Chapter

Methodology for Agricultural Flood Damage Assessment

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Abstract

This chapter describes a method for assessing flood damage to the agricultural sector, specifically focusing on flood damage to rice crops. The chapter also includes the case studies of flood damage assessment conducted in the Asian river basins, the Pampanga River basin of the Philippines, and the Lower Indus River basin of Pakistan. The assessment was performed by defining flood damage to rice crops as a function of flood depth, duration, and growth stage of rice plants and using depth-duration-damage function curves for each growth stage of rice plants. In the case studies, flood characteristics such as flood depth, duration, and distribution were computed using a rainfall-runoff-inundation (RRI) model. Flood damage to rice crops was assessed for the 2011 flood and 100-year flood events in the case of the Pampanga River basin and for the 2010 flood in the case of Lower Indus River basin. The calculated values of agricultural damage were compared with reported data for validation of methodology, and it was found that the calculated damage reasonably agreed with reported data. The rice-crop damage assessment method described in this chapter can also be applied in other areas for flood risk assessment.

Keywords: flood damage, agriculture, damage curves, RRI model, Asian river basins

1. Introduction

The impact of floods is becoming greater due to their increasing frequency and scale and the concentration of population and socioeconomic activities in river basins [1]. Developing countries are particularly vulnerable to flood disasters because of limited resources to cope with them. Flood disasters cause serious damage to properties and livelihoods as indicated in **Figure 1**, which shows the estimated value of flood damage to agriculture and infrastructure and also the number of houses totally or partially damaged by floods in the case of Region III of the Philippines. For the assessment of flood disaster risk and the evaluation of risk mitigation measures, flood risk needs to be quantified as accurately as possible [2]. Flood damage assessment is thus essential for flood management to mitigate risk and also to quantify flood risk.

Flood damage can be assessed quantitatively based on the analysis of hazard, exposure, and vulnerability. By conducting flood damage assessment, the effectiveness of countermeasures in reducing the intensity of a flood hazard can be quantified by comparing simulated damage before and after the implementation of

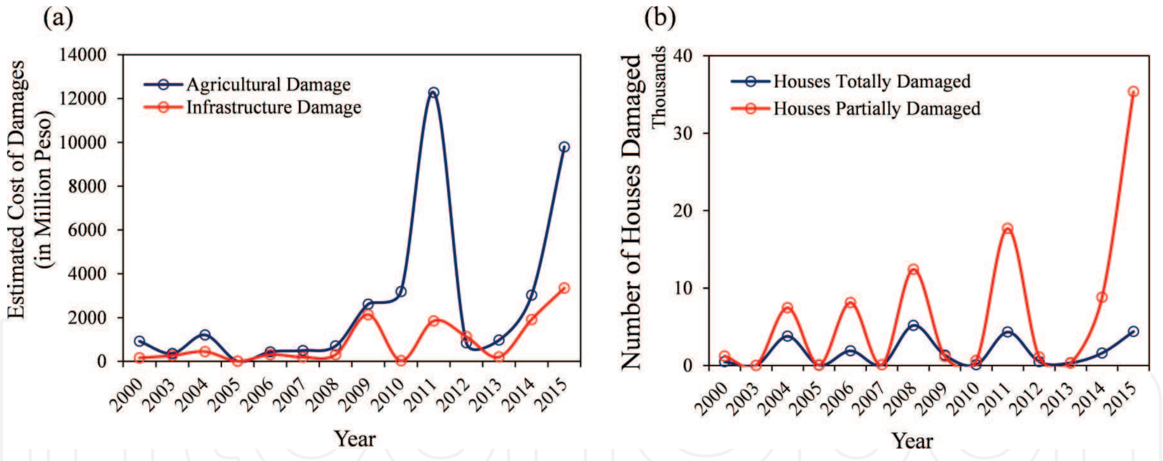


Figure 1.
Agricultural, infrastructure, and house damage due to the past floods in Region III of the Philippines [Data source: Office of Civil Defense, Region III, Philippines].

countermeasures. The quantification of the effectiveness of countermeasures is also essential in cost-benefit analysis to assess the effectiveness of preventive investment. For flood damage assessment, flood damage functions are generally derived from past flood damage data by relating flood characteristics, such as flood depth and flood duration, with damage [3]. Shrestha et al. [3] pointed out that past flood hazards and damage data and their relationships are very important for the development of an appropriate method as well as for validation of calculated results. In many countries, especially in developing countries where past damage data are very limited, more efforts should be made to improve a flood damage assessment method. Effort should also be focused on the collection of flood damage data for the development of damage curves, model validation, and adaptation of approaches [4]. It is thus essential to develop appropriate flood damage estimation methods for planning mitigation measures and preparedness activities in order to reduce flood damage in the future.

For flood damage assessment, numerous studies have focused mainly on flood damage to the residential, infrastructure, and industrial sectors, while less attention has focused on the agricultural sector [5, 6]. However, the agricultural sector is a major source of income in many developing countries in Asia and thus likely to play a major role in new flood management policies [6]. On the other hand, when a flood occurs, the agricultural sector of many developing countries is severely affected by flooding (**Figure 1**). Therefore, an appropriate methodology for assessing flood damage to the agricultural sector is essential. This chapter describes a method for assessing flood damage to the agricultural sector, specifically focused on flood damage to rice crops. Flood damage to rice crops is defined as a function of flood depth, duration, and growth stage of rice plants. The case studies of flood damage assessment in the river basins of Asia such as the Pampanga River basin of the Philippines and the Lower Indus River basin of Pakistan are discussed.

2. Categorization of flood damage

Flood damage refers to varieties of destruction and losses caused by flooding [7, 8], for example, harmful effects on humans; damage to buildings, residential properties, and other types of infrastructure; impact on lifeline and other public services; and losses of agricultural and industrial production [5, 7]. Flood damage is typically categorized as direct and indirect damage and further categorized as tangible and intangible damage depending on whether damage can be assessed in

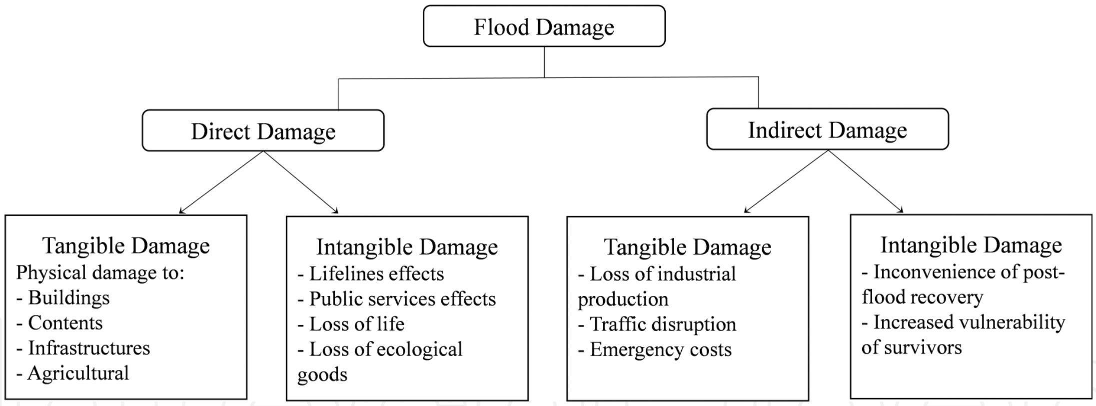


Figure 2.
Categorization of flood damage [5, 6, 8, 9].

monetary values [5, 7, 8]. **Figure 2** shows the categorization of damage with some examples.

2.1 Direct and indirect damage

Direct damage is damage caused by direct physical contact of floodwaters [5, 8], such as flood damage to buildings and residential properties; losses of crops, livestock, and human lives; immediate health impacts; and losses of ecological goods. Indirect flood damage is damage which is not directly due to flood exposure but mainly caused by disruption of physical and economic linkages and other losses, such as loss of production at flood-affected factories and companies and costs of traffic disruption and emergency services [5, 6–8].

2.2 Tangible and intangible damage

Tangible damage is damage which can be easily specified in monetary values, such as damage to buildings, residential properties, assets, and agricultural crops and loss of production. Intangible damage is damage which cannot be specified in monetary values, such as casualties, health impacts, and damage to ecological goods and to all kind of goods and services [5, 7, 8].

3. Method for agricultural damage assessment

3.1 Framework of flood damage assessment

Flood risk and damage assessment are essential for flood risk management. The main purpose of flood damage assessment is to identify areas at risk where mitigation actions are necessary. This chapter describes a grid-based method for flood damage assessment considering three major factors of risk: hazard, exposure, and vulnerability. Flood damage assessment starts with the identification of the target area and items exposed to a flood hazard using the results of flood hazard simulation and moves on to the evaluation of damage that might occur to exposed items because of the vulnerability of each item. **Figure 3** shows the estimation process of agricultural flood damage assessment. Flood damage can be assessed by combining knowledge of a flood hazard and an item exposed to the flood with vulnerability. Flood characteristics such as flood depth and duration can be simulated using a

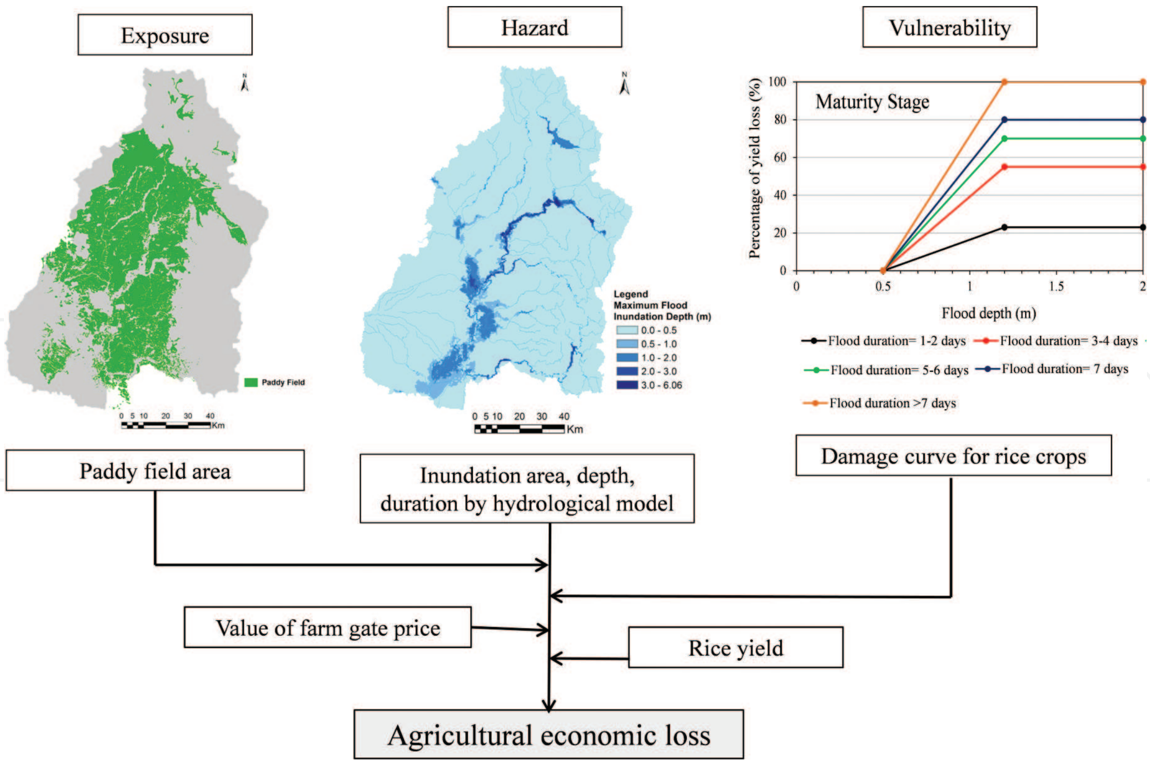


Figure 3.
Estimation process of rice-crop damage caused by flooding.

hydrological model, and paddy areas can be extracted from land-cover and land-use maps to identify exposed paddy areas in the hazard-risk areas. Then, the yield loss caused by flooding can be estimated by applying flood damage curves and converted to economic value based on the value of farm gate price and rice yield.

3.2 Flood hazard assessment

The identification of flood hazard areas and the intensity of a hazard by hazard assessment is the first step for flood risk and damage assessment. Flood hazard assessment is conducted by applying a hydrological/hydraulic simulation model using hydrometeorological data, topographic data, land-use data, and operation rules of river management structures. Information on past flood hazards, such as rainfall, river water level, discharge volume, and inundation area and depth, is required to develop and calibrate a simulation model.

For the case studies in the Pampanga and Lower Indus River basins, the rainfall-runoff-inundation (RRI) model, developed by Sayama et al. [10], was employed to compute flood characteristics such as inundation depth and duration. The RRI model is a two-dimensional model capable of simulating rainfall-runoff and flood inundation simultaneously [11]. The model deals with slopes and river channels separately. The flow on the slope grid cells is calculated with a 2D diffusive wave model, while the channel flow is calculated with a 1D diffusive wave model. The details of the RRI model can be found in Sayama et al. [10] and Sayama [11]. The model parameters were calibrated to the past largest flood event cases. Flood hazard assessment was conducted for the past largest flood event and 100-year flood cases in the Pampanga River basin and for the past largest flood event case in the Lower Indus River basin. For the simulation of the target flood of a specific return period, statistical analysis was conducted to identify the magnitude of a hazard of the target scale.

Generally flood risk assessment is conducted for a probable future flood event of a specific return period or for the past largest flood event. The target scale differs by river according to the socioeconomic activities, expected flood damage, and history

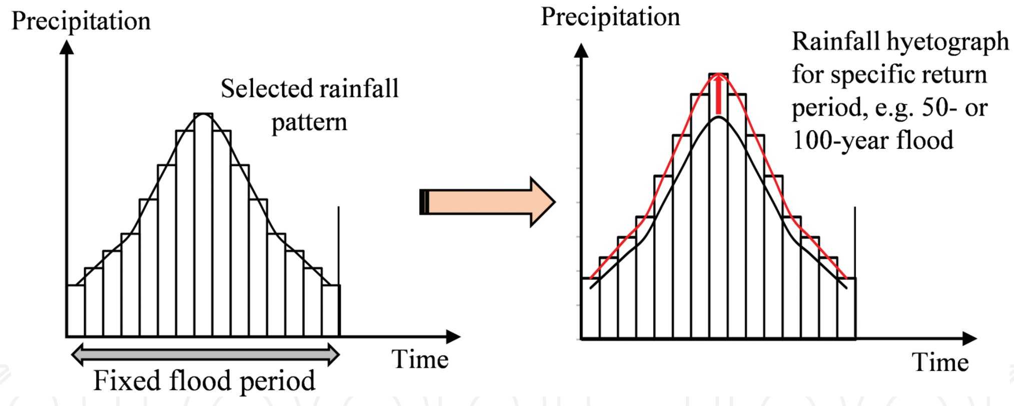


Figure 4.
Schematic figure for designing a rainfall hyetograph for a specific return period flood.

of disasters in the basin. The magnitude of damage due to the target flood is an important factor in identifying the target scale for flood management and can be simulated in the process of risk assessment. To identify the magnitude of a flood of a specific return period, rainfall data should be used for statistical analysis as the primary information of the target natural hazard. Discharge volume is also applicable to statistical analysis if no overflows from the river occur in the upstream of the measurement point and the land use of the catchment area has not changed. The water level of the river is not appropriate for statistical analysis because the river cross section at the water-level observation point often changes in an alluvial floodplain.

As mentioned above, rainfall data is normally employed as a statistical sample for a study on the design flood scale. To assess a flood hazard of a specific return period, a rainfall hyetograph for a specific return period can be estimated by multiplying the selected rainfall pattern of a past flood event by a conversion factor, as shown in **Figure 4**. The conversion factor for each return period can be calculated as the ratio of the corresponding rainfall of the return period and the rainfall volume of the selected rainfall pattern. Normally, the rainfall pattern with the highest rainfall volume is selected among the past flood events for designing a rainfall hyetograph for a specific return period.

3.3 Identification of exposed paddy fields

After assessing hazard areas by a hydrological/hydraulic simulation, paddy areas exposed to the flood can be identified by overlaying the flood hazard areas and the paddy areas to assess flood damage to rice crops. The paddy-field areas can be extracted from a land-cover map prepared by using satellite images or land-use and land-cover maps prepared by a local government. Several freely available global land-cover data are presented in **Table 1**.

For the case studies, paddy fields were extracted using a land-cover map prepared by NWRB and JICA [12] for the Pampanga River basin of the Philippines and a global land-cover map prepared by the Global Land Cover by National Mapping Organizations (GLCNMO) [13] for the Lower Indus River basin. The details will be discussed in the section of case studies.

3.4 Agricultural damage assessment

3.4.1 Depth-duration-damage function curves

After the identification of exposed paddy fields in the hazard areas, possible damage can be calculated using risk indicators. Each risk indicator represents the

Data description	Data provider	Specification	Website link
Global Land Cover Characterization (GLCC)	USGS	Spatial resolution: 30 arc-seconds	https://lta.cr.usgs.gov/glcc/globdoc2_0
Global Land Cover (GLCNMO)	ISCGM	Spatial resolution: 15 and 30 arc-seconds	https://globalmaps.github.io/
Global Land Cover-SHARE (GLC-SHARE)	FAO	Spatial resolution: 30 arc-seconds	http://ref.data.fao.org/map?entryId=ba4526fd-cdbf-4028-a1bd-5a559c4bff38
Climate Change Initiative Land Cover (CCI-LC)	European Space Agency	Spatial resolution: 300 m	https://www.esa-landcover-cci.org/
MODIS Land Cover	NASA/USGS	Spatial resolution: 500 m	https://lpdaac.usgs.gov/dataset_discovery

Table 1.
List of globally available land-cover data.

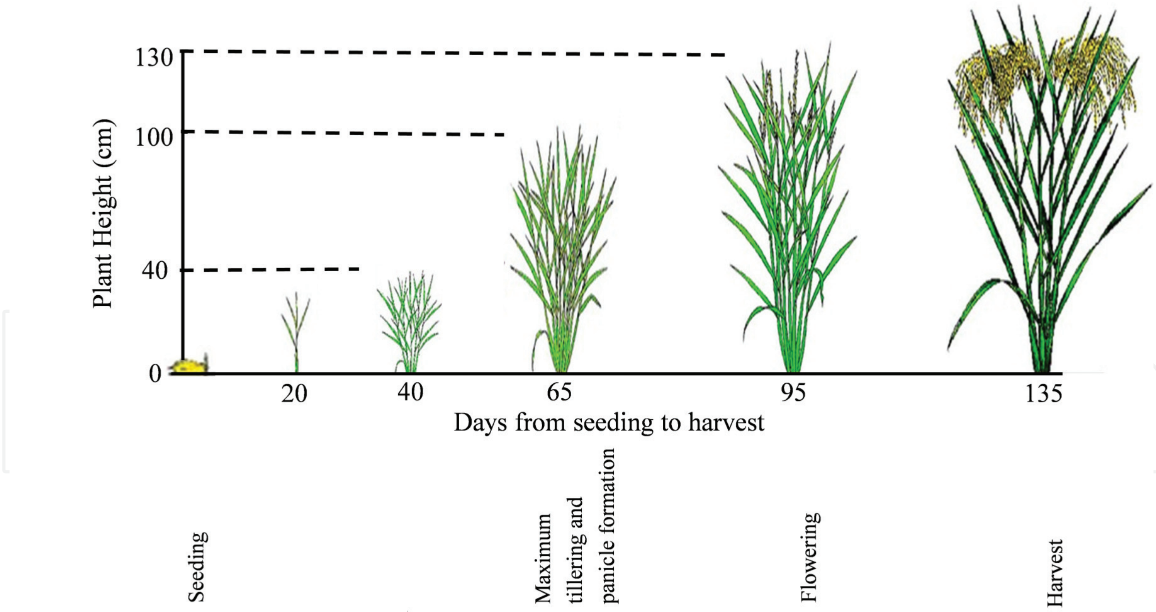
vulnerability of each item by showing the correlation of the intensity of a hazard with damage quantified by a damage curve. Therefore, flood damage curves are important in flood damage estimation. To estimate flood damage to rice crops, depth-duration-damage function curves are normally used.

Flood damage curves can be mainly derived from two approaches: (1) using actual damage data of past floods and (2) using synthetic data (expert estimation or questionnaire surveys) [8]. In the former approach, flood damage curves are developed based on data and information of past hazards and resulting actual flood damage. Therefore, accumulation of data on hazards (inundation records) and flood damage is essential. In the latter approach, damage curves are derived from hypothetical analysis, information obtained from questionnaire surveys, or land cover and standardized typical property types.

Table 2 shows the flood damage matrix for rice-crop damage published by the Philippines Bureau of Agricultural Statistics [14]. **Figure 5** shows the height of rice plants at each growth stage and its duration. Based on the flood damage matrix and the information on rice plant height at each growth stage, Shrestha et al. [16] proposed flood damage curves for rice crops as presented in **Figure 6**. Flood damage curves of rice crops vary with each rice growing stage. Based on the duration of each growth stage of rice plants and the information on a cropping calendar, the growth stage of rice plants during a flood event can be identified, and an appropriate damage curve corresponding to the growth stage of rice plants should be applied

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.
Flood damage matrix for rice crop published by the Philippines Bureau of Agricultural Statistics [14].



Duration (days)	20	20	25	30	40
Growth Stage	Seedbed / Seedling	Newly Planted	Vegetative Stage	Reproductive Stage	Maturity Stage

Figure 5.
Height of rice plants at each growth stage and its duration [14, 15].

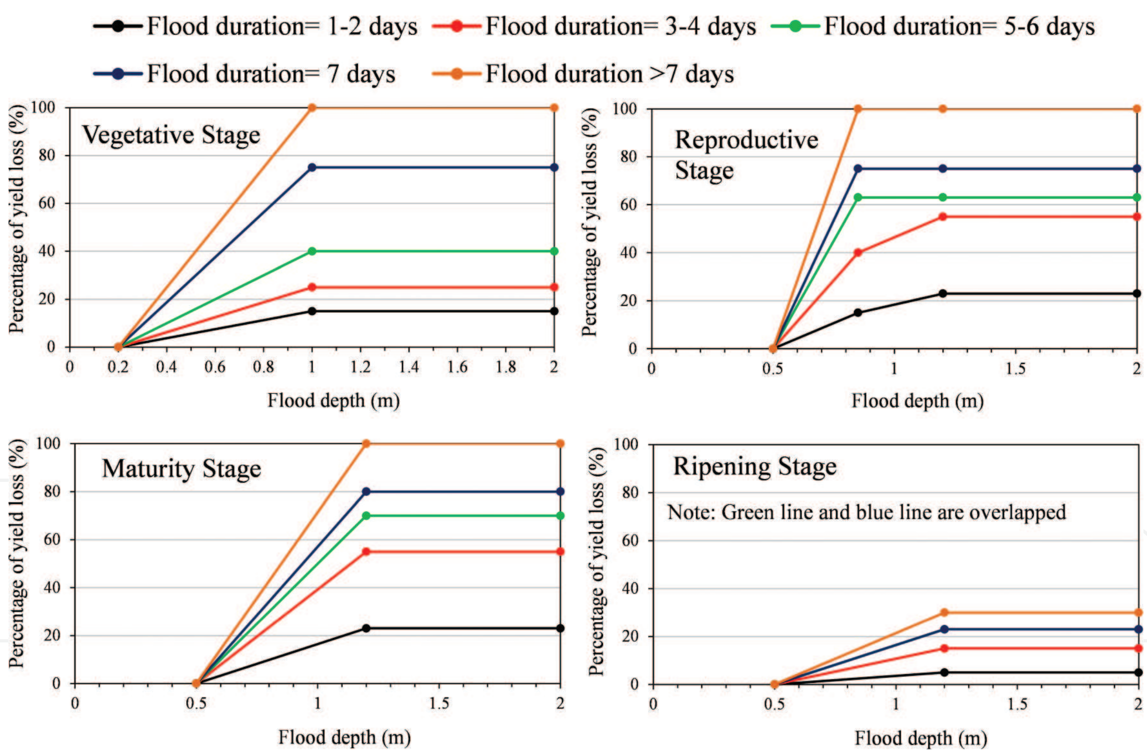


Figure 6.
Depth-duration-damage function curves for rice-crop damage [16].

for damage estimation. For the case studies in this chapter, the flood damage curves for rice crops presented in **Figure 6** were used to estimate agricultural economical losses.

3.4.2 Damage estimation method

Flood damage to rice crops is defined as a function of flood depth, flood duration, and growth stage of rice plants and can be estimated by using the calculation

Growth stage of rice	Calculation method
Seedbed/seedling (20 days from rice plant germination)	Value of production losses = area affected × cost of input/hectare × yield loss
Newly planted stage (1–20 days after sowing)	
Vegetative stage (21–45 days)	
Reproductive stage (46–75 days)	Volume of losses = most recent yield/hectare × area damaged × yield loss Value of production losses = volume of losses × most recent farm gate price
Maturing stage (76–115 days)	

Table 3.
Calculation method of flood damage to rice crop for each growth stage of rice plants.

method presented in **Table 3**. When flooding occurs during the early growth stage of rice plants, i.e., from the seedling to vegetative stages, at which no rice production is expected, farmers normally replant rice crops. In such a case, flood damage to rice crops can be estimated as losses of cost of input. On the other hand, when flooding occurs during the reproductive and maturity stages, at which rice production is usually expected, there is no time for replanting rice crops. In this case, flood damage to rice crops can be estimated as volume of production losses, i.e., yield loss, and then the value of production losses can be estimated based on farm gate price as calculation method presented in **Table 3**. The yield loss caused by flooding can be determined using a flood damage curve presented in **Figure 6**, according to flood depth and duration.

4. Agricultural flood damage assessment in developing countries

The method for flood damage assessment for rice crops presented in this chapter was applied to assess agricultural damage in the river basins of developing countries in Asia. The method was verified by comparing calculated damage with reported data. In this section, the case studies of the assessment of flood damage to rice crops in the Pampanga River basin of the Philippines and the Lower Indus River basin of Pakistan are discussed.

4.1 Pampanga River basin of the Philippines

The Pampanga River basin is located in the Region III of the Philippines, which is regarded as one of the most important river basins in terms of economic activities that influence the entire country. **Figure 7** shows the location of the Pampanga River basin. It is the nation's fourth largest basin and covers an area of 10,434 km^2. The main river is about 260 km long.

In the case of the Pampanga River basin, the results of flood damage assessment for the past largest flood event as well as for a 100-year flood case are discussed. To assess flood damage to rice crop in the Pampanga River basin of the Philippines, flood characteristics such as flood depth and duration were computed using the RRI model. A digital elevation model (DEM) of a 450 m × 450 m grid size, derived from the Interferometric Synthetic Aperture Radar (IfSAR), was used in the RRI Model simulation. The IfSAR data was obtained from the National Mapping and Resource Information Authority (NAMRIA) of the Philippines. The flow accumulation and flow direction data, which are also necessary to input in the RRI model, were

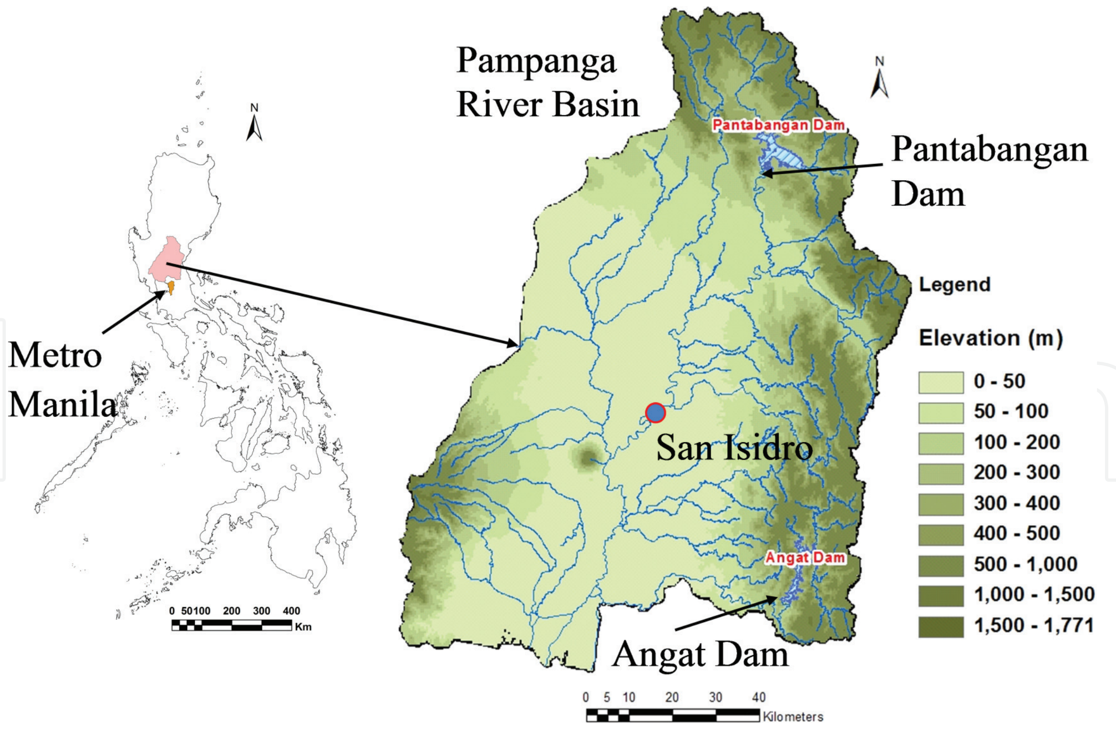


Figure 7.
Location of the Pampanga River basin in the Philippines.

created using DEM in ArcGIS. 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 based on recent flood events by comparing the calculated and observed flood discharges at the San Isidro station in the basin. The flood event in September 2011 was the biggest flood in the basin in the last 30 years. The model parameters were thus calibrated to the September 2011 flood event. The calibrated parameters were validated with the 2015 flood event. **Figure 8** shows the comparison of the calculated discharge with the observed discharge at San Isidro gauging station for the flood events in 2011 and 2015 and also the comparison of the calculated flood inundation depths with the recorded flood depth in the barangays (villages) of Calumpit Municipality. The calculated results reasonably agreed with the observed data. The flood event in 2011 was due to Typhoons Pedring and Quiel. Typhoon Pedring was directly followed by Typhoon Quiel, and rice crops were severely damaged by this flood event. The flood event in 2015 was due to Typhoon Lando, which also damaged rice-crop areas in the basin.

To calculate the flood inundation depth and duration for a specific return period, flood frequency analysis was conducted by using 48-hour maximum annual rainfall data. Flood frequency analysis is essential for calculating expected damage. The main objective of flood frequency analysis is to relate the magnitude of extreme events to their frequency of occurrence through the use of probability distributions [17, 18]. The Gumbel distribution method was used for rainfall analysis. Since the rainfall volume of the September 2011 flood during Typhoon Pedring was the highest rainfall volume in the last 30 years, the rainfall pattern of the September 2011 flood (only for the Typhoon Pedring case) was selected for designing a rainfall pattern for a specific return period. **Figure 9** shows the results of flood frequency analysis using the Gumbel method and the estimation of a design hyetograph for an event of a specific return period such as a 100-year flood. To calculate flood characteristics for a 100-year flood, a design hyetograph for a 100-year return period was estimated by multiplying the rainfall hyetograph of the September 2011 flood by a conversion factor. The conversion factor for a 100-year return period was

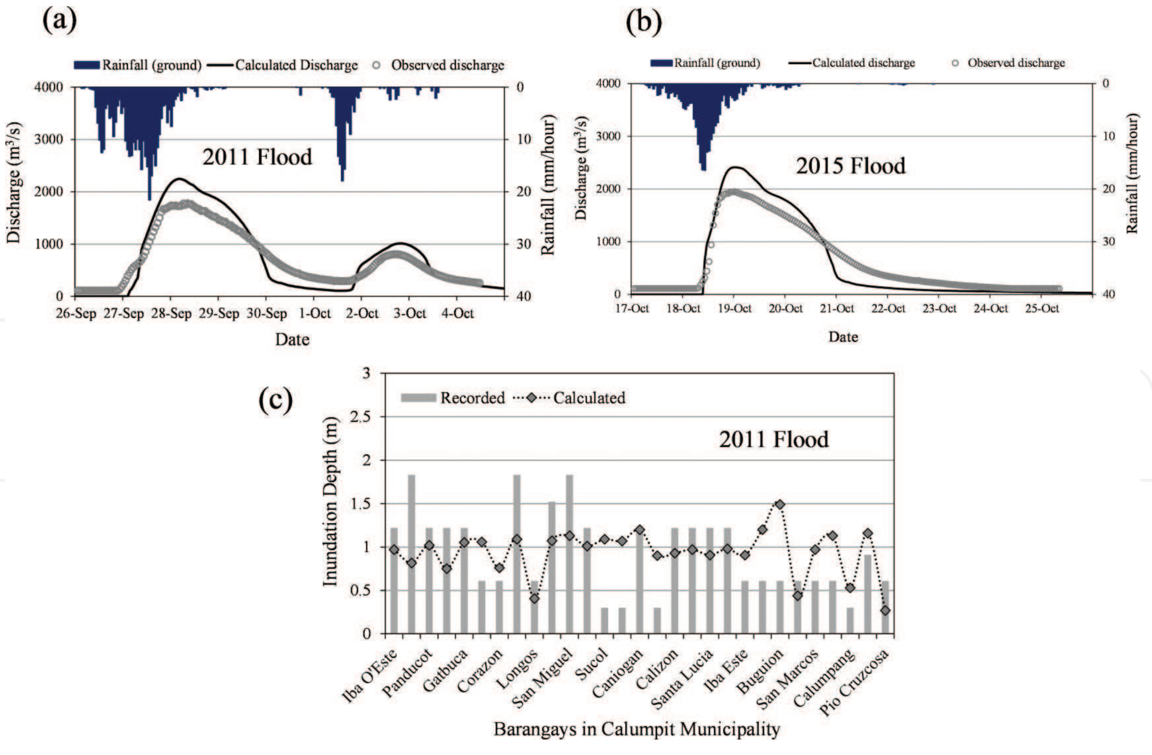


Figure 8.
Comparison of calculated discharge with observed discharge at San Isidro station (a), (b) and comparison of calculated flood depth with recorded depth at each barangay (village) of Calumpit municipality (c).

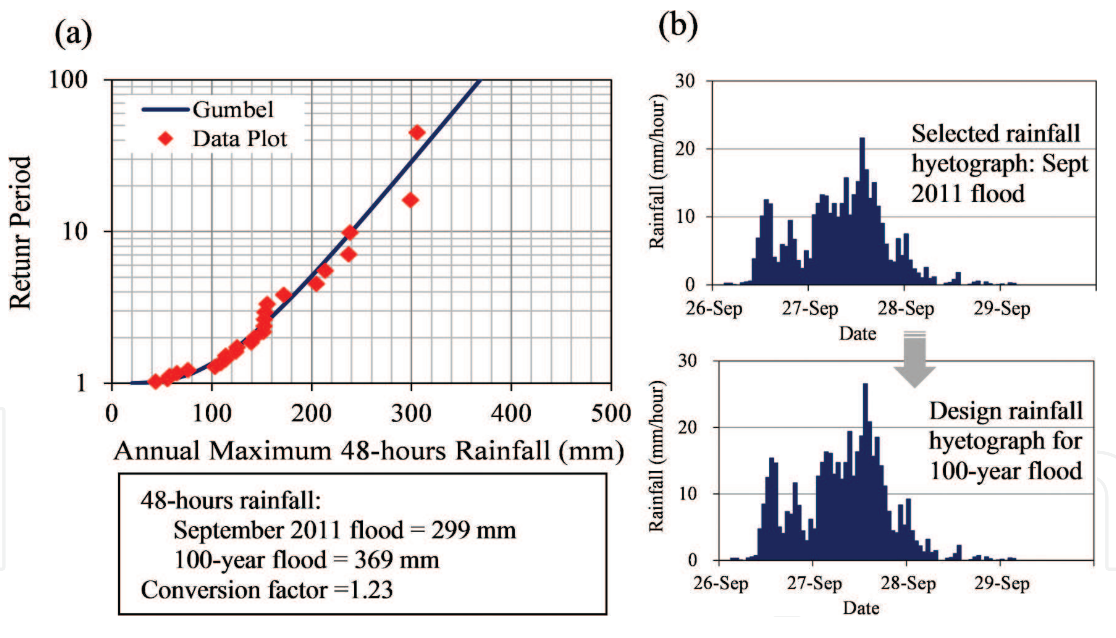


Figure 9.
Flood frequency analysis and estimation of the design hyetograph for an event of a specific return period such as 100-year flood.

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 period of the September 2011 flood event was about 28 years. The flood characteristics for a 100-year flood were simulated by using the RRI model and the calculated design hyetograph.

Figure 10(a) shows the paddy fields in the Pampanga River basin, extracted using a land-cover map prepared by NWRB and JICA [12]. The rice-crop areas in the basin are about 397,247 ha. The paddy fields account for about 38% of the basin area in the Pampanga River basin. **Figure 10(b)** shows the cropping calendar for the

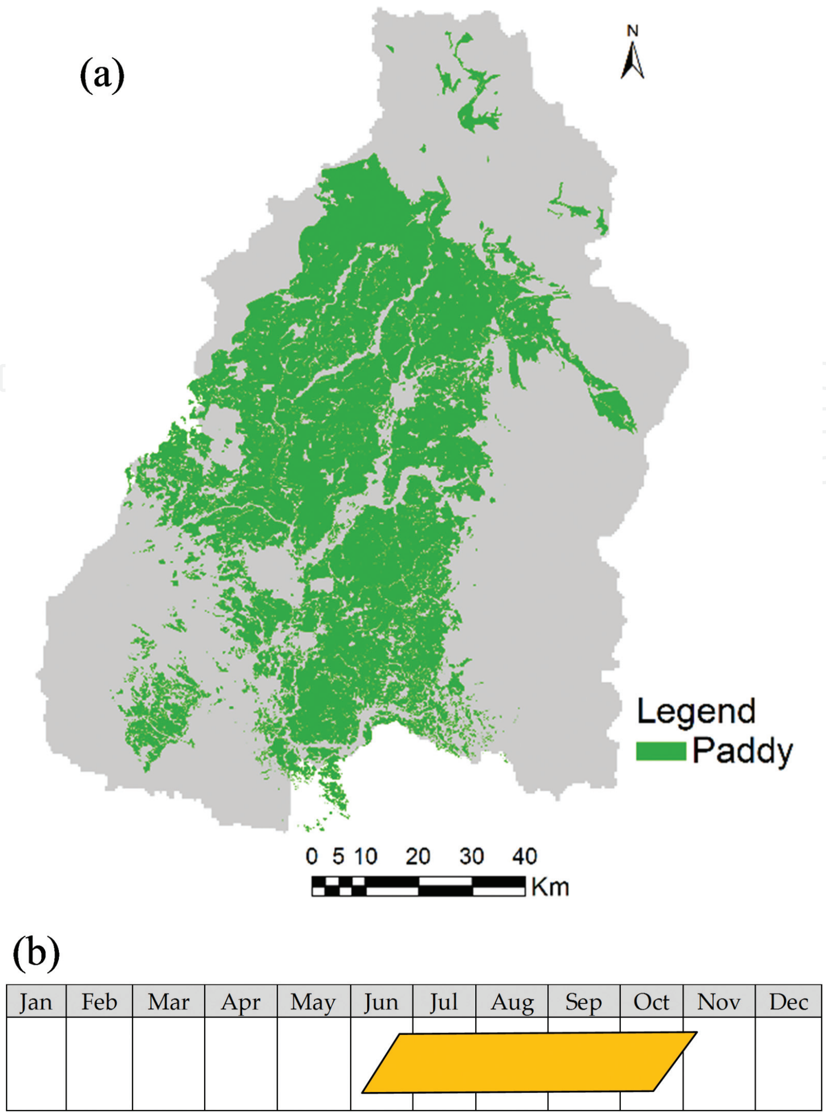


Figure 10.
Paddy field and cropping calendar for wet-season rice crop in the Pampanga River basin.

wet-season rice cultivation in the Pampanga River basin. The cropping calendar is based on the cropping calendar prepared by the National Irrigation Administration-Upper Pampanga River Integrated Irrigation System. The wet-season rice cultivation period in the Pampanga River basin is from June to October, and at least one flood event occurs every year during this period due to heavy rainfall or typhoons.

Flood damage was assessed for the 2011 flood event and 100-year flood cases. Based on the duration of the growing stage of rice crop and the cropping calendar (**Figure 5** and **Figure 10(b)**), the growth stage of rice crop during the flood event in 2011 was the maturity stage. The flood damage curves for the maturity stage presented in **Figure 6** were thus employed to estimate rice-crop damage. The rice-crop damage for a 100-year flood was estimated based on the current conditions, assuming that the rice plants were at the maturity stage, similar to the stage of rice crop during the past flood case. The flood damage to rice crop was estimated as volume of production losses using the calculation method presented in **Table 3**. **Figure 11** shows the calculated flood hazard areas and agricultural damage during the flood event from 26 September to 4 October 2011 caused by Typhoons Pedring and Quiel. The estimated flood inundation areas with a flood inundation depth greater than 0.5 m were 101,736 ha. The estimates of damaged rice-field area and rice-crop damage were 45,056 ha and 1475.78 million peso, respectively. The values of the farm gate price equal to 17 peso/kg [14] and the rice yield equal to 4360 kg/ha

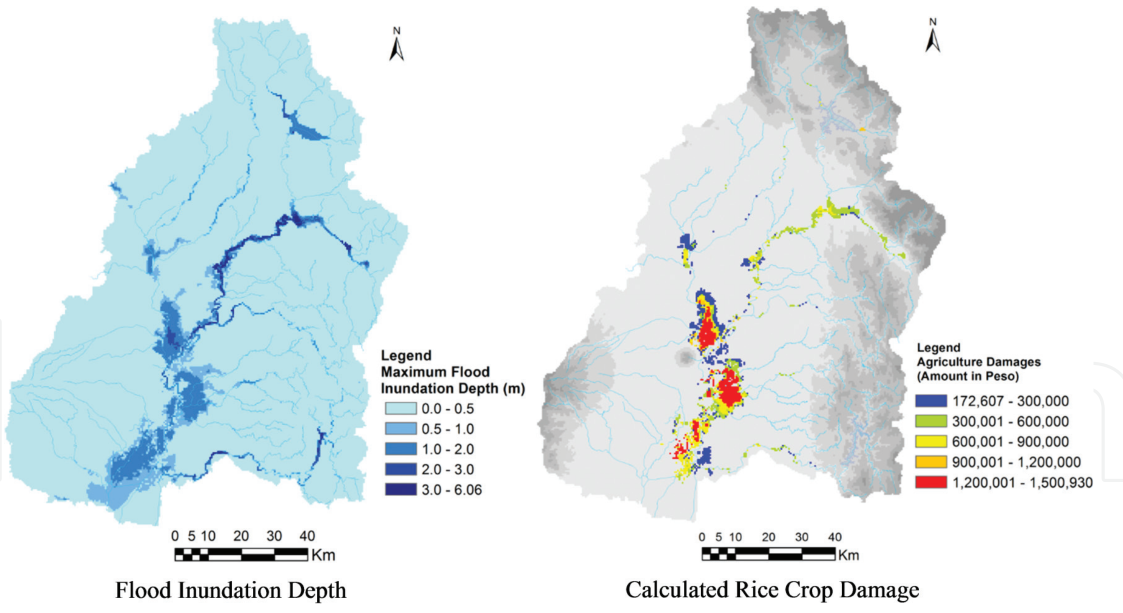


Figure 11.
Calculated maximum flood inundation depth using the RRI model and estimated flood damage to rice crop by the flood event from 26 September to 4 October 2011.

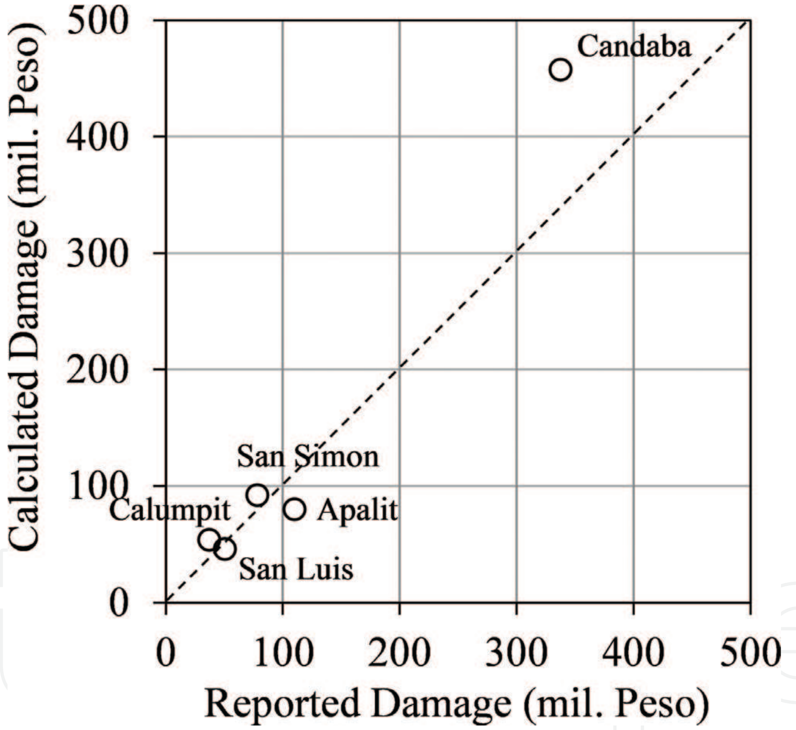


Figure 12.
Comparison of calculated value of rice-crop damage with reported data for five municipalities during the flood from 26 September to 4 October 2011. Reported data source: [19, 20].

[19] were used in the calculation. About 11.3% of the total paddy-field area in the basin was damaged during this flood event. **Figure 12** compares the calculated rice-crop damage with the reported data for five municipalities in the basin. The calculated results reasonably agreed with the reported damage, although some difference was found in the case of Candaba Municipality. This discrepancy between the calculated and reported damage can be attributed to a variety of reasons, for example, accuracy of topographical and land-cover data.

Figure 13 shows the calculated maximum flood inundation depth and flood damage to rice crop for a 100-year flood. The damaged paddy fields and value of rice-crop damage in the case of a 100-year flood were 67,655 ha and 2248.3 million

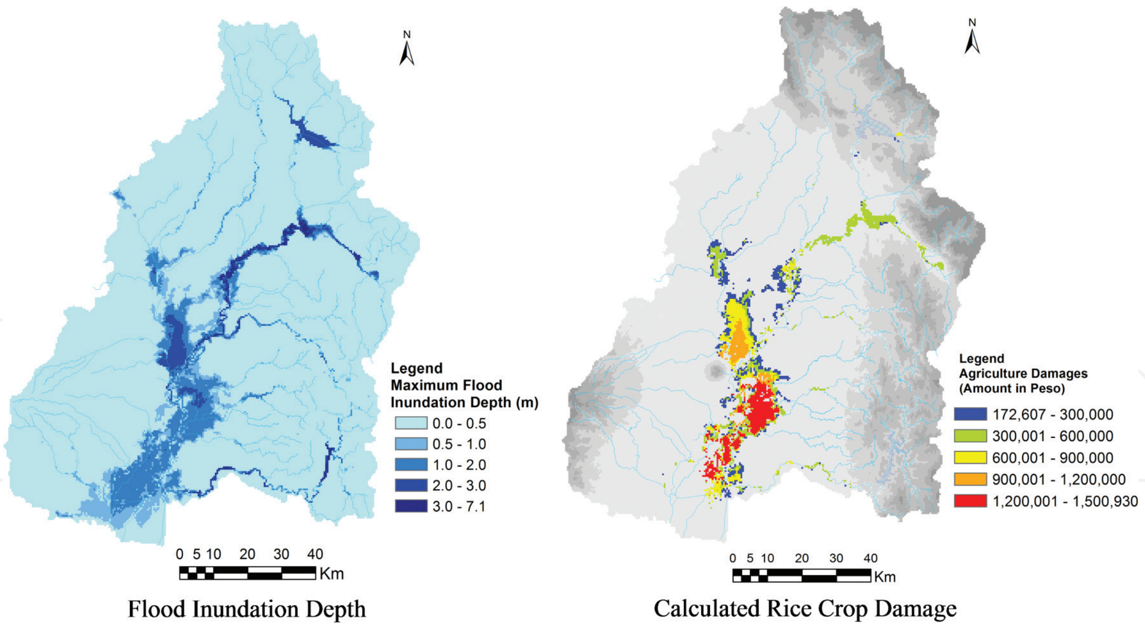


Figure 13.
Calculated flood inundation depth and rice-crop damage for a 100-year flood case.

pesos, respectively. In this case, the rainfall pattern and period of Typhoon Pedring were exclusively considered for designing a rainfall hyetograph for a 100-year flood. If the rainfall pattern and period of Typhoons Pedring and Quiel are considered, the damage might be more severe. The estimated value of rice crop in the case of a 100-year flood is about 1.52 times as high as that in the 2011 flood case. Identifying flood risk areas based on flood damage assessment provides essential information for designing future development activities. The results of flood hazard and damage assessment can be useful for implementing mitigation actions as well as for formulating policies for flood risk reduction including land-use management. To evaluate the risk of a flood with a specific return period, target scales for risk assessment should be determined. Basically, such target scales are decided based on the socioeconomic conditions of target areas and consensus among stakeholders such as national and local governments.

4.2 Lower Indus River basin of Pakistan

Figure 14 shows the location of the Lower Indus River basin in Pakistan. The area of the study basin is about 700,375 km^2. The global land-cover data of GLCNMO were used to extract paddy fields, and **Figure 15(a)** shows the paddy

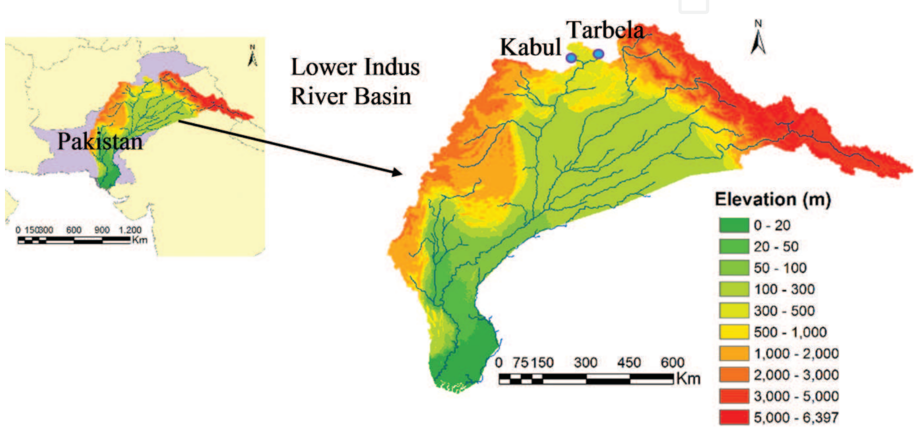


Figure 14.
Study area of the lower Indus River basin in Pakistan.

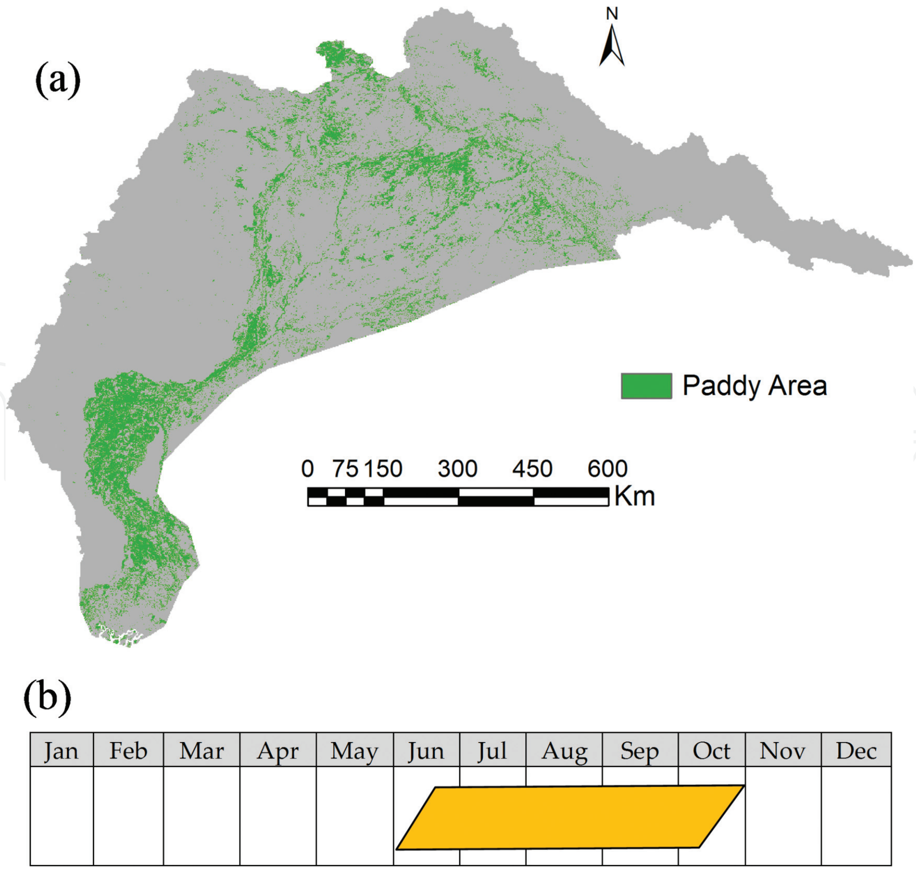


Figure 15.
Paddy field in the study area and cropping calendar for wet-season rice crop.

fields in the Lower Indus study area. The paddy fields in the area are about 8.62 million ha (12.3% of the study basin area). **Figure 15(b)** shows the wet-season rice cultivation calendar in the study area, which was prepared based on FAO [21]. The wet-season rice cultivation period in the basin is from June to October.

The flood hazard was analyzed using the RRI Model for the August 2010 flood. DEM, flow accumulation, and flow direction data downloaded from the HydroSHEDS were used for the analysis. Since the study basin area is quite large, flood hazard simulation was conducted using a 60 arc-second grid size (approximately 1.8 km). In the RRI Model simulation, the observed river discharge boundary conditions at Tarbela and Kabul were defined, and recorded rainfall was also considered. The details of calibration and validation of the RRI Model can be found in Sayama et al. [10].

Figure 16 shows the calculated maximum flood inundation depth and estimated flood damage to rice crop during the August 2010 flood event. The values of the farm gate price equal to 17.5 Rs/kg [22] and the rice yield equal to 2641 kg/ha, obtained from the Directorate of Agriculture Extension Sindh, Hyderabad, were used in the calculation. The damage curve for the maturity stage was used according to the cropping calendar and the duration of the growth stage. The calculated flood inundation areas with a flood inundation depth greater than 0.5 m and the damaged rice-field areas were found to be 1,611,252 ha and 662,580 ha, respectively. About 7.6% of the paddy-field area was damaged during the August 2010 flood. The total estimated flood damage to rice crop in the basin was found to be 19.72 billion Rs (Pakistani Rupees), while the reported damage was 21.17 billion Rs. The calculated damage values were also compared with the reported data for four provinces (**Figure 17**). The comparison results show that the calculated damage values reasonably agreed with the reported data. The results show that rice crops were severely damaged by flooding in Sindh and Punjab provinces.

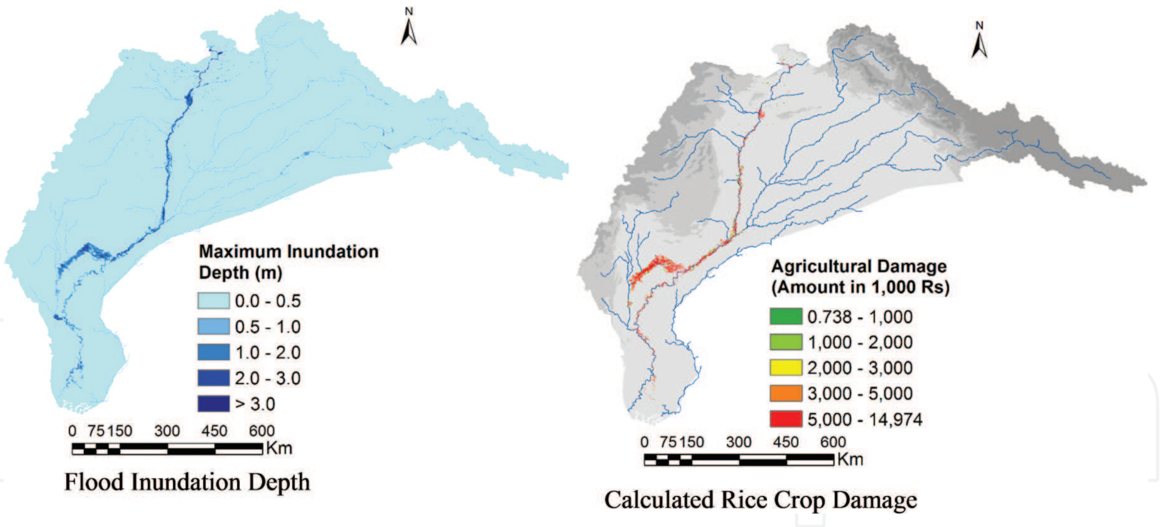


Figure 16.
Calculated maximum flood inundation depth and rice-crop damage during the August 2010 flood in the lower Indus River basin.

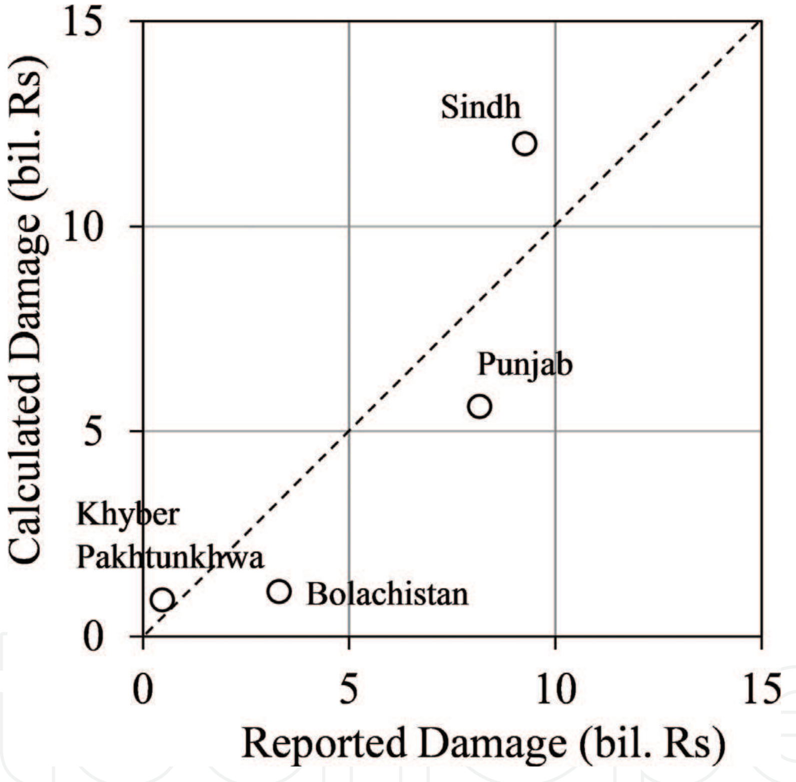


Figure 17.
Comparison of calculated value of rice-crop damage with reported data for four provinces during the August 2010 flood. Reported data source: [22].

5. Conclusions

The method for assessing flood damage to rice crop with case studies in the Asian river basins was discussed. The results of flood damage assessment in the Pampanga River basin of the Philippines and the Lower Indus River basin of Pakistan were also presented in this paper. The calculated values of rice-crop damage were compared with reported data. The comparison results show that the values of calculated damage reasonably agreed with the reported damage values. The rice-crop damage estimation method presented in this paper can be easily applied to estimate damage for future flood events and can also be applied to other river basins for flood risk assessment. The method was also introduced to the related organizations in several developing countries of Asia such as the Philippines, Indonesia, Cambodia, Thailand, and Myanmar. 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 accuracy of flood disaster risk assessment can be further improved by considering the following points:

- The accuracy of flood hazard assessment and damage assessment highly depends on the quality of topographical data. For the case studies in this chapter, agricultural damage was assessed using remotely sensed topographical data and global land-cover data. Damage assessment can be further improved by adjusting remotely sensed topographical data with ground observed elevation data for certain points and also by using locally available land-cover data to reflect actual local conditions.

- Generally, flood damage curves are prepared based on actual flood damage and inundated depth. Data and information on actual flood events and damage with their relationships are very important for developing damage functions, as well as for validating calculated results. It is thus important to collect damage data and hazard information during or after a flood disaster.

- Risk indicators such as flood damage curves can differ from place to place according to the characteristics of exposed elements such as agricultural products and residential houses, even though some similarities may be found between some places. It is recommended that each country should develop damage curves to reflect the actual characteristics of their rice-crop cultivation.

- This chapter focused on assessment of flood damage to rice crops. However, for flood risk management in the river basins, it is also necessary to consider flood damage to other agricultural crops and also flood damage to buildings, residential properties, and other types of infrastructure.

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Conflict of interest

The authors declare no conflict of interest.

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