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DEVELOPMENT OF FLOOD VULNERABILITY INDICES FOR LOWER MEKONG BASIN IN CAMBODAIN FLOODPLAIN

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Floods frequently occur in the world, which cause serious damage of properties and loss of lives. It is thus important to identify flood vulnerability in flood-prone area. This study identified flood vulnerability in the Lower Mekong Basin of Cambodian floodplain and developed flood vulnerability indices for the average and extreme floods in order to avoid big damages and cope with flood in their life. The flood vulnerability was defined as amount of potential damages. The agricultural and house damages were considered to develop flood vulnerability indices, because both are major income and stocks. The agricultural damage was defined as the function of flood water depth during the cultivation period and its duration. The house damage was defined as the function of maximum flood water depth.

Key Words : *flood vulnerability, agricultural damage, house damage, Lower Mekong Basin, Cambodian floodplain*

1. INTRODUCTION

Floods frequently occur in recent years in the world, which cause serious damage of properties and loss of lives. Especially the developing countries are most vulnerable to flood disasters such as Lower Mekong Basin (LMB) of Cambodia and others. LMB is frequently affected by floods, particularly, the low-lying floodplains of Cambodia[1)]. **Fig. 1** shows the location of LMB in Cambodia and river systems. The flooding process is a part of regular life in the LMB and it provides irrigation for crops, water for the fisheries and navigation purpose[2)]. However, occurrence of flooding in many parts of the LMB causes damage to properties in the area. Populations living in LMB area of the Cambodian floodplain are vulnerable to flood disasters. It is thus necessary to identify flood vulnerability in flood-prone area of LMB to support decisions for flood management.

The flood vulnerability in LMB is still poorly identified, although FMMP[3),4)] provided valuable information on floods in LMB and some socio-economic damages. However, these information are only limited to few districts level. Furthermore, some investigation in LMB area can be found only on flood inundation and hydrological analysis[1),5)] and satellite based flood inundation[6)].

This study identified flood vulnerability in LMB of Cambodian floodplain and developed Flood Vulnerability Indices (FVIs). The flood vulnerability was defined in terms of amount of potential damages. The agricultural and house damages were considered to identify flood vulnerability indices, because both are major income and stocks in the area. The agricultural damage was defined as the function of flood water depth during the cultivation period and its duration. The house damage was defined as the function of maximum flood water depth by relating with average year flood level.

2. METHODOLOGY

In our grid-based distributed methodology, hereafter we refer as ICHARM Hydro-Geo Method (IHGM), the definition chosen for vulnerability is amount of potential damages[7)]. Agriculture is a major industry in the LMB and houses and assets are also important properties of people. Thus, flood vulnerability was calculated for agricultural and house damages (**Fig.2**). Agricultural damages

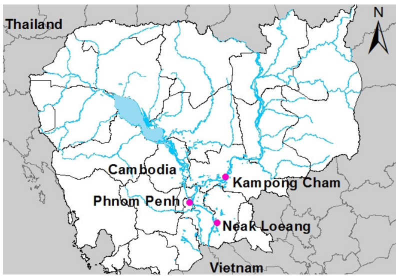

Fig.1 LMB in Cambodian floodplain and river system.

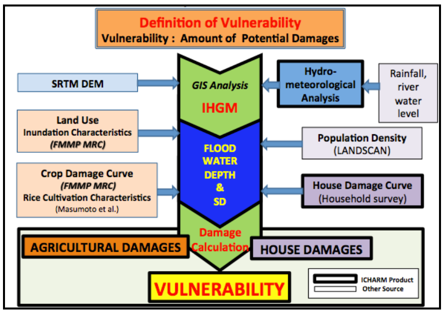

Fig.2 Flowchart of IHGM for flood vulnerability assessment.

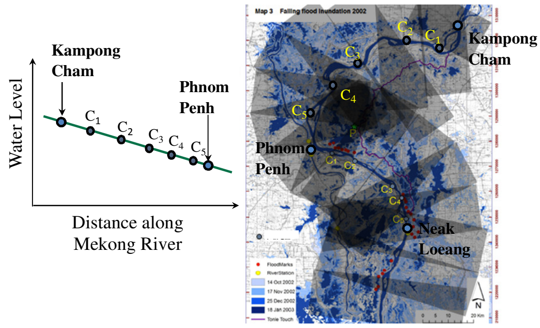

Fig.3 Description of water level calculation in floodplain.

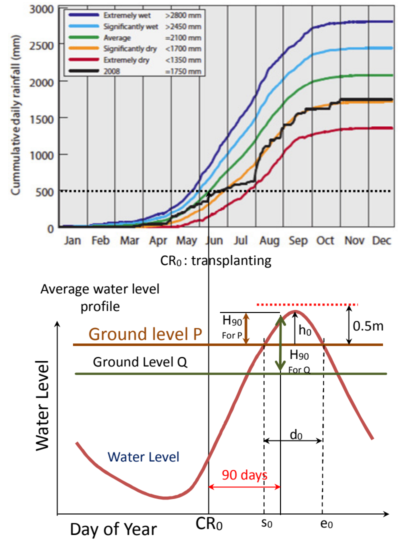

Fig.4 Schematic of agricultural cultivation and damage with water level hydrograph.

referred here as damages occurring to wet-season rice crops. House damages account for damages occurring to household residential assets and were calculated based on household survey data for 2006 flood from Flood Management and Mitigation Programme (FMMP) of Mekong River Commission Secretariat (MRCS). Through IHGM integrating hydro-meteorological analysis and Digital Elevation Model (DEM) of HydroSHEDS which obtained from Shuttle Radar Topography Mission (SRTM) data, flood water depth was calculated as difference between flood water level and ground level at 3 arc-second cell (approximately 91.8m×91.8m cell size). In HydroSHEDS data, the corrections were made in original SRTM elevation data where necessary for accuracy assessment. As DEM data is available at 3 arc-second resolution, flood water level is calculated at 3 arc-second cell.

(1) Calculation of water depth

Plinston[8)] identified that in the Cambodian floodplain, the river water level approached floodplain inundation water level during past floods; indeed, once floods were high enough, flood level and river water level coincided. Based on this concept, water depth in floodplain was calculated as difference between flood water level and elevation at grid level. We obtained long term 1991 to 2007 years water level and rainfall data of all the stations in Cambodia. Water level in the floodplain or flood level is approached as the river water level at the closest gaging station or by interpolation between two consecutive gaging stations. For example of calculation, the area between Kampong Cham and Phnom Penh is set, which extends about 168km x 130km. The obtained water stage data at Kampong Cham and Phnom Penh, were interpolated on 31 points on the river between two stations in order to allocate a water level value to those 31 points, according to the distance of each point from both stations (**Fig.3**). Thus, floodplain between two stations was divided into 31 stripes along the river, centered on a point on the river, C_i, and hydrographs were plotted for each stripe from the interpolated water levels for the same flood event (**Fig.3**). For cells in the floodplain where several stripes overlap, it gets attributed median water level of all the overlapping stripes. Then, flood water depth was calculated by subtracting ground level from flood water level at each cell. Through this process, flood water depth was hence calculated for each 3 second (91.8m) cell for the whole Cambodian floodplain.

(2) Calculation of agricultural damages

About 80% rice in Cambodia produces from wet-season rice and these crops are damaged during flood. Thus, we considered wet-season rice crops damages as agricultural damage. Usually farmers in Cambodia start to cultivate wet-season rice when accumulated rainfall reach 500mm as land becomes soft enough to be cultivated[9)]. It takes 90 days for rice growth (**Fig.4**). During that period of 90 days, damages occur if flood water depth reaches over

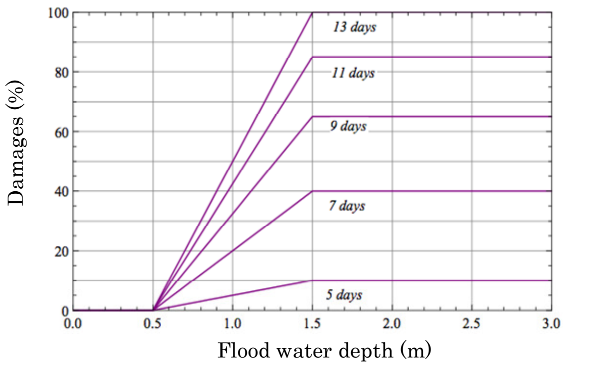

Fig.5 Damage curves for wet-season rice according to flood water depth and flood duration[4].

0.5m as it is minimum damageable depth of water[4]. An agricultural damage was defined as function of flood water depth and its duration. From IHGM, the maximum daily water depth and their duration for each grid were calculated. Agricultural damages in each grid were calculated according to damage curves as shown in **Fig.5** developed by FMMP[4]. Then amount of agricultural damage for each grid was calculated by multiplying damage ratio with average yield (average yield 392 US$/ha, based on data of Ministry of Planning, Cambodia). The cultivation area of wet-season rice was considered based on agricultural land use data made in 2003 by Ministry of Public Works and Transport, Cambodia. The agricultural damages were calculated for each 3 second cell (91.8m cell). It was assumed that one cell is a plane with same height of wet-season rice.

(3) Calculation of house damages

House damages are the damages encountered at household level and defined as the function of water depth. We used household survey data for 2006 flood of FMMP project, MRCS, Cambodia. The survey sample included 262 households in three districts Koh Andet in Takeo province, Koh Thom in Kandal province and Kampong Trabek in Prey Veng province. Based on survey data, gamma distributions well fitted to house value distributions according to water depth in the yard or water depth over house floor (**Fig.6**). **Fig.7** shows the damage curve (ratio of house damage to house value) calculated from actual damages after 2006 flood and potential damages that would have occurred if 2006 water depth had been 0.5m, 1.0m, 1.5m and 2.0m higher. Based on household survey data, it was assumed that gamma distribution fits the house value distribution according to water depth in the yard. Then by integrating multiplication of house value distribution curve and damage ratio curve, we can get the house damages as follows.

$$HD_k = N_k \cdot HV \int_{h=h_k}^{\infty} \left(g(x,\alpha,\beta) \cdot DamageRatio(h) \right) \cdot dh \tag{1}$$

where, HD_k and N_k are the house damage and total number of people respectively in cell k, HV is the average house value per people, h is the water depth at yard, $g(x,\alpha,\beta)$ is the house value distribution function and *DamageRatio(h)* is the unit damage at h. The house value 245 US$ per person was used, which was determined based on household survey for 2006 flood from FMMP project[4]. Population data derived from the LandScan 2009 global population at 30 arc-seconds (918m cell) was used to consider household distribution in the each cell. In Cambodian floodplain, people usually construct elevated houses by using stilts to avoid flood damages. So, if we use relative water depth from average peak flood level of each location, we can deal with them using house value distribution obtained from household survey data in other area.

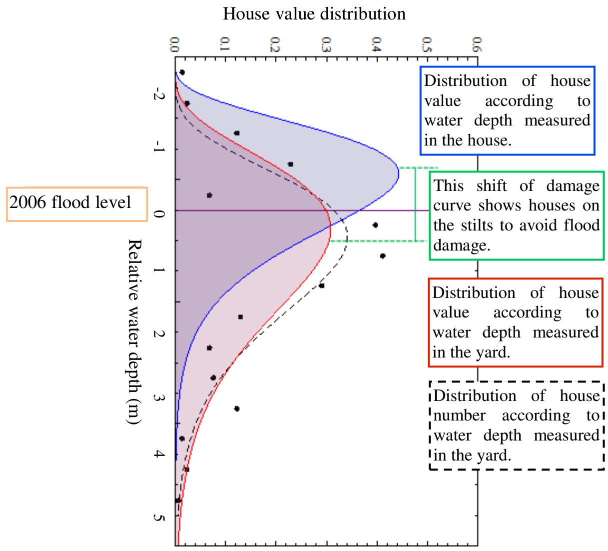

Fig.6 House value distribution curve.

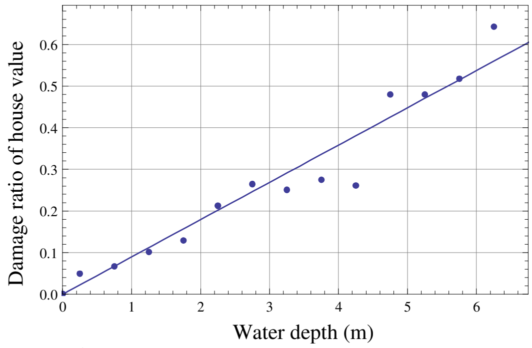

Fig.7 Damage ratio curve of house value.

(4) Development of flood vulnerability indices

We developed two kinds of flood vulnerability indices. First one is flood vulnerability indices for average flood and second one is flood vulnerability indices for extreme flood. The average water depth of flood in 2006 is almost equal to average water depth of years 1991-2007. Thus, we evaluated FVI for 2006 flood as average flood. The Flood Vulnerability Indices for Average Flood (FVI-AF) are identified by normalizing calculated value of

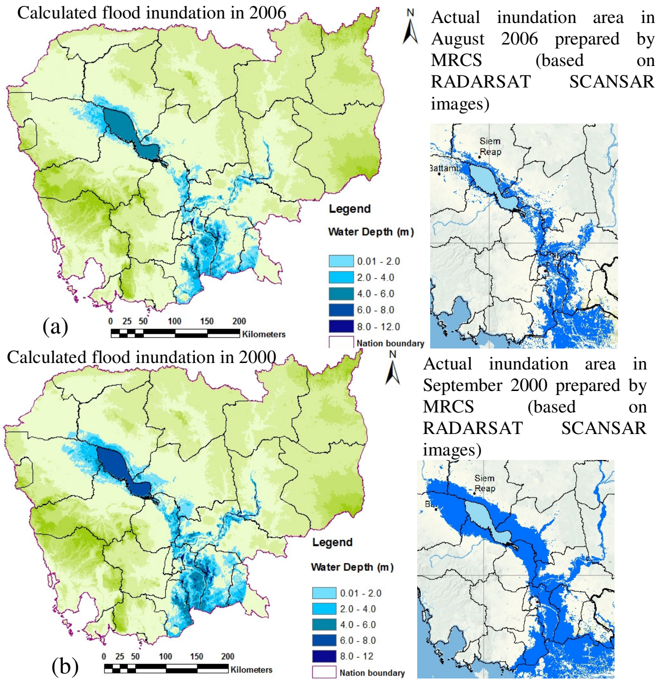

Fig.8 Flood inundation depth (a) 2006 flood, (b) 2000 flood.

damages in each grid. To normalize the value, the calculated value in each grid is divided by maximum value of calculated damages as follows.

$$FVI\text{-}AF\ (AD\ or\ HD) = \frac{Value\ of\ damage\ in\ a\ grid\ (AD\ or\ HD)}{Maximum\ value\ of\ damage\ (AD\ or\ HD)} \quad (2)$$

where, AD or HD is agricultural or house damages.

As we defined vulnerability as amount of potential damages, vulnerability is combination of agricultural damages and house damages. However, agricultural and house damages do not have same impact on a household. The main source of income of farmers is from agriculture and they give higher priority on agriculture. They consume some amount of income from agricultural production. However, they also use their saving amount of income from agricultural production to houses or assets. So, amount of house damage also includes some saving amount of income from agricultural production. Also if we look their expenditure on food with their total expenditure based on Engel's coefficient, their expenditure on food is about 75% of their total expenditure[10]. As main source of food expenditure of farmers is consumed from agricultural production, they give high priority on agricultural production. So, in this study we give the weightage on agricultural damages based on food expenditure and we gave 0.75 weightage to agricultural damage based on Engel's coefficient. As total weightage of both agricultural and house damages is 1, we gave 0.25 weightage to house damage. The weighted total damage (TD) is calculated as follows.

$$TD = Wa \times AD + Wh \times HD \quad (3)$$

where, Wa and Wh are the weightage factor for agricultural and house damages, respectively. To calculate FVI-AF for total damages, weightage total damages were also normalized same as Eq. (2).

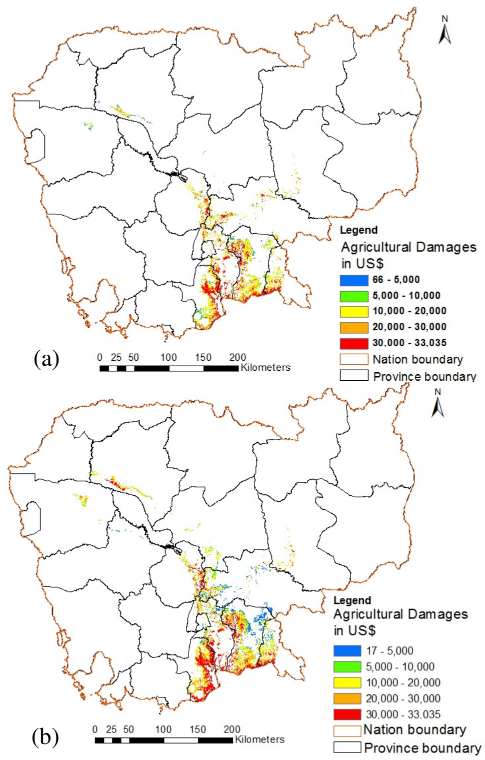

Fig.9 Distribution of agricultural damages in Cambodian floodplain (a) 2006 flood, (b) 2000 flood.

Flood Vulnerability Indices for Extreme Flood (FVI-EF) are defined to identify damages gap area between average flood and extreme flood. The average flood brings some damages but extreme flood brings big damages. It means serious preparedness for extreme flood is needed in such area. Based on flood observation data from 1991-2007, average water depth of flood in 2000 is higher in the period. Thus, flood in 2000 was referred as extreme flood. The variations of gap area of flood vulnerability of extreme flood are identified by relating it with average flood for agricultural, house, or total damages as follows.

$$FVI\text{-}EF = \frac{Damage\ (2000\ Flood) - Damage\ (2006\ Flood)}{Damage\ (2006\ Flood)} \quad (4)$$

3. RESULTS AND DISCUSSIONS

As house damage calculation is in 30 second cell (918m), calculated water depth and agricultural damages data from 3 second (91.8m) (100 cells) are up-scaled to 30 second cell (918m). **Fig.8** shows the maximum flood inundation depth in average flood (2006) and in extreme flood (2000) and compares calculated inundation area with actual inundation area. The flood inundation depth is higher in downstream reach of Cambodian floodplain.

Fig.9 shows distribution of agricultural damages in the cases of flood in 2006 and in 2000. In average

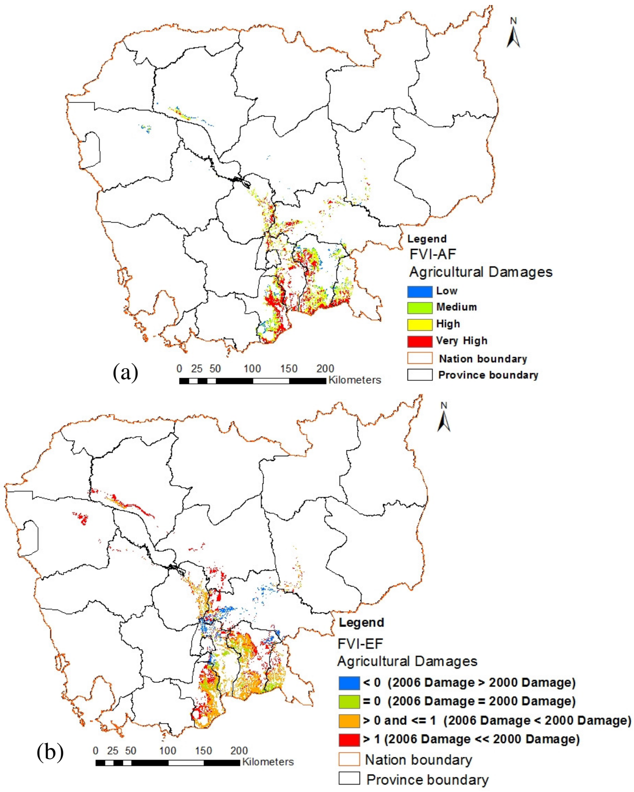

Fig.10 Flood vulnerability indices of agricultural damages (a) for average flood, FVI-AF, (b) for extreme flood, FVI-EF.

flood case (2006 flood) also, they experienced some agricultural damages. The agricultural damages in middle and downstream area of floodplain are higher compared to upstream area.

Fig.10a shows FVIs of potential agricultural damages for average flood. The FVI-AF is defined from low to very high vulnerable area based on normalization value ranges from 0 to 1. The normalized value ranges 0 – 0.25, 0.25 – 0.5, 0.5 to 0.75 and 0.75 to 1 respectively defined as low, medium, high and very high vulnerable. In average flood also, people living in the area often faced agricultural damages. Based on the FVI-AF map they can identify which area is highly vulnerable to flood and which area is low vulnerable to flood.

Fig.10b shows FVIs of agricultural damages for extreme flood. The figure shows identification of agricultural damages gap area between average flood (2006 Flood) and extreme flood (2000 Flood). In red color area of figure, agricultural damages are very higher in extreme flood than average flood. In blue color area, agricultural damages are higher in average flood than extreme flood case. During the growing period, flood water depth in blue color area is higher in average flood than extreme flood case. In average year also agricultural damages can be higher than extreme flood case, because the agricultural damage is caused by significant inundation during growing period which is determined with accumulated rainfall of that area.

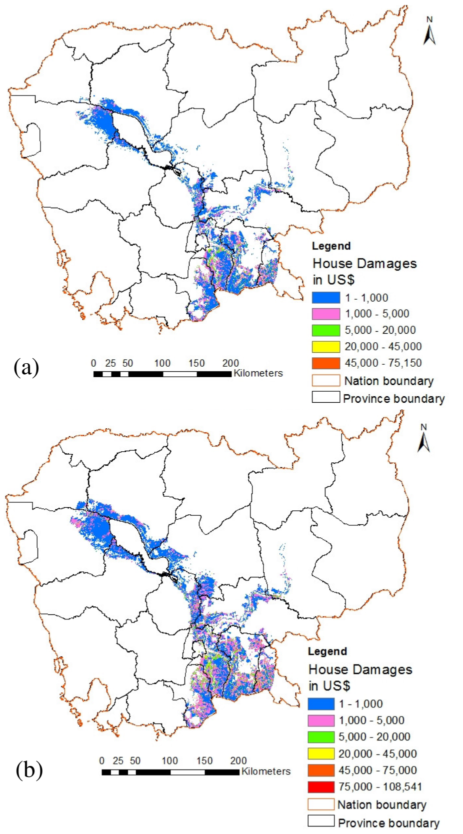

Fig.11 Distribution of house damages in Cambodian floodplain (a) 2006 flood, (b) 2000 flood.

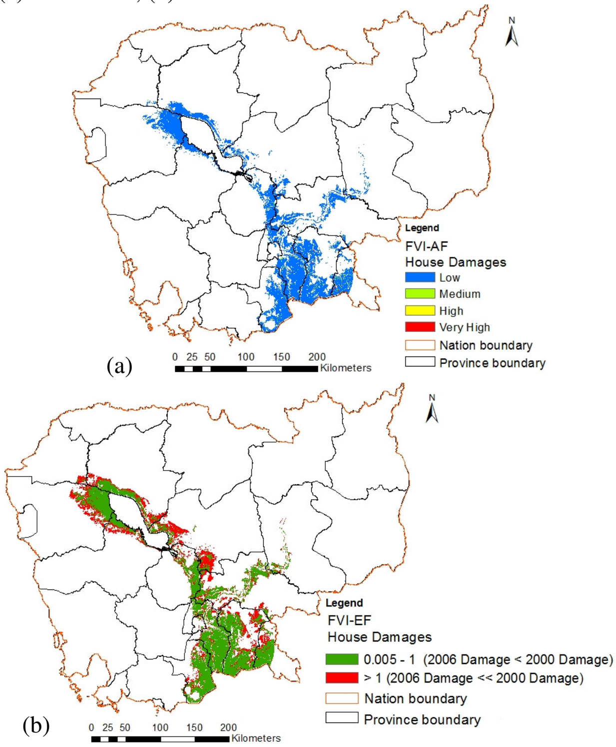

Fig.12 Flood vulnerability indices of house damages (a) for average flood, FVI-AF, (b) for extreme flood, FVI-EF.

Fig.11 shows calculated house damages distribution. The statistical data of house damages based on FMMP survey for 2006 flood are about 508,000 US$ and 1,817,632 US$ in Koh Andet and Koh Thom districts, respectively. The calculated

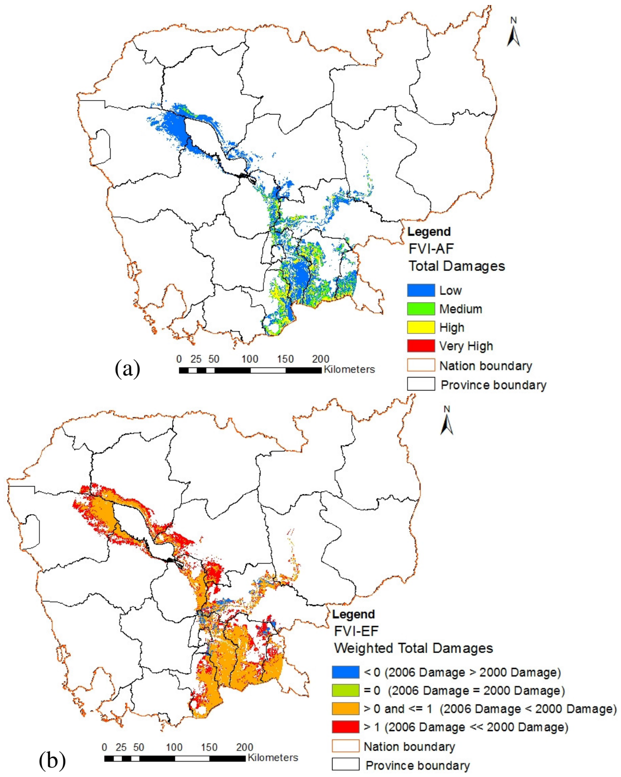

Fig.13 Flood vulnerability indices of weighted total damages (a) for average flood, FVI-AF, (b) for extreme flood, FVI-EF.

house damages in 2006 flood in Koh Andet and Koh Thom districts are found to be 826,585 US$ and 1,404,623 US$, respectively. The calculated house damages are reasonable with statistical data.

Fig.12 shows FVIs of house damage for average flood and extreme flood. During average flood, they experienced some house damages. However, in extreme flood, they experienced big house damages in the area. The map of house damages gap area between average flood and extreme flood is very useful to identify the area where big house damages occur during extreme flood.

The weighted total damages were calculated for 2000 and 2006 floods using Eq.(3). **Fig.13** shows FVIs of total damages considering agricultural and house damages. By utilizing FVI-AF, we can easily find information of vulnerable area and we can easily identify where preparedness is needed. In average flood also, they experienced some damages in Cambodian floodplain. But when extreme flood occurs, the big damages occur in the area. It means serious preparedness for extreme flood is needed in such area. By utilizing FVI-EF to identify gap area between average flood damages and extreme flood damages, we can recognize the area where serious preparedness for extreme flood is needed.

4. CONCLUSIONS

The flood vulnerability was defined as amount of potential damages. The agricultural damages and house damages were considered to develop FVIs. The agricultural damages depend on flood water depth and its duration as well as accumulated rainfall in the area. The house damages depend on maximum flood water depth. The FVIs were developed for agricultural, houses and total damages in LMB of Cambodian floodplain. The FVIs identify area which easy to be affected by flood. The results of FVIs guide well preparedness for flood in agricultural as well as house and assets. The developed FVIs can be useful for local community, decision makers and developers when translation tools are well prepared. The proposed methodology can be a good initiative to apply in other area.

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