*Research article*

# Toward Measuring the Vulnerability of Agricultural Production to Flood: Insight from Sangkae River Catchment, Battambang Province, Cambodia

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**Abstract** The study proposes an indicator-based analysis on the vulnerability of agricultural production to flood issues in a river catchment area. The study site is the Sangkae River catchment area located in the Northwestern region of Cambodia and the unit of observation is the commune. Flood hazards are not restricted to the downstream lowland Tonle Sap plain; the study also considers river overflow and run-off flood events occurring upstream in Sangkae River catchment. We address the concept of vulnerability in three dimensions (exposure, sensitivity and adaptation capacity) and operationalize it in a multi-level analytical framework.We first identify indicators relevant with each of the three dimensions of vulnerability. We then combine the standardized and weighted indicators into composite exposure, sensitivity and adaptive capacity indexes, which we analyze statistically and spatially with a geographic information system. We further integrate the indicators in a hierarchical cluster analysis to establish a typology of commune vulnerability across the catchment. The results of the study showed the link between the vulnerability of agriculture to flood and the different farming systems of rural communities.

**Keywords** flood management, vulnerability assessment, agricultural production, watershed management, Cambodia

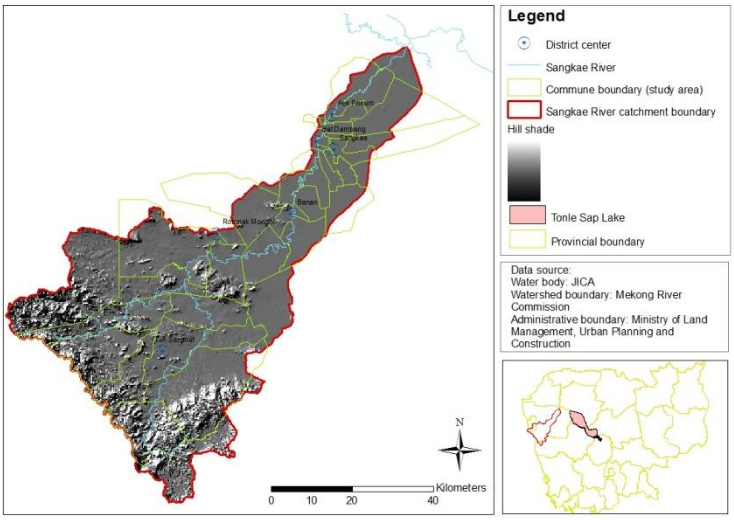
## INTRODUCTION

Cambodia is one of the most vulnerable countries to climate change in Southeast Asia (Yusuf and Fransico, 2009). The processes of climate change are complex and diversified but are mainly at play through the intensification of the water cycle (Huntington, 2006). Climate change increases the occurrences of extreme weather phenomena, such as heavy rainfall, flood, drought, storms, etc. (Solomon et al, 2007). The modification of rainfall pattern has affected the water level of Mekong River and Tonle Sap Lake (MRC, 2010). Due to the river run-off from upper Mekong River, the water level of the Tonle Sap is projected to increase from 1 meter to 2.3 meters by the year 2030 (Eastham et al., 2008).

However, flood is not a new phenomenon in Cambodia. Many parts of the country have flooding experiences every year, particularly in the central area of the country where floods are associated with the reversal of water in the Tonle Sap River and the flooding of the large Cambodian central plain. People have developed ways to practice agriculture and fishing, which are well adapted to this unique phenomenon. As Suon rightly put, floods are usually good for rice-based agriculture but their irregularity and unpredictability bring negative impact on agricultural production and rural livelihood systems (Suon, 2007). Major flood events, such as the one that occurred in 2011, had for instance very serious consequences in the Cambodia economy. The loss of agricultural productions and degradation of physical infrastructures were worth over $400 million (CRED, 2011).

Over the last 10 years, Battambang has witnessed a dramatic agricultural colonization of peripheral forest areas. Forest cover has become the substitute for agro-industrial cash crops very rapidly, in a process fuelled by important internal immigration movements of people coming from the lowland densely populated areas (PMPSWG, 2011). The conversion of the upland evergreen forest areas into agricultural land is also very likely to affect the hydrological system and to increase surface and river water run-off (Kirsch, 2010). Future flood patterns are thus very likely to be modified by the combined effect of climate and land use change. These transformations are very likely to result in a change in agricultural production and the challenges at stake are important as agriculture is the main source of livelihood for a very large majority of Cambodian household living in the rural and who make up to 80% of the entire population (RGC, 2010a). Flooding may contribute to increased poverty in rural Cambodia and have serious consequences in terms of availability and accessibility to food (NAPA, 2006; Helmers and Jegillos, 2004).

Flood risk management has been considered as key priority for poverty alleviation and development of Cambodia (RGC, 2010b). Several institutions and committees have been established from national down to local level to respond to natural disasters (Committee for Disaster Management). In Battambang province, principles and concepts of Integrated Water Resources Management (IWRM) have been introduced for the management of water resources at the catchment level (Yem, et al., 2011) and integrated in the provincial spatial plan (PMPSWG, 2011). However, weak cross-sector coordination and the lack of tools to support decision-making have considerably impeded effective flood management (Eng, 2009). The involvement and participation of Battambang Provincial Spatial Planning Team in this research process can be viewed as a first step toward the design of a flood management, decision-making tool for provincial authorities.



Data source:
Water body: JICA
Watershed boundary: Mekong River Commission
Administrative boundary: Ministry of Land Management, Urban Planning and Construction

Fig. 1 Sangkae River catchment area

## OBJECTIVE

The study aims to achieve two things. First, we aim to understand the vulnerability of agricultural production in Sangkae River catchment area and second, to provide recommendations to improve flood management as part of an integrated water resource management system.

## METHODOLOGY

### Conceptual framework

The concept of vulnerability of social and environmental systems has a history of several decades. One of the best known definitions was formulated by the International Strategy for Disaster Risk Reduction (UN/ISDR), which defines vulnerability as "the condition determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazard" (UN/ISDR, 2004). Originally envisaged in the context of natural disaster reduction, the concept of vulnerability was further developed with contributions made by climate change scientists (IPCC, 2001). Adger (2006) stresses that vulnerability is most often conceptualized as being constituted by components that include exposure to change or external stresses, sensitivity to change, and the capacity to adapt. Exposure comprises the degree, duration, and/or extent in which the system is in contact with a hazard, or subject to the change (Kasperson et al., 2005; Adger, 2006). Sensitivity is the extent to which a human or natural system can absorb impacts without suffering long-term harm or other significant state change (Adger, 2006). The system's coping capacity (Turner et al., 2003), or capacity of response (Gallopin, 2006), is also called adaptive capacity by the IPCC (2001); Adger (2006) and Smit and Wandel (2006). As noted by Smit and Wandel (2006), some authors apply "coping ability" to shorter-term capacity or the ability to just survive, and employ "adaptive capacity" for longer-term or more sustainable adjustment.

Following the IPCC framework, we address the concept of vulnerability of agriculture production to flood with three lenses: exposure, sensitivity and capacity of responses. While exposure refers to the occurrence, magnitude, and locations of the flood events; sensitivity concerns the impacts of the flood events on agricultural land and production in the River catchment. Capacity of responses deals with both the short-term coping mechanism and long-term adaptive strategy to respond to the flood impacts (Fig.2).

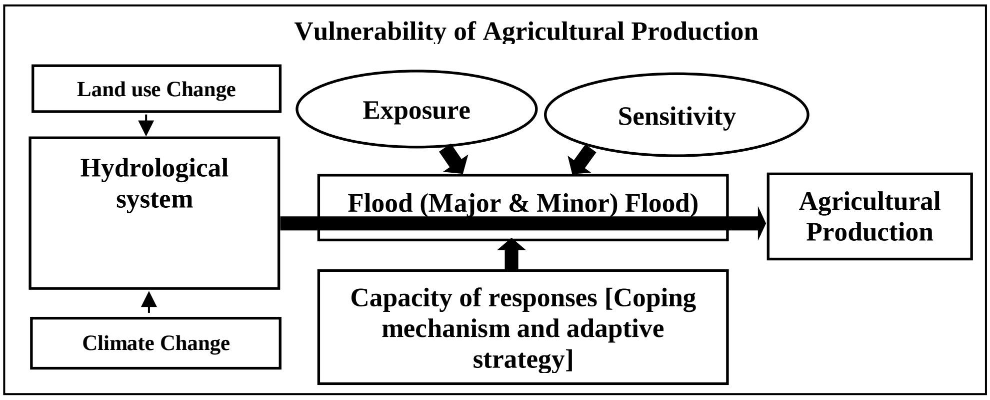
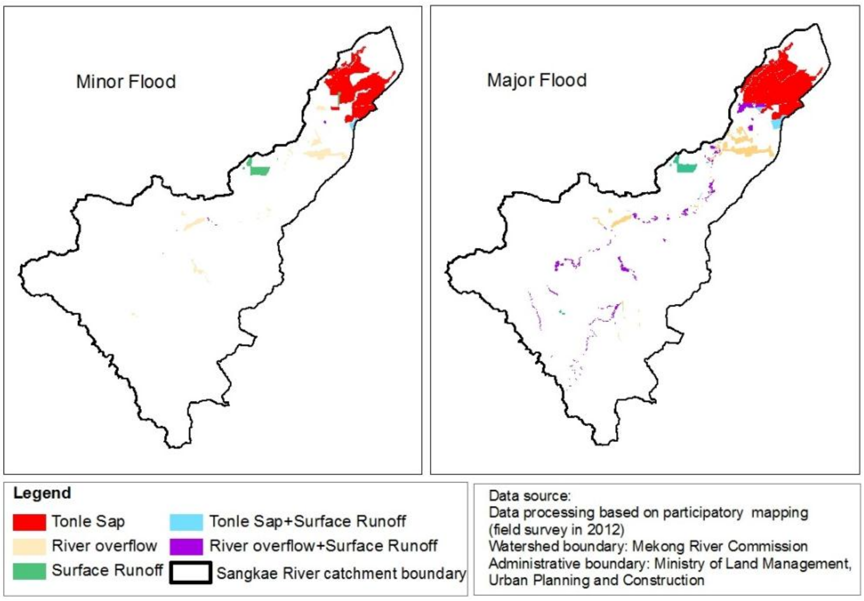


**Fig. 2 Research conceptual framework**

Helmers and Jegillos (2004) reported that there are two types of flood usually occurring in Cambodia: flash flood and central area flood. Flash floods result from heavy downpours upstream on the Mekong River and affect the provinces along the Mekong as well as in the southern areas of the country. The central area floods result from a combination of run-off from the Mekong and heavy rains around the Tonle Sap Lake (Helmers and Jegillos, 2004). We retain the central area flood as one separate type of flood. However, our study differentiates between river overflow flood (Sangkae river and its tributaries) and surface water run-off flood. The combinations of these floods are also considered (Fig. 3). As flood may not solely affect the down-stream part of the Sangkae River catchment (Tonle Sap flood plain), but also the up-stream part of the catchment; we decided to investigate flood in the whole Sangkae River catchment.

According to the Mekong River Commission, flood intensity is classified into three categories: minor flood, medium flood, and major flood, with frequency of occurrence of respectively every one, ten and twenty years (MRC, 2002). Our study focuses on two types of flood: normal flood considered here as a usual annual flood (minor flood according to MRC classification), and the severe 2011 flood, equivalent in magnitude to a medium flood according to MRC classification.



Data source:
Data processing based on participatory mapping (field survey in 2012)
Watershed boundary: Mekong River Commission
Administrative boundary: Ministry of Land Management, Urban Planning and Construction

**Fig. 3 Flood incidence in the Sangkae River catchment**

## Analytical framework

The assessment framework designed to approach, analyze and understand the vulnerability of agricultural production to flood in the study area is based on indicators. Each dimension of vulnerability (exposure, sensitivity and adaptive capacity) is measured through a number of indicators along several data sources (Table 1). The values of each indicator are standardized, weighted by a coefficient determined with local stakeholders and then combined into composite exposure, sensitivity and adaptive capacity indexes, which we analyze spatially with a geographic information system. We compute an overall vulnerability index by using the formula “Vulnerability = [(Exposure +Sensitivity)-Adaptive Capacity]”. We further integrate the indicators in a hierarchical cluster analysis to establish a typology of commune vulnerability across the catchment, which we interpret by computing, for each vulnerability type, the mean values of each index.

## Data collection and tools

Primary data collection on the vulnerability of agricultural production to flood was mainly carried out through commune workshops organized in each commune in 2012 with a group of 10-15 participants for each commune. These workshops started with a participatory flood mapping exercise focusing on the exposure and sensitivity dimensions of vulnerability. The mapping of flood areas in normal year (minor flood) and in 2011 rests on the knowledge of local authorities, as they are the main information providers. Aerial photos retrieved from the Google Earth Pro server (www.googlearth.com) covering the entire communal territory were printed on A0 size paper and were overlaid with plastic covers. The group of participants was invited to identify the main water ways and bodies in the commune as well as the agricultural land areas. They were then asked to map out the agricultural land affected by a usual flood and affected by the 2011 flood and for each flood area, to provide information on the type of flood, their duration and their actual impact on the different agricultural productions. Lastly, a structured questionnaire provided data on the institutional capacity of the commune to adapt to flood. This included questions on i) the efficiency of the flood warning system, ii) the mobilization of self-help groups in case of flood, iii) the existence and efficiency of external support, iv) the allocation of communal funds for post-disaster management, v) the efficiency of the natural disaster management committee, vi) the provision and quality of training programs for farmers and how well these training programs address flood management and vii) the existence of farmer organizations in the commune.

In addition, secondary datasets were consulted to build a number of other indicators. The GIS provincial spatial planning database was useful to calculate indicators based on spatial layers: the agricultural land area and road density network (PMPSWG, 2011). The commune database provided useful updated statistical references for other indicators (http://db.ncdd.gov.kh/cdbonline).

**Table 1 Survey analytical framework**

| Dimension | Indicators | Weight in overall composite index | Data source |
|---|---|---|---|
| Exposure | Major (2011) flood area size, expressed as a percentage of the total agricultural area in the commune | 0.4 | Commune workshop conducted in 2012 |
| | Minor flood area size, expressed as a percentage of the total agricultural area in the commune | 0.4 | |
| | Major (2011) flood area size weighted by the duration of the flood and expressed as a percentage of the total agricultural area in the commune | 0.2 | |
| Sensitivity | Total agricultural land area expressed as a percentage of the total commune area size | 0.3 | Interpretation of Land sat satellite image (2010) |
| | Percentage of population involved in agriculture in the commune | 0.1 | Commune data base (2010 update) |
| | Major (2011) flood area weighted by impact on production and expressed as a percentage of the total agricultural area in the commune. | 0.3 | Commune workshop conducted in 2012 |
| | Total cultivated area during flood period expressed as a percentage of total cultivated area in commune. | 0.3 | Commune data base (2010 update) |
| Adaptive capacity | Institutional capacity of commune | 0.3 | Commune workshop conducted in 2012 |
| | Percentage of population in commune above poverty line | 0.25 | Commune data base (2010 update) |
| | Density of road network in commune | 0.2 | GIS-based calculation based on road information (2010) |
| | Literacy rate in commune | 0.25 | Commune data base (2010 update) |

## RESULTS AND DISCUSION

Annually, flood affects 252.83 km$^2$ of agricultural land area in the Sangkae River catchment. The flooded area in 2011 was 32% larger than the area flooded during a normal flood (Table 2). Among the three different types of floods, the Tonle Sap flood is by far the most important in terms of affected area size and duration, if compared with river overflow and surface run-off floods. However, the difference of flooded area size between a minor flood and the 2011 flood is proportionally much more important for a river overflow and surface run-off flood than for the Tonle Sap flood (54% against 25% increase).In the event of more frequent extreme flood events driven by climate change, our preliminary results suggest that flood management strategy in the catchment should pay greater attention to upper stream areas where floods hit and are likely to become more important in the future.

## Exposure

There are several factors that determine the level of exposure of the communes; the topography, the origin of the flood and flood duration. Figure 4 shows that not only communes located in the Tonle Sap flood plain are exposed to flood. Some communes located in the middle and up-stream also have high exposure levels where the effects of river overflow are aggravated by surface run-off flood (Fig. 4). Second, flooding by Tonle Sap has a longer duration than both of the other types of flood (Table 2). This duration factor reinforces the high exposure levels of the down-stream communes.

**Table 2 Flood impacts, duration and occurrence**

| Flood types | Agriculture flooded area (km$^2$) | | Percentage of increasing flood area size | Duration (mean values in days) | | Occurrence (mode of values) | |
|---|---|---|---|---|---|---|---|
| | major flood | minor flood | | major flood | minor flood | major flood | minor flood |
| Tonle Sap (central area) | 249.94 | 188.45 | 24.60 | 63.6 | 66.35 | Sep-Oct | Sep-Nov |
| Direct river overflow | 62.72 | 46.44 | 54.08 | 15.26 | 23.89 | Aug-Oct | Sep-Oct |
| River overflow & Surface run-off | 40.62 | 1.01 | | 8.31 | 24.75 | Jul-Nov | Aug-Sep |
| Surface run-off | 16.88 | 16.93 | | 32 | 40.25 | Aug-Oct | Aug-Oct |
| Total | 370.16 | 252.83 | 32 | | | | |

## Sensitivity

The factor being the most determinant in explaining the sensitivity of communes to flood is the possibility for the commune to diversify its agriculture production. We refer here to both the development of multi-cropping systems and the development of dry season production. The agro-ecological environment is of primal importance. The communes with high sensitivity are logically the communes in which agriculture land dominates in the land use. Amongst this group, the communes with little crop diversification besides the rain-fed rice are particularly sensitive. For the communes located at the down-stream of Sangkae River catchment where the agro-ecological environment allows for crop diversification and the practice of a dry season recession rice to avoid the flood peak period, the level of sensitivity decrease sharply even for commune which are located in the Tonle Sap plain. In the up-stream, the commune implements a multi-cropping system covering both dry and rainy seasons and are less sensitive to flood (Fig. 4).

## Adaptive capacity

Down-stream communes have higher adaptive capacity (Fig. 4). This is due to the proximity with the city of Battambang, which greatly improves access to external intervention. The proximity of the city also offers opportunities of labor diversification away from agriculture, which can be considered here as an important adaptation strategy. We also noted that communes with extensive experience with floods have developed more efficient adaptation mechanisms and strategies. We also note important differences of adaptive capacity between communes that are located in the up-stream area of the catchment. What explains these differences is the relative capacity of the commune councils to mobilize resources internally and externally to address post-flood management.

## Vulnerability

The interpretation of the multivariate statistical analysis of all indicators allows for the identification of five main types of vulnerability that we further ranked into five classes from “very low” to “very high” vulnerability (Table 3 and Fig. 4).

Table 3 indicates that exposure and sensitivity have a preponderant influence on the vulnerability of agricultural production to flood. The exposure and sensitivity indices are positively correlated (Tab.3). However, exposure is more decisive in explaining the highest vulnerability level. However, the measures that need to be addressed to reduce the exposure implies heavy civil engineering works (dikes, riverbanks reinforcement), which are far beyond what the communes and communities can actually afford. In the upstream areas, measures to reduce exposure could be the terracing of steep land in a view to reduce water surface run-off.

Notwithstanding, the communes have more options and opportunities to reduce their sensitivity to flood: diversification of cropping systems, water storage systems and the parallel development of dry season agriculture are processes that could considerably reduce the vulnerability of agriculture to flood. Table 3 also indicates that the level of commune vulnerability is also quite influenced by the adaptive capacity. This is a domain where provincial, district, and commune authorities should prioritize their action. What is particularly needed is the establishment of an effective institutional platform where communes could formulate their need to improve flood management (pre/post disaster) and through which support and external assistance should be delivered. The watershed management committee may play this role.

**Table 3 Commune vulnerability index**

| Commune vulnerability* | Overall exposure Index (mean of Z-score) | Overall sensitivity Index (mean of Z-score) | Overall adaptive capacity index (mean of Z-score) |
|---|---|---|---|
| Very low | Very low [-0.7323808] | Very low [-1.5983150] | Low [-0.3817778] |
| Low | Medium [-0.3817195] | Medium [0.4457365] | High [1.0304744] |
| Medium | Low [-0.7077337] | Low [-0.2380573] | Very low [-0.8889612] |
| High | High [1.1328966] | Very high [0.9314991] | Very high [1.0362228] |
| Very high | Very high [1.8084319] | High [0.6203428] | Medium [-0.2394899] |

* *Vulnerability classification made with a hierarchical cluster analysis (Ward's method)*

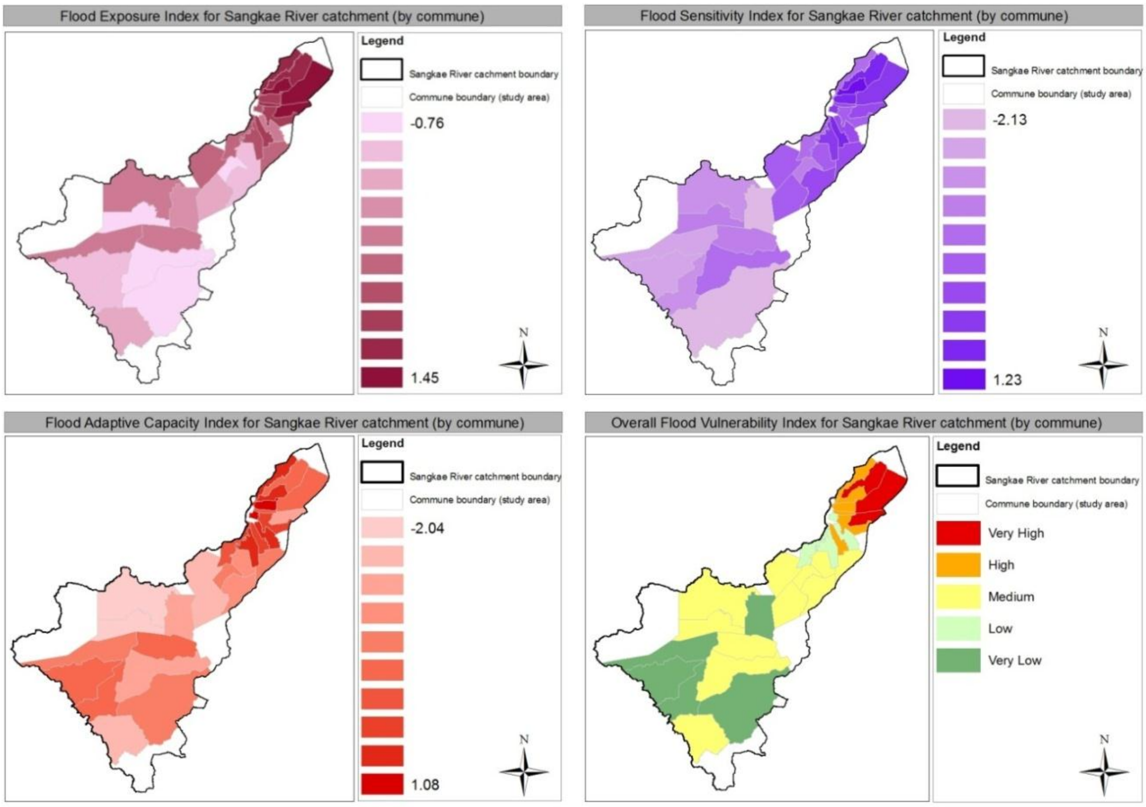


**Fig. 4 Flood exposure, sensitivity, adaptive capacity and overall vulnerability indexes by commune in across the Sangkae River catchment area**

## CONCLUSION

Our study has presented a methodology to analyze and understand the vulnerability of agricultural production to flood. A great deal of information collected through the research process was provided by local stakeholders who are directly affected by flood. The tools and data collection methods are easy to grasp and the approach can be easily replicated in the context of other river basins. The approach is based on the measurement of specific indicators related to three dimensions of vulnerability, namely exposure, sensitivity and adaptive capacity. It further develops composite indexes that integrate a large number of factors in a single value. The use of a geographic information system enables us to comprehend the geography of vulnerability across a river basin area. Additionally, the indicators can be compared over time so that they are indicative values to watershed authorities for making strategic and operational decisions to improve flood management. The framework can be refined further in a number of ways. One is by revising the existing indicators and by identifying new ones. Another could be by incorporating rainfall data so that better links can be made with climate change. The survey has been realized in partnership with a spatial planning team from Battambang and should be considered as a step towards developing a flood management decision-making tool for provincial authorities.

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