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Reducing Irrigation water requirements of the Chao Chet - Bang Yihon Operation and Maintenance Project by Defining New Cropping Calendar based on Time Series NDVI.

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ABSTRACT

The Chao Chet - Bang Yihon operation and maintenance project (CCBY) is low-laying and frequently flooded. During the flood season of 2017-2018, the CCBY project area was planned to be used as flood detention to mitigate the violence of floods in the lower Chao Phraya basin. Therefore, the cropping calendar was required to shift the in-season rice cultivation ahead of schedule in May and complete harvesting before mid-September. Paddy fields in the CCBY project were reserved as flood detention areas from mid-September to mid-December. After the flood had been drained, the off-season rice could be cultivated.

This study proposed the new cropping calendar based on the historical rice cropping pattern derived from the time series NDVI of the Terra/MODIS satellite. The Reservoir Operation Study (ROS) is a water requirement calculation developed under Royal Irrigation Department (RID) guidelines. The new cropping calendar was applied to ROS to calculate the water requirement. In addition, land preparation water for the off-season rice cultivation had been excluded by assuming that the farmers could take advantage of the remaining floodwater.

The new cropping calendar illustrates that the in-season and off-season rice cultivation should be started in mid-April and mid-December, respectively. The total irrigation water requirements could be saved about 185.05 MCM (11.01%) and 117.98 MCM (8.54%) in 2017 and 2018. This study will benefit the RID for water delivery planning in lowland areas.

Keywords: Low-laying area, NDVI, Water requirement, Cropping calendar

1.Introduction

Due to the unprecedented flood catastrophe in 2011, Thailand is considered vulnerable to future climate change impacts over the next 30 years, which urgently require countermeasure plans for flood prevention, flood mitigation, and flood adaptation (1). There are several flood adaptation strategies for farmers to change their cultivation practices, such as changing cropping calendars, changing crop varieties, and changes in the area for cultivation (2). Shifting the planting date could be a low-cost adaptation strategy that is likely more effective for large-scale implementation in a changing climate (3)(4).

Generally, Royal Irrigation Department (RID) has an irrigation water allocation plan of in-season cultivation according to the cropping calendar in May – October. However, Chao Chet - Bang Yihon operation and maintenance project (CCBY), mostly lowland paddy fields, was limited to cultivation due to repeated flooding during September – November. Under the traditional RID's cropping calendar, paddy fields are particularly vulnerable to flooding in the pre-harvest in-season rice cultivation. In 2017-2018, RID announced the flood prevention and mitigation strategy plan by applying the low-laying areas over the Lower Part of the Chao Phraya River Basin as flood detention areas. Therefore, farmers were suggested to bring forward the in-season rice cultivation and complete the harvest before mid-Sep. Moreover, farmers can take advantage of the remaining floodwater for land preparation for off-season rice cultivation.

Regarding cropping calendar adjustment, the land preparation and sowing date change are the most important since all the remaining agricultural activities depend on it (5). Also, the shift of the cropping calendar certainly affects irrigation water requirements calculation. This study aimed to compare water demand in the CCBY using the traditional RID's cropping calendar and the actual rice cropping pattern derived from the time series NDVI of the Terra/MODIS satellite. The results of this study could be used as an alternative water allocation planning to cope with flood risk.

2. Material and methods

2.1 Study Areas

Chao Chet - Bang Yihon operation and maintenance project locates between the west bank area of the Chao Phraya River and the east bank area of Tha Chin River (Fig. 1.). The CCBY project is controlled by Regional Irrigation Office 11 (RIO.11). The total irrigated area of the CCBY project is 65,000 ha, 80% of the area (approximately 56,000 ha) is rice paddy fields. The main type of rice is photo-insensitive, medium tillering varieties. In a normal year, RIO.11 has established an irrigation water allocation plan from 1st May to 30th October for the wet season and from 1st November to 30th April for the dry season.

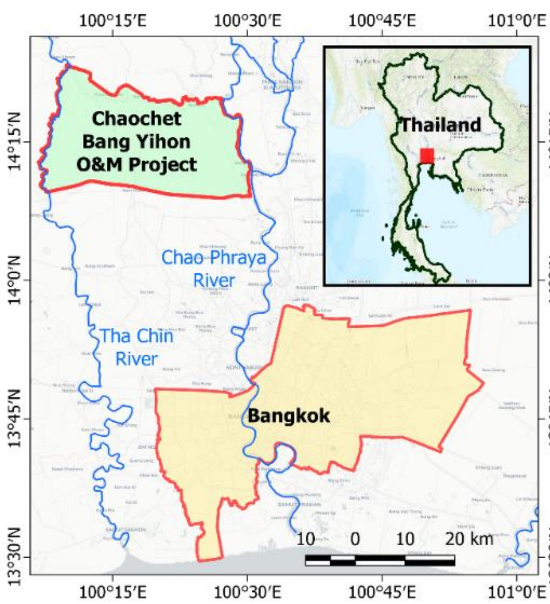

Fig. 1. Location map of the study area.

The CCBY is a low-laying and regularly reserved as a flood detention area to prevent urban flooding downstream of the Chao Phraya River. Flood volumes are recurrently stored from mid-September to mid-December. In 2017-2018, the Ministry of Agriculture and Cooperatives (MOAC) announced a policy to setting flood detention areas in the Lower Chao Phraya Basin, and commandment integrated various government agencies to support farmers. RIO.11 is necessary to reschedule the water allocation plan to ensure enough irrigation water for farmlands during the shifted cropping calendar. The 2017-18 cropping calendar was assigned wet season from 1st May to 15th September and dry season from 15th December to 30th April. During the flood detention period (15th September to 15th December), most of the paddy fields in the CCBY were inundated and could not cultivate, as shown in Fig. 2. Flood detention areas could be utilized as temporary aquaculture. The Number of fish supported by the Department of Fisheries was released in flood detention areas to maintain the farmer's income.

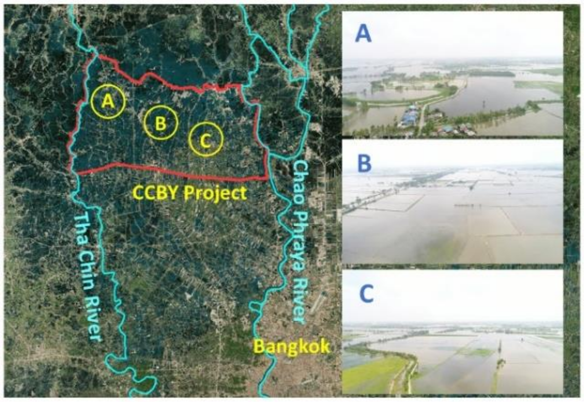

Fig. 2. Flooding on 8th October 2017.
(A) Bang Pla Ma District, Suphan Buri Province
(B) Bang Sai District, Ayutthaya Province
(C) Sena District, Ayutthaya Province

2.2 Methods

The flowchart of this study has shown in Fig. 3. Reservoir Operation Study (ROS) calculation sheet was used to determine the irrigation water requirements of the CCBY project on 2017-18. Two cropping calendars were compared, i.e., the traditional cropping calendar assigned from RIO.11 and the actual cropping calendar retrieved from historical time series NDVI from Terra/MODIS satellite data.

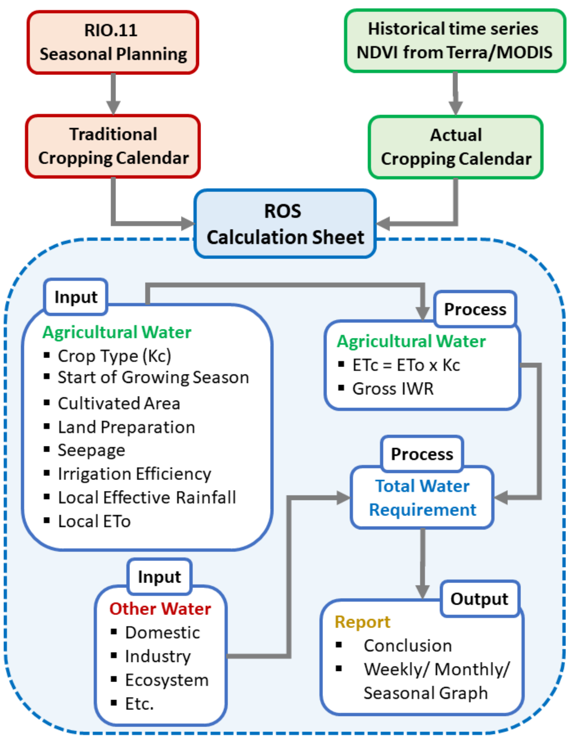

Fig. 3. Flowchart of the study.

2.2.1 Time series NDVI data

Terra/MODIS 8-day composite products (MOD09Q1) at 500m resolution were downloaded from United States Geological Survey (USGS) Earth Explorer (URL http://earthexplorer.usgs.gov/). Each scene, Band 1 (red band, 620-670 nm) and band 2 (near-infrared band, 841-876 nm), were selected to calculate Normalized Difference Vegetation Index (NDVI), which is defined as follow:

$$\mathrm{NDVI} = \frac{\rho_{\mathrm{NIR}} - \rho_{\mathrm{RED}}}{\rho_{\mathrm{NIR}} + \rho_{\mathrm{RED}}} \qquad (1)$$

Where ρ_{RED} and ρ_{NIR} are the surface reflectance of visible red (RED) and near-infrared (NIR) bands, respectively, the range of NDVI values is between -1 to 1. In general, high values of NDVI (0.6 - 0.8) indicate a dense green vegetation canopy. Low values of NDVI (near zero) characterize bare area or urban area, whereas negative values of NDVI mainly correspond to water and cloud.

2.2.2 Reservoir Operation Study (ROS)

Reservoir Operation Study (ROS) is a Microsoft Excel sheet to calculate irrigation water requirements (6). RID developed this program for water allocation planning of the irrigation schemes. The main processes of the ROS irrigation water requirements calculation are as follow.

1) Select the provincial area of the irrigation scheme to set reference crop evapotranspiration (ET_o) and effective rainfall (R_e).
2) Select crop type to set crop coefficient (K_c).
3) Input cropping pattern, cultivated area, water depth of land preparation and seepage, irrigation efficiency
4) Input the volume of water for other activities, including domestic consumption, industry, and ecosystem conservation.

The actual cropping calendar obtained from the time series NDVI was used to determine the cropping pattern as a substitute for RIO.11's cropping pattern. In 2017 and 2018, in-season rice areas were expected to be 56,000 ha and 53,216 ha, whereas off-season rice areas were expected to be 53,083 ha and 39,859 ha. An irrigation efficiency of 45% was used. Land preparation and seepage of 240 mm week^{-1} and 7 mm week^{-1} were assigned. The gross irrigation water requirements (W_g) (equation 2-4) could be estimated (7).

$$W_g = \frac{W_n}{E_i} \qquad (2)$$

$$W_n = ET_c - R_e \qquad (3)$$

$$ET_c = K_c \times ET_o \qquad (4)$$

Where W_n is the net water application, E_i is the irrigation efficiency that considers the water lost during the diversion from the canal to the field, ET_c is the crop evapotranspiration (mm day^{-1}) which depends on the growing stage of the crop and is used to quantify crop water requirement, R_e is the effective rainfall (mm day^{-1}), K_c is the crop coefficient representing important parameters for irrigation scheduling and water allocation, and ET_o is the reference evapotranspiration (mm day^{-1}).

In this study, ET_o was calculated using the Penman-Monteith method. K_c values were obtained from RID's crop coefficient database. Effective rainfall was calculated using the weighted rainfall method from RID, as shown in Table 1.

TABLE 1 Effective rainfall for rice (RID method)

Rainfall (mm.)	Effective Rainfall (mm.)
0-10	0
11-100	Rainfall x 0.80
101-200	Rainfall x 0.70
201-250	Rainfall x 0.60
251-300	Rainfall x 0.55
301-up	Rainfall x 0.50

3.Results and discussion

Fig.4. shows the average NDVI obtained from Terra/MODIS satellite during 2012 -2019. The graph reveals that the in-season rice cultivation starts on April – September and the off-season rice cultivation starts on December – April. The flood detention period always occurs from September – December. The maps in Fig.5. show the changes in the distribution of NDVI during the dry season of 2016-2017. According to a study by Huang et al. (2012), NDVI of 0.15 is a threshold value between vegetation and water surface area (8). Therefore, an NDVI value of less than 0.15 is defined as the water surface area. The NDVI map on 1st November and 11th December 2016 shows that some parts of the CCBY still was inundated. After that, on 17th January and 18th February 2017, the rice fields in the CCBY were cultivated. However, NDVI maps exposed that rice is not planted simultaneously. NDVI values on the eastern area were higher than that of the western area, which could be interpreted as the flooding on the eastern area could be drained before the western area.

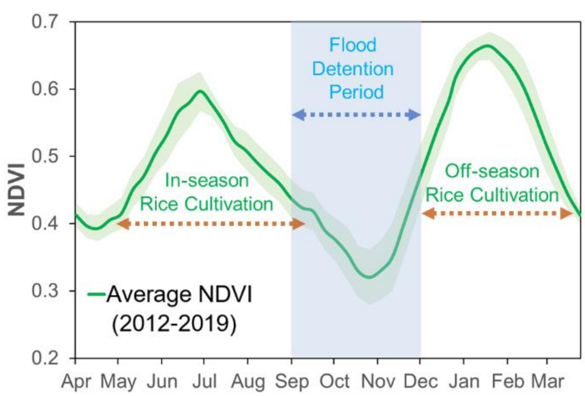

Fig.4. Average NDVI obtained from Terra/MODIS satellite during 2012-1019.

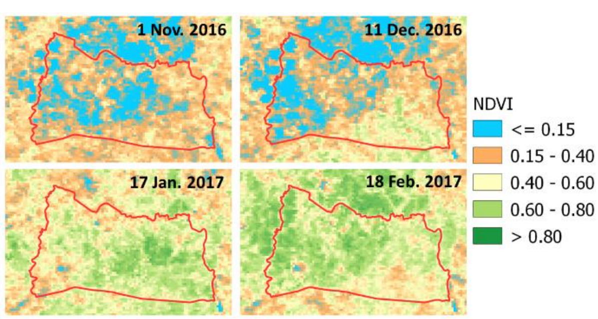

Fig. 5. NDVI maps of the CCBY during the dry season of 2016/17.

Fig. 6. shows the comparison of irrigation water requirements (IWR) for rice cultivation. The IWR based on the traditional cropping calendar of RIO.11 was shown in the red dash line, whereas IWR based on historical NDVI was shown in the green line. During the flood detention period, both methods have not estimated IWR. The graph illustrated that the flood detention period of NDVI retrieving is more extended than that of RIO.11 planning. In addition, the off-season rice cultivation of the NDVI method has been shortened than that of the RIO.11 method. The RIO.11 method planned the start of the in-season rice cultivation on 9-15 May, whereas the historical NDVI detected the start of the in-season rice cultivation on 4-10 April. It could be explained that the farmers in the CCBY have been adapting to avoid flood damage by shifting their cropping calendar for several years. Therefore, the policy of shifting the cropping calendar in 2017-18 is not well-matched with an identical pattern according to the historical NDVI.

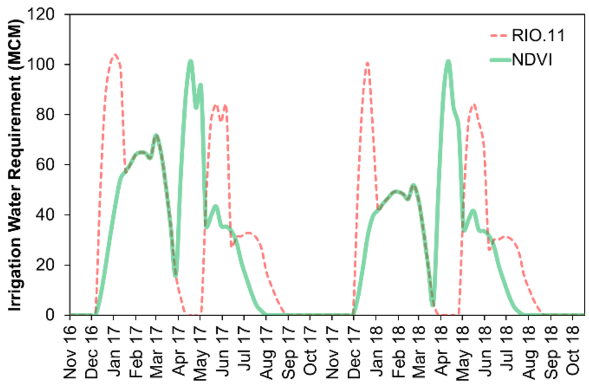

Fig. 6. Weekly irrigation water requirements of the CCBY during 2017- 2018.

Furthermore, RIO.11 method still required the water for land preparation for both seasons. Farmers can use the inundation water as land preparation water for off-season rice cultivation. Thus, for the NDVI method, land preparation water had been excluded by assuming that the farmers could take advantage of the remaining floodwater. As a result, the IWR of the NDVI method was less than that of the RIO.11 method at the beginning of the growing season in December (Fig. 6.). According to the gross IWR calculation in 2017 and 2018 (Table 2), the results from ROS have shown that the gross IWR for off-season rice cultivation decreased from 1,060.56 MCM to 777.45 MCM in 2017 and decreased from 792.50 MCM to 579.92 MCM in 2018. On the other hand, the gross IWR for in-season rice cultivation of the NDVI method was higher than the RIO.11 method because of early start cultivation in April. In general, the rainy season in central Thailand starts around mid-May. Therefore, starting rice cultivation in April may require more irrigation water due to less effective rainfall.

TABLE 2 Gross irrigation water requirements of the CCBY

Year	Season	Gross IWR (MCM)	
		RIO.11	**NDVI**
2017	Off-season rice	1,060.56	777.45
	In-season rice	619.18	717.19
	Total	1,679.69	1,494.64
	Difference	**185.05 (11.01%)**	
2018	Off-season rice	792.50	579.92
	In-season rice	589.66	684.26
	Total	1,382.16	1,264.18
	Difference	**117.98 (8.54%)**	

Since the physical characteristics of the CCBY are lowland and frequent flooding, flood mitigation and adaptation practices were necessary. There are various flood adaption methods for agricultural farmland in the flooded area, including engineering and non-engineering options. The most widely adopted adaptation practices include altering the timing of planting or adjustment in the cropping calendar to avoid flood season (10-11). The shifted rice cropping pattern derived from the time series NDVI indicated that farmers had an autonomous adaptation to flooding before the Ministry of Agriculture and Cooperative policy was promulgated. To enhance resilience to flooding, the shifted rice cropping calendar for the wet year should be modified according to the results of this study. In addition, floodwater during the benefit period is valuable for preparing the land to cultivate rice (12). Thus, land preparation water should not be taken into account in the gross IWR calculation after the flood detention period.

The study results could be used as an alternative water allocation planning to cope with flood risk. However, changing the cropping calendar is suggested to photo-insensitive rice varieties only due to the constant crop duration and not affecting irrigation water requirements. Also, RID should further consider saving off-season land preparation water for flood detention areas and ensuring sufficient irrigation water for the subsequent in-season cultivation.

4.Conclusion

This study proposed a new crop calendar based on the historical rice cropping pattern derived from the time series NDVI of the Terra/MODIS satellite during 2017 -2018 to calculate irrigation water requirements in the Chao Chet - Bang Yihon Operation and Maintenance Project using Reservoir Operation Study (ROS). The results revealed that the appropriate starting date of growing rice in the wet and dry season should be 4-10 April and 13-19 December, respectively. Due to the long flood period, irrigation water requirements in the dry season could be reduced because farmers can take advantage of the remaining floodwater for land preparation of the off- season rice cultivation. According to the results, it was found that irrigation water could be saved about 185.05 MCM (11.01%) and 117.98 MCM (8.54%) in 2017 and 2018.

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