Flood damage map and economic loss assessment by Google Earth Engine in case of rice sector in 2021 of Ayutthaya Province, Thailand.

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Abstract

The central region of Thailand is the most economical flow. Nevertheless, Ayutthaya Province has suffered from flood events annually. Near real-time flood mapping has potential for flood damage reduction measurement. This flood map is generated, using Google Earth Engine (GEE) Cloud-based by gathering the global surface imageries from Sentinel-1 synthetic aperture radar (SAR) by analyzing the pre- and post-flooded images, with land use dataset from MODIS and digital elevation model (DEM) from WWF's HydroSHEDS to determine the affected areas and to evaluate direct-damage of rice in term of economic loss. This research concentrates on the damage matters to rice only. In 2021, a storm named Dian-Mu was the worst that impacted the central region of Thailand. As a result, Ayutthaya flooded over 475,512.36 RAI, and we estimated rice would be lost 1.877 billion THB.

***Keywords*: flood damage map, economic loss, Ayutthaya 2021, rice damaged.**

1. Introduction

Flood disaster is the major cause of economic loss in Thailand. In addition, floods affected the production sectors, transportation and logistics system, population lives and health. Therefore, flood damage and loss assessment play a significant part in flood risk management.

Flood damage assessment has been identified with suitable data collecting methods like, questionnaires, interviews, field surveys and official data released, and insurance agency's reports related to flood events. Therefore, high-quality, reliable, and rapid access are required for socioeconomic damage assessment [1, 2]. However, flood component parameters are challenging to collect both insufficient during the flood and lack of resources (personnel, budget, or time) in a period after flood. The outer space earth observation plays in the missing data and information in disaster damage and loss assessment. In addition, flood monitoring early warning systems and rapid flood damage assessment have greatly improved together with remote sensing and geographical information system advancement [3].

This research aims to (i) identify the flood location and estimate the flood damage extent of rice in Ayutthaya from the affected agricultural land, and (ii) estimate damage and economic loss of rice due to floods in year 2021 by using Google Earth Engine (GEE).

2. Study area

Ayutthaya is a province of Thailand located in the Central Region, up north of Bangkok around 75 km, and covers almost 2,547.62 sq.km (figure 1). Ayutthaya is in a junction of Chao Phraya, Pa-Sak, Lop-Buri and Noy rivers, with a flat floodplain landscape. Since 1980 the Thai government has enhanced Ayutthaya from agricultural-based to industrialization, commercial and services [4]. However, the Office of Agricultural Economics [5] report that most area of Ayutthaya Province is used for Agricultural purposes, 90% of which are rice paddy fields. And Kotera, Nagano [6] has researched that rice production loss in the Ayutthaya was from flood submergence. Also, the inundation period occurs between mid-August to mid-November, with the peak discharge of Chao Phraya River during the rainy season (figure 2).

Thai Meteorological Department, TMD descripted the climate in Ayutthaya Province is influenced by two tropical monsoons: the North-East monsoon, and the South-West monsoon. The weather in Ayutthaya divided to three seasons:

cool season from October to February; hot season starts with the end of the North-east monsoon, approximately February to May and the rainy season from May to November. Ayutthaya Province had rainfall accumulation annually in ranged of 800-1,200 mm, the highest rainfall density was in September, and totally around 105 raining-days per year [7].

In 2021, there were 20 storms occurred around Thailand, and 7 of them were significantly affected by rainfall density in Thailand. Furthermore, 2 of them were directly flown into the country; Jawad impacted the Southern provinces on October 30. The another, Dian Mu affected a significant area of the country's Northern, North-Eastern Central, and Eastern regions from September 23 to the November and caused extremely high rainfall density [8].

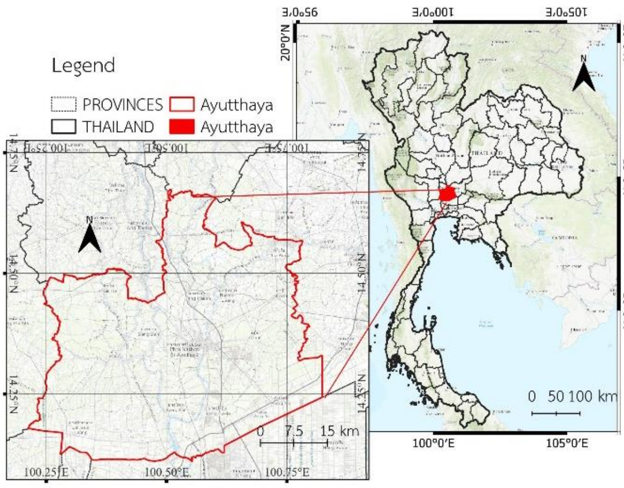

Figure 1: Location of the study area

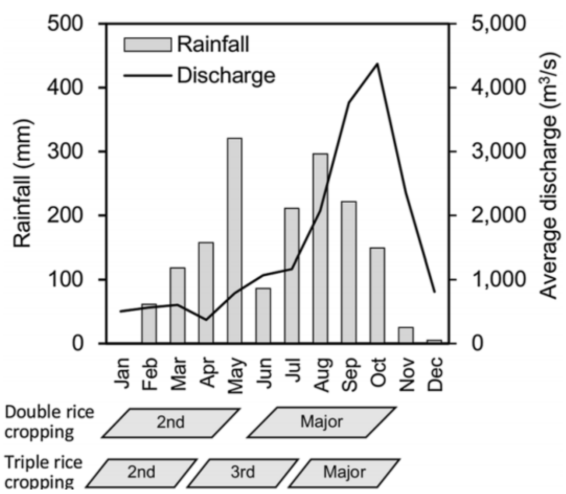

Figure 2: Monthly rainfall and Chao Phraya River discharge observed at Nakhon Sawan 2011 and rice cropping patterns in Chao Phraya delta [4]

Ayutthaya covered over 1.592 million RAI (2,547.24 sq.km), agricultural land used is nearly 1.176 million RAI (1,882.94 sq.km), and approximately 1.065 million RAI (1,704.42 sq.km) is paddy field. Rice production is two times (double rice cropping) in an average of total areas: major rice (May/June to November) and second rice (January to April); the impact of flood considering in this research is only the major rice which used short-term varieties (around 90-100 days).

3. Material and method

3.1 Flood mapping

The flood maps in this research use imagery data from *Sentinel-1 SAR* (actives since April 3, 2014 to present) during the rainy season and early of the cool season (June 1 to December 31, 2021), with IW instrument mode, VV polarization band, and 1.25 threshold different. Sentinel-1 satellite provides global coverage with a revisiting period of 12 days through composite images [9] and overlayed with the JRC Global Surface Water Mapping Layers, v1.4 [seasonality] to subtract the pixel of water detection that is more than 8 months for permanent water resources. Also, using MODIS Land Cover Type Yearly Global 500m (MCD12Q1) version 6.1 dataset with a resolution of 500 meters was used to classify pixels as cultivated cropland (at least 60% cultivation, designated as LC_Type1 eq. 12) or small-scale cultivated land (40-60% cultivation, with natural tree, shrub, or herbaceous vegetation, designated as LC_Type1 eq. 14). To exclude pixels located on terrain with slopes greater than 5%, a digital elevation model (DEM) from WWF HydroSHEDS Void-Filled DEM, 3 Arc-Seconds dataset with a resolution of 92.77 meters was employed. This was done as areas with slopes steeper than 5% are unlikely to contain flood water, i.e., riverbanks.

The process of generating flood maps involved selecting an observation period (representing a no-flood duration) and an inspection period (representing a flooded duration). The hydrological changes were extracted by overlaying the two periods and identifying pixels that were detected as inundated in the inspection period but not in the observation period, which were referred to as "true detected" pixels. The surface water layer was then used to exclude pixels that were matched with permanent surface water pixels. To verify the flooded pixels, the DEM layer was used to exclude pixels located on terrain with slopes steeper than 5% to eliminate non-flood pixels. Finally, the Google Earth Engine (GEE) function was used to gather and generate the flood extent and prepare the data for exportation in vector data.

To confirm the flood maps, we used data from Thailand's Geo-Informatics and Space Technology Development Agency (GISTDA), Hydro Informatics Institute (HII) and Department of Disaster Prevention and Mitigation (DDPM). The validation was performed on QGIS by identifying the flood extent in the study area and comparing the matching points of flooded and non-flood in term of area (Rai or sq.m.). The verification parameters implemented in this research are probability of detection (POD), false alarm ratio (FAR), critical success index (CSI) and accuracy rate (ACC). While the ACC tells the overall correction of simulated product, the POD represents the hit rate of the product to the observed. FAR valued the number of data that were not matching to observed data. The validation would tell by the POD=1, FAR=0, CSI=1 and ACC=1 [10].

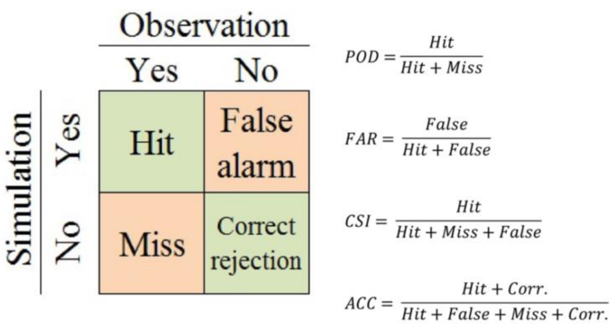

Figure 3: the detection analysis for inundation data between observed and simulated [10]

3.2 Flood damage and economic loss assessment

Flood damage is defined as the total or partial destruction of physical objects in the affected area during and immediately after the flood event. Moreover, economic losses could be identified as direct economic losses and indirect economic losses [2]. The direct economic losses are shown in changes in economic flow from the time of the flood to the time of economic recovery and reconstruction in the flooded area. Such as, the production chain is interrupted because the products have been gone from the system. On the other hand, the indirect economic loss meant the value and production changes were not limited to the time of flood and ended when the economy fully recovered, but it resulted in long-term or larger economic scales.

The common damage assessment procedure requires the on-filed survey to address the actual cost of lost [11]. However, the off-field methodology for near real-time assessment has been proven in recent years.

For a natural disaster event with an intensity affecting a selected area, the worth of economic losses connected to direct damages to objects/goods/items depends on the quantity and economic value of the unit of each element and on the damage degree (vulnerability) to the exposed unit [11].

$$\text{DIRECT ECONOMIC LOSS} = \sum_i \left(\text{UNIT VALUE}_i \times \text{DAMAGE DEGREE}_i \times \text{N}^\circ \text{unit EXPOSED ELEMENT}_i\right) \quad (1)$$

This research concerns only rice, so the element of the exposure will determine rice production. The unit value is the latest price at the farmer gate or the farmer sale price, the degree of damage is the degree of loss of rice at flood impact with flood intensity and duration, number of exposed areas of rice refers to inundated paddy by also the final amount of rice harvestable area.

$$\text{ECONOMIC LOSS} = f\left(\text{AREA, PRODUCTION RATE, REDUCTION RATE, PRICE}\right) \quad (2)$$

However, the flood map from Sentinel-1 by GEE did not directly tell the inundation depth and duration of the flood event. The rice reduction rate could be varied from 0% (undamaged) to 100% (fully damaged). This research set conditions that we could filled-up all significant parameters (a) rice was growing in varieties stage (table 1) and (b) the plant was fully submerged. The simulated product was not detecting types of agriculture. Referring to the Office of Agricultural Economics (OAE), Ayutthaya's agricultural land uses 90.52% rice paddy (average from 2015-2021), we estimated the rice area was affected by 90.52% of agricultural inundated land.

$$\text{AREA}_{\text{Affected}} = \text{AREA}_{\text{Agri-flooded}} \times 90.52\% \quad (3)$$

The new equation would be:

$$\text{ECONOMIC LOSS}_{\text{POTENTIALLY}} = \text{PRODUCTION YIELD} \times \text{PRICE} \times \text{AFFECTED AREA} \times \left(\%\text{REDUCTION}\right) \quad (4)$$

Table 1: Rice loss rate in varieties of growing stages [12]

Rice growing stage	Rice loss degree (%)			
	Days of submergence in clear water			
	1	3	5	7
Tillering	10	20	30	35
Panicle forming	10-25	30-45	65-80	80-100
Flowering/gains forming	15	25	30	70
Ripening	0	15	20	20

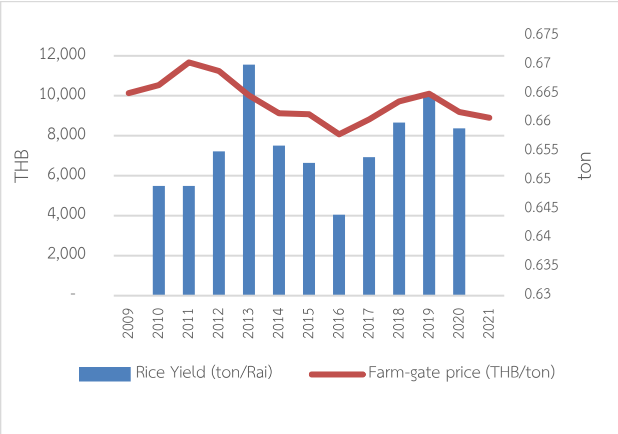

Figure 4: Major Rice production yield and price at farmer-gate, 2009-2021 [5]

Hydro Informatics Institute (HII) reported that in 2021, September and October were 43 provinces affected from flood consequence from the Dian Mu storm, and the flood event in Central, Eastern, Northern and North-Eastern region had been solved in November. The total flooded areas were 5.59 million, 5.94 million and 4.36 million RAI in September, October and November, respectively [8].

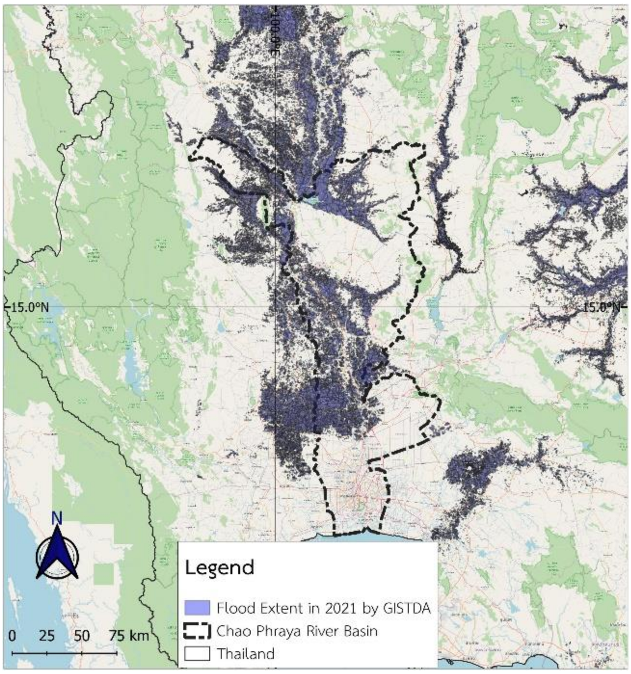

Figure 5: Flood extent in Central region and Chao Phraya River Basin, 2021 by GISTDA

4. Result and Discussion

Figure 6 shows a map of agricultural purpose land used in Ayutthaya in 2021 by MODIS MDC12Q1 V6.1, produced on January 1, 2021. The total area of agricultural land was a sum of the detected pixels, of 1.115 million RAI, with the percentage of paddy fields in the province and plannable rice land approximately 1.00 million RAI. Meanwhile, the map validation was completed using a statistic of land used from OAE and GEE from 2015 to 2021; the root mean square error (RMSE) and decision coefficient (R-square) for agricultural land were 99,957.26 RAI and 0.896, respectively.

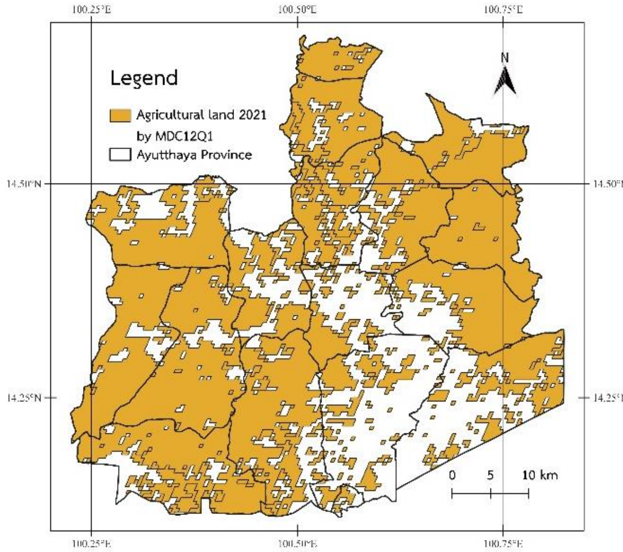

Figure 6: Agricultural land detected by MDC12Q1 in Ayutthaya, 2021

The flood extent map from GEE shows in figure 7. The total inundation area detected by Sentinel-1 during a flood season inspection from June 1 to December 31, 2021, was 475,512.36 RAI. In comparison, GISTDA estimated flood area was 539,178.36 RAI, so the POD or hit rate was 0.72, FAR was 0.28, CSI was 0.51, and overall accuracy was 0.8. Therefore, the flood map by Sentinel-1 from GEE is acceptable and usable.

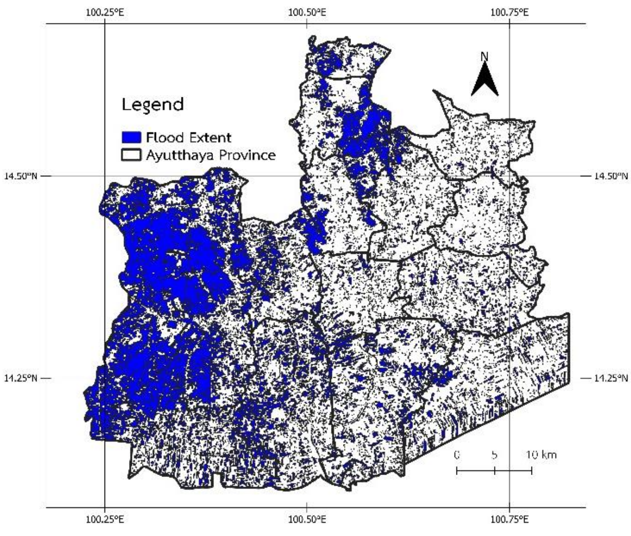

Figure 7: Map of flood extent in Ayutthaya 2021 by Sentinel-1

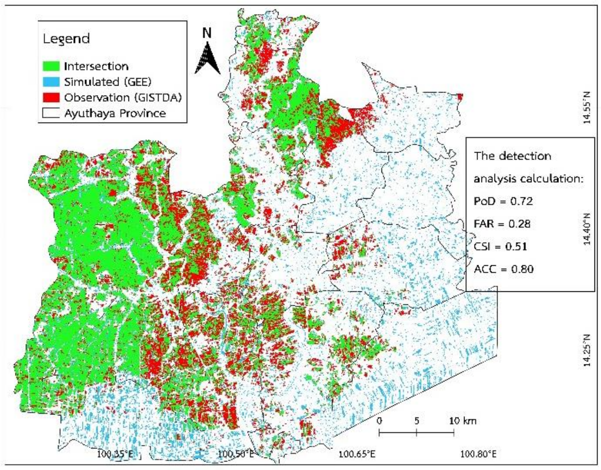

Figure 8: The comparison of flood extent between the simulated (GEE), the observation (GISTDA) and the intersection extent of 2021

Figure 9 shows a map of agricultural land that was inundated by flood within the inspecting time, the total area was 285,896 RAI and the estimated rice-affected area was 258,793 RAI.

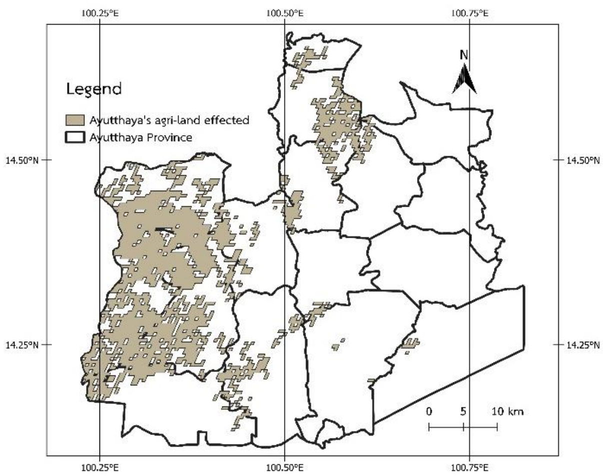

Figure 9: Agricultural land affected by flood in Ayutthaya, 2021

In 2021, the flood affected to area of 475,512.36 RAI, and 258,793 RAI was identified as rice area affected. Production yield was 0.699 ton/RAI, the price was 9,189 THB/ton (price in January 2021) [5]. The damage from flood was computed below table:

Table 2: Economic loss in billion Thai Baht varies by percentage of rice loss from full submergence for seven days.

Year	Affected Area (RAI)		ECONOMIC LOSS (b.THB) Varies by percentages of rice loss			
	agriculture	Rice	100%	70%	35%	15%
2021	285,896	258,793	2.681	1.877	0.938	0.402

Table 2 shows the potential economic loss caused by the flood in rice sector in Ayutthaya 2021. The losses varied into different degrees from 15, 35, 70, and 100% of loss under the assumption that rice started planting time or in any growth stage, but the rice was submerged under inundation for over seven days. The results of fully damaged rice (100% loss) were estimated to impact the regional economy up to 2.6 billion THB or nearly 20% of Ayutthaya's gross agriculture province product (GPP) and 0.67% of the province GPP based on the year 2020 (estimated). Though the time of flood and crop calendar pattern in figure 2, the reasonable loss was calculated with 70% of rice yield reduction and estimated the economic loss was 1.87 billion THB, equivalent to 17% of Ayutthaya's agriculture GPP and 0.47% of the province GPP (estimated base-year 2020). The GPP growth rates mentioned earlier were estimated without considering the impact of COVID-19. The pandemic has caused significant disruptions in supply chains and logistics systems, business closures due to lockdown measures in cities, and changes in consumer spending behavior due to employment and unemployment effects. These factors have been reflected in increased closures and bankruptcies, particularly in the food and service sectors.

5. Conclusions

The objective of this study was to estimate the economic loss and damage from a flood that occurred in Ayutthaya Province in 2021. For the identification of flood location and flood extent, we produced flood maps using Sentinel-1 images and MODIS Land Use Layers Mapping [MDC12Q1 V6.1] applied to GEE. The products tell that in 2021, flood inundation affected Ayutthaya Province of Thailand was approximately 0.476 million RAI (760.8 sq.km). While HII reported in November 2021, there were 447,771 RAI of area inundated. The flood map and flood damage and loss in Thailand are most commonly validated with the Thailand's Mega Flood 2011, but Sentinel-1 was not activated until April 2014. So, the simulated data was confirmed based on the most recent update from the authorities, GISTDA, OAE, and DDPM. The results suggested that our flood map simulation could be reproduced the actual flood extent.

As the economic analysis attempted data from the Bank of Thailand (BOT), OAE, and National Statistical Office (NSO), the loss was divided to direct economic loss approx. 1.87 billion THB and the indirect damage loss was about 0.47% of Ayutthaya's GPP. Furthermore, the number of losses was not represented in the government compensation. Whereas in 2020 afterward, Thailand suffered from the COVID-19 pandemic, which has had an economic impact on the nation or region, our research did not include the pandemic impacts on the study as estimating the actual economic effects of COVID-19 is complex and subject to multiple interpretations. Moreover, the indicators of these impacts surpass the scope and limitations of this research.

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