CLIMATE CHANGE VULNERABILITY ASSESSMENT FOR AGRICULTURE SECTOR IN TUYEN QUANG PROVINCE

Nguyen Xuan Hien[(1)], Pham Tien Đat[(1)], Doan Thi Thu Ha[(1, 2)], Nguyen Thi Phuong[(1)], Dang Linh Chi[(1)]

[(1)]Viet Nam Institute of Meteorology Hydrology and Climate Change

[(2)]Sejong University, Korea

Received: 19 June 2017; Accepted: 18 August 2017

Abstract: *Climate Change (CC) has significant impacts to socio-economic development in Viet Nam and agricultural is one of the most affected sectors. The most impacted provinces are those where economic activities are highly dependent on ecosystem services such as Tuyen Quang. This study applies vulnerability assessment framework proposed by Allison et al (2009) and the unequal weights methodology developed by Iyengar and Sudarshan (1982) to assess climate change vulnerability for agriculture sector in Tuyen Quang province. The results show that, in the 21st century, Son Duong and Na Hang districts are highly vulnerable to climate change while Tuyen Quang city is less vulnerable than other districts. This study presents useful results to help local governments and communities to respond to climate change impacts in the future.*

Keywords: *climate change, agricultural, impact, vulnerability assessment.*

1. Introduction

Many studies have shown that vulnerability to climate change in developed and developing countries have significant differences (IPCC, 2001). Poor countries, developing countries, or small island states are more vulnerable to the adverse effects of climate change such as extreme weather events than developed countries (UNDESA, 2010).

The study of climate change vulnerability should base on a full consideration of major components: exposure, sensitivity and adaptive capacity [IPCC, 2001; Heltberg et al., 2009; Moss et al., 2002; Polsky et al., 2007]. Vulnerability assessments usually aim to answer the following questions: who and what is vulnerable, what are the underlying reasons, how to respond to the problems to reduce climate change impacts and increase adaptive capacity. However, the identification of indicators to quantify vulnerability are sometimes difficult and the available dota is limited.

To assess climate change vulnerability, many studies have been using "vulnerable index" approach in which an index was conducted based on several set of indicators to represent the vulnerability. This method allows a quantitative assessment of vulnerability and a relative comparison between different regions [Torresan et al., 2008, Hahn et al., 2009]. Torresan et al., (2008) applied the DIVA tool (Dynamic International Vulnerability Index) to assess the vulnerability of Venetia Beach (Italy) based on two sets of the coastal vulnerability indicators: (i) topographic and slope; (ii) geomorphology; (iii) vegetation distribution, and (iv) population and population density. However, the indicators used to assess were mainly natural vulnerability index, not pay much attention on socio-economic vulnerability index. Hahn et al. (2009) used a set of Livelihood Vulnerability Index (LVI) to assess the impact of climate change through the impact assessment of natural disasters and the variability between individual populations in two counties includes: Mabote, Moma in Mozambique. However, in this study, the weight of all indicators is considered

Correspondence to: Nguyen Xuan Hien
E-mail: nguyenxuanhien@gmail.com

equal when the evaluation affected the results of the study. Alex de Sherbinin et al. (2007) base on climate change scenarios combined with bottom-up vulnerability assessment approaches to study vulnerability in the three cities including Mumbai, Rio de Janeiro and Shanghai.

The Intergovernmental Panel on Climate Change (IPCC) has developed definitions of vulnerability based on scientific studies in the world over many years. In 1990, the first IPCC's Assessment Report on Climate Change (FAR 1990) identified vulnerability as the inability to cope with the consequences of climate change and sea level rise. In 1995, the second IPCC's Assessment Report (SAR 1995) identified vulnerability as the degree that climate change could cause harm or disadvantages to the system. The vulnerability does not only depend on the susceptibility of the system but also on the adaptive capacity of the community with new climatic conditions and are considered as the remaining impacts of climate change after adaptive solutions implemented (Downing, 2005). This definition includes: exposure, susceptibility, resilience of the system to climate change.

The Third IPCC Report on Climate Change (TAR 2001) explained that vulnerability is the degree to which a system (natural or human) is susceptible to, or unable to cope with, adverse effects of climate change. Vulnerability is a featured function of the intensity, speed of climate change when the system is exposed, including susceptibility and adaptability. This concept is used in future IPCC's reports (AR4, AR5).

This study conducted a vulnerability assessment for Tuyen Quang - a mountainous province in northern Viet Nam (Figure 1). The natural area of the province is 5,868 km^2, accounting for 1.78% of the country area. Agricultural sector plays an important role in the socio-economic development of the province. Hence, climate change vulnerability assessment may provide local government and other agencies having an overview of how climate change would affects this area.

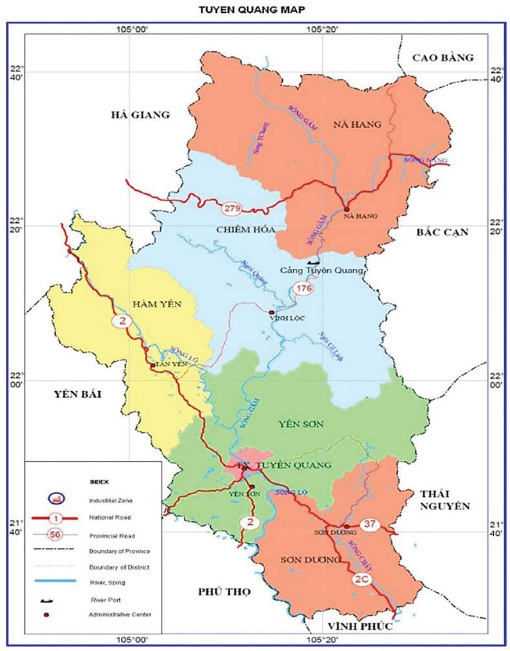

Figure 1. Administrative map of Tuyen Quang Province

2. Methodology and procedure of climate change vulnerability assessment in the agriculture sector

2.1. Data

The vulnerability assessment is based upon data from the agricultural sector, socio-economic data including data from forestry and fishery that have been collected from sources such as: statistical yearbook 2015 of Tuyen Quang province, the analysis of climate change impacts in Tuyen Quang with scenarios greenhouse gas emissions RCP 4.5 extracted from the climate change scenarios for Viet Nam and for the districts Tuyen Quang [MONRE, 2016; IMHEN, 2011].

2.2. Methodology

This study recommends using the concept of vulnerability (to climate change) of the IPCC (2007). Vulnerability to climate change is defined as "the degree to which geophysical, biological and socio-economic systems are susceptible to, and unable to cope with, adverse impacts of climate change, including climate variability and extremes".

The term "vulnerability" may therefore

refer to a function of three main components: “Exposure” (E), “Sensitivity” (S) and “Adaptive Capacity” (AV).

$$V = f(E, S, AC) \quad (1)$$

where: E=“The nature and degree to which a system is exposed to significant climatic variations”; S=“the degree to which a system is affected, either adversely or beneficially, by climate variability or change”; AC=“The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences”.

Based on the IPCC’s vulnerability concept, the study proposes a vulnerability assessment for Tuyen Quang province using a relative method (Gleick, 1998; IPCC, 2007, Keskinen, 2009; Babel and Wahid, 2009).

The vulnerability is evaluated by using factors/indicators causing vulnerability, normalizing indicators and then calculating weights for each indicator. Finally, result is an average quantitative value allowing a relative comparison between districts in the province, which will be mapped. Vulnerability assessment’s framework proposed by Allison et al. (2009) assesses exposure, sensitivity, potential impacts and adaptation capacity. The functional relationship to normalize data and then applying the method of unequal weights developed by Iyengar and Sudarshan (1982) was used to calculate the weight indices.

Steps for CVI calculations are shown below:

Step 1: Data normalization

Data normalization is to convert the collected raw data with different units to the dimensionless value ranging from 0 (minimum value) - 1 (maximum value) to be able to compare between administrative units. If higher the value of sub-index more will be the vulnerability of the region to climate change, we apply the following formula:

$$x_{ij} = \frac{X_{ij} - \underset{i}{\mathrm{Min}}\{X_{ij}\}}{\underset{i}{\mathrm{Max}}\{X_{ij}\} - \underset{i}{\mathrm{Min}}\{X_{ij}\}} \quad (1)$$

If vice versa, we apply the formula:

$$y_{ij} = \frac{\underset{i}{\mathrm{Max}}\{X_{ij}\} - X_{ij}}{\underset{i}{\mathrm{Max}}\{X_{ij}\} - \underset{i}{\mathrm{Min}}\{X_{ij}\}} \quad (2)$$

where: x_{ij} is normalized value; X_{ij} is raw data of the i^{th} sub-index at j^{th} administrative unit; Max{X_{ij}} and Min{X_{ij}} is the maximum and minimum values of *ith* sub-index, respectively.

Step 2: Calculate weights

This study chose the unequal weight method proposed by Iyengar and Sudarshan (1982). A brief summary of this method is given below:

The weights of each sub-index is determined by:

$$w_j = \frac{C}{\sqrt{Var(x_j)}} \quad (3)$$

where: w_j: weight of the sub-index j of E, S and AC; Var(x_j) is variance of sub-index j determined by:

$$Var_{xj} = \sum_{j=1}^{n} \frac{\left(x_{ij} - \overline{x}_j\right)^2}{(n-1)}$$

C is normalizing constant and is determined by:

$$C = \left[\sum_{j=1}^{m} \frac{1}{\sqrt{Var(x_j)}}\right]^{-1} \quad (4)$$

where: *m*: the number of sub-indices;

Note that the sum of weights of each sub-index group must equal 1.

$$\sum_{j=1}^{K} w_j(E,S,AC) = 1$$

$$0 < w_j < 1$$

After identifying the weights, values of each sub-index group are determined by:

$$M_i = \sum_{J=1}^{N} w_j x_{ij} \quad (5)$$

i = 1 ÷ m, the number of administrative units.

where: M_{ij}: value of sub-index group j of administrative unit i; W_j: weight of sub-index j.

Step 3: Construction of vulnerable index (VI)

After identifying the weights and the values of each sub-index group, we calculate the value of each major component (E, S and AC) for each administrative unit. For example, the exposure component is determined by:

$$E_i = \left(\sum_{i=1}^{n} M_i \times m_{M_i}\right) / m \quad (6)$$

Where: E_i is value of exposure of administrative unit i_{th}, m_{Mi} is the number of sub-indices of M_i and m the total number of sub-index groups.

Repeat the same calculation for S and AC. Finally, the vulnerable index (of each districts) is defined as:

$$V_i = \frac{\left(E_i + S_i + AC_i\right)}{3} \qquad (7)$$

3. Results and discussions

Identifying vulnerable factors is an important step to determine the relationships between the factors (presented as sub-indices) and vulnerable components so that the correct standardized function will be applied. Sub-index group will be determined as a basis for calculating the value of the main component E, S and AC. Table 1 below lists the sub-indices (in groups) of the main components with the trend of relations with vulnerability index VI. The exposure-index group such as climate fluctuations (rainfall - E_1, temperature - E_2) is determined from the climate change scenario for Tuyen Quang (RCP Scenario 4.5); The sensitive-index group (structure and agroforestry area - S_1, socio-economic - S_2, the area of food crops and industry - S_3, livestock - fishery - water demand - S_4) is determined from the statistics data. The adaptation-index group (Agricultural, Forestry, Aquaculture - AC_1, Education - Health - Infrastructure - AC_2) is determined from statistics data.

Table 1. Indices and relationship with CVI

No	Components	Indices	Relationship with CVI
I	**Exposure**		
1	Climate variability - indices of precipitation	Minimum changes of precipitation in the winter	↓
2		Maximum changes of precipitation in the winter (E1-2)	↑
3		Minimum changes of precipitation in the summer (E1-3)	↓
4		Maximum changes of precipitation in the summer (E1-4)	↑
5		Minimum changes of annual precipitation (E1-5)	↓
6		Maximum changes of annual precipitation (E1-6)	↑
7		Minimum changes of maximum daily precipitation (E1-7)	↓
8		Maximum changes of maximum daily precipitation (E1-8)	↑
9		Minimum changes ofmaximum 5-day average precipitation (E1-9)	↓
10		Maximum changes ofmaximum 5-day average precipitation (E1-10)	↑
11	Climate variability - indices of temperature (E2)	Minimum changes of minimum temperature (E2-1)	↓
12		Maximum changes of minimum temperature (E2-2)	↑
13		Minimum changes of maximum temperature (E2-3)	↓
14		Maximum changes of maximum temperature (E2-4)	↑
15		Minimum changes of average temperature in the summer (E2-5)	↓
16		Maximum changes of average temperature in the summer (E2-6)	↑
17		Minimum changes of average temperature in the winter (E2-7)	↓
18		Maximum changes of average temperature in the winter (E2-8)	↑
19		Minimum changes of annual temperature (E2-9)	↓
20		Maximum changes of annual temperature (E2-10)	↑

No	Components	Indices		Relationship with CVI
II	**Sensitivity S**			
1	Agricultural indices (S1)	Percentage of agricultural land (S1-1)		↑
2		Percentage of forestry land (S1-2)		↑
3		Structure of agricultural land (S1-3)		↑
4		Structure of forestry land (S1-4)		↑
5	Social-Economy indices (S2)	Percentage of women (S2-1)		↑
6		Population density (S2-2)		↑
7		Percentage of rural population (S2-3)		↑
8		Number of kindergarten (S2-4)		↑
9		Number of poverty villages (S2-5)		↑
10		Percentage of families to live in poverty (S2-6)		↑
11		Poverty of families to live in poverty threshold (S2-7)		↑
12	Food and Industrial crops indices (S3)	Acreage of food crops (S3-1)		↑
13		Acreage of potatoes and wheat (S3-2)		↑
14		Acreage of sugarcane (S3-4)		↑
15		Acreage of tea (S3-5)		↑
16		Acreage of orange (S3-6)		↑
17	Livestock - Aquaculture - water demand indices (S4)	Number of cattle (S4-1)		↑
18		Number of poultry (S4-2)		↑
19		Acreage of aquaculture (S4-3)		↑
20		Acreage of aquaculture development (S4-4)		↑
21		Water demand of early century (S4-5)		↑
22		percentage of changes of water demand (S4-6)		↑
III	**Adaptive capacity (AC)**			
1	Commercial activities (AC1)	Number of operations (AC1-1)		↓
2		Number of farms (AC1-2)		↓
3		Agricultural manufacturing values (AC1-3)		↓
4		Food-crop yields (AC1-4)		↓
5		Potatoes and wheat yields (AC1-5)		↓
6		Sugarcane yield (AC1-6)		↓
7		Tea yield (AC1-7)		↓
8		Orange yield (AC1-8)		↓
9		Forestry manufacturing values (AC1-9)		↓
10		Aquaculture manufacturing values (AC1-10)		↓
11		Aquaculture yield (AC1-11)		↓
12		Development of aquaculture yield (AC1-12)		↓
13		Cattle yield (AC1-13)		↓

No	Components	Indices	Relationship with CVI
14	Education - Health care and Infra-structure indices (AC2)	Number of teachers (AC2-1)	↓
15		Number of kindergarten schools (AC2-2)	↓
16		Cultural families (AC2-3)	↓
17		Health care development (AC2-4)	↓
18		Total of staff working in health care (AC2-5)	↓
19		Percentage of doctors (AC2-6)	↓
20		Length of road (in km) (AC2-7)	↓
21		Number of female owner (AC2-8)	↓
22		Acreage of forest (AC2-9)	↓
23		Index of forestry development (AC2-10)	↓

The sub-index group $E_{i,j}$, $S_{i,j}$, and $AC_{i,j}$ for each administrative unit at district level in Tuyen Quang province is calculated and normalized according to formula (1) and (2) respectively. The weights of each sub-index is calculated according to (3) and (4). Table 2 shows equations the results of E, S and AC indexes in Tuyen Quang province.

Table 2. Values of groups of each component

No	Units	E1	E2	E3	S1	S2	S3	S4	AC1	AC2
1	Tuyen Quang City	0.570	0.463	0.205	0.257	0.626	0.036	0.138	0.820	0.285
2	Na Hang	0.640	0.193	0.135	0.495	0.372	0.136	0.377	0.833	0.660
3	Chiem Hoa	0.446	0.370	1.000	0.687	0.529	0.479	0.641	0.609	0.507
4	Ham Yen	0.412	0.408	0.452	0.643	0.409	0.689	0.696	0.410	0.489
5	Yen Son	0.513	0.496	0.000	0.687	0.516	0.642	0.703	0.354	0.432
6	Son Duong	0.341	0.913	0.355	0.648	0.553	0.680	0.703	0.397	0.393
7	Lam Binh	0.195	0.333	0.000	0.434	0.341	0.052	0.564	0.894	0.718

The results of E, S, AC calculation of Tuyen Quang administrative units when the weights of each index is calculated according to equations (6). Table 3 shows the results of E, S and AC in indexes Tuyen Quang province.

Table 3. Values of E, S, AC and Vulnerability index VI

No	Units	E	S	AC	VI
1	Tuyen Quang City	0.506	0.334	0.233	0.061
2	Na Hang	0.219	0.218	0.386	0.385
3	Chiem Hoa	0.683	0.614	0.457	0.388
4	Ham Yen	0.729	0.716	0.552	0.539
5	Yen Son	0.526	0.594	0.146	0.484
6	Son Duong	0.568	0.303	0.389	0.124
7	Lam Binh	0.607	0.722	0.394	0.509

The projection of climate change vulnerability indexes (E, S, AC and VI) of agricultural sector by the end of the XXI century calculated for the districts and city of Tuyen Quang province have been normalized once again then classified into 4 levels including: very high, high, medium and low based on the assessment results. Figure 2 shows the maps of exposure, sensitivity, adaptive capacity and climate change vulnerability of agricultural sector of Tuyen Quang province.

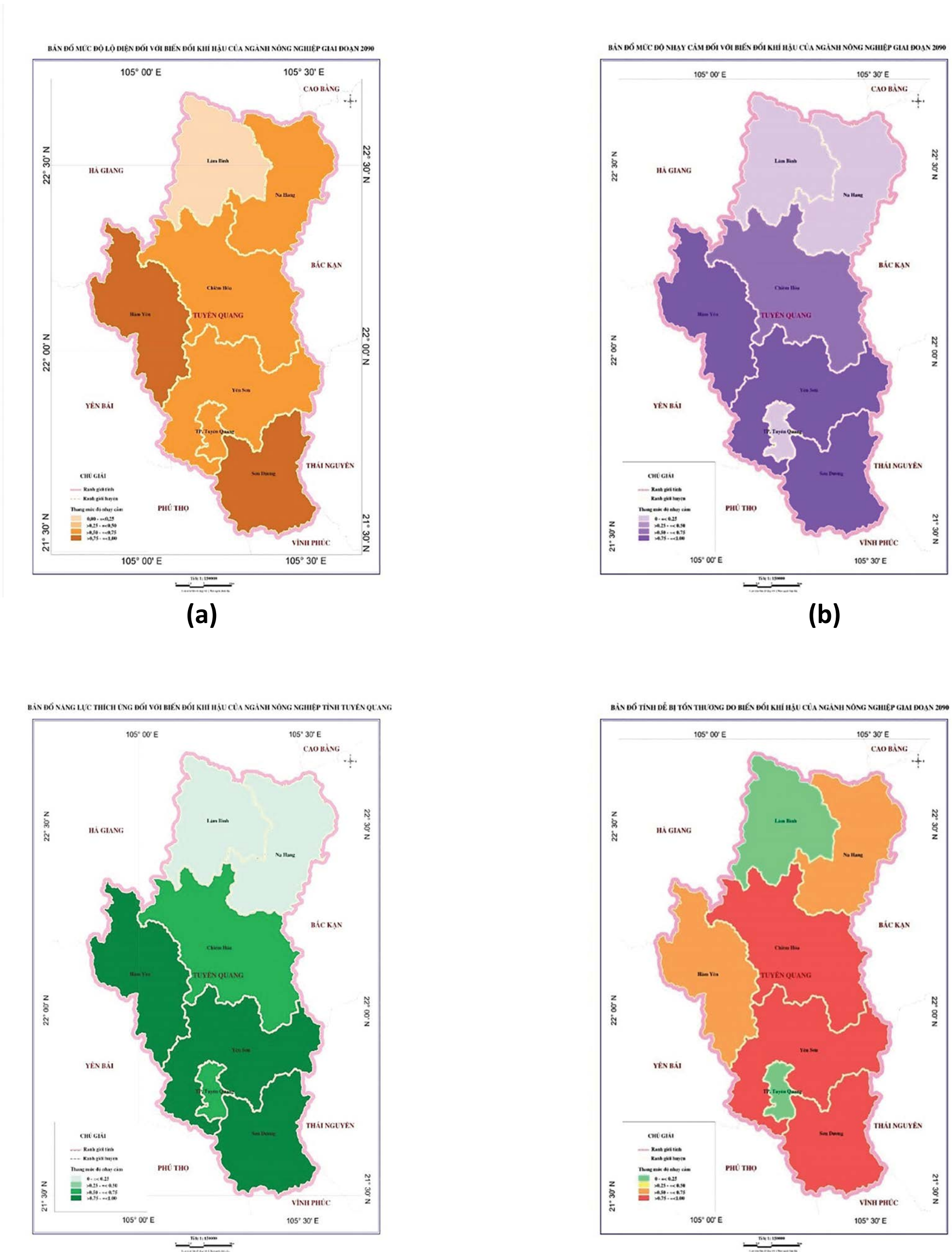

Figure 2. Vulnerability to climate change map for agricultural sector in Tuyen Quang province at the end of century: (a) Exposure; (b) Sensitivity; (c) Adaptive capacity and (d) Vulnerability to climate change

The results show that, Son Duong district is most exposed to climate change impacts. The district is located in the southern area of Tuyen Quang province with large acreage of agricultural and forestry lands thus would be heavily affected by natural disasters. In contrast, Lam Binh district is the least exposed one. This district has high topography that lead to very minor effect of flooding. Other districts that have high level of exposure are Chiem Hoa, Yen Son and Tuyen Quang city. The sensitivity to climate change in agriculture depends on indices of land use, rural population, livestock-cultivation and water demands for agricultural activities. The results show that, by the end of this century, Tuyen Quang city is least sensitive to climate change compared to the rest of other districts and followed by Na Hang. In contrast, Ham Yen,Yen Son and Son Duong are among highest sensitivity districts. The adaptive capacity of administrative units of Tuyen Quang province is assumed unchanged in the future. Yen Son, Son Duong and Ham Yen districts are the highest adaptive capacity. Those districts have active agricultural and other social-economic activities. Tuyen Quang city and Chiem Hoa district are both highly adaptive to climate change. While Tuyen Quang is strong at economic, social and cultural indicators, Chiem Hoa district has a strong position in cultivation and forestry, especially food crops and industrial crops such as sugarcane. Adaptive capacity of Na Hang district and Lam Binh district are low compared to other districts in the province. These areas are often subjected to many natural disasters. Therefore, agricultural activities are difficult that results in low productivity and crop yields. In addition, the economic, social and cultural indicators of these areas are relatively low in comparison with other areas in the province.

The results of vulnerability to climate change in agriculture show that Tuyen Quang city is less vulnerable than other districts in the province. Son Duong, Chiem Hoa and Yen Son districts are high vulnerabe.

4. Conclusions and Recommendations

This article presents a method for calculating the vulnerable index (VI) for Tuyen Quang province. Data are also collected and combined with results from model calculations to ensure the accuracy. The results of VIs are logical and scientific. The calculations are presented in detail and clearly, not too complicated to implement. This provides a useful tool to help local authority to calculate and assess impacts of climate change not only for agriculture but also for other sectors.

The article also points out that data (completeness and reliability) play an important role for the calculation of VI. Therefore, statistical data should be updated and supplemented (at least every 5 years). Indicators of other natural disasters (floods, landslides, droughts,... should also be considered to have a more comprehensive assessment. In addition, recent studies have shown the need to integrate climate change into socio-economic development planning. Especially, the integration of climate change into development planning processes (mainstreaming) through strategic environmental assessments at local level can be very beneficial. This contributes to enhance the autonomy of local prevention against the adverse effects of climate change.

References

1. Allison et al. (2009), *Vulnerability of national economies to the impacts of climate change on fisheries*, FISH and FISHERIES, Blackwell Publishing Ltd.
2. Dow, K. and Downing, T.E. (2005), *The Atlas of Climate Change:Mapping the World's Greatest Challenge*, Berkeley: University of California Press.
3. Hahn, M.B., Riederer, A.M. and Foster ,S.O. (2009), *The Livelihood Vulnerability Index: Apragmatic approach to assessing risks from climate variability and change,* A case study in Mozambique,

Global Environmental Change.
4. Heltberg, R., Siegel,P.B. and Jorgensen, S.L. (2009), "Addressing human vulnerability to climate change: Toward a ‘no-regrets’ approach", *Global Environmental Change*, 19(1), 89-99.
5. IMHEN (2011), *A guidance for climate change impact assessment and adaptation measures*, Viet Nam Publishing House of Natural Resources, Environment and Cartography, Hanoi (In Vietnamese).
6. IPCC (1990), *Climate Change 1990: Impacts Assessment of Climate Change. Contribution of Working Group II to the First Assessment Report of the IPCC*, Australian Government Publishing Service, Canberra, Australia, 294 pp.
7. IPCC (1995), *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses*, Contribution of Working Group II to the Second Assessment Report of the IPCC.
8. IPCC (2007), *Climate Change 2007: Impacts, Adaptation and Vulnerability.Contribution of Working Group II to the Fourth Assessment Report of the IPCC*, Cambridge University Press, Cambridge, UK, 976pp.
9. IPCC (2001), *Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the IPCC*, Cambridge University Press, Cambridge, 1032pp.
10. MONRE (2016), *Climate change and sea level rise scenario for Viet Nam*, Viet Nam Publishing House of Natural Resources, Environment and Cartography, Hanoi (In Vietnamese).
11. Moss, R.H., Malone,E.L. and Brenkert, A.L. (2002), *Vulnerability to climate change:A quantitative approach,* Joint Global Change Research Institute.
12. Polsky, C., Neff,R. and YarnalB. (2007), “Building comparable global change vulnerability assessments: the vulnerability scoping diagram”, *Global Environmental Change,* 17(3-4), 472-485.
13. Sherbinin,A., Schiller,A. and Pulsiphe,A. (2006), “The vulnerability of global cities to climate hazards”, *Environment & Urbanisation*, (12), 93-102.
14. Torresan, S., Critto, A., Valle, M.D, Harvey, N. and Marcomini, A. (2008), *Assessing coastal vulnerability to climate change: Comparing segmentation at global and regional scale*s, Sustainability Science.