



Climate Change Vulnerability Assessment of Patuakhali Municipality in Bangladesh

A.S.M. Maksud Kamal, Shamima Ferdousi Sifa, S.M. Mahmudul Islam, Md. Asif Rafsan, Md. Imran Hossain Alve, Tonoy Mahmud, Md. Shakhawat Hossain and Md. Zillur Rahman*

Department of Disaster Science and Climate Resilience, University of Dhaka, Dhaka 1000, Bangladesh

ARTICLE INFORMATION

Received : 28 November 2021
Accepted : 23 December 2021

Keywords:

Climate change vulnerability assessment (CCVA)
Exposure
Adaptive capacity
Sensitivity
Coastal area of Bangladesh

ABSTRACT

Climate change will create adversative impact on the growth and development of future cities due to the proliferation of the extreme events, which will increase human, social, and economic losses over time. Therefore, it is necessary to move towards sustainable urbanization processes to reduce the impact of climate change. This research is aimed at carrying out climate change vulnerability assessment (CCVA) for Patuakhali Municipality, which is one of the most vulnerable municipalities in Bangladesh located in the south-central coastal region of Bangladesh. The vulnerability of the study area is derived by overlaying the factor maps using equal class interval weighted index (ECIWI) and principal component analysis (PCA). Both methods show similar results in case of exposure and adaptive capacity assessment, but the results of vulnerability assessment are slightly different for some of the wards due to variation in the level of sensitivity obtained from two different methods. ECIWI and PCA show that Ward 9 and Ward 1 are the most and least vulnerable wards, respectively. Although exposure to hazards is similar in the study area, the degree of sensitivity and adaptive capacity for these two areas are different, which mainly contributes to their vulnerability. CCVA will help the local government to build resilience for the urban poor to reduce climate change-induced vulnerability, which can be utilized by the policymakers to increase awareness and to mitigate risk through planned interventions.

Introduction

The climate change vulnerability assessment (CCVA) is a systematic procedure where the potential future impact of climate change on a system or a particular region is identified in order to determine the degree of resiliency of the existing system to develop, implement, and monitor the more effective and resilient climate change adaptation measures (EuropeAid, 2010). In other words, this assessment will help to establish an understanding of the extent to which changing climate will affect the system in question and estimate the actual extent of impact on the system and prioritize necessary interventions based on the sensitivity of its elements (MoEF&CC, 2014). Vulnerability in the case of a climate change context refers to a system that is susceptible to climate variability and extremes making it unable to adapt itself to or recover from the adverse impact (IPCC, 2007). This degree of susceptibility can be

better explained by a system's or a region's level of exposure, sensitivity, and adaptive capacity towards climate change-induced disasters, such as flood, cyclone, sea-level rise, etc., which increases the frequency and severity of the several hazards persisting in the area of concern (IPCC, 2007).

Climate change thereby affects communities throughout the world and its adverse impact becomes increasingly evident mostly in cities (MoEF&CC, 2014) that are facing several development challenges as economic and life losses have been increasing substantially (Brugmann, 2013). Rapid urbanization is creating additional risk and pockets of vulnerability for the poor population, which is further exacerbated by the negative consequences of climate change. Since climate change will affect the development pattern of the city along with its spatial growth (Prasad et al., 2009), it is a prerequisite to inform the city dwellers and all the relevant stakeholders about the consequences of climate change. Therefore, UNISDR (2005) in its report stated that this type of assessment in the long term ensures disaster risk reduction and sustainable development as it increases awareness among the

* Corresponding Author
E-mail: zillur@du.ac.bd (Md. Zillur Rahman)

policymakers and within the local population about the risk persistent in a given area, which can be mitigated through planned interventions.

The methods of vulnerability assessment can be changed from a theoretical concept (Moss et al., 2001) to an observable concept (Hinkel, 2011) and it can be carried out through top-down or bottom-up approaches (Dessai and Hulme, 2004). In case of a top-down approach, more emphasis is given on climate change analysis and determination of its impact, which can be quantified, thereby it is carried out at global, national, and regional levels. This process involves quantification of higher-order socio-economic impacts through quantitative models, such as global circulation models (GCMs), climate impact simulation process, showing a degree of biophysical effects due to climate change (MoEF&CC, 2014), which can be used in the policy formulation and decision making processes (Dessai & Hulme, 2004). The main advantage of the process is to provide a projection of the future state of the system or a region (either positive or negative) due to climate change through cause-effect relationships (MoEF&CC, 2014). But it has some major drawbacks, such as the uncertainties inherent in the modeling are difficult to estimate introducing further uncertainties and more importantly, the models mostly focus on the ecological component rather than the social components (Hinkel et al., 2010). On the other hand, the bottom-up approach is more concerned with the local level population who are susceptible to climatic hazards (van Aalst et al., 2007). Therefore, it addresses issues related to the different degrees of sensitivity of the people, their exposure to the hazards, and their capacity to adapt to the threat or any external stimuli. It is a participatory approach that does not rely on data obtained from climate modeling but

involves the collection of information from a specific location about different social groups (Hinkel et al., 2010). This has a major disadvantage as many people can be vulnerable to more than one hazard, thereby, making difficulties in generalization. Therefore, each approach has its strength and weaknesses, but the integration of both the top-down and bottom-up approaches can address some of the drawbacks. Since, climate change vulnerability involves multifaceted dimensions, which are interconnected (Dessai and Hulme, 2004). Therefore, an integrated climate change vulnerability approach is used in this research, which uses a combination of scientific and field data. This research aims to carry out climate change vulnerability assessment at Patuakhali Municipality to engage local stakeholders, to develop their understanding, and to support them in identifying climate change that can make people, places, and systems particularly vulnerable and inform them about how to respond to the adverse impacts.

Study Area

Patuakhali Municipality located in the south-central part of Bangladesh (Figure 1) is highly susceptible to the adverse impact of climate change as it lies close to the Bay of Bengal. Natural hazards, such as cyclones, floods, and storm surges mostly affect the study area, but there are other hazards, such as riverbank erosion, drought, irregular rainfall, tidal flood, waterlogging that affect the lives and livelihoods of the population. It has been predicted that due to climate change, these hazards are likely to intensify and be more frequent in the future (IPCC, 2007) threatening the poor population of the area making it important to undertake mitigation and adaptive measures in advance to reduce the risk of the area.

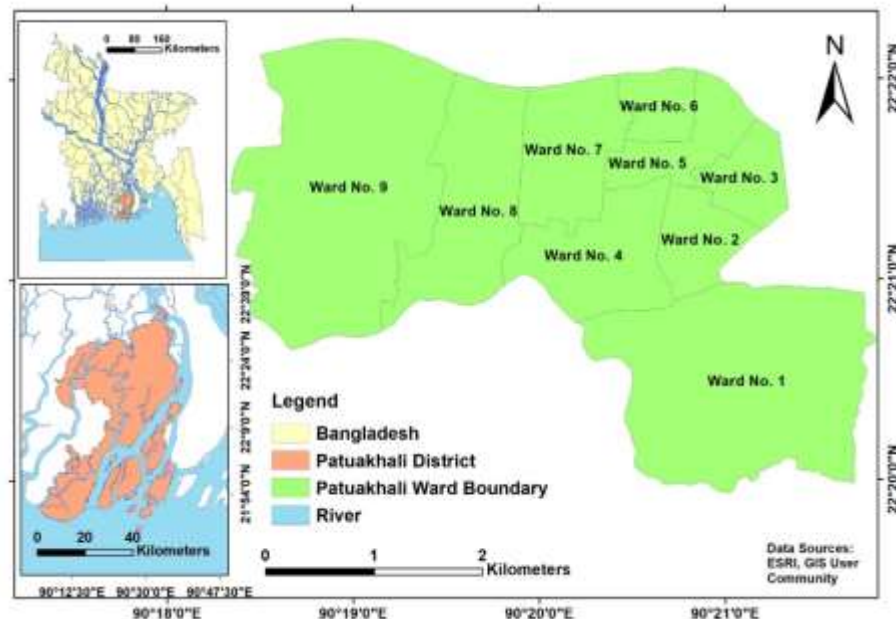


Figure 1: Map of the study area (Patuakhali Municipality)

Materials and Methods

Data and Software

The data and information for Patuakhali Municipality have been collected mostly from secondary sources. Data related to social-economic vulnerability (both sensitivity and adaptive capacity) have been collected from the latest available population census and socio-economic study reports of the Bangladesh Bureau of Statistics (BBS), the respective City Corporation/Municipality, and other city-level government agencies (Figure 2). A field survey was also conducted to collect information related to adaptive capacity. These data are processed using GIS-based tools and techniques to carry out the assessment (CCVA) and mapping using ArcGIS software. Statistical analysis and weighting were carried out using SPSS software.

Methods

Climate Change Vulnerability Assessment

Vulnerability is a function of exposure, sensitivity, and the adaptive capacity of the system to adapt to climate change (Figure 3). Hazard assessment is a prerequisite for exposure analysis to determine the degree of physical vulnerability in the area of concern. The process involves

hazard identification and characterization by its level of severity, frequency, geographical extent, etc. (Satterthwaite and Dodman, 2013). On the other hand, it is also important to identify the extent to which a system is exposed to a hazard. According to IPCC (2007), exposure is a function of the geographic location of the elements at risk and co-existence of hazards at the same location. Sensitivity and adaptive capacity also play a major role as sensitivity shows the responsiveness of a system and the degree to which it will be affected, whereas adaptive capacity is the robustness or ability of the system to adapt or adjust to external stimuli, such as climate change-induced natural hazards. There is no universally accepted methodology for vulnerability assessment. Different schools of thought, including disaster management, environmental change research and development studies, have developed methodologies to assess vulnerability for different types of natural hazards at different physical scales and for different purposes. One of the issues to be addressed is to balance the use of qualitative versus quantitative methods (UN-Habitat, 2014). The equation (Eq. 1) below shows that the assessment can be carried out by combining the exposure, sensitivity, and adaptive capacity of the community.

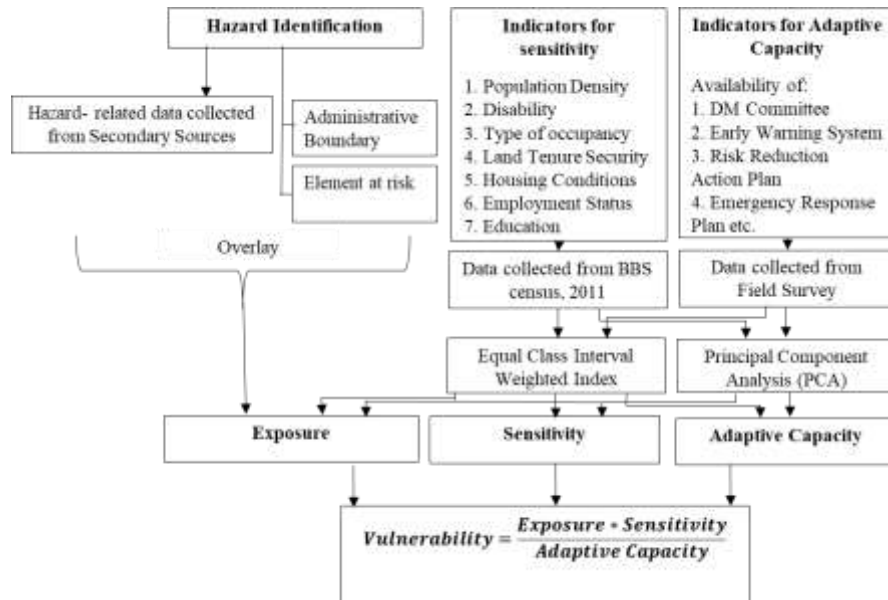


Figure 2: Methodological framework describing the climate change vulnerability assessment (CCVA)

$$V = \frac{E * S}{A_c}$$

where, V= Vulnerability
 E= Exposure
 S= Sensitivity
 A_c= Adaptive Capacity

Equation 1

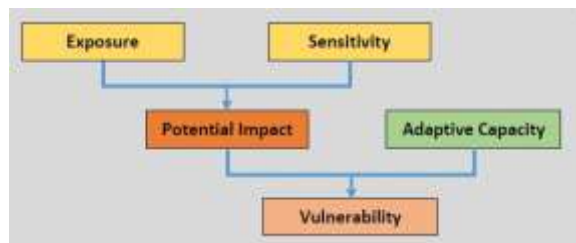


Figure 3: Relationships between vulnerability and defining concepts (Fellmann, 2012 modified from Allen Consulting (2005))

Weighting using Equal Class Interval

A vulnerability assessment score sheet is used to capture the collected data. Hazard assessment is determined through the mean weight method or equal class interval method by some criteria, such as geographical limits, historical and geological records, the likely impact of disasters, and an overall rank of the identified risk (scale: from not likely to occur = 1 to extreme =5). Similarly, sensitivity and adaptive capacity assessment are also determined through the equal class interval weighting method of each different criterion. Later, the vulnerability is calculated from the final score value for each hazard and prioritized based on descending order. Each criterion is classified with an equal interval (Odu, 2019) in order to assign score values to each class, which ranges from 1 to 5. All the alternatives will be determined through the scoring of each different variable. Lastly, all the values are to be added again and divided to get equal intervals as shown in Eq. 2 below:

$$\text{Interval} = \frac{\text{max value} - \text{min value}}{\text{number of section}} \quad \text{Equation 2}$$

Then, to get the first segment, add the minimum value with the interval that is calculated from the above equation. The first segment value is needed to be added with the interval value to get the value of the second segment. Keep on adding until a maximum value is reached and assign scores accordingly. Then, overlay the equal class interval factor maps and carry out the equal interval class method to obtain index value.

Weighting using Principal Component Analysis (PCA)

Principal component analysis (PCA) is a mathematical procedure where principal components are uncorrelated variables, which is prepared by transforming a large number of correlated variables. The variables are standardized (e.g., z-values) and principal component analysis is carried out in order to check their dimensionality and avoid redundancy followed by composite vulnerability index score for every administrative unit (Kolli et al., 2016). For a set of y-variables ($y_1, y_2, y_3, \dots, y_n$) of each administrative unit, PCA generates w principal components like $w_1, w_2, w_3, \dots, w_n$. The z-score represents normalized values of the variable that is $z_1, z_2, z_3, \dots, z_n$ for each administrative unit (Eq. 3).

$$z = \frac{\text{Variable} - \text{Means of Variables}}{\text{Standard Deviation of Variables}} \quad \text{Equation 3}$$

Finally, the principal components and z-scores for an administrative unit is used to combine the indicators that are weighted into the single composite index as shown in Eq. 4. The Statistical Package for Social Sciences (SPSS) is used for PCA. Varimax rotation is used to simplify the dimensions and produce more independence among the factors. Eigenvalues higher than one is used to exclude outliers and substitute the missing values. Kaiser-Meyer-Olkin (KMO) of sampling adequacy and Bartlett's Test of Sphericity, are used to check the fitness of the statistical model (Bartlett, 1950; Kaiser, 1960). The components that will contribute to increase the vulnerability are considered as positive, and vice versa (Solangaarachchi et al., 2012).

$$V_j = \sum w_i (x_{ij} - \bar{x}_i) / s_i \quad \text{Equation 4}$$

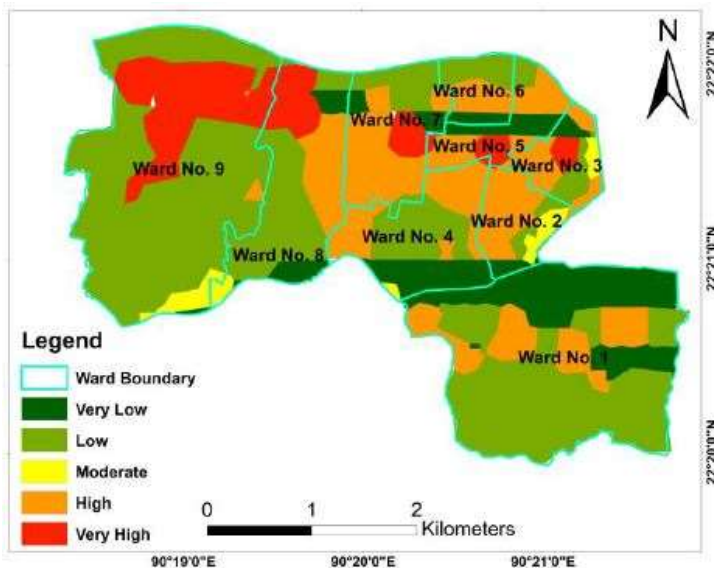
where,
 $i = 1, \dots, n; j = 1, \dots, J$

Results and Discussion

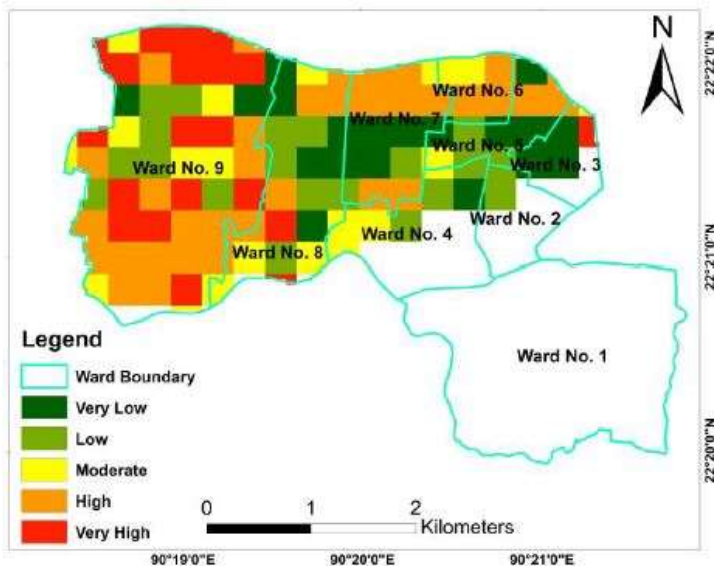
Hazard Assessment

Patuakhali Municipality is at the greatest risk for multiple hazards, which has increased over time due to climate change. As per the literature, cyclone, storm surge, tidal flood, waterlogging, riverbank erosion, and water scarcity are some of the hazards that frequently affect the study area regularly causing the people in the north-eastern region of the city to suffer from the adverse impact of the disasters. In this research, cyclone, storm surge, and flood hazards are considered for the study areas due to data constraints. The hazards are classified into different classes, which range from very high to very low to determine which region of the municipality is highly susceptible to a particular hazard using Natural Jenks. Different classes are represented by different color compositions, where the red indicates that the area is highly susceptible to that hazard that is the intensity of the hazards will be greater in that region. The white area within the administrative boundary represents no data. Figure 4 shows the hazard map of cyclone, flood and storm surge and Ward 9 is highly affected by these hazards.

a)



b)



c)

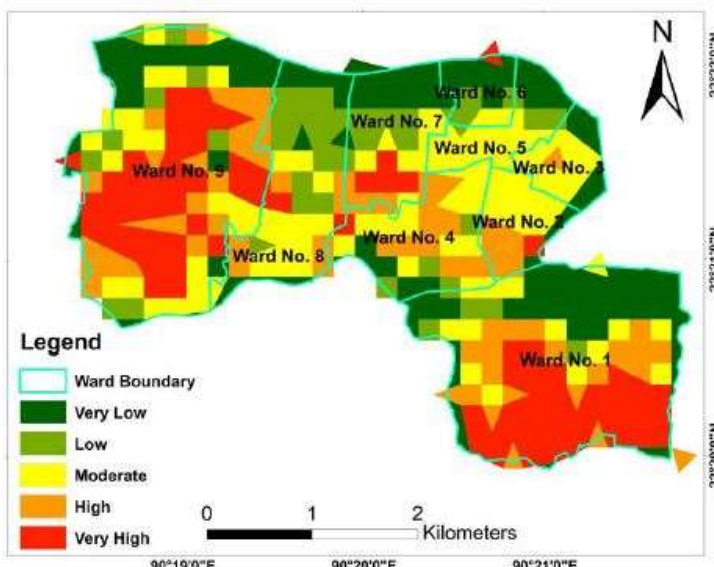


Figure 4: Hazard Map of the Patuakhali Municipality (a) cyclone, (b) flood, and (c) storm surge hazards.

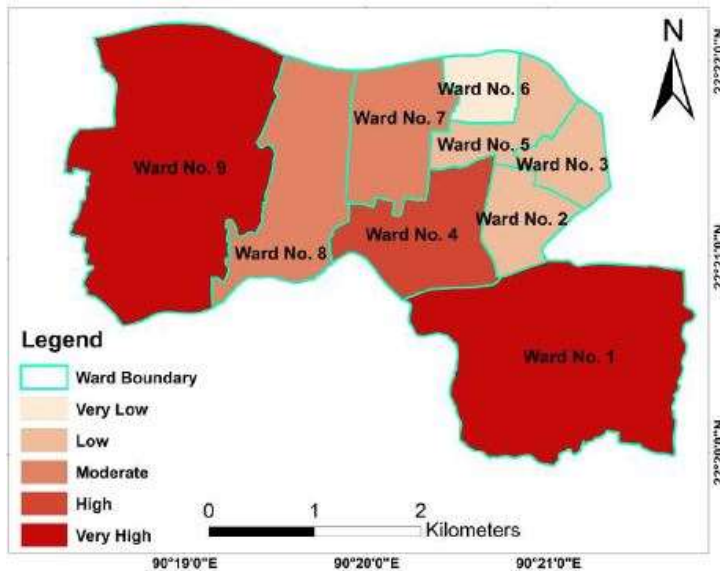
Exposure Assessment

Exposure assessment is carried out to determine which region (ward) is highly exposed to the climate change-induced multiple hazards. According to Filmer & Pritchett, (2001), the first single component is used for assigning the weights since the majority of the variance is covered by this component. The absolute value of the component score is used to construct the exposure map of the study area. The Principal Components (PC) that has eigenvalues greater than one are retained to avoid a higher degree of uncertainty due to significant dimension reduction throughout the PCA analysis. All the hazards are superimposed on one another, and the result obtained was categorized within a range of 1 to 5 using the

weighted index method. The index values 5, 4, 3, 2 and 1 indicate very high, high, moderate, low, and very low exposure towards the climatic hazards.

The analysis clearly shows (Figure 5a) that Wards 1 and 9 are the most exposed wards at Patuakhali. However, the poor communities of those wards are most exposed to climatic hazards, which will further increase their vulnerability. On the other hand, Word 6 has the least exposure to the hazards. In case of PCA, Figure 5b shows that Wards 1 and 9 are highly exposed (very high exposure class) to climatic hazards whereas Ward 6 is the least exposed. Wards 7, 8, and 4 fall under moderate exposure class and Wards 2, 3, and 5 into low exposed class. None of the wards is classified under high exposure class.

a)



b)

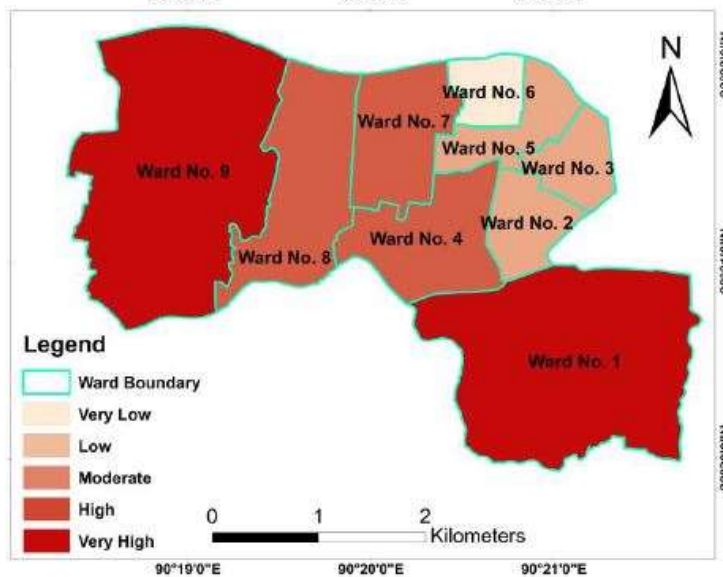


Figure 5: Exposure Map of Patuakhali Municipality using (a) Equal Class Interval and (b) Principal Component Analysis

Sensitivity Assessment

Sensitivity assessment has been carried out from the demographic and socio-economic factors of the study area to determine how the community will be affected by climate change related hazards. The

indicators are chosen in such way that it reflects the characteristics of the community, which will, in turn, affect their vulnerability towards climate change-induced multiple hazards. The indicators used in the analysis are given in Table 1.

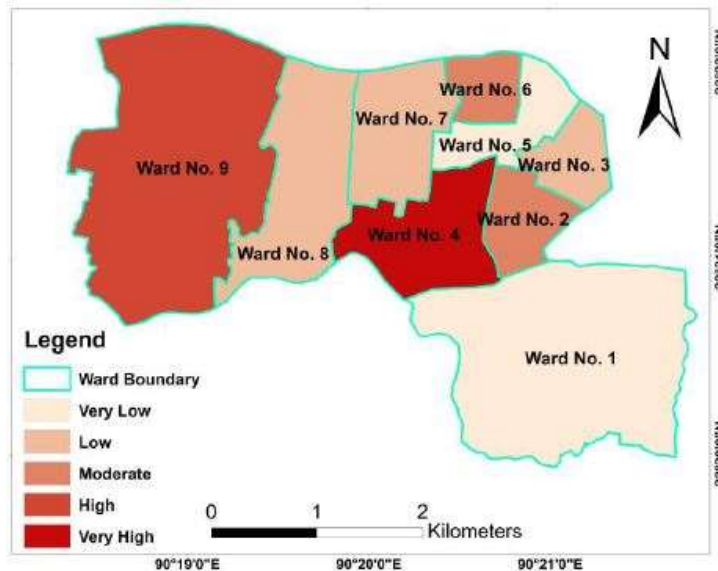
Table 1: Indicators used in the analysis

		Indicators	Rationale	Unit
Sensitivity	Demographic Indicators	Population Density	To understand the distribution of the population in the study area	Number/sq. km
		Age group under 5 years	Age group under 5 years and above 65 years have high sensitivity. It is used to identify the degree of dependency.	Number/sq.km
		Age group above 65 years		Number/sq.km
		Disable population	Identify the degree of dependency	Percentage (%)
		Ethnic group	To understand their sensitivity due to their culture and social position	Number/sq.km
		Sex ratio	Identify the gender pattern and their sensitivity due to their gender role	Male/100 female
	Socio-economic Indicator	Literacy rate	To understand the degree of accessibility to information and literacy condition	Percentage (%)
		Number of population employed	These will show the employment pattern of the study area	Number
		Number of population unemployed		Number
		Occupation as an agricultural farming	It is used to understand the livelihood options in the study area and how these are sensitive to natural hazards	Number
		Occupation as an industrial labor		Number
		Occupation as a service provider		Number
		Brick-Built (Pucca) house	To identify the living condition of the population in the area as well as their sensitivity towards natural hazard	Percentage (%)
		Semi-Pucca house		Percentage (%)
		Tin Shed (Katcha) house		Percentage (%)
		Thatched (Jhupri) house		Percentage (%)
		Access to proper sanitation (sealed)	To understand the hygiene and sanitation status of the households	Percentage (%)
		Access to sanitation (non-sealed)		Percentage (%)
		Access to electricity	To see the development pattern of the study area	Percentage (%)
Adaptive Capacity	Disaster Management	Availability of active Disaster management Committee	To understand the degree of preparedness and response of the community	Scale (1 to 5)
		Availability of updated emergency response plan		Scale (1 to 5)
	Non-structural Disaster Management	Availability of active community-based organization (CBO) and non-government Organization (NGO)	CBO and NGO will contribute in capacity development, and how well the community is risk-informed	Scale (1 to 5)
		Availability and number of active community volunteers	This will contribute in dissemination of risk information, evacuation, response and relief operation	Scale (1 to 5)
		Availability and access to welfare or safety net programmes	To understand the accessibility to social safety net programmes	Scale (1 to 5)
		Availability of early warning system	To identify the existing warning mechanism of the community	Scale (1 to 5)
	Structural Disaster Management	Availability and distance to nearby emergency shelters	To understand the availability of the structural measures in the area to mitigate the risk	Scale (1 to 5)
		Availability of infrastructure improvement programmes		Scale (1 to 5)
		Availability of infrastructures, such as embankment, sluice gate		Scale (1 to 5)

The sensitivity indicators have high values in Ward 4 (Figure 6). The demographic as well as the economic conditions result in the ward to be more sensitive to hazards. The population density played the main role here. The map shows (Figure 6a) Ward 4 to be the most sensitive and Ward 1 and 5 to be the least sensitive ward among the study area. Vulnerability therefore depends on diverse perspectives to determine the characteristics of the community, which is contributing to vulnerable conditions, a large set of indicators is assessed to determine the level of sensitivity of the communities towards climate change-induced multiple hazards. Different kinds of people experience vulnerability in various ways. Climate change-induced disasters will also increase the risk of disease and death among children, such as waterborne and food-borne diseases. Children, disabled, and elder people are very sensitive to climate change, as they have more limited mobility, resources, and a high degree of dependency on others. During a

climate event, they may not have enough awareness or means to evacuate and are more limited in terms of adapting to new conditions and ways of living. There are about 46410 and 23985 children under 5 and elder people (above 65), respectively, in the study area. Ward 9 that has high sensitivity (Figure 6a) has many children and elder people than other areas. Ethnic minorities are also sensitive to because of the issues associated with the social stigma, inadequate land tenure security, less recognition by authorities, and therefore, lower institutional adaptive capacity. The ethnic community, for example, has occupied land for a longer period, but still is threatened with eviction, meaning they are not able to invest in building their homes with robust housing materials. Besides, while many are qualified workers, they struggle to find jobs as they have been socially stigmatized, this lowers their wage-earning capacity and increases economic vulnerability. Only Ward 7 has ethnic minorities in their administrative boundaries.

a)



b)

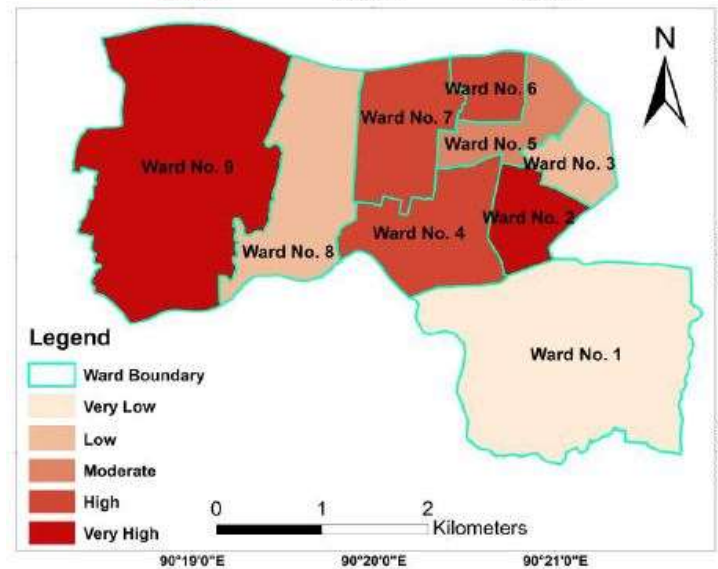


Figure 6: Sensitivity Map of Patuakhali Municipality using (a) Equal Class Interval and (b) Principal Component Analysis

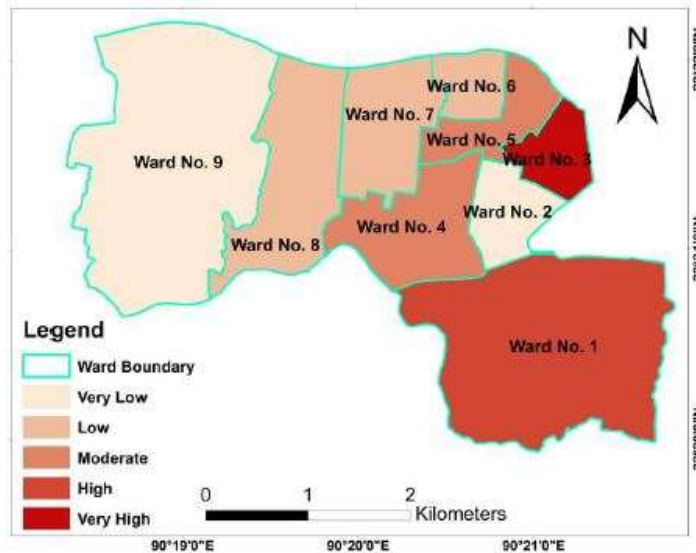
The result in PCA method (Figure 6b) shows a similar trend, albeit the sensitivity has been increased. Wards 2 and 9 have the higher sensitivity here, although the wards found most sensitive in the weighted matrix method is Ward 4. According to both the methods, Ward 1 has the lowest sensitivity to climatic hazard. However, the two methods show a little different in moderate and low-level sensitivity as shown in Figure 6 where the sensitivity of Wards 7 and 5 have increased when PCA method is used, but the degree of sensitivity has decreased for Ward 4. The reason behind this difference has resulted because of the sub-indicators used under the indicators selected for sensitivity analysis as the correlation matrix becomes nonpositive definite (NPD) because of the presence of a greater number of indicators than the number of available observations. Another reason for the variation occurred because not all sub-indicators are used in the sensitivity analysis using PCA method to avoid linear dependencies among the indicators and to make sure that no variable is

reproduced by a weighted sum of other variables (sub-indicators).

Adaptive Capacity

Adaptive capacity is used to determine how well the community can respond, recover, and absorb the stresses from climate change. In this study, institutional adaptive capacity in terms of risk reduction and disaster management is assessed to see how resilient and prepared the community towards climatic hazards as shown in Table 1. The adaptive capacity as always is more robust in the central business district area. Ward 3 is the only ward that has a very high level of adaptive capacity compared to Wards 1, 4, and 5, which falls in the high and moderate adaptive capacity region (Figure 7). Those wards have a disaster management committee in action, availability of early warning system (EWS), emergency response plan (ERP), active community volunteers and several structural measures in place to prevent or reduce the impact of the hazards persisting in the study area.

a)



b)

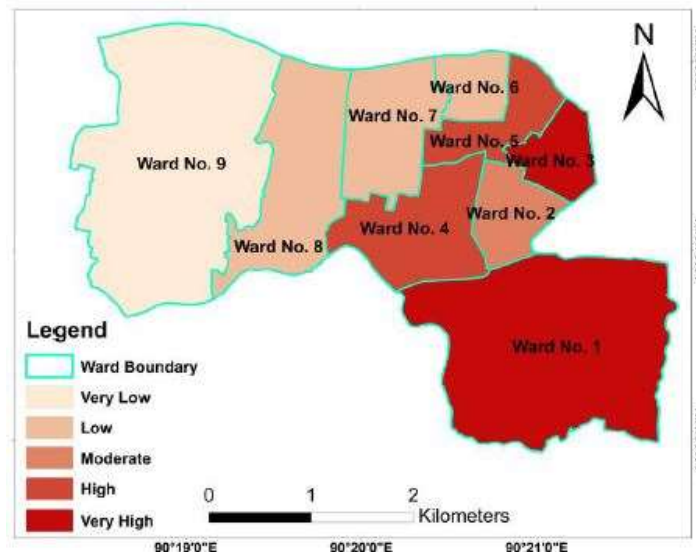


Figure 7: Adaptive Capacity Map of Patuakhali Municipality using (a) Equal Class Interval and (b) Principal Component Analysis

Institutional adaptive capacity through the development of town-level disaster management committees will coordinate the disaster risk reduction and disaster preparedness activities to ensure adequate and efficient response at the time of disaster. Nonstructural measures, such as capacity development, awareness-raising through an education campaign, the introduction of several welfare and safety net programmes will also reduce the risk of the community and increase their resilience, because they will be risk-informed and will have the capacity to be able to recover from the adverse impacts of climatic hazards more efficiently and effectively than before since they are more socio-economically stable. Welfare and safety net programmes aim to help the most marginalized population, such as women-headed households or families with disabled members that are the vulnerable groups of the community. Poor community members can collectively save money and offer loans to each other. Small loans can serve to support needy families in the event of an emergency, such as a health problem or recovering from an extreme climate event. Similarly, communal saving groups can further support other households and profits stay within the community. On the other hand, structural measures, such as the construction of embankment, sluice gate, cyclone shelter along with improvement of the existing infrastructures also contribute to the risk reduction as it safeguards the community against climate-induced multiple hazards.

Wards 2 and 9 (Figure 7a) have a very low adaptive capacity as most of the indicators, which account for disaster management is absent in those regions. Although there is an emergency response plan for Ward 9, but there are no active disaster management committees, volunteers, and any structural measures available in the region to ensure proper implementation of disaster risk management activities. Another reason for the low adaptive capacity of Ward 9 can be its location that is may be these wards failed to attain sufficient attraction because of their peripheral location. In most cases, it is usually found that the high hazard-prone area tends to have higher adaptive capacity than other regions, because the people of the affected area are more aware of their susceptibility, they are more risk-informed and they tend to adapt from a lesson from preceding disasters. But some areas have not taken adequate disaster management options despite their high exposure to climatic hazards. On the other hand, Figure 7b shows that Wards 1 and 3 have the most capacity and Ward 9 has the least institutional adaptive capacity. There is a negligible number of differences in

adaptive capacity derived from the equal class weighted index and principal component analysis (PCA) method.

Vulnerability Assessment

Vulnerability assessment is carried out by combining the exposure towards climatic hazard with sensitivity and adaptive capacity (as per IPCC 2007) to determine which wards of Patuakhali Municipality are vulnerable to climate change. The assessment is carried out using two different methods that are equal-interval weighted index and principal component analysis (PCA) as shown in Figure 8a and 8b, respectively. Both methods show similar results. Equal interval weighted index and PCA (Figure 8a and 8b) show that Wards 9 and 1 are the most and least vulnerable wards, respectively, in the study area. From exposure analysis, it has been found that Wards 9 and 1 have the highest degree of exposure towards multiple hazards. However, the degree of sensitivity and adaptive capacity for these two regions are different. Ward 9 has high sensitivity but low institutional adaptive capacity, which thereby, contributes to the vulnerability. In contrast, Ward 1 has low sensitivity and high adaptive capacity to address the adverse impacts of the disaster.

Equal interval weighted index has identified Wards 8 and 7 of the region as moderate vulnerable areas, whereas according to PCA, Wards 7 and 4 fall under that category. However, all the regions have high exposure and sensitivity towards multiple climatic hazards with inadequate adaptation activities, which could have reduced, prevent, or enable them to respond effectively and efficiently towards any imminent hazards. Both the method classified Wards 3 and 5 as low vulnerable zone. The differences are due to the use of different weighting methods, which have several constraints of their own thereby resulting in a difference in the degree of vulnerability. The arbitrary strategy of assigning equal interval weights to indicators affects the results because not all indicators can have an equal influence on vulnerability. Assigning higher weights to indicators that have lower variance can avoid large variations and unduly domination, but can distort comparisons between different regions. On the other hand, PCA usually deals with those which are statistically significant and have an influence on vulnerability which can be measured through correlation. Assessing vulnerability from the single index is not adequate. Therefore, a composite index where a combination of sub-indicators should be used to support the argument adequately. An equal interval weighted index, however, better explains the main sources of vulnerability and the influence of different components of vulnerability.

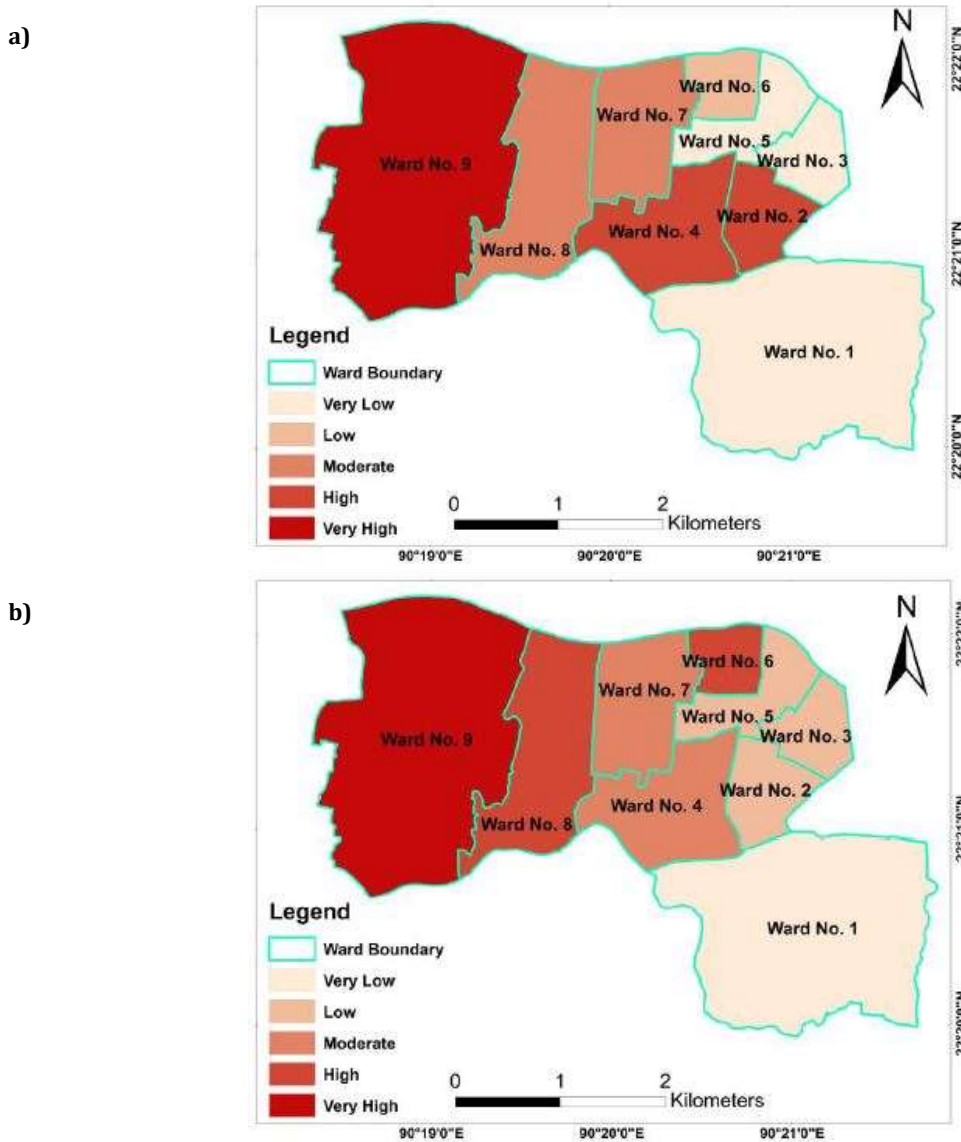


Figure 8: Vulnerability Map of Patuakhali Municipality using (a) Equal Class Interval and (b) Principal Component Analysis

Conclusion

Bangladesh is urbanizing rapidly as people are migrating to cities as centers of economic opportunity, where a large portion of the country’s assets and economic production is concentrated. Cities now house over 35% of the total population (2017); the rate of urbanization is estimated at 3.2%. However, the inability to secure safe housing and jobs has forced new residents into informal settlements that lack infrastructure and services. Evidence demonstrates that climate change accelerates this process, putting more pressure on already overstretched urban services and scarce land resources, leading large numbers of the poor to be exposed to the precarious and vulnerable living in urban areas. This study is assessed the vulnerability to climate change at Patuakhali Municipality through a semi-quantitative approach. For the vulnerability assessment, the conceptual framework for IPCC 2007 is

used, which constitutes the three components of vulnerability: exposure, sensitivity, and adaptive capacity. The weighting methods are the Equal Class Interval Weighted Index and Principal Component Analysis (PCA), which show that the results obtained from two methods are slightly different for some of the wards due to variation in the level of sensitivity obtained from two different methods. The equal interval weighted index and PCA show that Wards 9 and 1 are the most and least vulnerable wards, respectively, in the study area. From exposure analysis, it has been observed that Wards 9 and ward 1 have the highest degree of exposure towards the multiple hazards induced by climate change. But the degree of sensitivity and adaptive capacity for these two regions are different, which mainly contributes to its vulnerability. Wards 8 and 7 of the region are classified as moderate vulnerable areas by equal interval weight, whereas according to PCA, Wards 7 and 4 are identified in this

category. Both the methods classified Wards 3 and 5 under the low vulnerable zone. Many of the hazards persisting in the study area are not included in the study due to time constraints and due to the presence of a greater number of indicators compared to the number of observations, the correlation matrix becomes nonpositive definite (NPD). Another reason for the variation occurred because not all sub-indicators are used in the sensitivity analysis using PCA method to avoid linear dependencies among the indicators and to make sure that no variables are reproduced by a weighted sum of other variables (sub-indicators). However, in case of further study, it will be recommended to include other hazards, such as coastal erosion, change in the temperature, salinity hazards in the study to make it a comprehensive vulnerability assessment.

Overall, the climate change vulnerability assessment (CCVA) will help the local governments to build resilience for the urban poor to climate change as it will develop their understanding and supports them in identifying climate change that can make people, places, and systems particularly vulnerable. This research will also inform how cities best respond to climate hazards through the development of a Pro-Poor Climate Resilience Strategy (PCRS). Community-level responses will especially benefit poor, urban communities in protecting themselves from climate-related hazards.

Acknowledgments

The authors acknowledge the Department of Disaster Management (DDM), Ministry of Disaster Management and Relief, Government of the People's Republic of Bangladesh, and Asian Disaster Preparedness Center (ADPC) for providing us with hazard related and adaptive capacity-related data. The authors are also thankful to the University Grant Commission (UGC) of Bangladesh for partial financial support and to the Department of Disaster Science and Climate Resilience, University of Dhaka for providing access to remote sensing and GIS laboratory facilities.

References

- Bartlett, M. S. (1950). Tests of Significance in Factor Analysis, *British Journal of Statistical Psychology*. John Wiley & Sons, Ltd., 3(2), pp. 77–85. doi: 10.1111/J.2044-8317.1950.TB00285.X.
- Brugmann, J. (2013). Building Resilient Cities: From Risk Assessment to Redevelopment, Finance Sector & Senior Programme Manager, Climate Change, University of Cambridge Programme for Sustainability Leadership.
- Dessai, S. and Hulme, M. (2004). Does Climate Adaptation Policy Need Probabilities?, *Climate Policy*, 4(2), pp. 107–128. doi: 10.1080/14693062.2004.9685515.
- EuropeAid (2010). Manual for Climate Change Vulnerability Assessment of Coastal and Marine Protected Areas.
- Fellmann, T. (2012). The Assessment Of Climate Change-Related Vulnerability in the Agricultural Sector: Reviewing Conceptual Frameworks, Building resilience for adaptation to climate change in the agricultural sector, (i), pp. 37–62.
- Filmer, D. and Pritchett, L. (2001). Estimating Wealth Effects Without Expenditure Data--or Tears: An Application to Educational Enrollments in States of India, *Demography*. 38(1), pp. 115–132. doi: 10.1353/DEM.2001.0003.
- Hinkel, J., Schipper, L. and Wolf, S. (2010). Review of Methodologies for Assessing Vulnerability – Report Submitted to GTZ in the Context of the Project Climate Change Adaptation in Rural Areas of India.
- Hinkel, J. (2011). Indicators of Vulnerability and Adaptive Capacity: Towards a Clarification of the Science–Policy Interface, *Global Environmental Change*, 21(1), pp. 198–208. doi: 10.1016/j.gloenvcha.2010.08.002.
- Intergovernmental Panel on Climate Change (IPCC). (2007). IPCC Fourth Assessment Report: Climate Change 2007 (AR4).
- Kaiser, H. F. (1960). The Application of Electronic Computers to Factor Analysis, *Educational and Psychological Measurement*, 20(1), pp. 141–151. doi: 10.1177/001316446002000116.
- Kolli, Z., Jouannic, G., Marchetti, M., Legendre, T., Gastaud, P., Gargani, J. and Arki, F. (2016). Flood Risk Vulnerability Assessment: Hierarchization of the Main Factors at a Regional Scale, *E3S Web of Conferences*, 7. doi: 10.1051/e3sconf/20160708014.
- Ministry of Environment, Forest and Climate Change (MoEF&CC) (2014). A Framework for Climate Change Vulnerability Assessments.
- Moss, R. H., Brenkert, A. L. and Malone, E. L. (2001). Vulnerability to Climate Change - A Quantitative Approach
- Odu, G. O. (2019). Weighting Methods for Multi-Criteria Decision Making Technique, *Journal of Applied Sciences and Environmental Management*. doi: 10.4314/jasem.v23i8.7.
- Prasad, N., Ranghieri, F., Shah, F., Trohanis, Z., Kessler, E. and Sinha, R. (2009). *Climate Resilient Cities: A Primer on Reducing Vulnerabilities to Disasters*. World Bank Publications.
- Satterthwaite, D. and Dodman, D. (2013). *Towards Resilience and Transformation for Cities within a Finite Planet, Environment and Urbanization*. SAGE Publications UK: London, England, 25(2), pp. 291–298. doi: 10.1177/0956247813501421.
- United Nations Human Settlements Programme (UN-Habitat) (2014). Hoi An, Viet Nam – Climate Change Vulnerability Assessment.
- United Nations International Strategy for Disaster Reduction Secretariat (UNISDR) (2005). *Hyogo framework for Action 2005–2015: Building the Resilience of Nations and Communities to Disasters*, In World Conference on Disaster Reduction. Kobe, Hyogo, Japan.
- Van, A., M. K, Canon, T and Burton, I. (2007). Community level Adaptation to Climate Change: The Potential Role of Participatory Community Risk Assessment, *Global Environmental Change*, 18, pp.165–179.