RICE-CROPS FLOOD DAMAGE ASSESSMENT IN THE PAMPANGA RIVER BASIN OF THE PHILIPPINES

Badri Bhakta SHRESTHA[1], Hisaya SAWANO[2], Miho OHARA[3] and Naoko NAGUMO[4]

[1]PhD (Eng.), Senior Researcher, International Centre for Water Hazard and Risk Management (ICHARM), Public Works Research Institute (PWRI) (1-6 Minamihara, Tsukuba 305-8516, Japan)
[2]Member of JSCE, M. Eng., Chief Researcher, ICHARM, PWRI (1-6 Minamihara, Tsukuba 305-8516, Japan)
[3]Member of JSCE, PhD, Senior Researcher, ICHARM, PWRI (1-6 Minamihara, Tsukuba 305-8516, Japan)
[4]PhD, Research Specialist, ICHARM, PWRI (1-6 Minamihara, Tsukuba 305-8516, Japan)

This study proposed a method for assessment of flood damage to rice-crops. In the method, the hazard characteristics such as flood depth and duration were computed by using Rainfall Runoff Inundation (RRI) model. To estimate rice-crop damage, damage functions were derived from past observation data of rice-crop damage, growth stages of rice crop, and height of rice plants. The rice-crop damage was defined as function of flood depth, flood duration and growing stage of rice plant. The rice-crops damages were estimated based on flood inundation characteristics, growth stage of rice plants and developed damage function. By using proposed methodology, rice-crops flood damage assessment was conducted in the Pampanga river basin of the Philippines for September 2011 flood event and 50 and 100 years return period flood events cases. The estimated rice crops damages were compared with reported values.

Key Words **:** *Rice-crop damage, flood risk assessment, damage estimation, damage function, hazard, Pampanga River basin, the Philippines*

1. INTRODUCTION

Risk of flood disaster has been increasing by rapid urbanization and development activities constituting threat to economic, population and sustainable development, which will be increased more by climate change impact[1)]. Developing countries are particularly vulnerable to flood disasters[1),2)]. Flood risk assessment is thus an essential part of flood risk management[3)]. For risk assessment and evaluation of risk mitigation measures, it is indispensable to quantify flood risk as accurately as possible[4)]. Flood damage assessment is essential for flood management to mitigate risk and also to quantify flood risk. However, it has not received much scientific attention[5)]. Furthermore, a number of studies have focused mainly on assessment of physical damage to residential building, household assets and infrastructures[6),7),8),9)] and there is a less attention on assessment of flood damage to agriculture[2),7)].

In this study, a method to estimate rice-crops damage which is composed of flood hazard, exposure and vulnerability characteristics is proposed for risk assessment and flood damage to agriculture (rice-crops) was assessed in the Pampanga River basin of the Philippines. Flood hazards were analyzed by using the Rainfall Runoff Inundation (RRI) hydrological model developed by Sayama et al.[10)], and flood inundation characteristics such as flood depth and duration were estimated. Damage functions to estimate expected damages were derived based on past observation data of rice-crop damage, growth stages of rice plants and its height. The damage functions for each growth stage of rice-crop were defined as the function of flood depth and flood duration. By using proposed methodology, assessment of rice-crop flood damage was conducted in the Pampanga river basin of the Philippines for flood events of September 2011, 50-

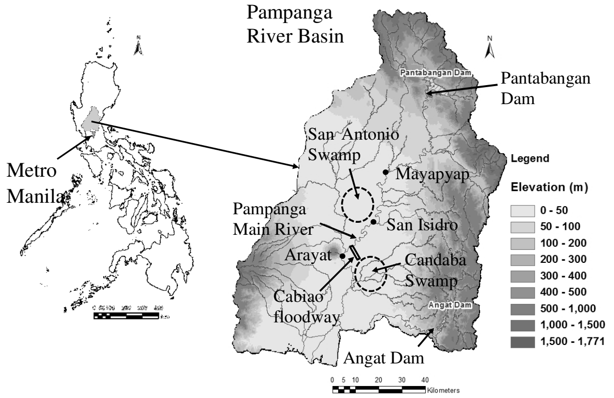

Fig. 1 Location of study area.

and 100-year return periods. Estimated values of rice-crop damage in the 2011 flood event were also compared with the reported values for confirming the estimated values.

The Pampanga river basin is located in Region-III of the Philippines. **Fig. 1** shows the location of the Pampanga river basin. The Pampanga river basin is the fourth largest basin in the Philippines and covers an area of 10,434 km^2, including an allied Guagua river basin. The main river is about 260 km long. The average annual rainfall in the Pampanga basin is 2,155 mm[1)]. On average, the Pampanga river basin experiences at least one flood event in a year.

2. METHODOLOGY AND DATA

The grid-based flood damage assessment method to access the rice-crop damage was proposed. The hazard characteristics were analyzed by the RRI model[10)]. The rice-crop damage functions were formulated based on past observed data, height of rice plants and their growth stages. The rice-crop damage was estimated at 15-arc second grid (approximately 500 m grid size). The detail methodology and data used are described in following section.

(1) Flood characteristics analysis

The RRI model developed by Sayama et al.[10)] was used to calculate flood characteristics such as flood depth and duration. The RRI model is a two-dimensional model capable of simulating rainfall-runoff and flood inundation simultaneously. The model deals with slopes and river channels separately. The flow on the slope grid cells is calculated with the 2D diffusive wave model, while the channel flow is calculated with the 1D diffusive wave model. Details of the RRI model can be found in Sayama et al. [10)].

A Digital Elevation Model (DEM) of HydroSHEDS, which obtained from Shuttle Radar Topography Mission (SRTM) data at 15-arc second grid (approximately 500 m grid), was used in the study. The hourly rainfall and water level data were collected from the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA). The RRI model parameters were calibrated to the September 2011 flood event, which was the biggest recorded flood in the basin. The model parameters such as roughness coefficients and infiltration parameters were calibrated. The calibrated parameters were validated with the August 2012 flood event.

Flood frequency analysis was also conducted by using 48-hours maximum annual rainfall data to analyze the flood hazards for specific return period such as 50- and 100-years. The Gumbel distribution method was used for rainfall analysis[11)]. To calculate flood characteristics for an event of a specific return period, design hyetographs for specific return periods were estimated by multiplying the rainfall hyetograph of the September 2011 flood by a conversion factor. The conversion factor for each specific return period was calculated as the ratio of the corresponding rainfall of the return period and the 48-hour maximum annual rainfall of 2011 based on a frequency curve. The return periods of the September 2011 and August 2012 flood events are 41 and 3 years, respectively. The flood characteristics for flood events of return periods of 50 and 100 years were simulated by the RRI model by using calculated design hyetograph for each return period.

(2) Rice-crop flood damage assessment

Rice-crop damage curves vary with each rice growing stage. **Table 1** shows flood damage matrixes based on past experiences and damage data[12)]. **Table 2** shows the height of rice plants in each growth stage and its duration. Flood water provides irrigation to rice plants when it is at a certain flood depth. Based on information collected

Table 1 Flood damage matrixes for rice-crops[12)].

Growth stage of rice plants	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

Table 2 Days and plant height in rice growing stage[12),13)].

Stages of Rice Plant	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

during field investigation and discussion with local experts and farmers, damage occurs if the flood depth reaches over 0.2 m during the newly planted and vegetative stages. However, in the cases of the reproductive, maturity, and ripening stages, damage occurs if the flood depth reaches over 0.5 m. In the reproductive, maturity and ripening stages, if the flood depth is at the level of partial submergence, damage could be less serious. According to BAS[12)], partial submergence means leaves (9 to 15 cm long) remain above the water surface. In these stages, this study adopted the threshold that partial submergence is the one where 10-cm-long leaves remain above the water surface. If the water level reaches over the level of 10 cm below the height of rice plants, it is considered as completely submergence in the cases of reproductive, maturity and ripening stages. Rice-crop damage curves as a function of flood depth and duration were proposed based on linear interpolation of flood damage matrix data shown in **Table 1** by introducing minimum damageable flood depth and by considering partial or complete submergence water surface levels corresponding to each growth stage of rice plants (**Table 2**). The average value of flood damage matrix presented in **Table 1** was used to derive the damage function. It was assumed that this damage value corresponds to the damage in the completely submergence case. In case of reproductive stage, it is also assumed that average value of flood damage for partially inundated case presented in **Table 1** corresponds to damage at the middle between minimum damageable level and starting level of completely submergence. **Fig. 2** shows the proposed flood damage functions for rice crop.

Based on the developed damage functions and flood inundation characteristics, rice-crop damage can be estimated by the following equations:

$$Loss\ Volume = Rice\ Yield \times Damaged\ \ Area \times Yield\ Loss \quad (1)$$

$$Damage\ Value = Loss\ Volume \times Farm\,Gate\ price \quad (2)$$

The used values of farm gate price and rice yield are 17 Peso/kg[12)] and 4,360 kg/ha[14)], respectively. The cropping calendar published by the National Irrigation Administration, Upper Pampanga River Integrated Irrigation Systems (NIA-UPRIIS) in 2013 was used to identify the stage of rice plant during the flood event. To consider rice-crop areas, the land cover map prepared by NWRB and JICA[15)] for Pampanga river basin was used.

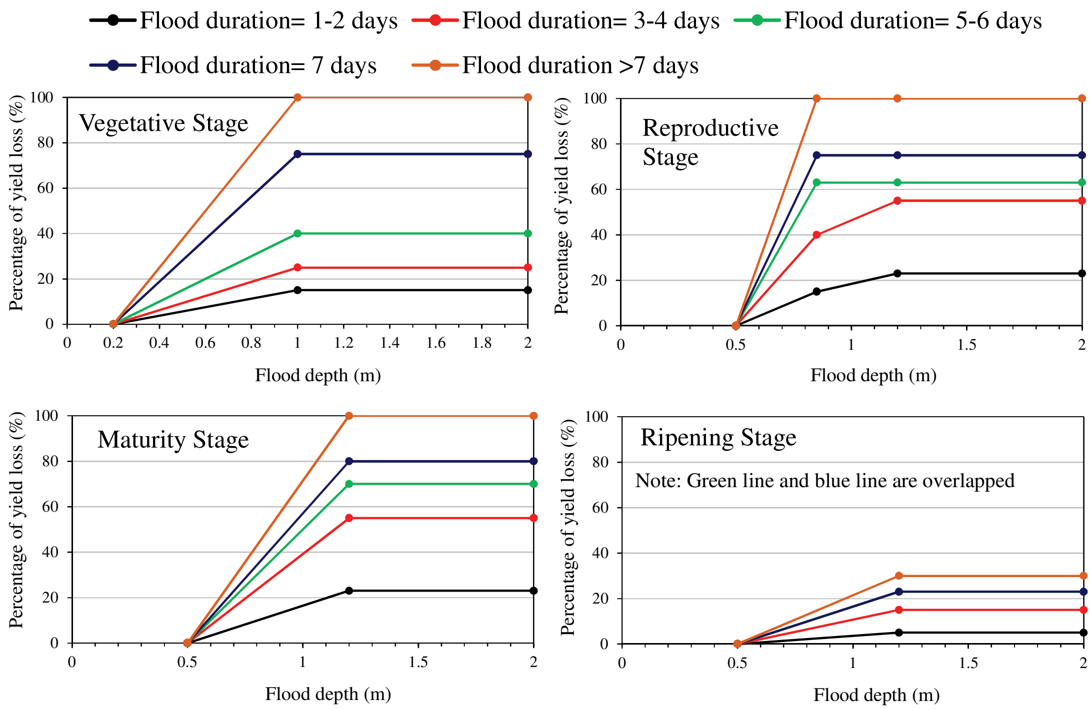

Fig. 2 Proposed rice-crop damage functions.

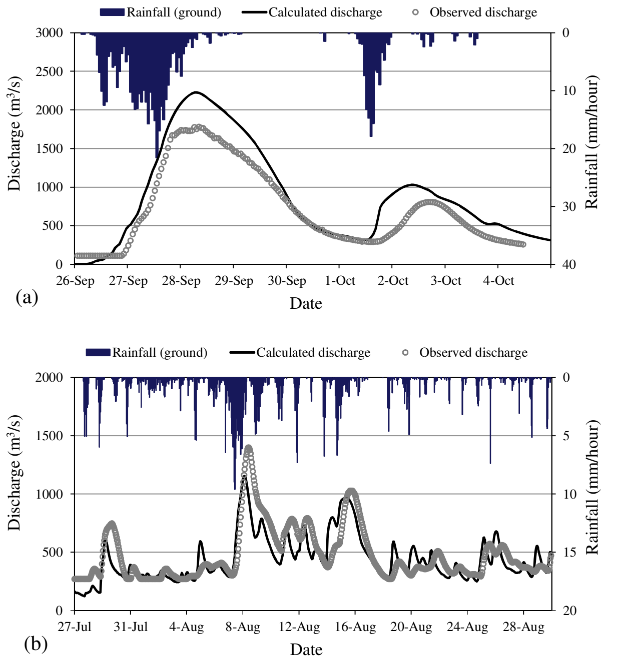

Fig. 3 Comparison of calculated and observed discharges at San Isidro Station (a) the September 2011 flood case and (b) the August 2012 flood case.

3. RESULTS AND DISCUSSIONS

Fig. 3 shows the comparison of the calculated discharges after the calibration and observed discharges at the San Isidro station for the September 2011 and August 2012 flood events. The simulated results of discharge are consistent with the observed discharge. **Fig. 4** shows the calculated maximum flood inundation depths for the September 2011 flood and flood events of 50- and 100-year return periods. The flood inundation depth and duration were calculated at each 500 m x 500 m grid cell. The flood inundation mainly occurred in the middle and downstream part of the Pampanga River. The estimated flood inundation areas with a flood inundation depth of greater than 50 cm for September 2011, 50- and 100-year return periods are found to be 1,085.25, 1,284.0 and 1,850.5 km^2, respectively.

Fig. 5 shows the estimated rice-crop damage distribution in the Pampanga river basin in case of September 2011 flood. The rice-crop damage was estimated at each grid as an amount of production loss by using flood characteristics, damage function and land cover map. According to the cropping calendar published by the NIA-UPRIIS in 2013 and days of rice crop as shown in **Table 2**, the rice plants during the September 2011 flood was at the maturity stage. Thus, the damage functions of the maturity stage were used to estimate the production loss of rice crop for the September 2011 flood event. The affected area with rice-crop damage in the

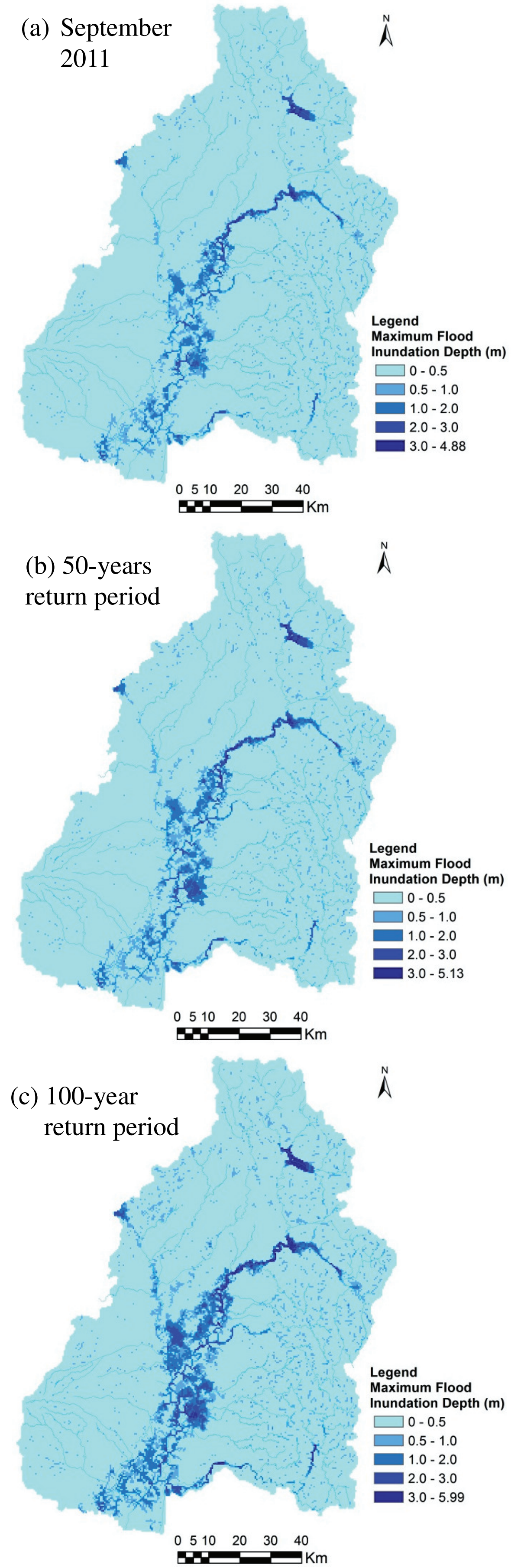

Fig. 4 Calculated maximum flood inundation depth: (a) September 2011 flood, (b) 50-year return period flood, and (c) 100-year return period flood.

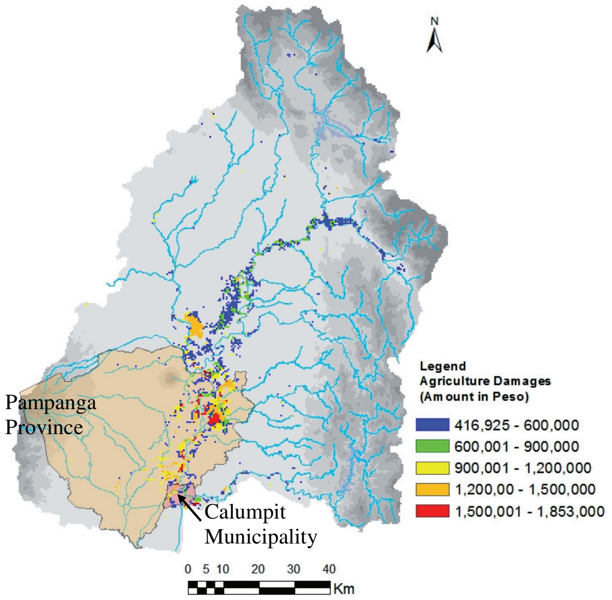

Fig. 5 Calculated rice-crop damage distribution for the September 2011 flood (500 m × 500 m grid size).

Table 3 Calculated and reported rice-crop damage during the September 2011 flood event

Descriptions	Rice crops damages (million Pesos)	
	Reported values	Calculated values
Pampanga River Basin (Affected area 45,900 ha)	-	1,461
Pampanga Province (Affected area 15,900 ha)	1,376	652
Calumpit Municipality (Affected area 1,250 ha)	37	42

Pampanga river basin was estimated to be 45,900 ha in the case of the September 2011 flood event. The agricultural damage in the whole basin was estimated to be about 1,461 million Pesos. The calculated rice-crop damage was compared with the reported values for Pampanga Province and Calumpit Municipality. **Table 3** compares calculated rice-crop damage in Pampanga Province and Calumpit Municipality. For Calumpit Municipality, the value calculated for rice-crop damage is approximately the same as the reported damage value. For Pampanga Province, however, the reported value of rice-crop damage also includes rice-crop damage due to strong winds in the area; thus, there is a difference between the calculated and reported rice-crop damage values in Pampanga Province. The flood event of September 2011 was caused by Typhoon “Pedring” and rice-crop damage occurred due to strong winds during the event.

Fig. 6 shows the calculated rice-crop damage for flood event of 50- and 100-year return periods. Rice-crop damage for different return periods was

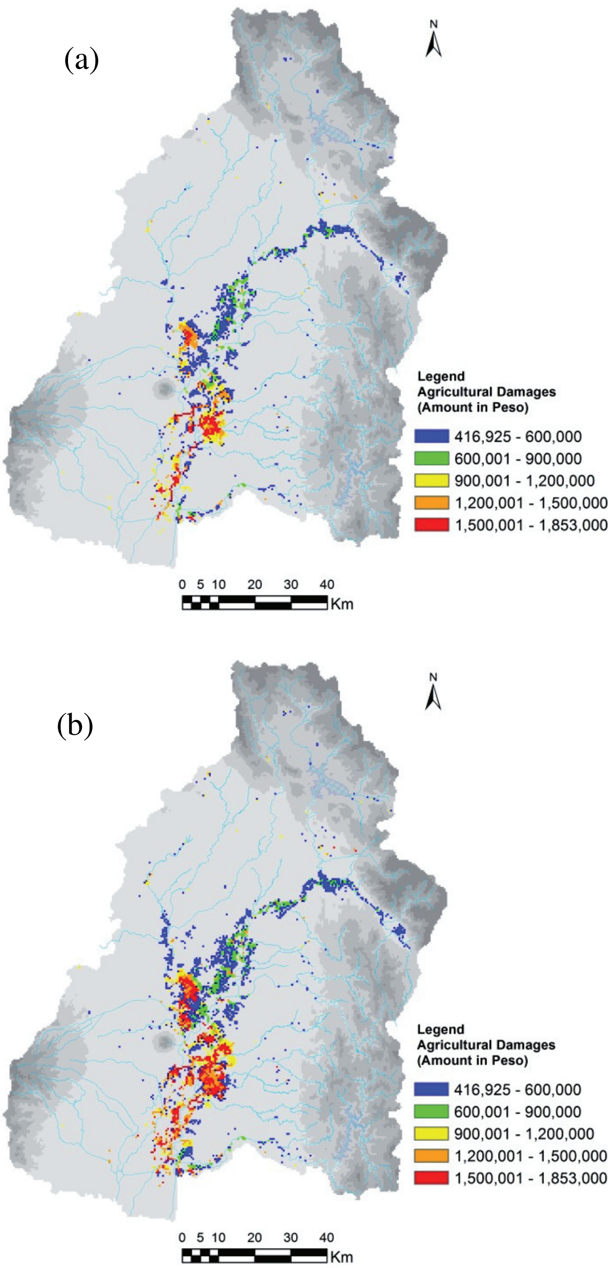

Fig. 6 Calculated rice-crop damage during the flood events of (a) 50- and (b) 100-year return periods, (500 m × 500 m grid size).

estimated based on current conditions, and it was also assumed that the rice plants are at the maturity stage. The affected farmland estimated during flood events of 50- and 100-year return periods are 52,800 and 78,100 ha, respectively, while the values of rice-crop damage are 1,777.8 and 2,888.5 million Pesos, respectively.

4. CONCLUSIONS

Flood damage to rice-crops in the Pampanga river basin of the Philippines was assessed. The rice-crop damage was estimated based on flood characteristics and flood damage functions. The agriculture damage mainly depends on flood depth, duration and growth stages. Data on past flood events and damage with their relationships are very important for developing damage functions as well as validating calculated results. The rice-crop damage varies, depending on plant height and growing stage of rice. The estimated flood inundation areas with an inundation depth of greater than 50 cm for September 2011, 50- and 100-year return periods in the Pampanga river basis were found to be 1,085.25, 1,284.0 and 1,850.5 km^2, respectively. In the Pampanga river basin, the area with rice-crop damage was estimated to be 45,900 ha with an agricultural damage, or production loss, of 1,461 million Pesos during the September 2011 flood event. The calculated values of rice-crop damage were compared with the reported values for Calumpit municipality and Pampanga Province. The calculated value of rice-crop damage in the case of Calumpit municipality was consistent with the reported value. The areas with rice-crop damage in the flood events of 50- and 100-year return periods were 52,800 and 78,100 ha, respectively, while the values of rice-crop damage were 1,777.8 and 2,888.5 million Pesos, respectively.

In the Pampanga river basin of the Philippines, most of the flooding event occurred due to Typhoon and agriculture was also damaged by strong wind. It is thus also necessary to consider damages due to strong wind in further study. The BAS[12)] has already developed agriculture damage matrix for Typhoon induced by strong wind.

The results of flood damage provide a basis to identify areas at risk, and these results can be useful for planners, developers, policy makers and decision makers to establish policies required for flood damage reduction. The results may also be useful for them to implement flood mitigation actions including agricultural land use regulations while taking into account the risk areas of rice-crop damage and adaptation measures. The rice-crop damage estimation method presented in this paper can also be applied to other areas for flood risk assessment.

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