Flood Damage Assessment on Rice Field: Case Study for Cambodia

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Abstract

Flood is the primary natural hazard occurrence in Cambodia causing damage in both direct and indirect on majorities of development factor. Due to inadequate flood preparedness and mitigation, the damage estimation of flooding during historical extreme flood occurrences revealed significant damage to rice fields. The objective of this study was to estimate the damage value of rice over the whole country of Cambodia during the flood event in 2020. The flood map data in October 2020 through the World Food Program was used and overlaid with rice field map to generate rice damage map. The value of rice damage was estimated based on flood damage curve and average value of rice, showing value with different damage levels including 25%, 50%, and 100% damage. The resulting damage area was compared with government field-scale investigation and shown 66% consistency. From the result of this study are expected to support decision-making for better understanding of flood impact on rice to implement rice monitoring and update for planning to help mitigate damage impact and managing the restoration program over flood-vulnerable area after disaster.

Keywords: Flood Damage Assessment, Rice Field, Rice Damage Map, Rice Damage Value, Cambodia.

1. Introduction

Flood is one of all-natural hazard occurring in the world and impacting both direct and indirect on majorities of development factors including human live, infrastructure and property damages, environment, ecosystem, agriculture, cultural heritage, and creating great losses of economic given the current population growth and the ongoing accumulation of valuable assets in river basins [1, 2]. It can happen at any time of the year and is typically driven on by typhoons, heavy rainfall, tropical storms, and the collapse of man-made dams. Over the past few decades, floods have become more severe due to climate change, the increase in urbanization, and the inadequate planning and management of these events [3]. Floods are the primary natural danger to which Cambodia is vulnerable, followed by drought, sporadic epidemics, and storm [4, 5]. According to Mekong River Commission (MRC) reports that large flood resulted from mainstream floods and combined flood caused by backwater around the Tonle Sap Lake that arises due to a combination of runoff and heavy rain [6].

Agriculture contributes a big part of Cambodia's GDP with its averaged around 30% of the total during 2000-2014 and it is estimated to be about 22.1% of the total in 2019 [7]. Production of paddy rice has traditionally been an important source of income, contributing for around 80% of Cambodia's GDP [8]. In 2011, the rice cultivated area was reported to be around 2.9 million hectares and increased annually to 3.4 million hectares in 2020 with the 10 years average of 3.1 million hectares [9].

Cambodia experienced serious flood events in 1997, 2000, 2011, 2013, and 2020 in several provinces and damaged thousand hectares of rice field and production. In 2000, damage of paddy fields was approximately 27,000 hectares and about 4 million people were affected. The 2011 flooding impacted 18 provinces and over 1.5 million people were affected. About 164,00 hectares of rice fields were destroyed with the total value of 178.8 million dollars and reduced milled rice export by 43.6 million dollars compared to potential [10]. In October 2020, Cambodia encountered the worst flood event in the past decade as the result of multiple tropical storms which affected over 175,000 households and 329,000 hectares of agricultural land was damaged [11]. With the historical damages estimation of flooding on agricultural land, especially paddy rice, must be thoroughly investigated to reduce potential losses and damage in Cambodia floodplain and vulnerable areas.

Flood risk analysis and assessment is a scientific subdiscipline or a set of techniques based on the combine of flood hazard, probability, and potential negative consequences of floods for economic activities, human health, the culture heritage and environment. The requests for flood risk management are flood vulnerability assessment, flood risk mapping, comparative risk analysis, financial appraisal for insurance sector, and financial assessment during and immediately after flood [12]. In order to conduct further research on flood mitigation strategies, either structural or non-structural, or a mix of both, it is regarded essential to first determine the lost value of elements at risk. Flood damage can occur either in direct or indirect way towards both tangible and intangible assets. The term of direct damage results from the flood water comes into direct contact with people, property, or other objects while the indirect damage is referred to any damage that occurs as a consequence of direct damage after a certain period of time or space [13, 14]. In general, both direct and indirect damage are categorized into tangible and intangible. The tangible damage refers to damage that can be evaluated in monetary terms while intangible damage refers to qualitative and untradeable [13, 15]. Indirect intangible damage is the indirect damage that is unable to be evaluated in monetary terms which in contract with the indirect tangible damage. The previous common methods such as questionnaire, interview, field survey and database released by the government or agencies related to flood were used for flood damage assessment studies in acquiring the data. However, the shift in technology led to a more advanced data collection technique including a satellite dependence database that eases the process of assessment. There are two approaches widely used for damage assessment methods. The empirical method, which is developed based on the features of the flood analyzed from the post-flood data collection. Another one is the synthetic method, which is a model based on the combination of land cover, land use patterns, types of objects and extracted data from questionnaire in performing a deduction based on the hypothetical rules [16].

Several approaches on estimation of flood damage commonly aim to calculate the cost of damage regarding to the damage function in different sectors [8, 17-20]. The unit cost estimation is the process of applying the average loss value to the individual damage element within the same type. It is possible to have many types of damage subcategory so that the average loss value of each type is even more accurate. The total cost of each type of damage can be computed by using the average loss value of single damage type multiplying by a number of unit cost estimation. The flood damage curve, also known as depth-damage curve, is a very important element for flood damage assessment. It is normally generated to estimate the flood losses. The graphic curves represent the relationship between the expected damage or losses and the varying inundated water depth from which the average annual damage can be further derived [21-23]. The two most common methods for developing the flood damage curve are the damage data of the previous flood event and using the hypothetical analysis mainly depend on land cover patterns, and type of elements at risk [24].

Reliable and long-term ground observation data are typically considered to be a crucial initial input to analysis for estimating flood damage. Furthermore, due to the lack and quality of flood damage records as well as the limited number of operating meteorological and hydrological stations, this condition is not applicable in some areas of developing countries. Therefore, having a thorough understanding of the effect of rice fields information helps local authorities in implementing rice monitoring and updates for planning and managing the post-flood compensation and restoration program over flood-vulnerable regions after disasters. The study of rice damage affected by flood event is very crucial for development in expanding agricultural land and reducing the loss of rice production in critical area. Despite the significant of such study, there is still limited research which investigated the damage of flood on rice field in Cambodia.

In this study, flood damage assessment is proposed which focuses on rice damage impacted by flood water with water depth and duration. With the availability of flood map data for the whole country of Cambodia which is carried out inundated area during flood event in October 2020, rice field data, the data information of rice from ministry report, and flood damage curves established by the MRC's Flood Management and Mitigation Program, it is expected to assess damage of rice during the period of flooding in the whole country and estimate average damage value on rice at a fine scale.

2. Methodology

2.1 Study area

Cambodia is bordered by Thailand to the northwest, Laos to the northeast, Vietnam to the east, and the Gulf of Thailand to the southwest. Considering most of the land is below 40 meters, it is vulnerable to flooding which is shown in Fig. 1. The Mekong River flows through Cambodia for nearly 500 km before entering the Mekong Delta, is where the majority of the water resources are found. The Mekong River Basin includes the catchments of the Bassac River, the Tonle Sap River, and the Great Lake and its tributaries, contains about 86% of the area of Cambodia. Tonle Sap Lake receives water yield as the average yearly inflow to the lake was 79.7 km^3. The main source of inflow is the Mekong River, which yields 51% of the inflow via the Tonle Sap River. Other sources of inflow are tributaries, overland flow from the Mekong and precipitation, which consist of 31%, 5% and 13% of the total inflow, respectively. Outflow from the lake is via the Tonle Sap River 70.4 km^3/year.

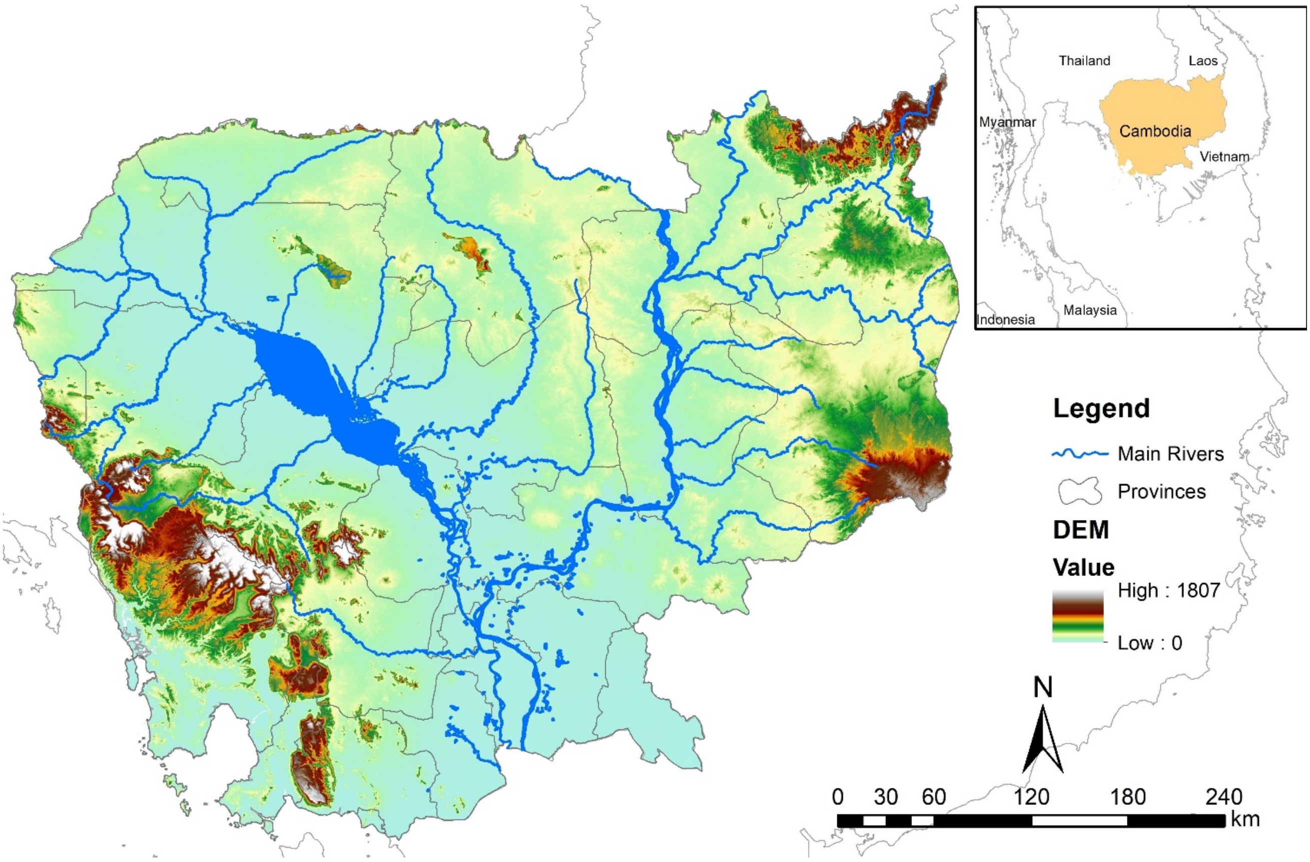

Fig. 1 the location map of study area, Cambodia.

Cambodia has a climate that is characterized by two different types of weather: the southwest monsoon which happens from May to October, and the northwest monsoon which happens from October to April. Throughout the year, the average annual rainfall is between 1000 and 1500 millimeters, and the relative humidity is high at night. During the dry season, humidity is about 50 percent or slightly lower during the day, but during the rainy season, it can be as high as 60 percent. Humidity levels usually vary from 65 to 70 percent in January to 85 to 90 percent in August. Evaporation rates vary between 2,000 and 2,200 mm per year. The highest evaporation rate is 200 to 240 mm in March and April, and the lowest evaporation rate is 120 to 150 mm in September.

2.2 Data collection

The approach that was used to achieve the objective of this study is based on 4 types of data which is shown in Table 1. The first type of data was rice field data for the whole country of Cambodia from International Rice Research Institute (IRRI). The second type of data was the flood extent map which illustrates the location of inundated area of the maximum flood from 27th to 31st October 2020 for the whole country. The map was downloaded from Sentinel-Asia cooperated with World Food Program (WFP) requested by ASEAN

Coordinating Centre for Humanitarian Assistance on Disaster Management using NASA Visible Infrared Imaging Radiometer Suite (NOAA VIIRS). Thirdly, flood damage curve which was represents the relationship

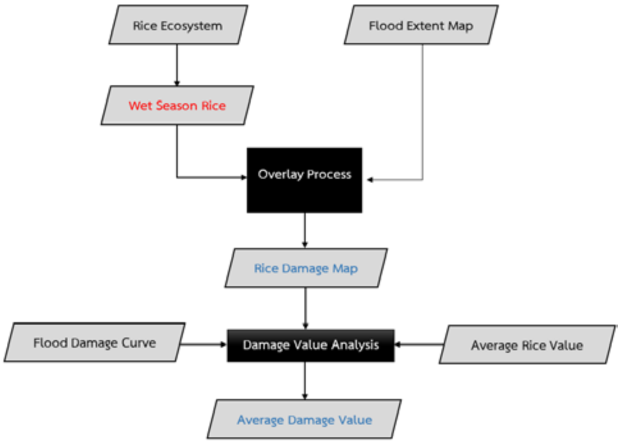

Fig. 2 Flowchart of the procedure for flood damage assessment.

between floodwater depth and flood duration related to rice damage present in the proportion of depth and duration and the data was based on a survey on 2006 flood event established by the MRC's Flood Management and Mitigation Program (FMMP). The fourth type of data was the average value of rice which is mentioned in the report of Paddy and rice in February 2020, and the data of rice cultivated areas and productions by type of rice from Summary report on agricultural, forestry and fisheries for 2020 and implementation direction for 2021, published by Ministry of Agriculture, Forestry, and Fisheries (MAFF).

Table 1 List of data for flood damage assessment.

List	Source
Rice Ecosystem	International Rice Research Institute' (IRRI)
Flood extent map	World Food Program (WFP)
Flood damage curve	MRC's flood management and mitigation program
Agricultural marketing information, Summary report on agricultural, forestry and fisheries for 2020 and implementation direction for 2021	Ministry of Agriculture, Forestry, and Fisheries (MAFF)

In order to obtain the objectives as mentioned above, the flowchart is shown in Fig. 2. illustrates the overall research procedure. The first step for estimating rice damage area impacted by flood was to extract wet season rice area among 4 categories of rice ecosystem data due to period of flood event was in wet season. The flood map which was received from WFP was then overlayed with rice field map to detect damage area. Consequently, the resulting damage map shows the damage to rice field during the inundated period. Then, the flood damage curve was used to analyze the damage level in different proportions and estimated the average damage value using average value of rice from the reports of MAFF.

2.3 Flood inundation extent from WFP

For the flood event in 2020 which is shown in Fig. 3, the flood data was released by World Food Program (WFP) requested by ASEAN Coordinating Centre for Humanitarian Assistance on Disaster Management and using NASA Visible Infrared Imaging Radiometer Suite (VIIRS) to generate the flood map. The main dataset used to process this flood detection with VIIRS imagery was the Suomi National Polar-Orbiting Partnership with moderate spatial resolution of 375 m. The data was published in Sentinel-Asia website. The data from the Suomi-NPP/VIIRS was confirmed satisfactory performance by validating with the visual inspection, inter-comparison with MODIS flood products, and qualitative validation with Landsat imagery [25].

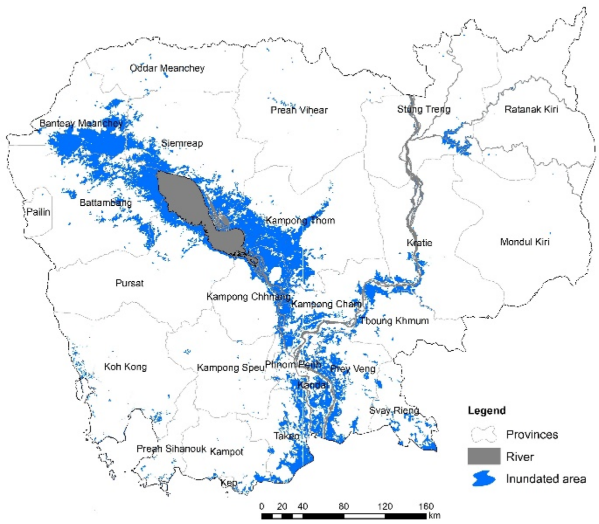

Fig. 3 Flood map for the whole country of Cambodia from World Food Program.

2.4 Rice damage area

To estimate the affected area of rice which was damaged by flood, the data of flood area and data of rice field are required. The flood map generated from SNPP/VIIRS flood product makes it possible to identify the inundated area on the whole Cambodia, especially for the areas with most flood in administrative levels. The wet season rice field data which was extracted from rice ecosystem data illustrated in Fig. 4, the total area of wet season rice was 2,858,596 ha. The form of flood data and rice data were in the same type of data which capable to composite and analyze the damage area of rice field using ArcGIS.

2.5 Damage assessment method

To estimate the damage cost of rice effected by flood water, rice information such as rice value and the ratio of rice types in each area are needed. The agricultural marketing information in February 2020 illustrated the average price of rice by provinces and cities. The report also included the separated price by rice type depending on the area. Summary report on agricultural, forestry and fisheries for 2020 and implementation direction for 2021 showed the total area of rice cultivation land and

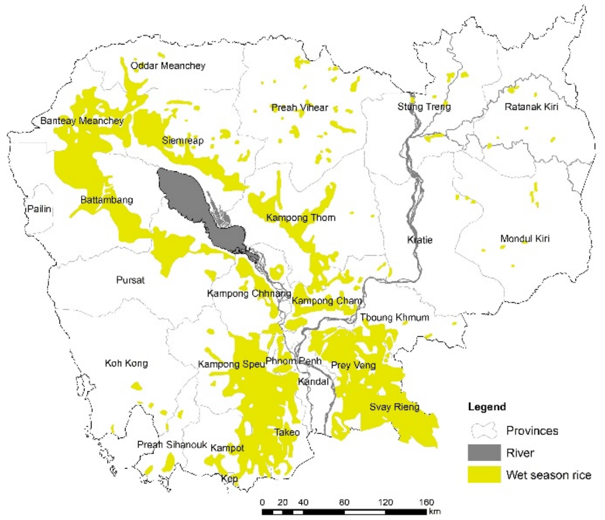

Fig. 4 Wet season rice map for the whole country of Cambodia.

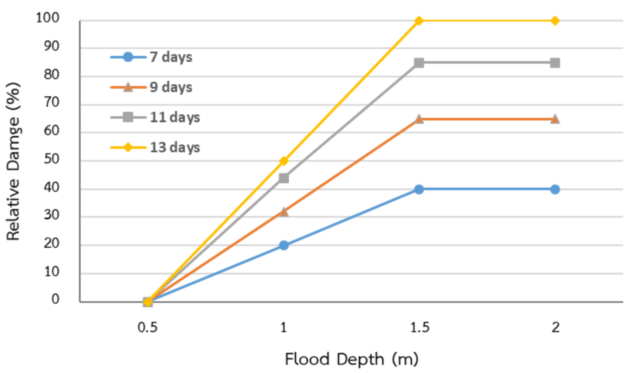

Fig. 5 Flood damage curve related with relative damages and flood depths from MRC [26].

production by each province according to the varieties of rice which was able to analyze the ratio of rice types in every part of Cambodia. Early duration maturity, medium duration maturity, and long duration maturity rice were considered as the three major varieties of rice in Cambodia on the total area compared to other rice. Both reports were published by Ministry of Agriculture, Forestry, and Fisheries of Cambodia (MAFF) [9, 27].

The majority of the insurable objects are directly affected and destroyed by water during flood events, and this damage is always either fully or partially included in the assessment of the damage. Direct tangible damage is the appropriate form of flood damage in this study. The flood impact parameter and the resistance parameters of the elements at risk can be used to estimate the amount of direct tangible damage. While the resistance factors consider the characteristics of an object in a flood-prone area, flood impact parameters refer to the characteristics of a flood. Additionally, the flood area, flood depth, and flood duration are also provided as flood impact characteristics. The damage of the rice field can be calculated as a function of two flood parameters, including flood depth and flood duration.

Due to the lack of water level data and flood map was limited to one map only, the flood depth and flood duration was not able to produce. Therefore, the flood damage curves from the MRC's Flood Management and Mitigation Program were used as the scenarios in this study. According to the flood damage curves from MRC, it presents damage increase in proportion to relative damage and flood duration during flood event 2006 based on flood survey for paddy cultivation and the survey indicated that the crop damage by flood from a period of mid-September to mid-October. The damage started effect rice fields when reaching 0.5 m of flood depth, which means only rice areas with flood depth 0.5 m was considered for estimating the damage. To produce this flood damage curve, the rice cultivation survey on 2006 flood events were conducted by dividing stage of damage into 100%, 85%, 65%, and 40% at flood depth of 1.5 m or more if flood duration is more than 13 days, 11 days, 9 days and 7 days respectively [26].

The report from Ministry of Agriculture, Forestry, and Fisheries in February 2020 which mentioned the average price of rice by type in unit of kilogram per riel for each province of Cambodia, and another report from the same ministry showing the rice yield, these data were able to contribute to estimating unit loss of rice per hectare. Rice damage areas, stage damage levels, and unit loss of rice by province, can be used to calculate the cost estimation of rice damage in each province.

3. Results and discussions

The flood damage assessment indicated the possibility to produce a distribution map for estimating rice damage by using rice field data and flood extent data. Fig. 6 visualized the spatial damage area of rice field in Cambodia during the flood event in 2020 based on rice field data from the shapefile of rice ecosystem (IRRI). The result of distribution map showed about 510860 ha of rice fields was affected by flood spread during the event. With the maximum inundated area, the flood inundated over 25 provinces of Cambodia and the provinces which considered as most rice-producing provinces including Battambang, Prey Veng, Takeo, Banteay Meanchey, Siemreap, and Kampong Thom, which produced million tons of rice production annually were immediately clear that large scale of rice fields was suffered from flood water compared to other provinces as shown in Fig. 6 and Fig. 7.

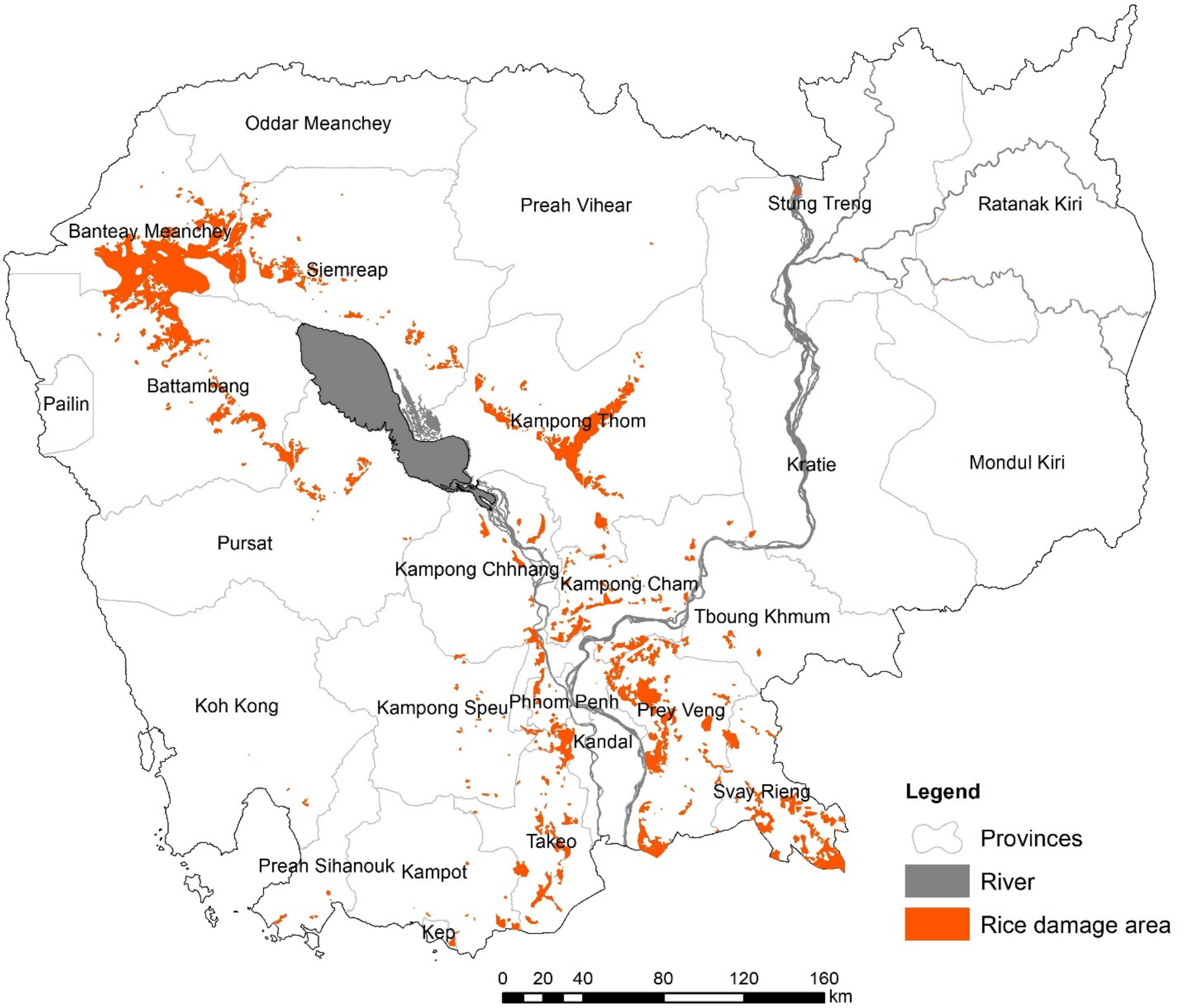

Fig. 6 Distribution of the total rice damage by the 2020 flood event in Cambodia.

The result of rice damage area was applied into flood damage curve from MRC using the same scenarios of flood duration and flood depth based on flood survey in 2006. Table 2 presented the stage damage level of rice field with four different levels. According to the table, the highest rice damage was in Banteay Meanchey province where about 127,000 ha of rice under 100% damage, about 108,000 ha under 85% damage, 82,000 ha under 65% damage, and 51,000 ha under 40% damage. Other higher damage of rice after Banteay Meanchey province were Prey Veng, Kampong Thom, Battambang, Svay Rieng, and Siemreap effected 28,000 ha to 53,000 ha at the stage of 100% damage. For the lowest rice damage, Ratanak Kiri province was shown with 19 ha of rice field damaged by flood in 100% stage of damage followed by Kep with 63 ha under 100% damage level. Among 25 provinces of Cambodia, only Pailin and Mondul Kiri province were resulted with no damage of rice during flood period. For the result of estimating the cost of rice damage which is shown in Fig. 8, rice damage of Banteay Meanchey province was estimated the cost to be 100,265,409 USD at 100% stage of damage level, 85,225,598 USD at 85% stage of damage level, 65,172,516 USD at 65% stage of damage level, and 40,106,164 USD at 40% stage of damage level. For Ratanak Kiri province, the cost estimation was 16,030 USD, 13,625 USD, 10,419 USD, and 6,412 USD at 100%, 85%, 65%, and 40% of stage damage level, respectively. Since the total damage area of rice field in this study was 427,006 ha with damage value of 346,502,867 USD, it was found an overlap 66% with the report from MAFF (316,734) [9].

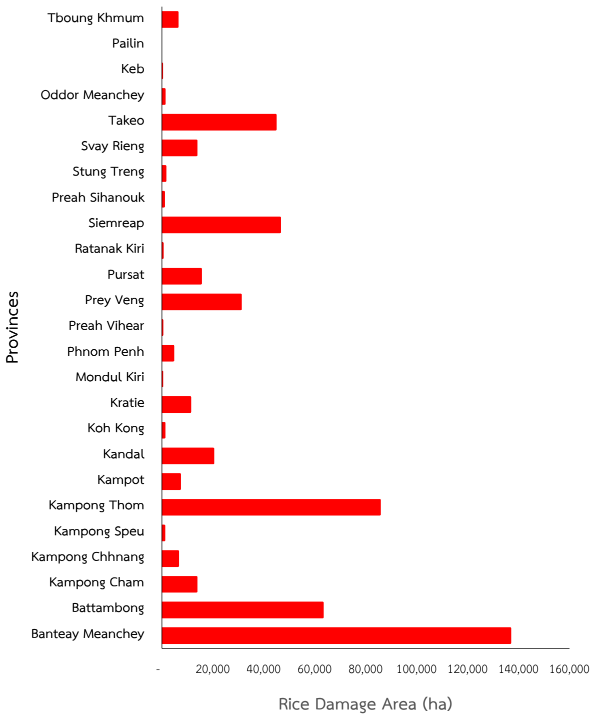

Fig. 7 Damage area of rice field by flood water in each province of Cambodia at 100% damage.

Table 2 Unit loss and stage damage level by provinces.

Provinces	Unit loss (USD/ha)	Stage damage levels (ha)			
		40%	65%	85%	100%
Banteay Meanchey	789	50,813	82,571	107,978	127,033
Battambong	756	19,068	30,985	40,519	47,670
Kampong Cham	754	7,982	12,971	16,962	19,956
Kampong Chhnang	869	3,220	5,233	6,843	8,050
Kampong Speu	869	716	1,164	1,522	1,791
Kampong Thom	859	20,742	33,705	44,076	51,854
Kampot	934	1,727	2,806	3,670	4,318
Kandal	859	5,149	8,367	10,941	12,872
Koh Kong	893	113	184	241	283
Kratie	757	168	273	358	421
Mondul Kiri	851	-	-	-	-
Phnom Penh	810	1,597	2,594	3,393	3,991
Preah Vihear	964	26	43	56	66
Prey Veng	843	20,905	33,971	44,424	52,264
Pursat	772	4,085	6,638	8,681	10,213
Ratanak Kiri	859	7	12	16	19
Siemreap	859	11,505	18,696	24,448	28,763
Preah Sihanouk	932	313	509	665	783
Stung Treng	838	206	335	438	515
Svay Rieng	800	14,044	22,822	29,844	35,110
Takeo	815	7,191	11,685	15,281	17,977
Oddor Meanchey	871	112	182	238	280
Keb	803	25	41	53	63
Pailin	858	-	-	-	-
Tboung Khmum	820	1,086	1,765	2,308	2,715
	Total	170,802	277,554	362,955	427,006

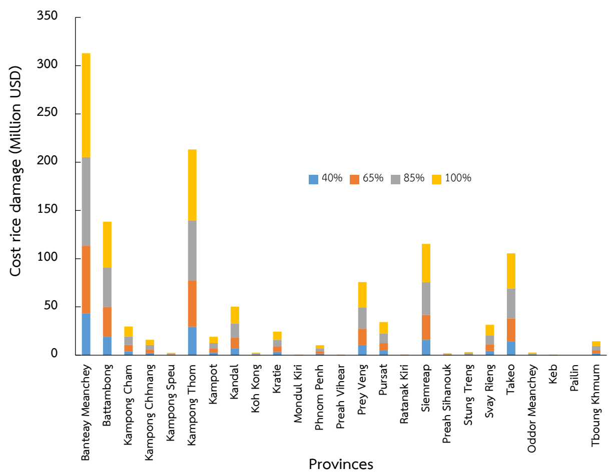

Fig. 8 Cost estimation of rice damage at 40% stage damage level, 65% stage damage level, 85% stage damage level, and 100% stage damage level.

4. Conclusion

The flood event in 2020 represents one of the worst floods since the extreme flood in 2013 and caused considerable damage to agricultural sector, especially rice production Cambodia. This study was conducted to assess flood damage on rice field in all provinces in Cambodia for the 2020 extreme flood event. The main goal was to visualize the damaged areas of rice field and give an adequate cost estimation of rice damage. By comparing the result of the damage area of this study with the real damage area from government report, accuracy of assessment was tested with the result of 66% overlapped. However, information of flood depth and duration from government are hard to find. The overestimation of damage area and damage value could be expected since an inundated area in a certain flood was assumed to equally affect different durations, water depths, and relative damages. In reality, flood water may extend differently depending on duration and the elevation is not the same in all rice area which the rice will thus have less damage or no damage at all. No information was available about the damage cost to rice due to the flood, thus this aspect could not be compared. The combined data that consist of flood extent from WFP, rice field data extracted from rice ecosystem data of Cambodia, rice information by provinces, and flood damage curves from MRC are possible to highlight exposure to existing rice areas for flood damage assessment and contribute as an important role not only in emergency response, but also reduction of present and future flood damage. It is possible to identify low-cost solutions and provide assistance for initial decision-making process for better understanding of the impact on rice to implement rice monitoring and update for planning to help mitigate damage impact and managing the restoration program over flood-vulnerable area after disaster.

5. Recommendation

The key limitation of this study is the lack of actual flood duration and flood depth during the flood event, which can provide higher consistency and accuracy representation of flood damage area and damage value. Hence, future research should consider using flood models or satellite images to produce near real time flood map which have abilities to simulate flood duration and flood depth. Additionally, flood damage curves in 2006 flood event can also be developed using simulated flood duration and flood depth to increase the accurate result.

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