P., &Herrero, M. ,2011, "*Mapping hotspots of climate change and food insecurity in the global tropics. CCAFS Report no. 5. Copenhagen: CGIAR"*

Gallopin, G. C., 2006, "*Linkages between vulnerability, resilience, and adaptive capacity"* Global Environmental Change, 16(3), 293-303

Hair, J. F., Black, W. C., Babin, B. J., Anderson, R. E., &Tatham, R. L., 2006, Multivariate data analysis (6th ed.). New Jersey: Pearson International.

Jolliffe, I. T. ,2002, Principal component analysis (2nd ed.). New York: Springer.

Yohe, G., &Tol, R. S. J. ,2002, "*Indicators for social and economic coping capacity moving toward a working definition of adaptive capacity"*. Global Environmental Change, 12(1), 25-40.

Metzger, M. J., &Schröter, D. ,2006, "*Towards a spatially explicit and quantitative vulnerability assessment of environmental change in Europe"*. Regional Environmental Change, 6(4), 201-216.

McCarthy, J. J., Canziani, O. F., Leary, N. A., Dokken, D. J., & White, K. S. ,2001,. *Climate change 2001: Impacts, adaptation, and vulnerability*. Cambridge: Cambridge University Press.

Liu, J., Fritz, S., van Wesenbeeck, C. F. A., Fuchs, M., You, L., Obersteiner, M., et al. ,2008, *A spatially explicit assessment of current and future hotspots of hunger in Sub-Saharan Africa in the context of global change*. Global and Planetary Change, 64(3-4), 222-235.

Schindler, S., Poirazidis, K., &Wrbka, T. ,2008, "*Towards a core set of landscape metrics for biodiversity assessments: a case study from Dadia National Park, Greece"*. Ecological Indicators, 8(5), 502-514.

Stelzenmüller, V., Ellis, J. R., & Rogers, S. I. ,2010, "*Towards a spatially explicit risk assessment for marine management: assessing the vulnerability of fish to aggregate extraction".* Biological Conservation, 143(1), 230-238.

WARPO, 2006, Coastal Development Strategy, Water Resources Planning Organization (WARPO), Ministry of Water Resources, Government of the People's Republic of Bangladesh, Dhaka, Bangladesh.