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DEVELOPMENT OF FLOOD RISK ASSESSMENT METHOD FOR DATA-POOR RIVER BASINS: A CASE STUDY IN THE PAMPANGA RIVER BASIN, PHILIPPINES

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ABSTRACT: In recent years, floods frequently occur in the world, which cause serious damage of properties and loss of lives. An assessment of flood risk in the river basin is thus very important for development activities and river basin management. In this study, the flood damage assessment method was developed for the assessment of flood risk in data-poor river basins by using physical based numerical model, satellite-based information and socio-economic factors. The Pampanga river basin of the Philippines was selected for the case study. For the flood damage assessment, the hazard characteristics such as flood depth and duration were computed by using Rainfall Runoff Inundation (RRI) model. Agriculture and household which are major exposures in the flood prone areas were taken into account for the flood damage assessment. The potential damages of agriculture were estimated by using the damage function of agriculture and flood characteristics. The damage functions of agriculture for its each growing stages were defined as the function of flood depth and duration. Field investigation and questionnaire surveys were conducted at the selected Barangays (Villages) in the Pampanga river basin to develop methodology for household damage estimation. The appropriate damage functions for household building and assets damages were developed based on the flood and household characteristics. The estimated damages of agriculture and household were consistent with the reported values. The developed method can be applied in other river basins where damages data are poorly available.

Key Words: Flood Risk Assessment, Hazards, Exposure, Vulnerability, Damage Function

1. INTRODUCTION

Recently, impact of floods is becoming wider due to their increasing frequency and scale, concentration of population and economic activities around river basins and economic inter-dependency due to globalization. Flood disasters cause serious damage such as loss of lives, loss of properties and loss of livelihoods. Especially the developing countries are most vulnerable to flood disasters (Shrestha et al., 2013, 2014). However, most river basins of developing countries lack baseline data for flood risk assessment. An assessment of flood risk in the river basin is thus very important for development activities and river basin management.

Flood risk management can be mainly categorized into two parts: (i) Flood risk assessment including damage analysis, and (ii) Risk mitigation. However, for both parts, risk assessment and the evaluation of risk mitigation measures, it is required to quantify flood risk as exactly as possible (Meyer et al., 2007). The flood damage estimation is important to quantify flood risk. The flood damage estimation in spatial distribution can be a powerful tool to build an efficient flood disaster mitigation policy (Dutta et al., 2003; Sugiura et al., 2013). Although flood damage assessment is an essential part of flood risk management, it has not received much scientific attention (Merz et al., 2010).

For flood damage assessment, development of flood damage function is very important. The relationships of flood characteristics such as flood depth and duration with damages based on past flood damages are very important to develop flood damage functions (Okazumi et al., 2013, 2014; Shrestha et al., 2014). Merz et al. (2010) distinguished two main approaches for development of flood damage function: (i) empirical approaches which use flood damage data collected after flood events and (ii) synthetic approaches which use damage data collected via what-if-questions. The choice of the approaches depends on the data availability (Messener et al., 2006; Merz et al., 2010). In developing countries, flood damages such as agriculture and house damages are mainly estimated in terms of partially or totally damages after the flood events (DSWD, 2011). Furthermore, there are lack of baseline data and appropriate flood damages estimation method in many developing countries.

Flood damage can be categorized into direct and indirect damages. This study will focus on direct damages, i.e. physical damages to agriculture and house buildings with assets. The rice production is a major source of income in developing countries and the house buildings with assets are major stocks of the people living in the flood-prone areas (Shrestha et al., 2013). Thus, in this study, agriculture and household damages estimation methods were developed for the risk assessment. The Pampanga River basin of the Philippines was selected for the case study. The hazard assessment has been done by using hydrological model (Rainfall Runoff Inundation (RRI) Model, Sayama et al., 2012) and flood prone areas were identified. Agriculture and household which are major exposures in the flood prone areas were taken into account for the flood damage assessment. The potential damages of agriculture were estimated by using the damage function of agriculture according to flood characteristics. The damage function of agriculture for its each growing stages was defined as the function of flood depth and duration. To develop household damage estimation method, field investigation and questionnaire surveys were conducted at the some selected Barangays (Villages) in the Pampanga river basin. The potential house buildings and assets damages were estimated by adopting appropriate damage functions for house buildings and assets. The estimated damages of agriculture and household were compared with the reported values.

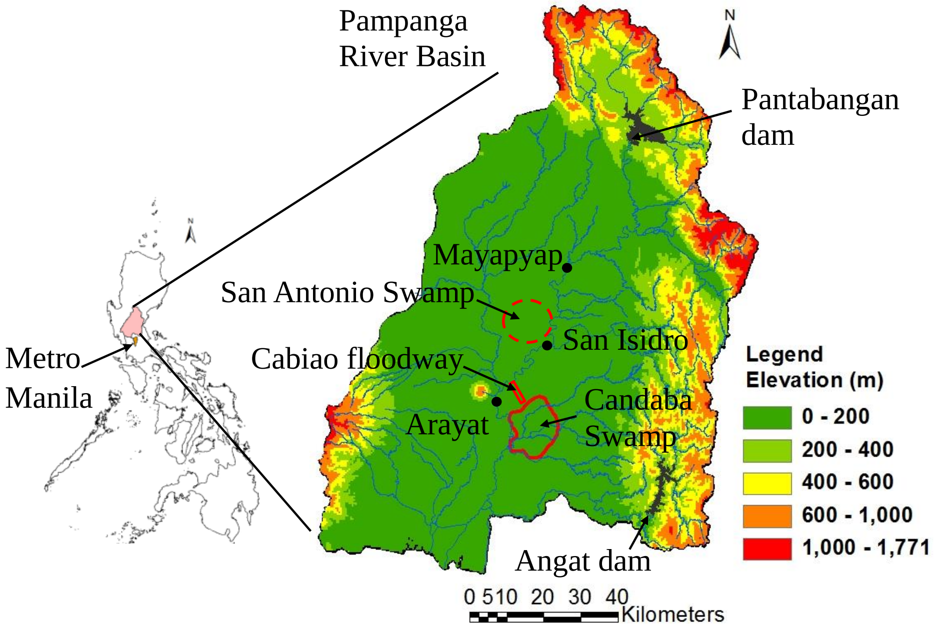


Figure 1: Location of the study site and digital elevation model of the Pampanga river basin

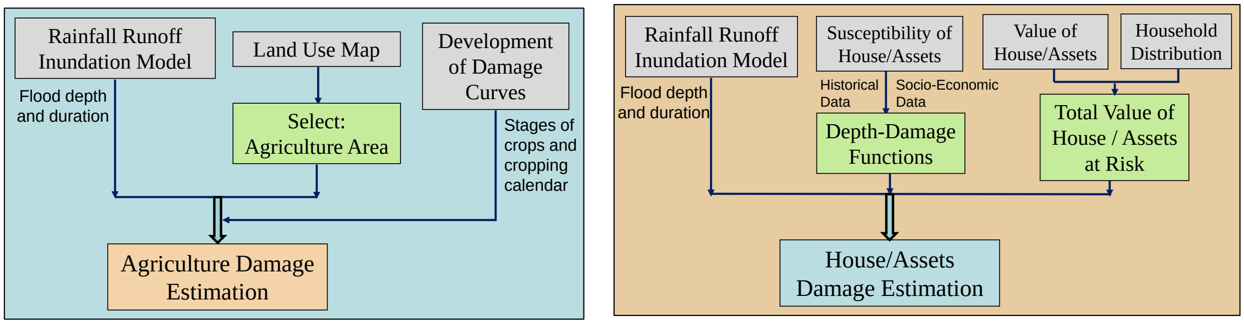
2. STUDY AREA

The Pampanga river basin is regarded as one of the most important river basins in the Philippines in terms of economic activities for the entire Philippines (Okazumi et al., 2014). At the same time, this basin experiences, on an average, at least one flood event in a year. Very catastrophic and exceptionally severe flooding in the river basin caused damage to agriculture and houses in the river basin. Thus, the Pampanga river basin has been chosen for the case study.

The Pampanga river basin is the fourth largest basin in the Philippines and covers an approximate aggregate area of 10,434 km^2 (including an allied basin of Guagua River). Figure 1 shows the location and Digital Elevation Model (DEM) of the study site. The total length of the main river is about 260 km. The average annual rainfall in the Pampanga basin is 2,155 mm. This river basin has two multipurpose dams i.e., Pantabangan (storage capacity of 2,966 million m^3) and Angat (storage capacity of 850 million m^3). There are two swamp areas Candaba (250 km^2) and San Antonio (120 km^2) in the river basin. However, only the Candaba swamp is regarded as a retarding basin absorbing most of the flood flows from the eastern sections of the basin and the overflowing of the Pampanga River via the Cabiao floodway.

3. METHODOLOGY AND DATA

The grid-based distributed flood damage assessment method was developed to estimate the agriculture and house buildings with assets damages for risk management. The methodology was developed by considering the major elements related to the potential flood damages: hazard, exposure, vulnerability and risk. The flood damages were estimated quantitatively in terms of amount of potential damages. Since rice crops are a primary source of income and house buildings with assets are major stock of people living in flood-prone areas, we focused on flood damage assessment of rice crops and households damages. Figure 2 shows the process of agriculture and house building and assets damage estimation. The damage assessment method is defined as a function of flood characteristics, damage function and socio-economic factors. By applying the developed methodology, the flood damages assessment in the Pampanga river basin of the Philippines was conducted.



(a) Process of agriculture damage estimation (b) Process of house building and assets damage estimation

Figure 2: Process of agriculture and household damage estimation

3.1 Flood Hazard Assessment

The hazard assessment for the damage estimation was conducted by using hydrological model. Rainfall Runoff Inundation (RRI) model developed by Sayama et al. (2012) is used to calculate the flood depth and duration and flood-prone areas were identified. The digital elevation model of HydroSHEDS which obtained from the Shuttle Radar Topography Mission (SRTM) data (15 arc-seconds grid size, approximately 500 m x 500 m grid size) is used in the study. The flood inundation depth and duration were calculated at 500 m x 500 m grid cell. The hourly rainfall and water level data were collected from the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA). The RRI model was calibrated and validated by comparing the calculated and observed flood discharge at San Isidro station in the Pampanga river basin. Since 2011 September flood event is the biggest flood in the basin in last 30 years, the hazard analysis is conducted for this flood event to estimate flood damages.

3.2 Flood Exposures and Damage Assessment

Agriculture and household in the flood prone areas were taken into account for the damage assessment. In the Pampanga river basin, rice crops are a major agricultural production. So, rice crops damages were considered as agriculture damage in this study. To consider rice crop areas, the land cover map prepared by NWRB and JICA (2010) for Integrated Water Resources Management in Pampanga river basin was used. The LANDSCAN 2009 global population data at 30 arc-seconds (approximately 1 km cell) was used to consider population distribution in the each cell (Bhaduri et al, 2007). Since flood water depth and flood duration were calculated at 500 m grid size, the population distribution data at 1 km grid size were downscaled to 500 m grid size by using ArcGIS tools. The number of houses distribution at each grid was calculated by dividing the population distribution by average family size. The average family size in the Pampanga river basin is about 4.75 (NSO, 2007). There was a severe rice crops and houses damages in the Pampanga river basin during typhoon “Pedring” in September 2011. Thus, it was considered to estimate rice crops and house damages in 26 September to 4 October 2011 flood event.

Table 1: Ranges of yield loss of rice crops due to flood published by BAS (2013)

Growth stage of rice crops	**Days of submergence**			
	1-2 days	3-4 days	5-6 days	7 days
	Estimated yield loss (%)			
Vegetative stage	10-20	20-30	30-50	50-100
Reproductive stage (Partially inundated)	10-20	30-50	40-85	50-100
Reproductive stage (Completely inundated)	15-30	40-70	40-85	50-100
Maturity stage	15-30	40-70	50-90	60-100
Ripening Stage	5	10-20	15-30	15-30

3.2.1 Agriculture damage assessment

The agriculture damage function varies with its stages. Table 1 shows the ranges of rice crops damage due to floods for different stages of crops published by the Philippines Bureau of Agricultural Statistics (BAS, 2013). The rice crops damage matrix developed by BAS (2013) only depends on flood duration. However, the rice crops damage function also depends on flood depth. Thus, new rice crops damage curves as a function of flood depth and duration were developed based on linear interpolation of flood damage matrix data shown in Table 1 by introducing minimum damageable flood depth and by considering height of rice crops in each stage. The flood water provides irrigation to rice crops at certain flood depth. Based on the information collected during the field investigation and discussion with local experts and farmers, damages occurs if flood depth reaches over 0.2 m in the cases of newly planted and vegetative stages. However, in the cases of reproductive, maturity, and ripening stages, damage occurs if flood depth reaches over 0.5 m. In reproductive, maturity and ripening stages, if the flood depth is partly inundated, the damage could be less. According to BAS (2013), partly inundated means leaves (9 to 15 cm long) remain above water surface. In this study, it is adopted that the partly inundated means leaves 10 cm long remain above water surface. The height of rice crops in each stage were used as shown in Table 2. Figure 3 shows the developed flood damage functions for rice crops. The rice crops damages were estimated at each grid as an amount of production loss by using flood characteristics, damage function and land cover map. According to cropping calendar published by National Irrigation Administration, Upper Pampanga River Integrated Irrigation Systems (NIA-UPRIIS) in 2013 and days of rice crops as shown in Table 2, the stage of rice crops during September 2011 flood period is maturity stage. Thus, the damage functions of maturity stage were used to estimate the production loss of rice crops for September 2011 flood event. The rice crops damages can be estimated by following equations.

$$\text{Loss Volume} = \text{Rice Yield} \times \text{Damaged Area} \times \text{Yield Loss} \quad [1]$$

$$\text{Production Loss Value} = \text{Loss Volume} \times \text{Farm Gate Price} \quad [2]$$

The values of farm gate price equal to 17 Peso/kg (BAS, 2013) and rice yield equal to 4,360 kg/ha (BPAO, 2011) were used in the calculation. Equations [1] and [2] can be used to estimate value of production losses in the cases of reproductive, maturing and ripening stages. However, in the cases of seedling, newly planted and vegetative stages, value of production losses can be estimated based on cost of input because the farmers do not expect any production in these stages (BAS, 2013).

Table 2: Days and plant height of rice crops at its each stage (IRRI, 2009; BAS, 2013)

Stages of Rice Crops	**Plant Height (cm)**
Seedling/Seedbed stage (20 days)	< 30
Newly planted stage *(1-20 days after sowing)*	30-40
Vegetative stage *(21-45 days from rice planting in paddy field)*	40-100
Reproductive stage *(46-75 days)*	100-130
Maturity stage *(76-115 days)*	130
Ripening stage *(116-130 days)*	130

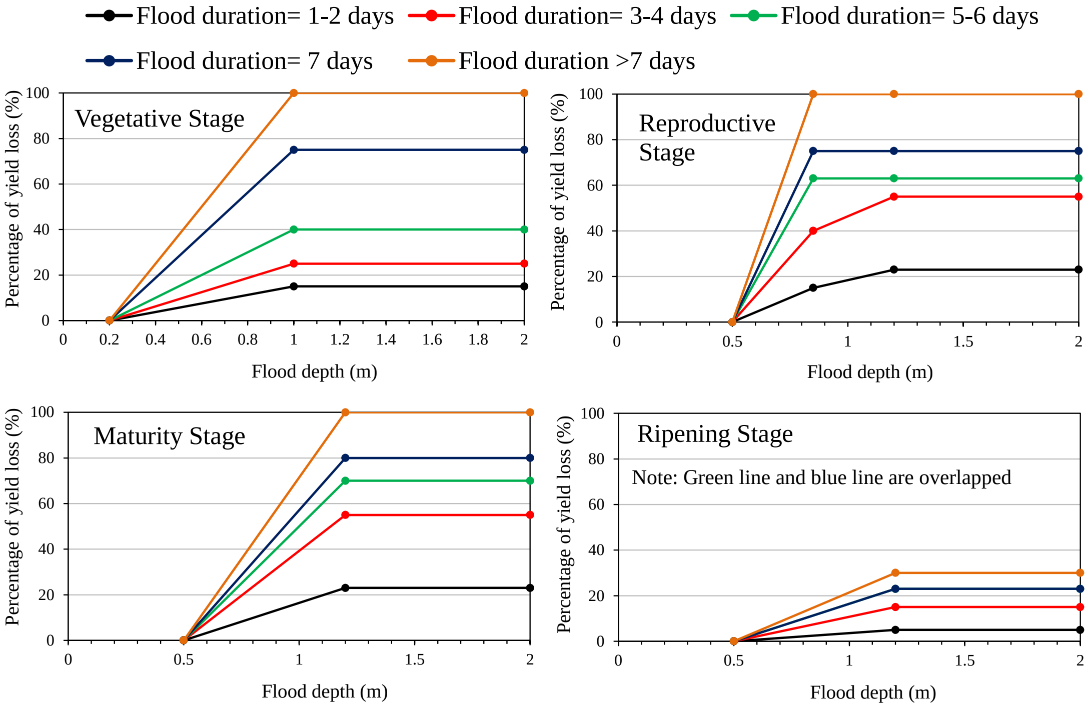


Figure 3: Developed damage functions to estimate percentage of rice crops yield loss due to flood

3.2.2 House damage assessment

The households with assets are major stocks of the people living in the flood-prone areas. It is thus necessary to consider household damages in flood risk assessment towards development of flood risk assessment model. To observe the household and flood characteristics in the Pampanga river basin, field investigations were carried out in June 2013 and in March 2014. In March 2014, the questionnaire surveys in flood prone areas of Candaba, San Luis and Arayat municipalities were also conducted with 37 individual households and 19 Barangay Leaders. The household information and past flood damages data were also collected through the questionnaire surveys. The floor level from the ground level and height of floor of the building were also measured during the field visit. Such household building data were also collected from the households and Barangay Leaders. During the field investigations, it was observed that elevated houses using concrete stilts can be found in the Candaba municipality where Candaba swamp is located.

Table 3: Categorization of house types, house and assets values, average floor level from the ground level and floor height of house with their percentage in the area

S.N.	House type	House building value per household (Peso)	Assets value per household (Peso)	Average floor level and floor height of house (m)			Percentage of houses in the area (%)		Remarks
				Height of floor level from ground / stilt height	Height of first floor	Height of second floor	In Candaba municipality	In other areas	
Normal House									
A	One-Storey house								
A.1	House with walls of concrete block/stone	704744	126692	1.1	3.05	-	44	46	
A.2	House with wooden walls	102813	76500	0.8	2.7	-	5	5	
B.	Two-Storey house								
B.1	House with walls of concrete block/stone	1023214	107857	1.1	3.05	3.05	19	35	
B.2	House with wooden walls	567857	120000	0.5	2.7	2.7	9	14	Including houses with stone wall in 1st floor and wooden wall in 2nd floor.
Elevated House with Concrete/Wooden Stilts									
C	Stilts House								
C.1	Stilts house with walls of concrete block/stone	647857	76000	3.1	3.2	-	16	-	Considered only in Candaba municipality
C.2	Stilts house with wooden wall	127679	45000	2.8	2.85	-	7	-	

Based on field investigation, the houses in the areas were categorized into different types. The stilts houses were also found in the most flood prone areas, particularly in the Candaba municipality. In the Candaba area, houses can be categorized mainly into two types: (a) Normal house and (b) Elevated house with stilts. Further, each house type can also be categorized into two groups based on materials of walls: (i) concrete block/stone wall and (ii) wooden wall. However, in other areas, house can be categorized as (a) normal house with concrete block/stone wall and (b) normal house with wooden wall. The normal type house also further can be categorized as one-storey house and two-storey house in both Candaba areas and other areas. Table 3 shows the categorization of house types in the flood prone areas. The estimated average values per household for house building and assets at each type of house based on household surveys are also shown in the table. The table also shows the average value of measured floor height from the ground level, floor height of each type of house building and percentage of each house type in the Candaba municipality and other areas. In the Pampanga area, most of the houses are constructed by wall of concrete block with concrete pillars. The floor level of this type of houses from the ground is elevated to avoid flooding. The average floor level of one- and two-storey houses with concrete block wall from the ground level is found to be about 1.10 m. The houses with wooden wall can also be found in the areas. The floor level of house with wooden wall from the ground is lower than that in case of houses with concrete block wall. The floor level of one-storey house with wooden wall from the ground is found to be 0.8 m. In two-storey house with wooden wall case, the houses with stone wall in first floor and wooden wall in second floor were also considered as houses with wooden wall. These types of houses are quite older than houses with concrete block wall. So, the floor level of this type of houses from the ground is very lower compared to houses with concrete block wall. The average floor level of this type of houses from the ground level is found to be 0.5 m. The floor height of houses with concrete block wall is found to be about 3.05 m, which is standard floor height found in the areas in the case of houses with concrete block wall. However, in the houses with wooden wall case, it was observed that the floor height varies with houses and the average value of floor height in this case is found to be about 2.7 m.

In this study, the existing of stilts houses is considered only in the Candaba municipality areas. Based on questionnaire surveys with Barangays leader and field observation, the percentage of houses with concrete/wooden stilts in the Candaba municipality is about 23 %. The heights of stilts in the cases of stilts house with concrete block and stilts house with wooden wall are found to be 3.1 m and 2.8 m, respectively.

Table 4: Damage rates for house building and assets

House Type	Flood Depth Criteria				
	Flood Depth over Floor Level				
One-storey house with concrete block/stone walls	0-0.5m	0.5-1m	1-2m	2-3m	>3m
One-storey house with wooden walls	0-0.5m	0.5-1m	1-2m	2-2.7m	>2.7m
Two-storey house with concrete block/stone walls	0-1m	1-2m	2-4m	4-6m	>6m
Two-storey house with wooden walls	0-1m	1-2m	2-4m	4-5.4m	>5.4m
Stilts house with concrete block/stone walls	0-0.5m	0.5-1m	1-2m	2-3m	>3m
Stilts house with wooden walls	0-0.5m	0.5-1m	1-2m	2-2.8m	>2.8m
Damageable value	**Damage Rate**				
House buildings	0.092	0.119	0.266	0.580	0.834
Household Assets	0.145	0.326	0.508	0.928	0.991

The direct damage of house building and assets varies according to the socio-economic group of the community, which can be estimated based on flood and household characteristics. The house building and assets damages were calculated at each 500 m x 500 m grid cell. Direct household building and assets damages at each grid were estimated by multiplying the damageable values of house building/assets by damage rates of house building/assets that vary according to flood depth. The damageable values of house building/assets were estimated by multiplying number of households at each grid by average value of household building/assets (Table 3). To estimate damages, parameters such as floor level and damage rates have to be determined. The floor level of each type house from the ground was adopted from the measurement during field investigation and household surveys as shown in Table 3. To develop damage rate, information and data on past floods and damages are necessary. However, there is lack of such data and information. Therefore, damage rates for house building and assets used in Japan (MLIT, 2005) are applied by adjusting flood depth criteria accordingly local household characteristics in the study area as presented in Table 4. During field investigation, data on past flood characteristics and household damages due to recent floods such as 2009, 2011, 2012 and 2013 flood events were also collected through the household questionnaire surveys. But these data are limited to damage information from 37 households only. Figure 4 shows the relationships of household damage rate with flood depth over floor level based on household surveys data. If we compare the damage rate of house building adopted in Table 4, mainly damage rates corresponding to 0 - 0.5 m and 0.5 - 1.0 m flood depth over floor level in the cases of one-storey/stilts house and the damage rates corresponding to 0 - 1.0 m and 1.0 – 2.0 m flood depth over floor level in the case of two-storey house, with damage rate obtained from the household surveys as shown in Figure 4, the adopted damage rates are reasonable with that obtained from the household surveys.

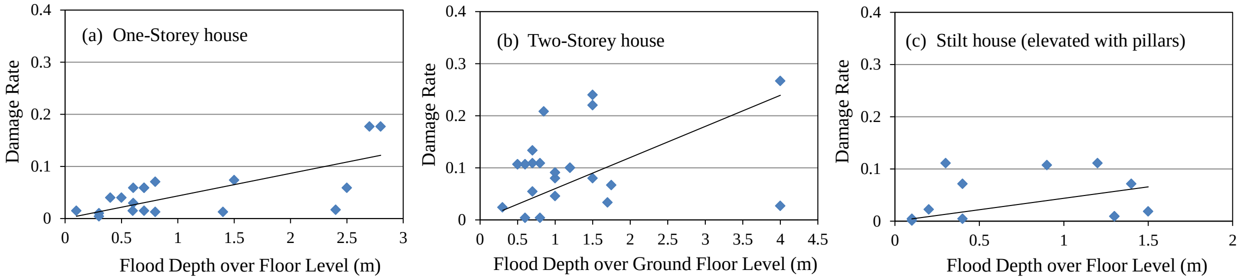


Figure 4: Relationships of household damage rate with flood depth over floor level based on household surveys data

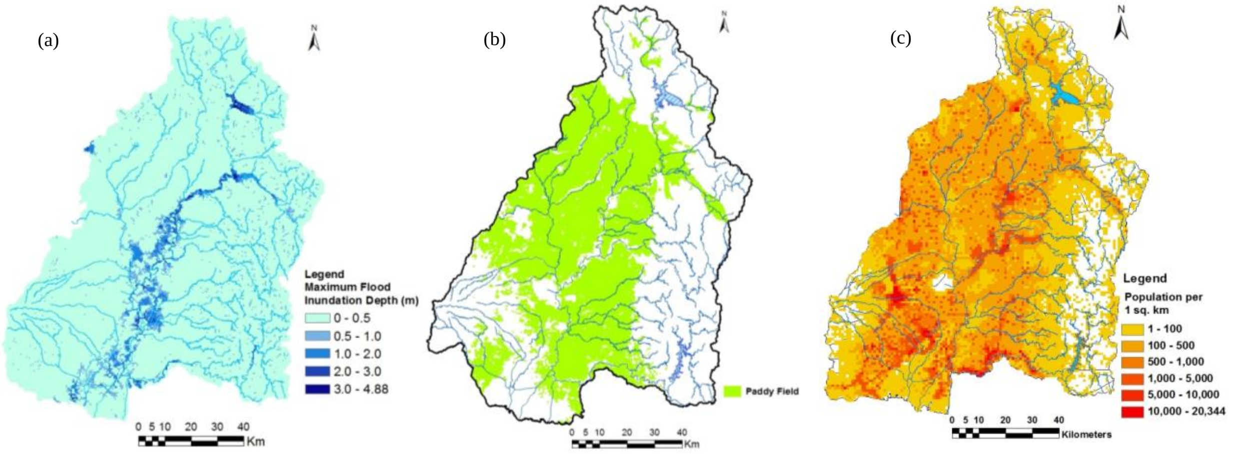
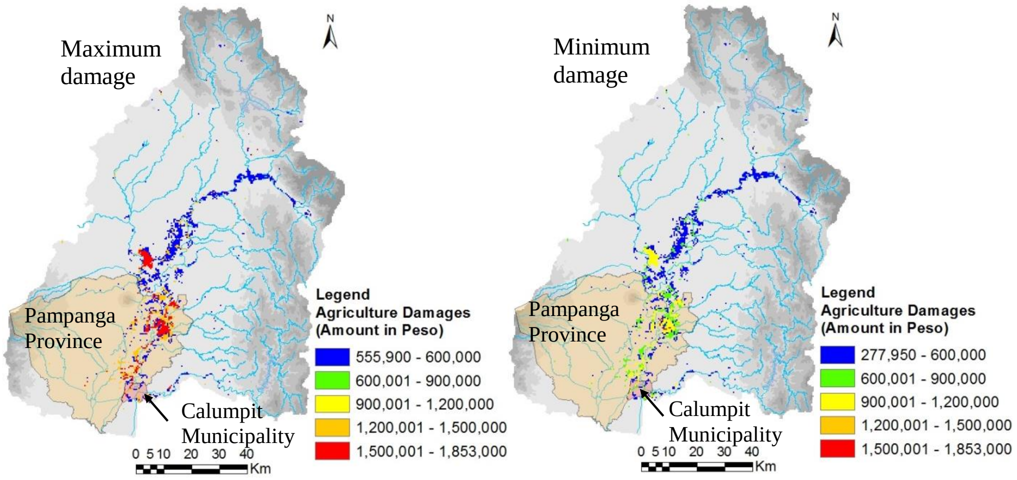
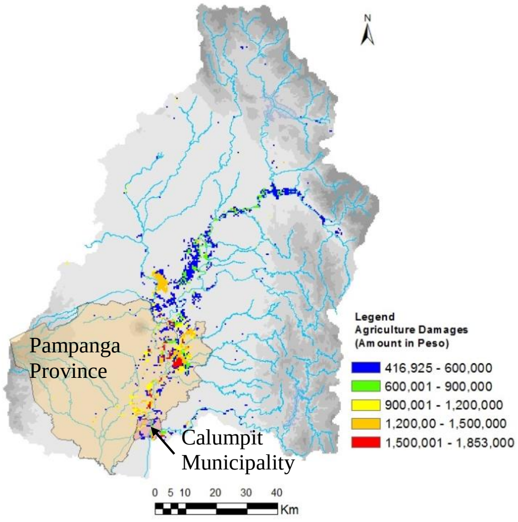


Figure 5: (a) Calculated maximum flood inundation depth in case of September 2011 flood (at 500 m x 500 m grid cell), (b) Map of paddy field (NWRB and JICA, 2010) and (c) Population distribution per 1 km^2 based on LANDSCAN data



(a) Maximum and minimum agriculture damages calculated by using damage function of BAS (2013)



(b) Calculated agriculture damages by using proposed rice-crop damage functions

Figure 6: Comparison of calculated maximum and minimum agriculture damages based on damage function of BAS (2013) and calculated agriculture damages based on proposed damage functions in case of September 2011 flood (at 500 m x 500 m grid cell)

4. RESULTS AND DISCUSSIONS

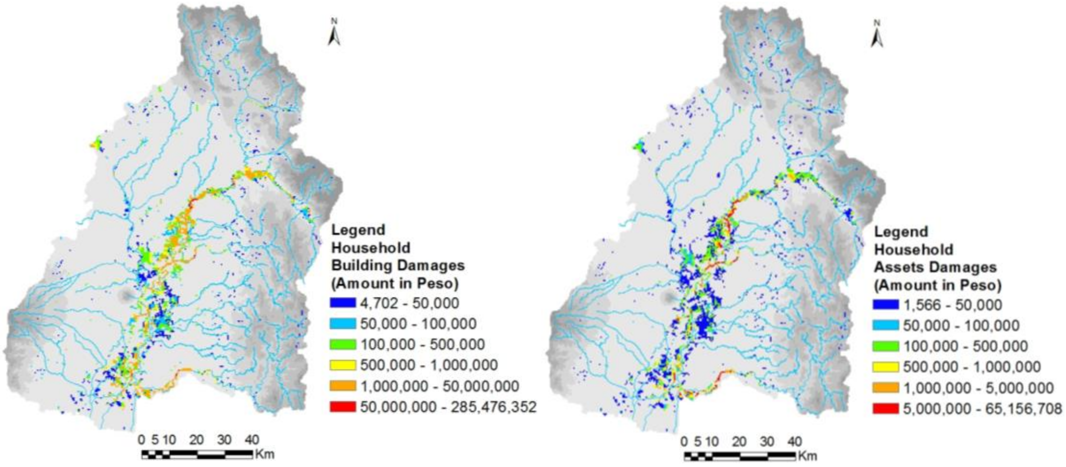
The calculated maximum flood inundation depth in the case of September 2011 flood event in the Pampanga river basin is shown in the Figure 5 (a). The flood inundation depth and duration were calculated at each 500 m x 500 m grid cell. Figure 5 (b) and Figure 5 (c) show the exposed rice-crop field and population distribution in the study area. The area of rice-crop field in the study area is about 397,246 hectors (NWRB and JICA, 2010). The exposed population based on 2009 LANDSCAN population data in the study area is about 6,293,776. The estimated population based on 2010 population census data (NSO, 2010) in the study area is about 6,581,122, which was estimated by assuming the population of each province multiplied with the percentage of administrative areas covered by the study area. The exposed population based on LANDSCAN data in the study area is consistent with the estimated population based on census data.

Table 5: Calculated and reported rice crops damages for September 2011 flood event

Descriptions	**Rice crops damages** (million Peso)			
	Reported values	**Calculated using damage functions of BAS (2013)**		**Calculated using proposed damage functions**
		Maximum	**Minimum**	
Pampanga River Basin (Affected area 45,900 ha)	-	1,754	966	1,461
Pampanga Province (Affected area 15,900 ha)	1,376	777	443	652
Calumpit Municipality (Affected area 1,250 ha)	37	54	30	42

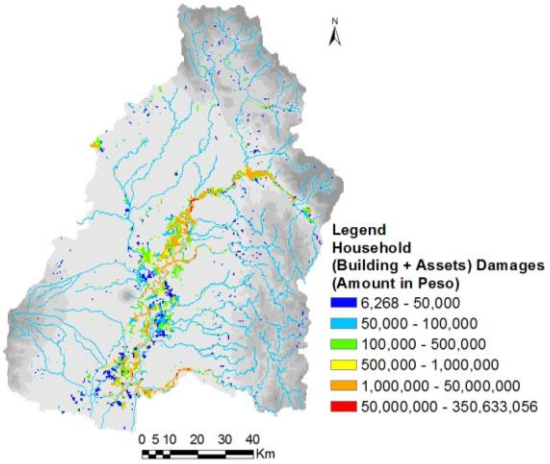
The agriculture damages were calculated for September 2011 flood event case. Figure 6 (a) shows the calculated results of agriculture damages from the maximum and minimum damage functions of BAS (2013). The damage functions of BAS (2013) only depend on flood duration as well as these functions have uncertainty ranges of yield loss of rice crops. Figure 6 (b) shows the calculated results of agriculture damages by using proposed damage functions of rice crops. The estimated affected area of the rice crops damages in the Pampanga river basin is 45,900 ha in the case of September 2011 flood event. The estimated amount of agriculture damages in the whole basin is about 1,461 million Pesos. Table 5 compares the calculated rice crops damages and reported damages. The reported values of rice crops damages in the Pampanga province and Calumpit municipality in the table are according to OCD (2011) and BPAO (2011), respectively. The calculated rice crops damages by using the proposed damage function are within the ranges of maximum and minimum damages. In the case of Calumpit municipality, the calculated value of rice crops damages by using proposed damage functions is approximately the same as the reported damage value. However, in the case of Pampanga province, the reported value of rice damage also includes rice crops damages due to strong winds in the area. So there is significant difference between calculated and reported values of rice crop damage in the Pampanga province. In overall, the calculated agriculture damage by using proposed damage functions is reasonably agreeable with the statistical data.

To estimate household building and assets damages, the flood depth above the floor level was calculated for each house type based on average value of floor level from the ground for each house type that obtained from the field survey. The damages for each house type were calculated and the total damages at the area were estimated by considering the percentage of each house type in the area. Figure 7 shows the calculated household building damages, household assets damages and total damageable value of household for September 2011 flood event case. The figure shows the distributed damage value at 500 m x 500 m grid cell. The total damageable value of household in the figure is total sum value of household building and assets damages. The estimated values of household building and assets damages are found to be 7,269.9 and 2,237.2 million Pesos, respectively.



(a) Household building damages

(b) Household assets damages



(c) Total damageable value of household

Figure 7: Calculated household building damages, household assets damages and total damageable value of household (building and assets damages) for September 2011 flood (at 500 m x 500 m grid cell)

Table 6: Comparison of calculated average value of household damages with actual damages estimated from household survey

Municipality	**Average per household value of household damages (Peso) (September 2011 flood)**	
	Calculated value	**Based on household survey data**
Candaba	102,383	55,333
San Luis	104,400	93,750
Arayat	93,130	80,000

The calculated household damages were validated with damages data obtained from the household survey. Table 6 compares the calculated average per household value of household damages in the Candaba, San Luis and Arayat municipalities of the study area with the household damages value obtained from the household survey in the areas. The household damageable value in the table includes household building and assets damages. The calculated average per household value of household damages in the table is average value of damaged houses in the area. Similarly, the average value of household damages obtained from the household survey is also the average value of household damages of surveyed houses in the areas. The average values of calculated household damages are consistent with the average values of household damages obtained from the survey. The estimated damaged houses and reported damages house based on DSWD (2011) in the areas for September 2011 flood are 72,680 and 20,303 numbers, respectively. The reported number of damaged houses was prepared for providing assistance to the damaged houses which may not consider houses with minor damages. So there is some variation between estimated and reported number of damaged houses.

5. CONCLUSIONS

For flood risk assessment, data on past flood hazards and past flood damage with their relationships are very important for development of an appropriate method for the basin as well as for validation of the calculated results. Agriculture and house damages were estimated by developing damage functions based on flood and household characteristics. The agriculture damage was defined as function of flood depth and duration. The household damage was defined as the function of maximum flood inundation depth above the floor level of the house. Based on comparison of calculated and actual damaged data of rice crop and households, the proposed damage functions of rice crop damages and household damages are appropriate for flood damage assessment.

In the Pampanga river basin, the estimated affected area and value of rice crops damages in September 2011 flood event case are found to be 45,900 ha and 1,461 million Pesos, respectively. The estimated values of household building and assets damages in the area for same flood event are found to be 7,269.9 and 2,237.2 million Pesos, respectively and the estimated damaged houses is 72,680 numbers.

Results from flood damage assessment can be useful for planners, developers, policy makers and decision makers to establish policies required for flood damage reduction. The agriculture and house damage estimation methods presented in this paper can be a good initiative to apply to other areas of developing countries for flood risk assessment.

6. ACKNOWLEDGEMENTS

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