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Vulnerability Index to Climate Change and its Application for Community-level Risk Assessment in Thailand

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Abstract

On the basis of the vulnerability-led approach, the Prevalent Community-level Vulnerability Index (PCVI) was developed as a simple composite index used to represent community-level vulnerability to climate change in the socioeconomic and hazard contexts. The PCVI consists of three major components which are Exposure & hazard, Socioeconomic-ecological fragility and Coping capacity. All of these components are further comprised of different indicators, representing different aspects of biophysical and social vulnerability of grass-root communities. Based on the results analyzed in the provincial pilot sites, the PCVI could represent both spatial patterns and magnitudes of vulnerability of each community in consistence with the local economic-social-environmental contexts. It generally reflects the differences in the local contexts and factors that determine overall vulnerability of each community. For the ease in calculating the PCVI especially for the provincial operating staffs and general public, the PREvalent Community Climate Change Vulnerability Tool (RECCC) was further developed as a user-friendly, Excel-based program. In conclusions, the outputs of this study that include the PCVI and its database as well as the RECCC program are useful not only for analyzing vulnerability and assessing risks of community to climate change, but also for supporting decision-making process in developing and implementing adaptation activities at provincial level. These outputs were also designed for further integrating as a supplementary part of Provincial's Decision Supporting System (DSS), with the purpose of promoting the participation of local organizations and stakeholders in coping with the adverse impacts of climate change. However, additional development of ERCCC program, together with dissemination of the vulnerability framework as well as the use of ERCCC program to local organizations needs to be continued.

Keywords: vulnerability; climate change; community; PCVI; RECCC

1. Introduction

Recent studies have indicated that Thailand is vulnerable to climate change. Many parts of the country have experienced changes in various climate-induced disasters such as flood, drought and heavy precipitation events that nowadays tend to increase both frequency and severity (Boonpragob *et al.,* 2011). In the early 2011, for example, the worst summer flooding unprecedentedly hit the South, causing severe damages in ten provinces that affected more than two millions of people and destroyed agricultural areas more than 160,000 hectares (Department of Disaster Prevention and Mitigation, 2011). A few months afterwards, there was the mega flood that hit 83% of Thailand's provinces, affected millions of people and left more than 800 people dead (World Bank, 2012; Rakwatin *et al.,* 2013). Economic losses were estimated at THB1.4 trillion (USD 45.7 billion), which make the flood of 2011 the costliest natural disaster events in Thai history (AON Benfield, 2012; World Bank, 2012). Given immensely high socioeconomic impacts of climate change and its extremes, appropriate measures for local communities in reducing the adverse impacts yet enhancing adaptive capacity pose scientific challenges. Methodological development for vulnerability analysis and risk assessment from climate change that is suitable for local context is therefore the first step to generate understanding and enhancing the potential of local organizations as well as to promote public participation in coping with such impacts. In this study, the community-level vulnerability index to climate change was developed as a simple tool for describing and illustrating the biophysical and social vulnerability in the pilot sites. Furthermore, a user-friendly, Excel-based program used to facilitate vulnerability index calculation for the operating staffs at provincial level and general public has been introduced.

2. Conceptual framework and analytical approaches for assessing climate change vulnerability

Vulnerability in the context of climate change is an interlink function of exposure, sensitivity and adaptive capacity (Adger, 2006). Basically, vulnerability falls into two categories which are biophysical and social vulnerability. Biophysical vulnerability is concerned with the ultimate impacts of a hazard event and is often viewed in terms of a function of the frequency and severity of a given type of hazard (Adger *et al.,* 2004). This vulnerability is usually measured by indicators such as monetary cost, human mortality and production cost (Adger *et al.,* 2004). Whereas, social vulnerability is known as an inherent property of a system arising come of a hazard event of a given nature and severity (Adger *et al.,* 2004). In the simple mathematical sense, biophysical vulnerability can be expressed as a combination of hazard and social vulnerability. Biophysical vulnerability has much common with the concept of risk with its definition based on the probability of occurrence of hazard, the likely consequences and social vulnerability (Adger *et al.,* 2004; Adger, 2006).

Integrated frameworks for assessing vulnerability to climate change have been steadily developed. The early studies relied on the models that show the human response to climate hazard rather than social conditions (Burton *et al.,* 1993). In the later studies, more social aspects have been incorporated as they play a crucial role in determining more complex status and dynamics of a system such as Pressure and Release (PAR) Model (Blaikie *et al.,* 1994). Cutter (1996) developed Hazard-of-place (HOP) model. In this conceptualization, risk interacts with mitigation to produce the hazard potential which is either moderated or enhanced by a geographical filter as well as the social fabric of the place. Finally, the social and biophysical vulnerability interacts to produce the overall place vulnerability.

Vulnerability assessments under the United Nations Framework on Climate Change Convention (UNFCCC) are classified into two groups which are top-down (impact-based) and bottom-up (vulnerability-based) approaches (UNFCCC, 2004). The impact-based approach employs scenarios downscaled from general circulation models (GCMs) to the national and sub-national scales, aiming to determine the likely impacts of climate change under alternation of future scenarios. Projections derived from GCMs are usually combined with biophysical analyzes and socio-economic scenarios in order to assess sector-specific impacts (UNFCCC, 2004). Spatial and temporal differences are often averaged out and trend curves are generally smooth, so that short-term changes, threshold effects and localized costs are not easily identified. Bottom-up approaches, on the other hand, focus on local level, community specific circumstances and short-term effects (UNFCCC, 2004). They tend to be qualitative and place-based and employ participatory approaches extensively. Vulnerability assessments gather information on a wide range of socio-economic issues that reflect exposure and vulnerability, as well as local options, coping strategies and adaptive capacities.

Based on above-mentioned frameworks, vulnerability analysis encounters various qualitative and quantitative methods. Participatory stakeholder approaches are a common tool for qualitative vulnerability assessment while the indicators which represent a characteristic or a parameter of a system of interest are usually used quantitative measures of vulnerability (Cutter *et al.,* 2009). The methodological development of vulnerability indices is focused on three major decisions: 1) the scale of the index; 2) the explicit proxies (or variables) included in the index; and 3) the method of aggregation (Cutter et al., 2009). Data and variables used to create indicators are usually selected on the basis of theoretical framework and functional relationships or combination of both. The criteria for indicator selection should be further based on simple, easily reproducible and transparent for the user. Gall (2007) analyzed and compared seven indices that have been used to measure vulnerability at regional/global scales. Four of them are social vulnerability which is Prevalent Vulnerability Index (PVI), Social Vulnerability to Climate Change for Africa (SVA), Disaster Risk Index (DRI) and Predictive Indicators of Vulnerability (PIV) while the remaining three indices which are Human Development Index (HDI), Human Well-being Index (HWI) and Environmental Sustainability Index (ESI) measure quality of life and sustainable development. The study of Gall (2007) revealed that all indices can satisfactorily present and describe socioeconomic status which indicates different potentials for adapting to natural disasters.

3. Data and Methods

On the basis of extensive reviews of the conceptual framework and analytical approaches, this study initially developed the vulnerability index to climate change as a simple composite indicator. The index developed is used to represent and describe community-level vulnerability in two pilot provinces which are Phang-nga and Burirum, and further extended the results in the first phase to develop the simple computer program for processing and calculating the index for the provincial operating staffs. These provinces were chosen on the basis of geographic contexts and natural hazard prone areas. The developed tools were designed for further

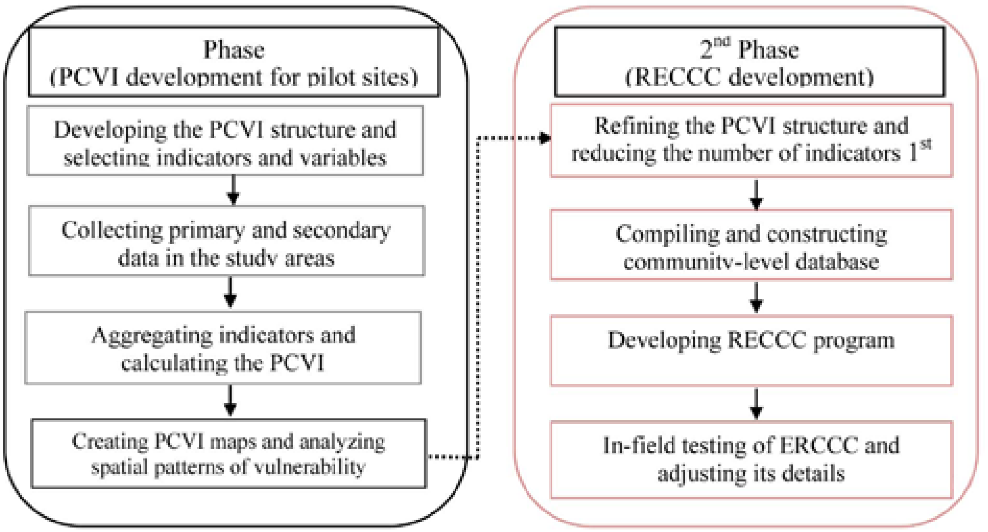

Figure 1. Major processes in developing the community-level vulnerability index to climate change

integration to Province's Decision Supporting System (DSS) that can be widely applied for climate-related disaster management in other areas. The Prevalent Community-level Vulnerability Index (PCVI) was developed based on vulnerability-led approach and the PAR/HOP models which consider local vulnerability in the context of multi-stressors of climatic and non-climatic factors. The PCVI and its sub-component indicators were derived primarily from socioeconomic, environmental and disaster data as well as physical settings and livelihoods of community that were compiled from relevant agencies and directly collected from the field. Geographical Information System (GIS) technique was applied for analyzing spatial patterns of vulnerability. The main processes in developing the PCVI index and its simple processing program consist of 1) constructing the PCVI and selecting the major components and sub-indices of the PCVI, 2) compiling and constructing community-level database of disaster, socioeconomic, environment and GIS for each province, 3) developing elements and output system of the simple processing program (PREvalent Community Climate Change Vulnerability Tool; RECCC), and 4) testing the RECCC in the field and adjusting its details. Fig. 1 shows the main processes of the study.

4. Results

4.1. The PCVI structure and components

Structure of the PCVI consists of three major components which are Hazard & exposure, Socioeconomic-ecological fragility and Coping capacity (Fig. 2). The PCVI considered 31 indicators in total, and compressed indicators into a composite index through two levels of aggregation. Basically, the indicators represent many aspects of hazard exposure, socioeconomic sensitivity and biophysical dimensions of the community. These indicators were further reduced to 10 sub-indices which were fused into the final index. Every aggregation was achieved by uniform weighting, i.e. input factors (indicators and sub-indices) were averaged using the arithmetic mean. In other words, the PCVI is an average its sub-indices which are an average of their indicators. Prior to numerical aggregation, indicators underwent numerous processing steps to enable comparison. It included 1) standardization, 2) imputation of missing variables, 3) scale and z-score transformations, 4) directional adjustment and 5) minimum-maximum normalization. The main equation used to calculate the final score of PCVI is also shown in Fig. 2. It is a balance between Coping capacity and sum of Hazard & exposure and Socioeconomic-ecological fragility.

It should be noted that the PCVI is a hybrid version of Prevalent Vulnerability Index (PVI) which is social vulnerability developed by Inter-American Development Bank (Cardona, 2007) and Livelihood Vulnerability Index (LVI) based on Intergovernmental Panel on Climate Change (IPCC)'s definition which Hahn *et al.* (2009) used to assess community-level vulnerability to climate change in the Mozambique. Table 1 compares the major components of PCVI and those of PVI and IPCC's definition. Overall, the PCVI represents risk, sensitivity and coping capacity that are believed to capture important issues of vulnerability at grass-root communities. Scale consistency between data used and indicators chosen as well as methods employed to address quality of the complied community-level data, together with explicit adoption of a theoretical

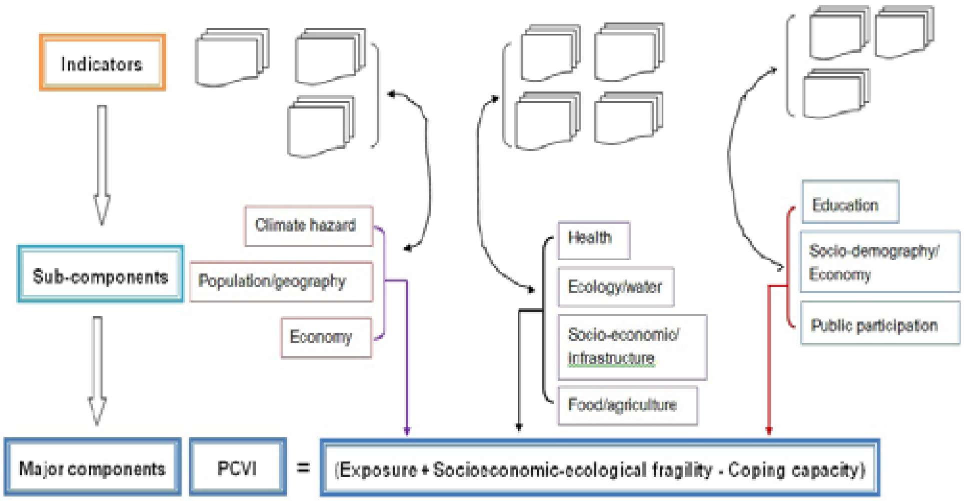

Figure 2. Structure, major components, sub-indices and indicators of the PCVI

vulnerability framework also ensures that the PCVI is applicable for addressing community-level vulnerability of the pilot provinces.

4.2. The PCVI and its spatial patterns in the pilot provinces

The scores of each major component of the PCVI after scale adjustment with minimum-maximum normalization and subsequent calculation based on the additive model for both provinces showed similarity with normal distributions. It was found that the values within 60% ranges from the means were relatively in balance. Spatial maps of major components of the PCVI in both provinces are illustrated in Figs. 3 and 4. The Exposure & hazard scores in Phang-nga and Burirum provinces ranged from 0.78-6.94 and 1.60-7.53, respectively. Most of them (> 60%) were lower than 4, whereas the values greater than 6 accounted for 1.6%. The first top ten highest values of the Exposure & hazard scores in Phanag-nga province were found in the communities located in Takuapa and Kaphong districts, whereas, in Burirum province, they appeared in Lam Plai Mat, Satuk, Napho, Phlapphlachai and Chaloem Phra Kiat districts (Figs. 3a and 3b). These higher values of the Exposure & hazard scores indicate greater risk and exposure to climate-related disasters of those communities compared to others. A further examination showed that geographical contexts especially the community locations prone to hazards in combination of more frequent occurrence of climate-related disasters in the recent years in those communities were major contributors to their greater risk and exposure.

The Socioeconomic-ecological fragility map for Phang-nga province showed higher than normal values in the communities located in Khura Buri, Kaphong, Muang, Thai Mueang, Thap Put and Takua Thung districts, indicating higher sensitivity of communities to hazards and environmental changes (Fig. 3c). Note that the lower score values of Socioeconomic-ecological fragility could be seen in Takuapa district. For Burirum province, most scores of Socioeconomic-ecological fragility as shown in the map had the values greater than 4 (Fig. 3d), implying that socioeconomic-ecological sensitivity is somewhat high. The first ten highest values of the Socioeconomic-ecological fragility scores were found in Mung, Chaloem Phra Kiat, Lam Plai Mat, Krasang, Nang Rong, Lahan Sai and Prakhon Chai districts.

The PCVI component in terms of coping capacity for both provinces had similar patterns. That is to say, most of coping capacity score (> 80%) had values

Table 1. Comparison of major components of the PCVI and those of the PVI and IPCC's definition index

PCVI	PVI	IPCC-definition index
1. Hazard & exposure	1. Exposure	1. Exposure
2. Socioeconomic-ecological fragility	2. Socioeconomic-ecological fragility	2. Sensitivity
		3. Adaptive capacity
3. Coping capacity	3. Resilience	

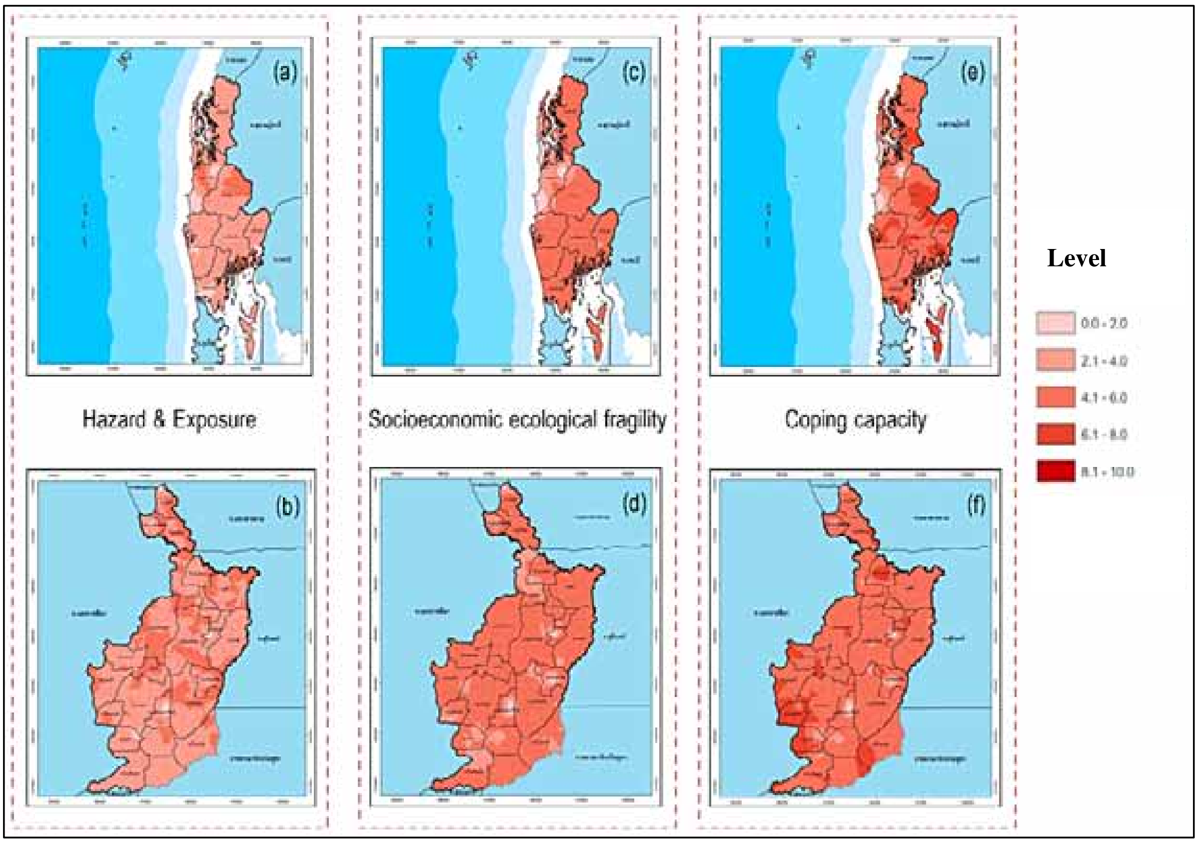

Figure 3. Maps of Hazards & exposure, Socioeconomic-ecological fragility and Coping capacity for Phang-nga (a, c, e) and Burirum (b, d, f) provinces

greater than 5, indicating that coping capacity as a whole when considering all relevant indicators into account had medium to high levels (Figs. 3e and 3f). However, low scores of coping capacity in Phangng-nga appeared in the communities located near the coast in the Takuapa district (Fig. 3e). Note that these communities were affected by the 2004 Indian Ocean Tsunami. For Burirum province, the communities with low coping capacity were found in some communities in Chaloem Phra Kiat, Lahan Sai, Phlapphlachai and Pakham (Fig. 3f).

The PCVI maps which represent spatial vulnerability of communities in Phang-nga and Burirum provinces were made by overlaying the individual map of Exposure & hazard, Socioeconomic-ecological fragility and Coping capacity through the equation shown in the Fig. 2. Based on the PCVI maps, it was found that most of communities in Phang-nga province had vulnerability in the normal range which the maximum frequency of PCVI was in range of 1.5-3. The communities with the vulnerability greater than average were observed in Khura Buri, Thai Mueang and Takua Thung districts (Fig. 4). When considered the first top ten communities with highest vulnerability in Phang-nga, they were situated in Takuapa, Kaphong and Khura Buri districts. In case of the PCVI map for Burirum province, the results showed that vulnerability of most communities was lower and comparable level with that of Phang-nga province. Note that the PCVI values were mostly lower than 3 (Fig. 4). These results might indicate that overall vulnerability of Burirum province, taking Exposure & hazard, Socio-economic-ecological fragility and Coping capacity into account, was considerably lower than that of Phanag-nga province. On the basis of analysis of the PCVI map, the communities which vulnerability was higher than mean (PCVI greater than 3) appeared in Phutthaisong, Satuk, Mung, Khu Mung, Krasang, Lam Plai Mat, Chamni, Prakhon Chai, Chaloem Phra Kiat and Lahan Sai districts (Fig. 4). The first top ten communities with highest vulnerability in Burirum province were found in Mung, Satuk and Lam Plai Mat districts.

4.3. RECCC program for processing and calculating the PCVI

For the ease for the provincial operating staffs in processing and calculating the PCVI with the ERCCC program, the PCVI structure was further modified to remain only the major components and indicators. The number of indicators of each major component was then reduced to be only 5 indicators. Totally, the indicators used to calculating the PCVI in the ERCCC program were 15 indicators. These indicators were

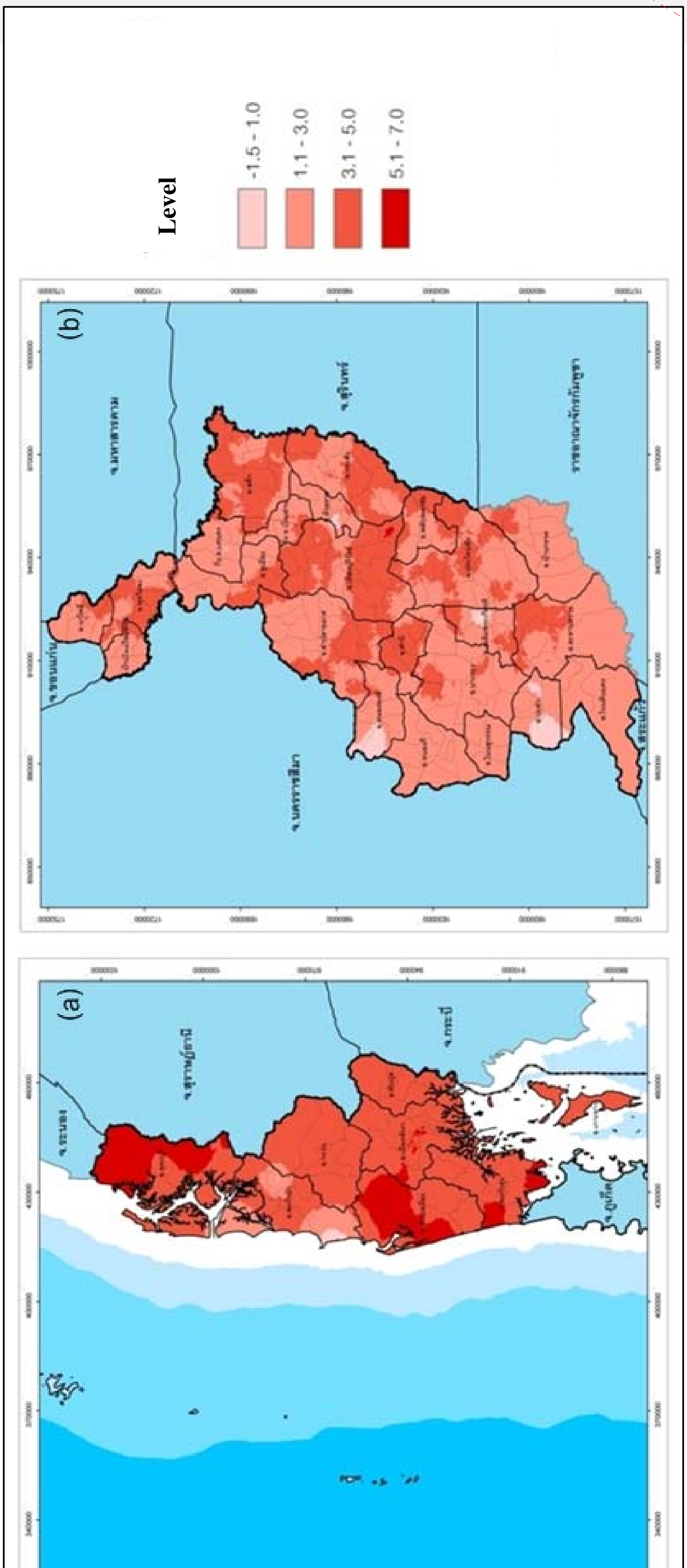

Figure 4. The PCVI maps for Phang-nga and Burirum provinces

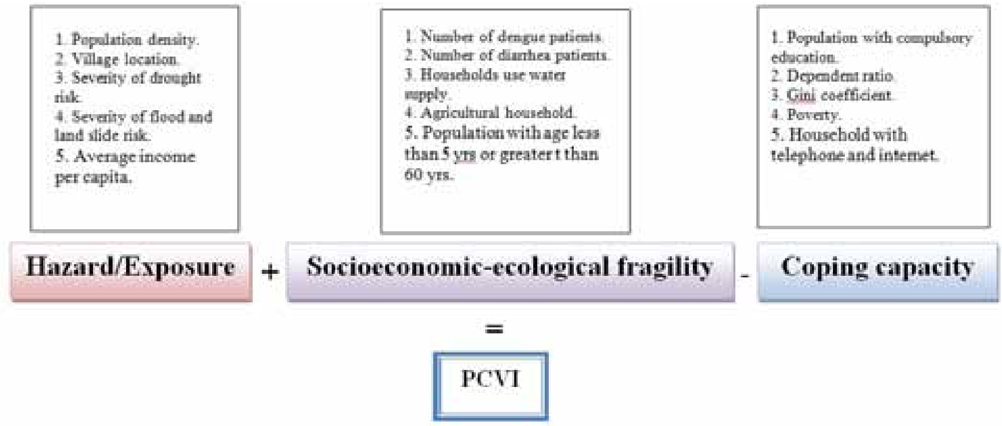

Figure 5. The structure of modified PCVI and indicators used for the ERCCC program

selected, since they are the main indicators expressing the important aspects of Exposure & hazard, Socioeconomic-ecological fragility and Coping capacity at the community level, which secondary data can be easily compiled and extracted from relevant provincial organizations. Fig. 5 shows the structure of modified PCVI and indicators used for the ERCCC program. Furthermore, the community-level database for socioeconomic, environment, disasters and GIS essential for calculating the PCVI were made for 39 provinces in this phase. The ERCCC program used to calculating and analyzing the PCVI was developed on the basis of macro functions of Microsoft Excel program. The developed program is capable for checking the quality of data, processing the missing values, calculating the scores of each component as well as the PCVI. Based on the in-field testing results with the operating staffs in Chonburi and Nakhon Ratchisima provinces, it was found that the provincial staffs with a less expertise in computer and climate change vulnerability could successfully deploy the RECCC program in terms of program installation, data inputs and quality control and the PCVI calculation. However, the data from field survey are further needed to compare co-consistency between the PCVI maps produced in Fig. 6 and real situations of local communities.

5. Discussions and conclusions

This study attempted to apply the framework of vulnerability to climate change with the index development to represent and describe community-level vulnerability. The products of the study includes database for calculating the PCVI, the major components of vulnerability as well as the RECCC program which is a simple processing tool for calculating community-level vulnerability. On the basis of the results applied in the Phang-nga and Burirum provinces, the spatial patterns of the PCVI could satisfactorily represent community-level vulnerability in consistence with the local contexts in terms of socio-economic, environment and climate-related climate. In brief, the PCVI indicated the communities with vulnerability greater than normal in both provinces where their geographical settings were prone to hazards and climate-related disasters were observed to frequently occur in the recent years. To our knowledge, this is one of initiatives to create simple mechanism in bridging between research processes and result dissemination and application at the community level. This is in line with the context of Article 5 (Research and Systematic Observation) and Article 6 (Education, Training and Public awareness) of UNFCCC. Database management and development of simple tools supporting the measures in coping with climate change problem are a particular focus of two article linkages. The outputs of this study are, of course, useful for community-level vulnerability and risk analysis from climate-related disasters. They can also be applied as a supporting tool for policy decision making processes at provincial level in prioritizing the communities needed immediate actions for socioeconomic development and adaptation to climate change and disasters. This database can be connected to the Provincial Decision Supporting System and other existing data bases of province, district and sub-district to support various activities of local organizations. In addition, the ERCCC program is a simple tool, enabling the provincial operating staffs in processing vulnerability to climate change and presenting this information to provincial governance, for further integrating it into adaptation plans and measures.

To enhance the efficiency and capability of the ERCCC program, however, the issues needed to be done in the next phase include 1) additional development of the ERCCC functions especially connection of the calculated results with GIS to present them as a map, 2) dissemination of vulnerability framework and the ERCCC program to local organizations and interesting

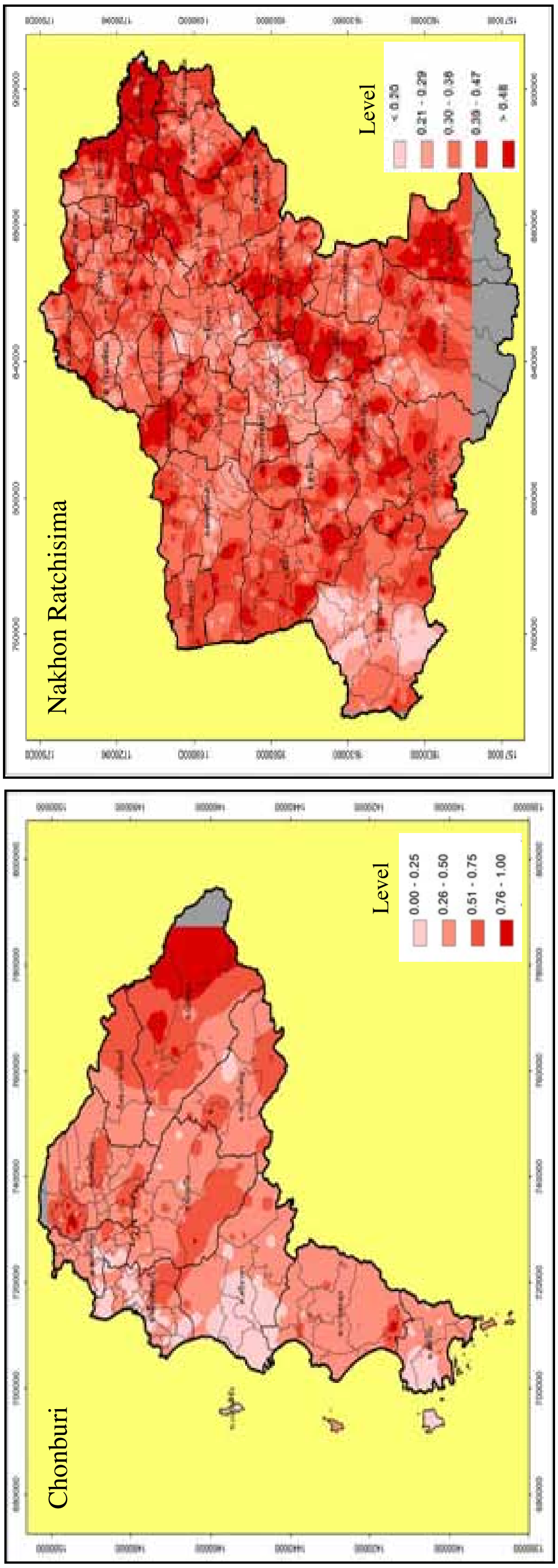

Figure 6. The PCVI maps for Chonburi and NaKhon Ratchisima provinces, made by the operating provincial staffs during the in-filed test of RECCC.

public, 3) capacity building of the provincial operating staff in updating the community-level database of socioeconomic, environment, disasters and GIS through training workshop, and 4) demonstration of integration of the ERCCC program into DSS of the provincial organizations and its application for development and adaptation to disasters in the pilot sites.

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