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Chapter 2 - A multi-scale flood vulnerability assessment of agricultural production in the context of environmental change: The case of the Sangkae River watershed, Battambang province

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CHAPTER 2

A multi-scale flood vulnerability assessment of agricultural production in the context of environmental change: The case of the Sangkae River watershed, Battambang province

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Section A

ABSTRACT

Flooding on Cambodian land use systems is not a new phenomenon but its significance has increased in the context of global environmental changes. This study aims to assess the vulnerability of agricultural production to floods in the Sangkae River watershed in Battambang province, Northwestern Cambodia. The study was conducted in conjunction with the provincial spatial planning team hosted by the Provincial Department of Land Management and can be viewed as a first step toward a flood management decision-making tool for provincial authorities.

The assessments rest on specific dimensions of vulnerability (exposure, sensitivity and adaptive capacity) at different levels in a multi-scale framework: spatial scale (watershed, commune and household); temporal scale (decade, year and season); and institutional scale (national policy, provincial operating rules and communal agencies). The analysis rests on triangulation of qualitative and quantitative data (time-series rainfall data, land use systems, participatory flood mapping, commune workshops (n=31), social-economic statistical databases, in-depth interviews with relevant institutions (n=5) and household surveys (n=162).

Intensification of rainfall since the 1920s has increased the risk of flooding in the Sangkae River watershed during the late rainy season, particularly in the upstream area. Using an indicator-based approach, we discovered that the vulnerability of communes is highly dependent on the agro-ecology of land use systems. The household assessment reveals the variability of adaptive capacity between households according to their food security status and income portfolio. Agricultural innovation and structural adaptation to flood are scarce; the households mostly cope with flood through credit, external aid and de-capitalization (sale of household assets). These coping mechanisms adopted by farmers do not reduce vulnerability but reinforce it.

The application of this assessment methodology provides nested pictures of vulnerability at different levels and scales and we argue that a dialogue between these levels and scales is necessary to understand the nature of the vulnerability and to act to reduce it. Using these different typologies of vulnerability, this approach enables recommendations to be formulated to reduce vulnerability through better horizontal and vertical integration of institutions and agencies, and effective collective action.

Key words: *rainfall pattern; environmental management; agriculture; water resources; adaptation; disaster management; flood; farming systems; food security*

INTRODUCTION

The impact of flooding on social-ecological systems is of global significance in the context of climate change. There is strong evidence to suggest that ongoing and future global intensification of the hydrologic cycle will continue due to global warming (Huntington 2006). The intensification of the water cycle leads globally to changes in water-resource availability and is manifested in an increasing frequency and intensity of floods and river run-off (Huntington 2006). In its most recent report, the Intergovernmental Panel on Climate Change (IPCC) suggests that extreme precipitation events over the wet tropics will very likely become more intense and more frequent by the end of this century as global mean surface temperature increases (Stocker et al. 2013). Monsoon precipitation, in particular, will likely intensify (Stocker et al. 2013). At the Mekong basin scale, climate projections are fairly uncertain but suggest that total annual run-off from the basin is likely to increase by 21 percent, with increased flooding affecting all parts, with an even greater impact in the downstream catchments, i.e. the Tonle Sap catchment of Cambodia (Eastham et al. 2008).

Flooding is not a new phenomenon for Cambodia. Many parts of the country have a long history of this, particularly the central areas where floods are associated with the reversal of water in the Tonle Sap river and the flooding of the large central floodplain (Keskinen 2006). In response, people have developed agriculture and fishing practices that are well adapted to this unique phenomenon. Flooding is actually a double-edged event. Floods are usually good for rain-fed rice-based agriculture but unpredictability in their occurrence can exert a negative impact on agricultural production and rural livelihood systems (Keskinen 2006). In a wider perspective, the entire social-ecological production system of the Tonle Sap Great Lake floodplain depends on the flood pulse cycle (Keskinen 2008). That said, globally, major floods cause human casualties and injuries, substantial infrastructure damage and agricultural production losses (Centre for Research on the Epidemiology of Disasters 2011). In 2011, for instance, the costs associated with loss of agricultural production and degradation of physical infrastructure resulting from the large flood in Cambodia amounted to more than USD 521 million and affected 1.64 million people, killing 247. It has been estimated that approximately 400,000 hectares of paddy fields were damaged by flood in that year (Gunjal et al. 2012).

The high vulnerability of Cambodia to climate change (flooding in particular) is mostly attributed to a low adaptive capacity, which is the result of the high incidence of poverty and the low provision of physical transport, energy, and water management infrastructures at different levels (Chhinh et al. 2013, Yusuf and Francisco 2009). The national projected increase in frequency and magnitude of extreme rainfall events will exacerbate flooding, particularly in small river watershed areas, and will affect the Cambodian economy and population. Consequently, it is likely that these extreme rainfall events will contribute to increased food insecurity and will substantially increase the challenges faced by populations who are already vulnerable to flood. The consequences for the agricultural sector are particularly significant given its central role in the development of the country; in 2011, the sector contributed 33 percent to the national GDP, employed around 67 percent of the national labor force, and remains a provider of key environmental goods and services (CDRI 2011, World Bank 2013).

These challenges lead to questions about the impacts of flooding on agricultural production. For instance, who, among farmers and stakeholders, are likely to be more or less affected (and where they are located) and how these impacts are amplified or attenuated by different ecological or social circumstances. Policy- and decision-makers, local organizations and development partners, at different levels, are deeply concerned with these questions. The rationale of this research project is, therefore, to provide scientifically sound information to help policy-makers to address these questions and to support effective decision-making to enhance flood preparedness, responses and adaptations. We acknowledge that there is no single 'best way' to bridge the science-policy gap (Vogela et al. 2007) and our endeavor is best understood as a contribution to a complex ongoing dialogue rather than as a universal panacea.

Vulnerability assessments are widely used to determine the impact of climate change, to enable decision-makers to target adaptation funds in the most efficient way, and to monitor the effectiveness of their investments (Moench 2011). But to serve these purposes, vulnerability analysis needs to overcome a number of challenges. First, it has to go beyond obvious simple statements that portray vulnerability as a correlation of poverty. Second, vulnerability analysis must develop robust and credible measures that reflect social processes as well as material outcomes within complex social-ecological systems, and clearly delineate those mechanisms that cause and perpetuate the underlying vulnerability (Adger 2006, Ribot 2011). Third, the vulnerability assessment should be part of a transformative learning process (Diduck et al. 2012). It should engage different actors so that they can contribute their understanding to support resource users and decision-makers in working together through methods of social learning, with the ultimate aim of reducing vulnerability on the ground.

Although we develop a cross-disciplinary approach, we focus on the influence of a single hazard (flood) on one sector (agriculture) in order to come up with specific and localized recommendations. The geographical context of this assessment is the Sangkae River watershed in the province of Battambang (Northwest Cambodia), which is considered to be the province in which flooding has the second highest impact on agriculture (Prey Veng being the most vulnerable province) (Royal Government of Cambodia 2006).

We maintain that there are no simple answers to questions surrounding flood vulnerability in the Sangkae River watershed. The nature and extent of this depends on the analytical scale and the conceptual framework developed to understand it. So, rather than focusing on one particular level, we suggest that a dialogue between and across levels and scales provides an appropriate basis to give the best account of vulnerability and to suggest the most effective path for intervention. The approach we developed allows us to identify typologies of vulnerabilities at different levels and to formulate differentiated sets of recommendations to achieve a more inclusive, multi-level dialogue between institutions to identify ways to reduce vulnerability.

METHODOLOGY

Study area

The Sangkae River watershed covers an area of 370,750 ha in Battambang province. The river originates in Phnom Kbal Lan (Pursat province) and extends for about 82 km from Battambang municipality to the Tonle Sap Lake (Figure 1). The catchment stretches along 31 communes in six districts including Samlaut, Ratanak Mondol, Banan, Battambang, Sangkae and Aek Phnom. It includes more than 200 villages comprising 522,725 people (104,035 families) (NCDD 2010).

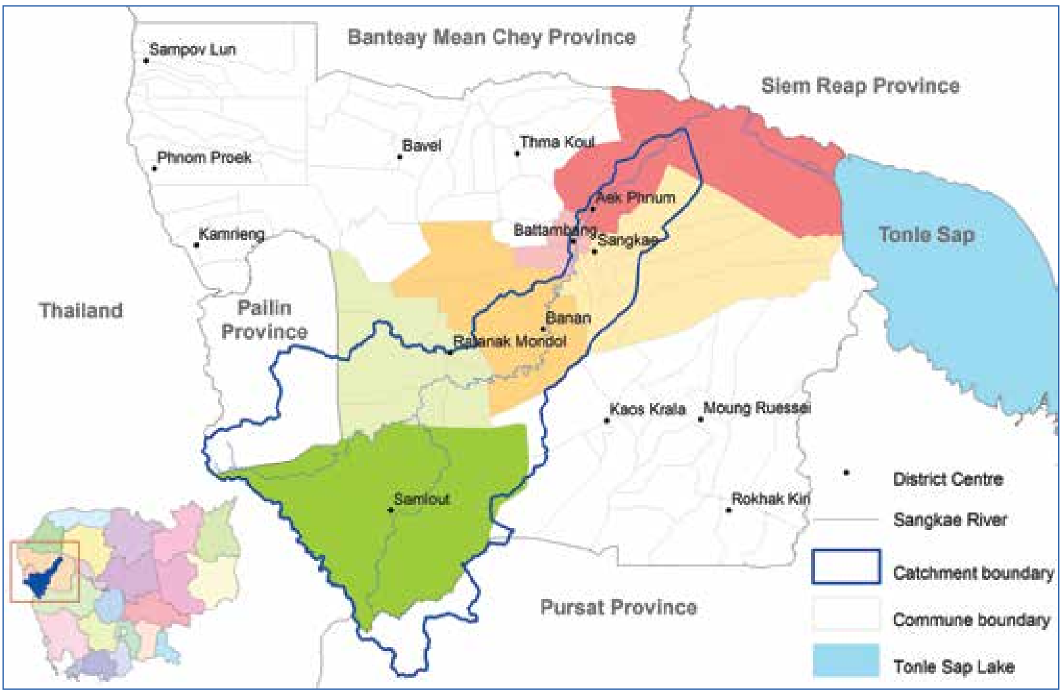


Figure 1: Sangkae River watershed and its commune boundaries

Framing the vulnerability assessment

Vulnerability

Since the release in 2001 of the third IPCC report on climate change, the term '*vulnerability*' has become a catch-all concept in environmental change research. *Vulnerability* is defined as the "degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes" (McCarthy et al. 2001). In this definition key parameters of *vulnerability* are the *stress* to which a system is exposed, its *sensitivity* and its *adaptive capacity*. The term *exposure* relates to the nature and degree to which a system undergoes environmental or socio-political stress. The characteristics of these stresses include their *magnitude, frequency, duration* and the *area size* (i.e. the geographical region it affects) of the hazard. *Sensitivity* is the degree to which a system is modified or affected by disturbances. *Adaptive capacity* is the ability of a system to evolve in order to accommodate environmental hazards or to respond with relevant policy changes which expand the range of variability with which it can cope (Adger 2006).

In this definition, IPCC places the risk within the hazard - in other words, within climate rather than society (Ribot 2011, Turner et al. 2003); *vulnerability* is conceived as an outcome - a result of the projected impacts of climate change on a particular social-ecological system, offset by adaptation measures. This definition of *vulnerability,* centered on the hazard, has been challenged by scholars who rather consider that both climate variability and change occur in the context of political, institutional, economic and social structures and that they interact dynamically (O'Brien et al. 2007). We adopt this latter approach of contextual vulnerability despite the methodological challenges it poses.

The framework of our assessment rests on a few principles, which now pertain to the mainstream of vulnerability science:

- *Vulnerability* is widely seen as an integrative concept that can link the social and biophysical dimensions of environmental change. The focus on the interactive social-ecological system (Low et al. 1999) suggests that *vulnerability* results from multiple stressors (climate, environmental, political, economic, institutional or cultural) which interact dynamically (O'Brien et al. 2007);
- *Vulnerability* is scale dependent insofar as the scale of analysis affects the vulnerability pattern being identified. Scale also affects the explanation of vulnerability as its drivers are at work at different levels on different scales (Cash et al. 2006, Gibson et al. 2000). The social-ecological system we investigate forms a nested hierarchy, and the analysis of its vulnerability therefore requires both a multi-level and multi-scale approach;
- *Vulnerability* of the social-ecological system is place-based because risks, changes and the ability to cope or adapt differ across space according to site-specific contexts and circumstances;

- *Vulnerability* is socially differentiated insofar as access to social, political and economic capital affecting the vulnerability is not equally distributed within a social group (Moench 2011, Ribot 2011);
- *Vulnerability* is dynamic as it alters over time on account of changes in drivers that are external to the social-ecological system or to the internal capacity of the system to restructure. These drivers amplify or attenuate the vulnerability of the system (Turner et al. 2003).

A multi-scale/multi-level framework

Our framework for assessment considers a three-tier nested social-ecological system (SES) in which vulnerability resides: household, commune and watershed levels. At the household level, the SES is conceptualized as farming systems, which are nested in the wider context of commune level (the lowest jurisdiction level with elected councils) using administrative boundaries to capture the institutional dimensions of vulnerability. In turn, communes are nested in a larger watershed area. An examination of vulnerability at different levels of political/social organization provides a more in-depth view of vulnerability; e.g. vulnerability might emerge within a commune that might not be considered to be vulnerable at watershed scale (Keskinen 2008).

Our conceptualization of the vulnerability of agriculture production to flooding is based on the framework developed by Turner et al. (2003) (Figure 2). The structure and dynamic of vulnerability at household, commune and watershed level are similar: the flood hazards acting on the system arise from influences outside ❶ and inside ❷ the system. The human-environmental circumstances (and the interplay between both) of the system determine its sensitivity ❸ to flood and condition the capacity of responses of the system, both short-term (coping ❹) and long-term (adaptation ❺). The agency for coping and adaptation is usually the household, although the driver might be autonomous or driven by external factors, e.g. policy. Importantly, the social and environmental responses or coping mechanisms influence each other, so that a response in the human sub-system could make the environmental sub-system more or less able to cope ❻ . At any given level, the framework considers the link with broader human ❼ and biophysical ❽ conditions and processes, which influence or are influenced by the social-ecological system responses. These influences occur through cross-scale/cross-level interactions: we refer to downward causation if the driver occurs at a higher level ❾ or upward causation if the driver is at play at a lower level ❿ (Gibson et al. 2000).

The multi-scale/multi-level[1] structure of the framework allows us to illuminate the nested scales of vulnerability (how the different drivers of vulnerability operate at various temporal, spatial and institutional scales). It also enables us to understand the vulnerability of a particular place (Turner et al. 2003). There is no, one ‘best scale of analysis’ to understand vulnerability (O’Brien et al. 2004): indeed, the one-size-fits-all measure is not suitable (Hinkel 2011). A deeper understanding can rather be reached through an analysis of the interactions within/between levels and scales.

[1] For a detailed discussion on scale and level see Cash et al. 2006

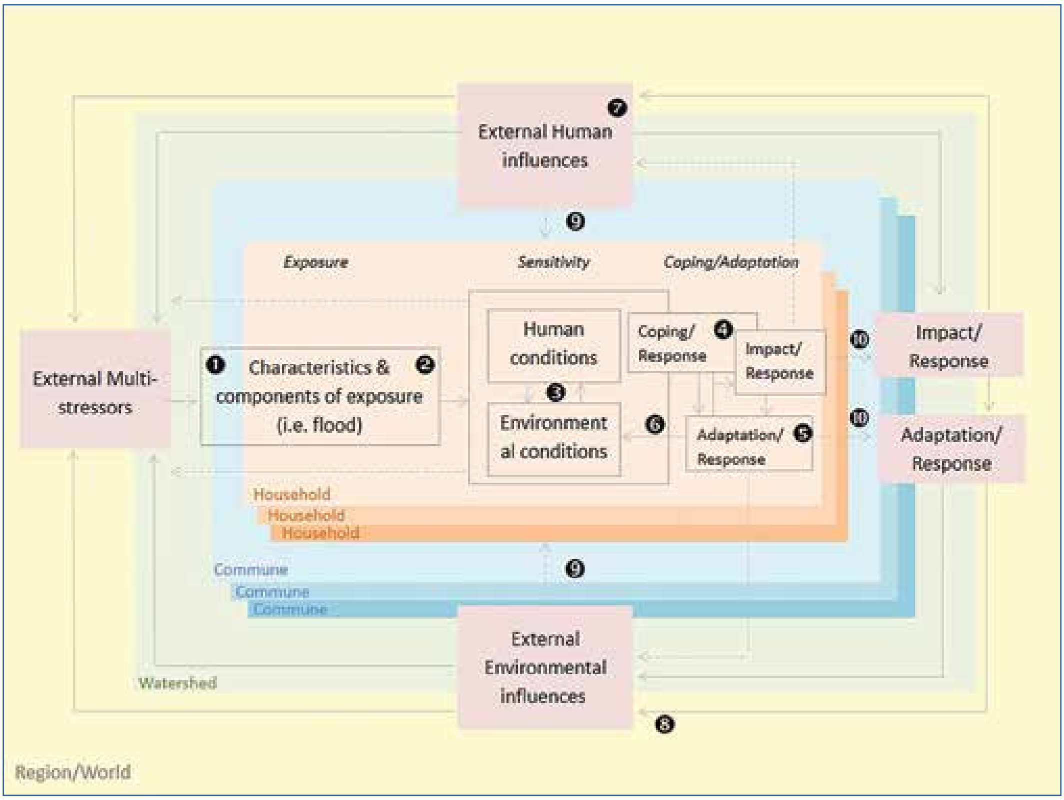


Figure 2: *Framework to study the flood vulnerability of agricultural production, adapted from Turner et al. 2003*

In the following section, we explain how the research conducts analysis on different scales in this framework: the spatial scale (watershed, commune and household), the temporal scale (decade, year and season) and the institutional scale (national policy, provincial operating rules and communal agencies). As the choice and the politics of scales influence the results of any vulnerability assessment (Lebel 2006), we also discuss the rationale for selection of these spatial, temporal and institutional scales.

Operationalizing the framework

Hinkel (2011) argued that guidance for designing vulnerability assessment methodologies must come from the specific case considered: the research relates to the specific context and to the specific policy questions. We operationalized our conceptual framework in that perspective using a diversity of complementary methods, measures and qualitative/ quantitative indicators at each level on the spatial scale.

Watershed level

The watershed was chosen as a first spatial level because it is an operational geographic unit to understand hydrological processes. Additionally, flood management is considered a key element of Integrated Water Resources Management at the river basin level (UNESCO

2009). Therefore, this flood vulnerability assessment could be viewed as a contribution to improve the overall management of the Sangkae River watershed.

Information about flood in the Tonle Sap central area is available (Hook et al. 2003), but is restricted in respect of the upper part of the catchment. Consequently, we started the survey by conducting a detailed assessment of the flood hazard through a participatory flood mapping exercise. This was organized in each of the 31 communes located within the watershed boundaries. Each workshop gathered 10-15 participants per commune, including all the heads of villages within the commune and some commune councilors. We defined flood as an 'overflow or inundation that comes from a river or other body of water that causes an impact'[2]. In order to capture the diversity of origin, three types of floods were considered: the central area flood in the Tonle Sap plain; river-overflow flood (Sangkae River and its tributaries); and surface water run-off flood. The combinations of these floods were also considered. Flood magnitude was classified into two categories: 'normal flood' considered as a usual annual flood; and 'severe flood' such as occurred in 2011. According to Mekong River Commission (MRC) standards, these two flood types are classified as 'minor' and 'medium', respectively (Hook et al. 2003).

Updated aerial photos retrieved from the Google Earth[3] server covering the entire communal territory were printed on large A0 size papers (spatial scale 1/5,000) and were overlaid with plastic covers to enable delineation of flooded areas. Not all participants had the knowledge and experience to orientate themselves on the map, so in order to facilitate the mapping process, all participants were first invited to identify the main waterways and water bodies in the commune as well as the agricultural land areas. They were then asked to map agricultural land that had been affected by the 2010 flood (minor) and 2011 flood (medium). For each flood area, they were asked to provide information about the generating mechanism of flood, the flood duration and its impact on the different agricultural productions.

We acquired datasets from the Ministry of Water Resources and Meteorology to identify rainfall and discharge/water levels. We also extracted monthly rainfall data for a time series from one meteorological station located in Battambang for the period 1920-2012[4] so that we could identify any significant trends in rainfall patterns (amount and distribution) to place recent flooding in a wider perspective. In addition, daily rainfall records for the period 1981-2012 enabled us to compute and analyze extreme rainfall indices[5].

2 http://water.usgs.gov/wsc/glossary.html#F

3 www.googlearth.com

4 Data was not available for 19 years including the whole of the period from1941-1950 and from 1975- 1980. Where specific monthly rainfall data was missing for other periods (six years), we replaced the missing values with the average value of rainfall of the specific month in the relevant decade

5 http://etccdi.pacificclimate.org/index.shtml

We also reviewed policy documents relevant to flood management. These usually have a national scope, so we looked at how they were interpreted and implemented at the watershed level. We also conducted interviews (n=5) with various governmental bodies involved in flood management at the provincial level (Provincial Committee for Natural Disaster Management, Spatial Planning Working Group, Department of Agriculture, Department of Water Resources and Meteorology and the NGO Caritas Cambodia) in order to examine the effectiveness of these institutions in reducing the vulnerability of agricultural production to flood hazards in the watershed.

Commune level

There were two reasons the commune was chosen as the second spatial level: the existence of reliable statistical indicators that allowed agro-ecological and social-economic indicators to be combined, and the possibility to evaluate the role and importance elected commune councils have in flood disaster management.

At the commune level, the analysis consisted of an indicator-based vulnerability assessment. Vulnerability indicators are useful in identifying particularly vulnerable people, regions or sectors (Hinkel 2011). The indicators combine/link the different dimensions of vulnerability conceptualized at the commune level[6] with a specific and measurable value (Annex 1). However, access to quality and updated data is a primary concern and a limiting factor in establishing indicators (Chann and Kong 2013). So, when comprehensive and reliable data could not be retrieved from secondary sources, we relied on survey methods to generate our own primary datasets. Based on a consideration of the availability of secondary data and the feasibility of primary data collection, we eventually selected 11 quantitative indicators for the assessment (Annex 1):

- The indicators that relate to exposure comprise measures of the flooded areas that were identified during the participatory mapping exercise organized during the commune workshops (*see above*). We focused on the areas of agricultural land that were flooded in 2010 and 2011, which we also weighted according to the duration of the flood in a particular area (Annex 1). Values were expressed as a percentage of the total agricultural area of the commune.
- The values indicating the sensitivity of communes to flood are diverse and are assumed not to be correlated. We first considered the total area of agricultural land in the commune as a percentage of total area. We then considered the actual impact of flood on agricultural production. During the commune workshop we asked the participants to assess the impact (loss and gain) of flood on rice production in 2011 (the year of medium flood), compared with 2010 (the minor flood). We then calculated an *impact coefficient* that was proportional to the loss or gain in production and we used it to weight the flooded area. As a measure of sensitivity, we also considered the percentage of the population who were

[6] We selected only those communes that had their centroid inside the catchment

engaged in agriculture. In addition, we considered the diversification of agricultural production in the dry season, assuming that a higher percentage of cultivated area during this period gives the commune an advantage.

- Commune adaptive capacity was measured using different indicators such as the density of the road network. We took into account two additional indicators, namely the literacy and the poverty rates (Annex 1), assuming that higher literacy rates and standards of living would improve people's capacity to cope and adapt. In order to capture the institutional capacity of the commune to adapt to flood, the survey included qualitative 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. The answers to each question were coded with ordinal values from 0 to 3. The institutional capacity index for each commune was obtained by summing up the score obtained with the answer to each questions.

All indicators were standardized (Z-score) and summed without weighting into a component index (exposure, sensitivity and adaptive capacity). The three component indices were then standardized and computed into an overall vulnerability composite index by using the usual formula 'Vulnerability = Exposure index + Sensitivity index-Adaptive Capacity index' (see, for instance, Hughes et al. 2012).

We further integrated all standardized indicators within a multivariate hierarchical cluster analysis (Palm 1996)[7] in an attempt to identify groups of communes that were relatively homogenous within each group and heterogeneous between each other. The rationale for this type of multivariate analysis was to synthesize relations between multiple aspects of social-ecological vulnerability and to establish a typology of commune vulnerability across the watershed. The integration of all indicators and values in a geographic information system allows for a spatially-explicit rendering of the commune typology, and for an interpretation of spatial data on agro-ecology (see agro-ecological transect in Annex 2) and land use dynamic across the watershed.

Household level

As a crucial element of our research we tried to capture the sensitivity of households to food insecurity and to assess the impact of flood on food security, as well as the different types of short-term and long-term adaptive responses that households had developed to deal with flooding. Assuming an increased intensity and magnitude of floods in the future, we

[7] A range of agglomerative cluster classification methods was tested. We selected the number of clusters (i.e. five) using the elbow-rule and used Ward's method of agglomeration as it provides results with low variability (standard deviation) within each group. We have tried to avoid a high degree of co-linearity between the variables, by keeping variables that have a correlation coefficient of less than 0.7

also engaged in a discussion with the interviewees about their readiness to adopt different agricultural and non-agricultural adaptive measures to reduce their future vulnerability. We were particularly interested in understanding the modalities and the extent to which local adaptive responses engaged the household in building flood-resilient cropping systems.

In each commune vulnerability type we selected one representative village (Table 1) to conduct a sampled quantitative household survey (n=162). The sample was randomly chosen from all households in each village using the formula $n=N/[1+N^*(e)^2]$ where n=sample size, N=population size and e=level of accuracy (10 percent) for the extrapolation from sample to population (Israel 1992). To some degree, all households in our sample had been affected by flood in both 2010 and 2011.

***Table 1**:Village and household (HH) selection design*

Vulnerability type	Commune	Village	Total HH	HH Sample
Very high	Preaek Luong	Bak Amraek	299	36
High	Samraong Knong	Samraong Tatok	578	42
Medium	Snoeng	Boeng Krasal	457	25
Low	Chheu Teal	Enteak Chit	273	36
Very low	Ta Sanh	Ta Sanh Khang Chheung	232	23
			1,839	162

The analysis of vulnerability (represented at five levels - 'vulnerability types') is also based on a grouping of households according to their degree of sensitivity (represented at four levels - 'sensitivity groups') in terms of food insecurity. To establish the sensitivity groupings (Figure 3), we first determined if their own agricultural production allowed the household to be self-sufficient year round. To determine the level of self-sufficiency, we considered a milled rice consumption rate of 143kg per capita, per year, and a milled rice/paddy ratio of 0.64 (Gunjal et al. 2012). All agricultural production was taken into account and the monetary value calculated (outputs-inputs). Non-rice crop production was converted into milled rice equivalents based on the average price of milled rice of 3,000 riels/kg (4000 riels= USD 1)

- If the household was food self-sufficient from it own agricultural production during a year with a minor flood event (e.g. 2010), we determined if this remained the case during a year with a medium flood event (2011).
- If the household was not self-sufficient from its own agricultural production in 2010, we took into account the importance of non-farm labor activities in the household's overall income portfolio in securing its access to food. Non-farm labor includes all wage- and self-employed non-farm activities.

In the categorization of households into the four sensitivity groups, each has a distinct land-holding size and income structure derived from farming, non-farm and wage labor activities. The four categories stretch along a gradient of sensitivity to food insecurity and flood, the 1 and 4 grading ranges from less to more sensitive.

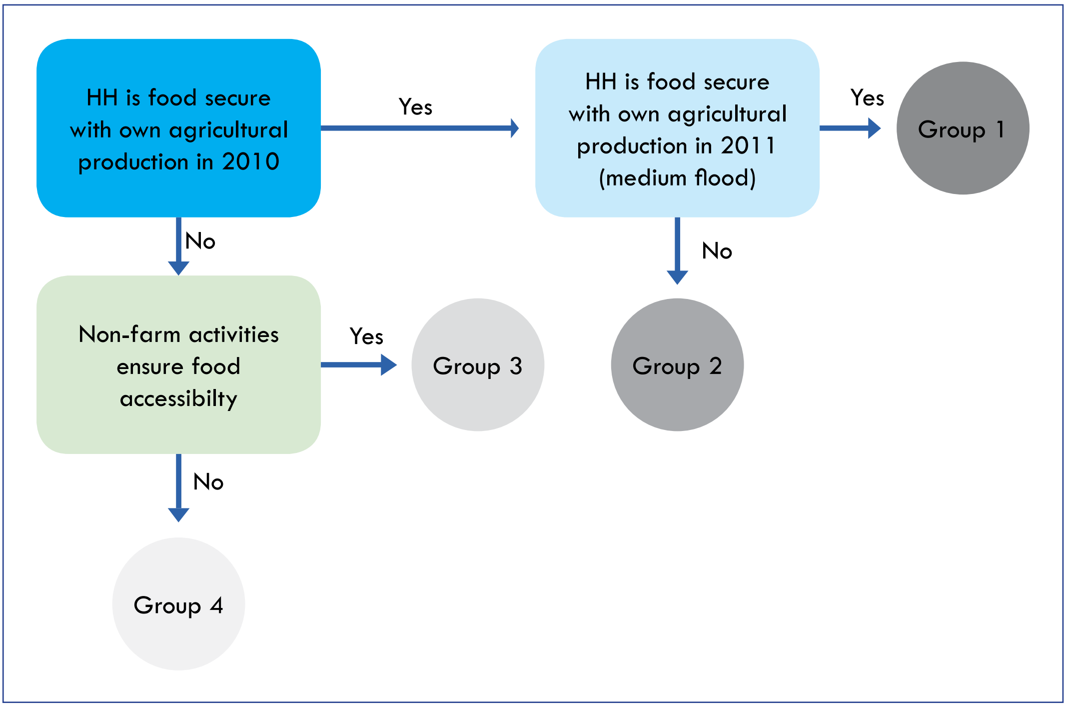


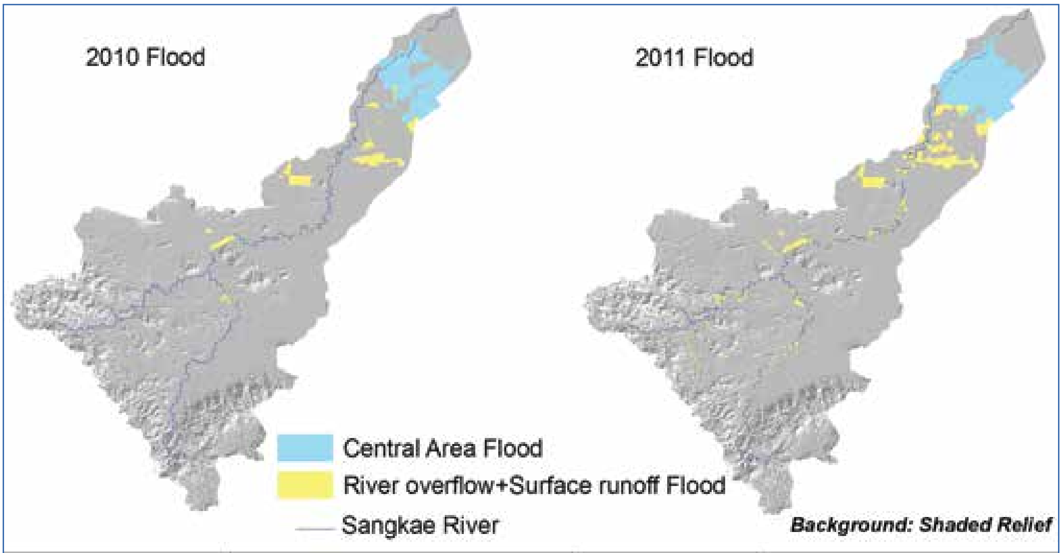
***Figure 3**:Design of the household assessment to determine sensitivity grouping*

RESULTS

The multiple floods in a context of changing rainfall distribution

Flooding affected an important area of agricultural land in both 2010 and 2011 (252.8 and 370.2 km^2, respectively, totaling 7 and 10 percent of the total catchment area size). In comparison, the central area (Tonle Sap) flood was the largest for both 2010 and 2011 (74 percent and 68 percent, respectively, of the total flooded area in the watershed). However, upstream flood resulting from the combination of river overflow and surface run-off has affected an appreciable area of 65.9 and 118.6 km^2 in 2010 and 2011, respectively[8] (Figure 4). These types of flood are obviously more localized along the river (see map), which contrasts with the vast Tonle Sap floodplain. In addition, we noted that the percentage increases in the area flooded between 2010 and 2011 is greater from river overflow (50 percent versus 26 percent in the Tonle Sap floodplain) (Figure 4). This suggests that upstream areas are relatively more vulnerable if these types of floods become more prevalent over time.

[8] Surprisingly, these floods are totally unrecorded in official statistics such as commune databases



Flood types	Flood on agricultural land (Km²/%)				Difference 2010-2011 flood area size (%)	Flood occurrence (mode of values)	
	2010		2011			2010	2011
Tonle Sap (central area)	186.96	74	251.73	68	26	Sep-Nov	Sep-Oct
River overflow + Surface runoff	65.86	26	118.55	32	50	Sep-Oct	Aug-Oct
Total	**252.83**	**100**	**370.15**	**100**	**32**		

Figure 4*:Incidence of floods on agricultural land in the Sangkae River watershed (2010 and 2011)*

Both types of floods have different origins. The magnitude of the Tonle Sap river depends to a large extent on the Mekong River discharge which pulses back into the Tonle Sap and floods the immense central plain. Kummu and Sarkkula (2008) note that the development of hydropower dams on the Mekong River has led to a clear drop in the flood peak and has increased the low water levels. In other words, they have decreased the amplitude of the flooding. They also suggest that the dry-season water levels in the Tonle Sap Lake are expected to rise due to upstream development on the Mekong River, which will lead to an increase in the area that is permanently flooded (Kummu and Sarkkula 2008).

Rainfall is key to explaining river overflow and surface run-off. Analysis of historical rainfall data for the period 1920-2012[9] shows that total annual precipitation has not significantly changed over the past century[10]. However, we note a significant change in seasonal and monthly rainfall distributions[11]. Figure 5 suggests that a higher proportion of rainfall in the

[9] Rainfall records for that period are available only for the Battambang station

[10] Given issues of data availability, the analysis allows for a comparison of rainfall between two distinct time periods: 1920-1939 and 1990-2009

[11] We owe the idea of this analysis about monthly and seasonal rainfall change to Someth Paradis who used a similar rainfall dataset in Kampong Chhnang with similar findings (see Chapter 3 of this volume)

rainy season (May to October) is due essentially to a reduction of rainfall in the dry season (November to April). Our analysis suggests that this has resulted from an increase in the dry period (with monthly precipitation less than 20 mm) from 1 month in 1920s-1930s to 3 months in 1990-2000s. Comparing the same time periods, the monthly rainfall distribution has also changed (Figure 6). Whereas the distribution used to be bi-modal (with two distinct peaks of rain in May and September), it has shifted to a mono-modal distribution with one peak in October. This suggests an intensification of rainfall towards the end of the year. The computation of extreme rainfall indices based on daily rainfall records for the period 1980-2012 confirms this intensification. Most notably, the annual count of wet days (with precipitation >1mm), the annual maximum consecutive five-day precipitation and the annual count of days when rainfall >20-30-50 mm are all increasing with the mode of occurrence in October (Annex 3). This intensification of rain towards the end of the year (October) is perceptible but has taken place very slowly. It is likely to put the upstream areas at higher risks of flood in the future.

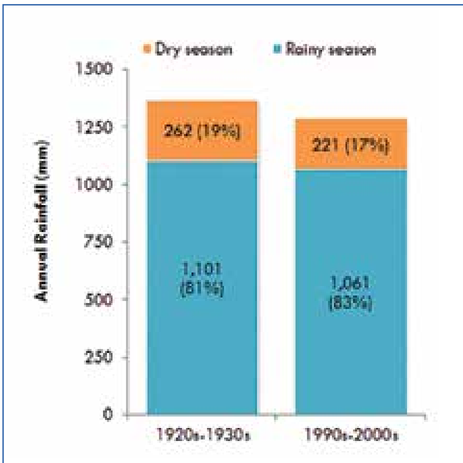


Figure 5:Seasonal rainfall distributions

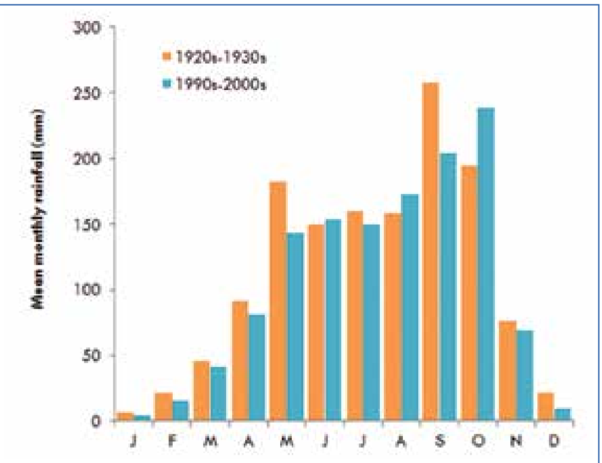


Figure 6:Monthly rainfall distribution change

Institutions are weak in dealing with flooding

In Cambodia there is no shortage of governmental bodies and institutions dealing with flood management. They have different approaches according to their roles and responsibilities. In addition to line administrations, which have an historical mandate in flood management, the programmatic strategies of the Royal Government of Cambodia relating to flooding have recently intensified in the context of the new 'Climate Change Governance'. Currently, flood management intersects the mandate and policies of at least four key governmental bodies.

The National Strategic Development Plan (NSDP, 2009-2013) promotes an alliance between the Ministry of Water Resources and Meteorology (MOWRAM) and the Ministry of Agriculture, Forestry and Fisheries (MAFF), which is outlined in a detailed policy paper 'Strategy for Agriculture and Water 2006-2010' (Ministry of Agriculture, Forestry and Fisheries and Ministry of Water Resources and Meteorology 2007). As far as floods are concerned, MOWRAM is responsible for pre-flood intervention measures such as rainfall records monitoring and early warning systems while MAFF is primarily focused on post-disaster intervention, assisting in the rehabilitation of rice fields after a flood. The strategy paper suggests that water resources are to be used and developed at the river basin level and according to the principles of Integrated Water Resources Management so as to minimize degradation of aquatic resources and avoid competition among users. The program aims to enable rural communities to avoid or respond without serious loss to the adverse effects of damaging floods, droughts or unexpected dry spells, for instance through participatory irrigation management and the development of flood and drought preparedness.

The National Committee for Disaster Management (NCDM), whose engagement is also part of the NSDP 2009-2013, is an inter-ministerial and multi-level body. It is a front-end institution in flood management responsible for disaster risk reduction - including early warning - evacuation and recovery strategic plans and actions. However, a recent ADB (2014) study concluded that NCDM operations are severely challenged. It drew attention to non-functional organizational structures that it attributed largely to the lack of financial resources (ADB 2014).

With respect to climate change, the Ministry of the Environment (MOE), and in particular the National Climate Change Committee (NCCC), has a lead role in coordinating and implementing the inter-ministerial policies, strategies, plans and programs contained in the National Adaptation Program of Action to Climate Change (NAPA) (Royal Government of Cambodia 2006). The NAPA mandate is to provide multi-sector mechanisms to guide the coordination and implementation of adaptation initiatives but it consists mostly of a list of spatially targeted and prioritized projects (39) to be implemented to enhance adaptive capacity. Five of the projects concern flood management. In the NAPA, adaptation is very much conceived of as a set of tools aligned to national development policies which frame the conditions under which adaptations are to take place. Little space is offered to develop and implement locally-designed and context-specific approaches with inclusive mobilization of actors. There is no indication that a transformative learning process is in place to frame the adaptation measures. More recently, the MOE has been involved in developing a Climate Change Strategy Plan (2013-2027) but this document does not provide a significant improvement.

The institutional scales for our research included the provincial level. The Provincial Committees for Disaster Management (PCDM) have been given the responsibility to lead disaster management efforts at their respective administrative levels without being provided with adequate resources. Although they have played an active role in coordinating the delivery of emergency relief aid, the role of these provincial committees in respect of flooding is now merely to tell different local and international organizations where to deliver rescue aid. The impacts of flood are addressed and managed post-disaster by these organizations with priority given to the downstream lowland (central area flood) and a clear emphasis put on providing emergency relief (food distribution, evacuation of people, and so on).

The Provincial Departments of MOWRAM have no reliable tools in place to study and predict a flood event. These provincial departments also face serious budget constraints in implementing a rigorous pre-disaster preparedness plan. For instance, although Battambang province is equipped with a spatial plan (Battambang Provincial Spatial Plan Sub-Working Group 2009) that covers a large number of land-related issues, natural disaster management is not mainstreamed in this plan.

Institutionally, there is a clear lack of balance between the plethora of institutions and coordination mechanisms designed to deal with flooding, and their effectiveness on the ground. The institutional resilience and the capacity of provincial institutions to learn from flood hazards are still limited, and this greatly hinders the reduction of flood vulnerability. However, repeated occurrences of large-scale flooding over the past five years have resulted in a notably increased awareness about the scope of flooding across the watershed, including in the upstream areas.

A diversity of commune vulnerability profiles: The importance of agro-ecology and access to the city

Five types of communes were identified on the basis of the hierarchical cluster analysis that integrates the 11 vulnerability indicators. These five 'vulnerability types' are primarily ranked according to the mean value of the total vulnerability index, scaled 0-1, in order to extract a preliminary measure of the overall vulnerability (Table 2). But a stand-alone metric value is of limited use and relevance as it tends to over-synthesize vulnerability and is actually very difficult to interpret. This limitation is apparent in other vulnerability assessments (Chann and Kong 2013, Yusuf and Francisco 2009). In contrast, it is more interesting - and meaningful - to characterize the actual types of vulnerability by looking at how the indicators relate to each other within each commune type, and to examine how they differ between types. To interpret and make sense of this classification, we compute the mean value of each indicator for each vulnerability typing (on a 0-1 scale for easier interpretation). We further map the commune vulnerability composite index and interpret its spatial distribution with the land use system classification established by the spatial planning working group.

Table 2: *Typology of commune vulnerability*

		Commune vulnerability types				
		Type 1 Very High (n=4)	Type 2 High (n=6)	Type 3 Medium (n=11)	Type 4 Low (n=5)	Type 5 Very Low (n=5)
Exposure	% of flooded area in 2011 (relative to total agricultural land area)	0.83	0.74	0.03	0.23	0.03
	% of flooded area in 2010 (relative to total agricultural land area)	0.74	0.53	0.03	0.06	0.01
	Flooded area in 2011 weighted by duration (relative to total 2011 flooded land area)	0.69	0.56	0.01	0.06	0.01
Sensitivity	% agricultural area size (relative to total commune area)	0.40	1.00	0.75	0.98	0.33
	% population involved in agriculture (relative to total population)	0.83	0.56	0.82	0.81	0.92
	Flooded area in 2011 weighted by damage (relative to total 2011 flooded land area)	0.71	0.77	0.57	0.33	0.43
	% cultivated area during flood period (relative to total cultivated area)	0.96	0.98	0.87	0.95	0.45
Adaptive Capacity	Flood management institutional capacity	0.64	0.69	0.35	0.71	0.39
	% literate population (relative to total population)	0.79	0.81	0.51	0.90	0.64
	% population above poverty line (relative to total population)	0.43	0.83	0.34	0.55	0.63
	Road density (km/sq. km)	0.08	0.43	0.12	0.51	0.06
	Legend: Values are scaled from 0 to 1 into 5 classes	[1-0.8[Very High	[0.8-0.6[High	[0.6-0.4[Medium	[0.4-0.2[Low	[0.2-0] Very Low

Type 1 (overall very high vulnerability) consists of communes located in the flat lowland Tonle Sap floodplain area (Figure 7) with very high exposure to flood in 2011 and high exposure in 2010. The proportion of agricultural area in these communes is relatively small due to the prevalence of flooded forest in the location, overall. However, the sensitivity of Type 1 communes remains important given that a very high percentage of the population are involved in agriculture and the concomitance between the cultivation and flood risk periods. Despite long-term experience in flood management, the communes have only a moderate institutional capacity to manage flood. The communes receive a fair amount of support from outside but remain particularly weak in terms of engaging internal mechanisms to deal with flood such as self-help groups or the mobilization of the commune budget. This poor performance is reinforced by a high incidence of poverty and low endowment in road infrastructure limiting accessibility and mobility, and, with it, the opportunities for coping and adaptation.

SECTION A

Type 2 communes (overall high vulnerability) are also located in the Tonle Sap floodplain and were highly exposed to the 2010 and 2011 floods. However, the variations in the topography allow farmers to keep agriculture out of the flood reach. Despite the fact that a more limited percentage of people live on the land and are engaged in agriculture, the sensitivity of this group of communes is high due to the prevalence of agriculture land in the land use inventory. As in Type 1, cropping activities are concomitant with the time of the rainy season when floods hit, and these have, therefore, a highly negative impact on crop production. The major difference between Types 1 and 2 revolves around their adaptive capacity, which we explain by the fact that these communes are located in the peri-urban area of Battambang city. They have a much better road network which improves mobility and gives better access to non-farm job opportunities (for coping or longer-term livelihood diversification strategies). This group of communes also performs well in mobilizing internal resources to manage flooding (organizing self-help groups and using commune budgets).

Type 3 communes (overall moderate vulnerability) comprise those that are not located in the Tonle Sap floodplain. Flooding occurs as a combined result of river over-flow and surface run-off. The degree of exposure is logically much lower than it is in communes in Types 1 and 2, and the flooded areas are geographically concentrated along waterways. The communes are mostly rural with large areas of land allocated to agriculture and a population mostly living off this occupation. Geographically, the zone comprising the Type 3 communes is large. It can be differentiated into two areas (Figure 7): the old alluvial terraces where current cropping systems are mostly dedicated to rice-based production; and an upland area with a cropping mosaic of rice and non-rice (usually agro-industrial) cash crops. Where flooding occurs, there is high impact, notably on cash crop productions. The institutional capacity of the commune to deal with flooding is weak in terms of both external support and internal capacity to mobilise resources. Flood is not a major concern and so communes are not well prepared or equipped to manage it. This low performance is reinforced by high incidences of poverty and illiteracy and a low endowment of road infrastructure that limits access to coping opportunities.

Type 4 (overall low vulnerability) communes are located at the edge of the Tonle Sap floodplain and, overall, the degree of exposure is higher than it is for communes of Type 3. They have a very low exposure when Tonle Sap flooding is minor (e.g. in 2010) but this becomes slightly higher when the Tonle Sap is in medium flood (e.g. in 2011). These communes are dedicated to rice-based agricultural production (both in terms of land use and labor force allocation) even if they are located in a peri-urban area of Battambang city (Figure 7). The proximity to Battambang gives this group of communes a large spectrum of adaptive capacity measures that actually balance the relatively high sensitivity. They have better road networks facilitating access to the city (which offers opportunities to support both long-term adaptation and short-term coping), and a high degree of mobility to cope when flood hits. The institutional capacity of these communes to deal with flooding is particularly high both externally and internally.

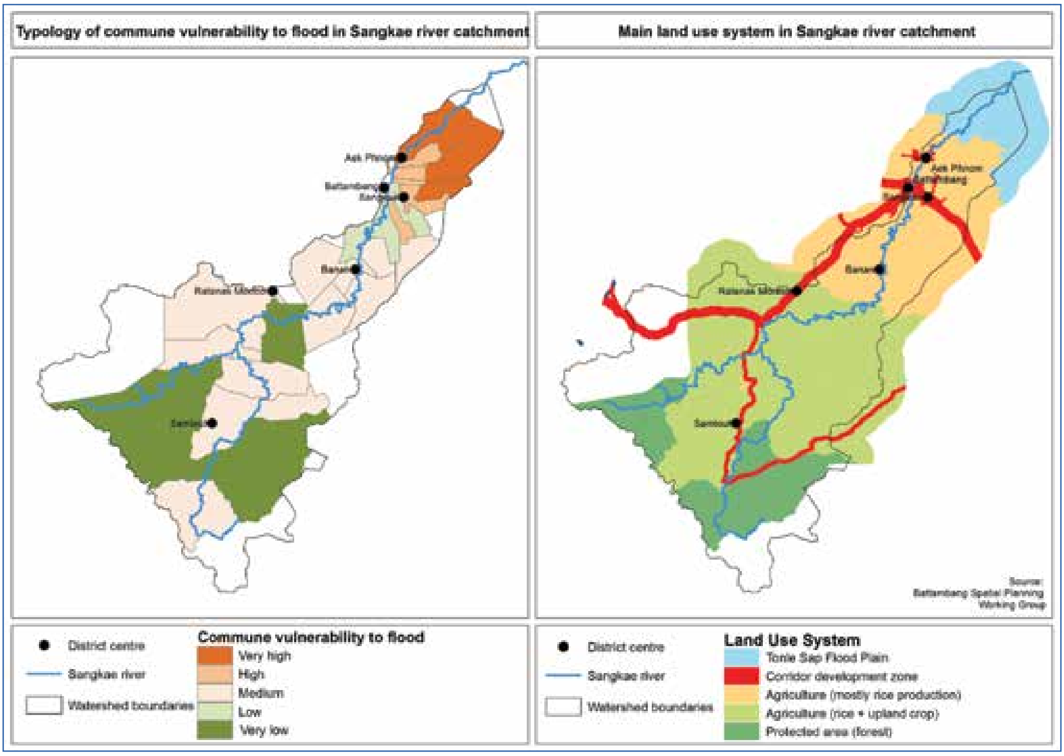


Figure 7: *Commune vulnerability and land use systems in Sangkae River watershed*

Type 5 (overall very low vulnerability) communes have a very low degree of exposure as they are located in mountainous upland areas. They were, therefore, away from the main flooded areas in both 2011 and 2010. Floods, when they do occur, are due to combined river overflow and surface run-off (as with Type 3). The overall sensitivity is very low due to a prevalence of upland forest in the overall land use system as well as a high degree of crop diversification in the dry season, thus limiting the impact of flood on the overall agricultural production (Figure 7). The adaptive capacity is rather low due to inexperience in flood management (no flood management mechanisms are in place) reinforced by a high incidence of poverty and a low endowment in road infrastructure.

Moving in and out of agriculture: The challenges of household adaptation to flood

Households cope with the impact of flooding in various ways. These include taking advantage of external support, and the internal adjustment of production systems, which can be either non-agricultural or agricultural. The difference between non-agricultural and agricultural responses is central here. The first moves the household further away from the system that has been affected, while the second changes it. Agricultural responses do not necessarily enhance resilience but at least they attempt to address the problem at its core.

However, the assessment of the households in this project against these coping strategies shows that a significant number do not seem to adapt at all (n=53, 33 percent of the total sample); they neither receive any external assistance nor do they internally adjust their production system. Some of these households have a low sensitivity (22 percent of HH pertaining to Group 1, and 6 percent to Group 2 in the sensitivity groupings shown in Figure 3) and have less need to adapt. The remaining 5 percent of households pertain to Group 4 (the most sensitive) and, for them, the absence of any adaptation measures means that the burden of the flood translates into a reduction in food consumption and food insecurity.

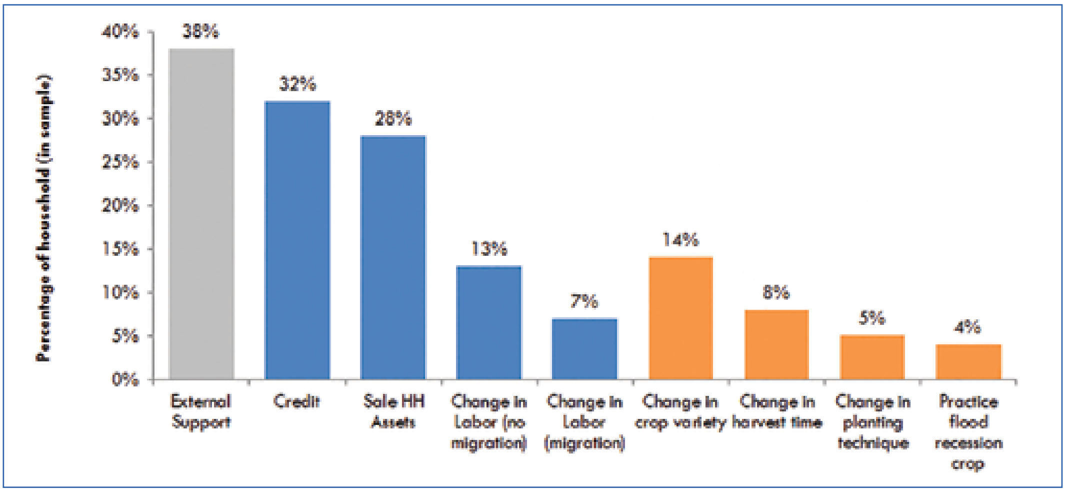


Figure 8: *Distribution of frequency of households by responses to flood*

NGOs involved in natural disaster relief - including the Cambodian Red Cross - usually provide external support for households by channelling aid packages to the target villages. These packages comprise rice bags, drinking water, and so on. Our survey shows that this external support to flood-affected households was not comprehensive as only 38 percent of households that were investigated had received such assistance in 2011 (Figure 8). As Figure 10 illustrates, we found that external aid reaches a higher percentage of households in more vulnerable zones but we also attribute this to an accessibility issue as most vulnerable areas are close to Battambang city. This Figure also shows that the external assistance actually reaches remote villages in the upland far less than it gets to downstream villages. We further note that a higher proportion of households with lower sensitivity (Groups 2 and 3) actually receive proportionally more emergency aid assistance than those in the highly sensitive Group 4, who should be prioritized (Figure 9).

The non-agricultural internal adaptations usually take the form of short-term responses to cope right after the flood. These include access to credit, sale of household assets and changes in labor (including possible migration). In 2011, a significant number of households (51 percent) relied on at least one of these non-agricultural responses. The most important is credit (32 percent of HHs sought credit to help them to cope immediately after the flood) and second most important is the sale of household assets such as cows, motorbikes, and jewellery (28 percent of HHs resorted to this) (Figure 8). In both cases, these responses to flood do not reduce vulnerability but actually reinforce it over the long-term in that people are surrendering their assets. We note that household non-agricultural coping is more important in regions of higher vulnerability (Figure 10) but our findings suggest that there are no sensitivity-group-specific, non-agricultural responses (Figure 9).

Unlike the adaptive responses that have previously been discussed, agricultural adaptation implies a change in household cropping systems. The number of households involved in at least one agricultural response (23.9 percent) sharply contrasts with those who adapt with non-agricultural means. The responses can be short-term adjustments - such as the practice of flood recession agriculture (4 percent) - or a change of harvest period (8 percent), while some other responses engage the households in more structural changes in their cropping systems such as the adoption of new planting techniques (usually favoring broadcasting rather than transplanting, 5 percent) or choosing alternative crop varieties (14 percent) (Figure 8). These observations emphasize the underlying difficulties faced by the household in building flood-resilient cropping systems.

A change in the varieties of rice cultivated is a clear strategy to deal with the period of high rain intensity and flood risk (October). The change of varieties implies abandoning rain-fed, photoperiod sensitive rice crops, harvested in October-November, for non-photoperiod sensitive short-cycle rice varieties. These shorter cycle varieties are usually improved varieties with higher potential yield. With access to water from irrigation or reservoirs, this non-photoperiod sensitive, short-term rice can also be cultivated in the early rainy season, from March/April to June. This change is substantial as it considerably alters the cropping and labor calendar. Yet changes in the rainfall pattern alone do not explain the adoption of these new rice varieties. In a move to boost rice production and rice export, the Ministry of Agriculture, Forestry and Fisheries has been active in promoting high yield non-photoperiod sensitive rice varieties (Ministry of Agriculture, Forestry and Fisheries and Ministry of Water Resources and Meteorology 2007). Another push factor for the adoption of those varieties has been the increased food demand driven by population increase. However, this pathway of adaptation has a high cost. It is reserved for households who can adopt the innovation because they have the necessary upfront investment capital to purchase seeds, fertilizers and pesticides. Our findings suggest that a higher percentage of Group 3 (more sensitive - see Figure 3) households have adopted the new rice varieties because they have a non-farm income to support upfront investment and to provide back-up in case of crop failure (Figure 9). This innovative form of adaptation also reinforces a social differentiation process between two categories of producers: successful farmers and coping peasants.

These difficulties were largely echoed by the farmers in our survey when they were asked about future prospects. A large majority of them were not willing to abandon agriculture (88 percent) or to sell land (91 percent), and an important part (52 percent) were considering reinforcing non-farm activities as a preferred adaptation option in the future, especially those who were most at risk (Group 4). Households who said they were ready to change their rice varieties represented 39 percent of the total but they were in the low sensitivity Groups 1 and 2.

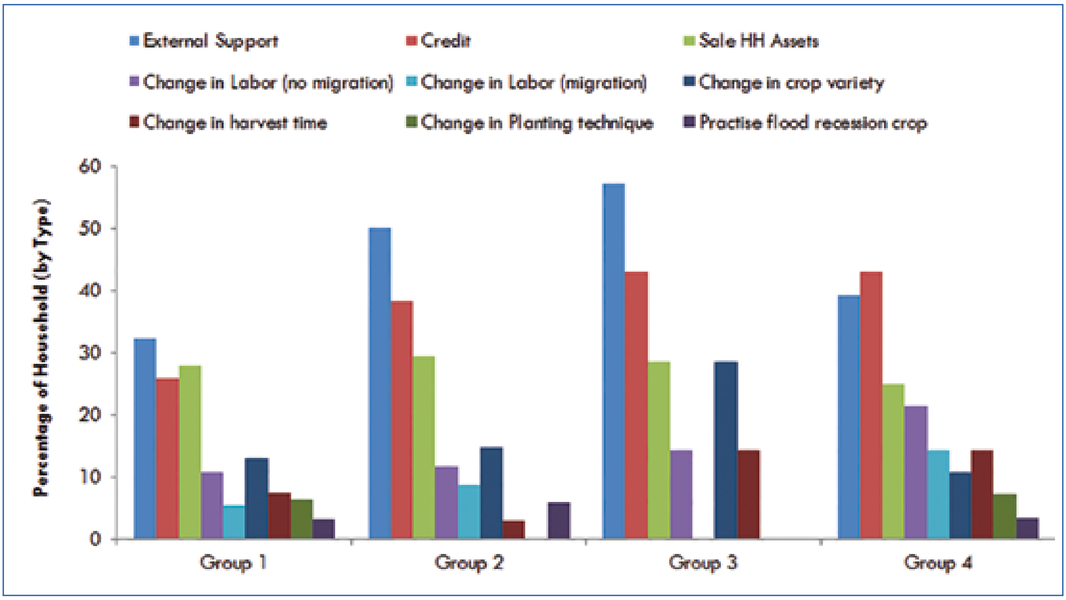


Figure 9: *Distribution of frequency of households by responses to flood and by sensitivity grouping*

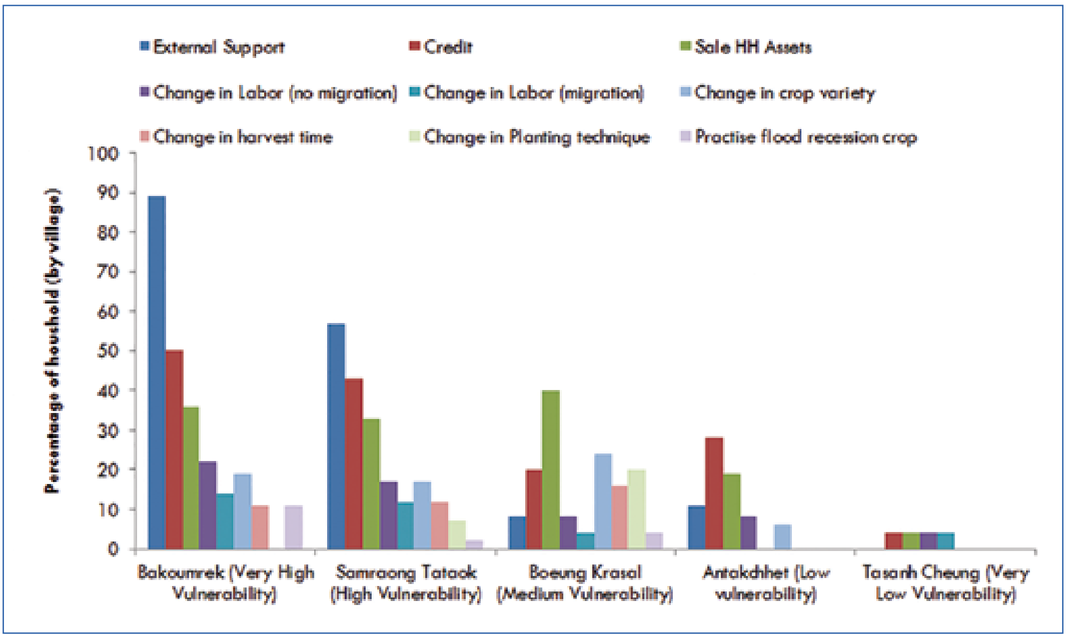


Figure 10: *Distribution of frequency of households by responses to flood and by vulnerability zone*

TOWARDS REDUCING FLOOD VULNERABILITY: WHAT IS NEEDED?

We have created a typology of vulnerability at different levels which is produced through the interaction of multiple and cross-scale drivers. This now allows us to make recommendations that are relevant at different levels of decision-making (provincial down to household levels). A particular concern is to find the fit between the scale of the vulnerability drivers (where and how they originate) and the scales of solutions. We are also concerned about providing recommendations that are directly meaningful and effective in enhancing flood-resilient agriculture for farmers and their communities.

Intensification of rainfall puts a higher pressure on all flood-prone areas across the watershed with a higher risk in the uplands where flood results from a combination of river-overflow and surface run-off. In mid-stream, the continued construction of irrigation canals will help to increase floodwater storage capacity within the watershed thus reducing flood exposure. But given the nature and magnitude of work needed here (engineering and infrastructure), the national and provincial agencies are best positioned to tackle it. In the upland area, though, low-key options to reduce exposure could be achieved by working concomitantly on limiting surface run-off (by soil terracing or ensuring a permanent land cover) and on improving the channelling and the reception of run-off water into natural or man-made storm-water basins.

As far as pre-disaster flood management measures are concerned much better coordination is needed between ministerial and inter-ministerial line agencies at provincial level. Provincial institutions need to join forces in order to provide more efficient responses to flooding across the watershed. The mandates of institutions with regard to flood management are actually quite explicit but a clear and definitive commitment to share efforts and information is lacking (World Bank 2003). All relevant institutions and government agencies should unite as a specific provincial flood management taskforce or *ad hoc* working group where information about rainfall data, flood prone areas, good practices and lessons learned could be shared and easily accessed by the stakeholders. Improved coordination could also be addressed through watershed management and spatial planning organizations. We recommend more systematic integration of natural disaster management in the provincial spatial plan, a district land use master plan and commune land use plan.

An early warning system could be greatly enhanced by rehabilitating existing rainfall stations throughout the watershed to make them operational. Accurate and reliable rainfall and water river level/discharge data could be recorded, monitored and disseminated quickly to all stakeholders. This could be done at low cost via a communication network that connects these stations and would enhance place-based flood management decision-making.

With regard to agriculture, the development of the so-called early season agriculture is central to promote flood adaptation but more generally to build a disaster-resilient cropping system. While early season agriculture would reduce the impact of flood, it would also enable cropping intensification and diversification. First of all, detailed social and agro-ecological diagnosis of the potential of, and constraints on, developing early season agriculture is necessary. The promotion of early season agriculture should be an inclusive process that supports all categories of farmers. This obviously requires the details of different farming systems to be understood, as well as support for farmers in discovering and pursuing their own adaptation pathway. At the household level, the promotion of integrated farming systems along agro-ecological principles is a key strategy in building disaster-resilient smallholder agriculture.

Support for this early season agriculture is not a panacea. Provincial authorities need also to promote innovative partnerships with commune councils, building information and knowledge bridges between provincial agricultural and resource authorities, and the farmers (e.g. through local development planning and budgeting processes). Key here is to build legitimate and inclusive dialogue forums with a strong and definitive commitment to learning between multi-level organizations and associated institutions involved in flood management. Local level stakeholders could also be supported in their own efforts at small-scale infrastructure construction (storm-water reservoirs) to better enable early season agriculture. Local authorities also have a role to play in monitoring the land markets to prevent land rent capture and land concentration in the hands of a few well-connected and wealthy famers.

As far as post-disaster flood management is concerned, the selection of target zones and households for aid rescue distribution should be improved and better based on sensitivity criteria.

TYPOLOGIES OF VULNERABILITY: CONCLUDING REMARKS

The multi-scale assessment we have proposed suggests that there is no simple answer to the questions posed in respect of flood vulnerability in the Sangkae River watershed. The nature and extent of vulnerability always depend on the analytical scale (O'Brien et al. 2004) and the politics of the assessment (Lebel 2006). To capture the complex nature of cross-scale and cross-level interactions, we have defined different typologies of vulnerability at different levels of analysis.

The analysis of historical rainfall patterns and extreme rainfall events in the watershed allowed us to identify a trend towards the intensification of the water cycle and the change of rainfall pattern into a mono-modal (one peak) distribution that culminates in October. So, throughout the watershed, flooding has become a more frequent problem. We found the risk has become higher in the upland area than on the Tonle Sap floodplain, through a combination of surface run-off and river overflow. However, if similar studies are to take place in other watershed areas, we recommend taking into account (if possible) rainfall data from other stations located in the catchment in order to allow for a more dynamic modeling of flood patterns. A more detailed analysis of vulnerability at the commune level provides a stronger basis for understanding where, how, and why certain regions are more vulnerable than others to flood. Our analysis reveals that the agro-ecology diversity and the accessibility to/from main urban centers are key in explaining this diversity. When the assessment takes into account the uneven distribution of land and income within villages, it is possible for social groups to be identified that are more vulnerable to flood than others.

The methodology we developed provides nested pictures of vulnerability at different levels and scales and our argument suggests that a dialogue between these levels and scales is necessary to make sense of vulnerability and to act to reduce it. This dialogue should be coordinated by the Provincial Committees for Disaster Management, with participation from provincial institutions of line ministries, NGOs and development partners, in order to improve pre-flood preparedness and foresee the interventions that would best help vulnerable areas. Based on these different typologies of vulnerability this approach supports the identification of sound recommendations that can contribute towards reducing vulnerability through better horizontal and vertical integration of institutions and agencies and through effective collective action.

SECTION A

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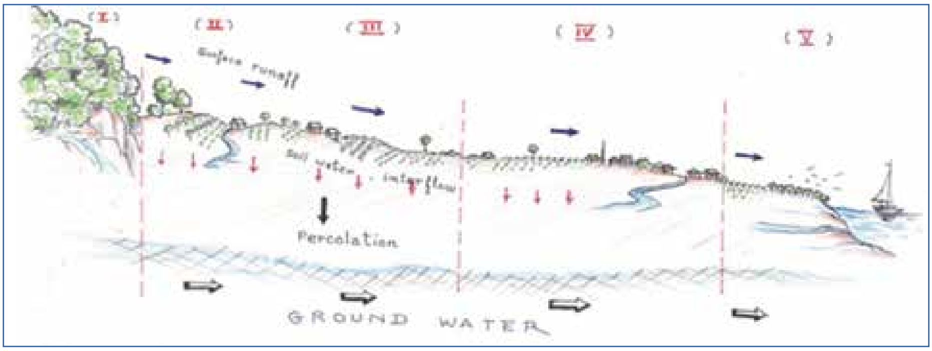
ANNEXES

Annex 1: List of indicators for commune vulnerability analysis

Dimension	Indicators	Data source
Exposure	% of flooded area in 2011 (relative to total agricultural land area)	Commune workshop conducted in 2012
	% of flooded area in 2010 (relative to total agricultural land area)	
	Flooded area in 2011 weighted by duration (relative to total 2011 flooded land area)	
Sensitivity	% agricultural area size (relative to total commune area)	Interpretation of Landsat satellite image (2010)
	% population involved in agriculture (relative to total population)	Commune database online (2010 update)
	Flooded area in 2011 weighted by damage (relative to total 2011 flooded land area)	Commune workshop conducted in 2012
	% cultivated area during flood period (relative to total cultivated area)	Commune database online (2010 update)
Adaptive capacity	Flood management Institutional Capacity	Commune workshop conducted in 2012
	% literate population (relative to total population)	Commune database online (2010 update)
	% population above poverty line (relative to total population)	GIS-based calculation based on road information (2010)
	Road density (km/sq. km)	Commune database online (2010 update)

Annex 2: Agro-ecological transect across Sangkae River watershed from the south-west (left) to the north-east (right)

An agro-ecological transect is a useful way to present the agro-ecological features of the watershed. A virtual line oriented south-west to north-east is drawn to simulate a walk across the watershed. The transect aims to describe the evolution of the agro-ecological features. Four distinct zones are identified. The figure shows the diversity and the transition in the social-ecological landscape.



Landform-Elevation (meters above sea level)	Moderate or steep inclines High: 1000-1250 m	Gently rolling highland with some lowland areas to rivers 250-1000 m	Mainly rain-fed lowland prone to flooding 15-50 m	Gently rolling low-lying land, entirely inundated for long periods 5-15 m
Water resources	Seasonal and perennial stream	Non flooded, perennial and season stream	Larger stream and river - occasional lake and ponds (perennial). Partly flooded	Seasonal flood, numerous lakes/ ponds
Climate	High rainfall (>2000 mm/ year) - 2 months dry	Rainfall: 1500–2000 mm/year Low drought risk, rains start east to west	Rainfall: 1000-1500 mm/year 3-month dry	Rainfall: 1000-1500 mm/year 2-month dry
Geology	Sandstone Triassic	Quaternary colluviums (pediments) + limestone	Quaternary lake deposits	Quaternary organics deposit
Soils	High drainage, superficial, erodible, fragile *Leptosols*	*Cambisols-leptosols-Nitisols*	*Luviols–Vertisols*	*Gleysols–Fluvisols*
Land use (2002) and main crop	Forest (timber extraction), hunting, charcoal, non-timber forest product (NTFP) collection	Highland agriculture with fruit production and livestock Abandoned crops covered by grass or shrub Some lowland paddy in depressions	Main rice plain - settlement, main infrastructure Significant fruit tree farming system Limited area of irrigated farming	Flooded plain (flooded grass-land, flooded shrub and forest) Capture-fish-based livelihood systems Migratory (seasonal) livestock systems Deep water rice
Land use dynamic	Conservation and effective production	Slight decrease in the forest cover Complete decrease of the wood-shrub land into agricultural land	Maintain or enhance the agricultural land and mainly rice production	Varied density between grass and shrub land

Source: *Battambang provincial spatial plan*

Annex 3: Computation of extreme rainfall indices

Comment	Trends 1981-2012	Month of Occurrence (Mode)	Slope	R^2 (linear)
Wdays>1mm Annual Count of wet days when precipitation >1mm	Increase	September (500 days btw 1981-20012)	0.3000	0.0705
PRCTOTO = Annual Total Precipitation on wet days (rainfall > 1mm)	Increase	N-A	2.3116	0.0141
SDII: Simple Precipitation Intensification Index = PRCTOT/Nb Wet days (rainfall>1mm)	Decrease	N-A	-0.0196	0.0206
Max. CWD>1mm CWD= (Annual) Number of consecutive Wet Day (when rainfall > 1mm)	Decrease	September (10 series out of 31)	-0.0065	0.0005
Rainfall during Max CWD>1mm	Increase	N-A	0.0155	0.000008
Max CDD<1mm CDD= (Annual) Number of consecutive Dry Days (when rainfall<1mm)	Decrease	N-A	-0.1343	0.0072
Rx1Day = (Annual) Maximum 1 day precipitation	Decrease	October (13 days out of 31)	-0.0638	0.0007
Rx5D = (Annual) maximum consecutive 5-day precipitation	Increase	October (12 series out of 31)	0.1086	0.0004
R20mm=Annual Count of days when Rainfall>20mm	Increase	October (124 days)	0.0157	0.0012
R25mm=Annual Count of days when Rainfall>25mm	Increase	October (89 days)	0.0056	0.0003
R50mm=Annual Count of days when Rainfall>50mm	Increase	October (32 days)	0.0234	0.0248