

TRACING CROP WATER DEMAND IN THE LOWER PING RIVER BASIN, THAILAND USING CLOUD-BASED IRRISAT APPLICATION

KHIN MUYAR KYAW

*Department of Civil and Environmental Engineering, Faculty of Engineering, Mahidol University, Nakhon Pathom, Thailand;
E-mail: khinmuyar.kya@student.mahidol.ac.th*

AREEYA RITTIMA*

*Department of Civil and Environmental Engineering, Faculty of Engineering, Mahidol University, Nakhon Pathom, Thailand;
E-mail: areeya.rit@mahidol.ac.th, *Corresponding Author*

YUTTHANA PHANKAMOLSIL

Environmental Engineering and Disaster Management Program, Division of Engineering, Mahidol University, Kanchanaburi, Thailand; E-mail: yutthana.pha@mahidol.ac.th

ALLAN SRIRATANA TABUCANON

Faculty of Environment and Resource Studies, Mahidol University, Thailand; E-mail: allansriratana.tab@mahidol.ac.th

WUDHICHART SAWANGPHOL

Faculty of Information and Communication Technology, Mahidol University; E-mail: wudhichart.saw@mahidol.edu

JIDAPA KRAISANGKA

Faculty of Information and Communication Technology, Mahidol University; E-mail: jidapa.kra@mahidol.edu

YUTTHANA TALALUXMANA

*Department of Water Resources Engineering, Faculty of Engineering, Kasetsart University, Bangkok, Thailand;
E-mail: fengynt@ku.ac.th*

VARAWOOT VUDHIVANICH

*Department of Irrigation Engineering, Faculty of Engineering at Kamphaengsaen, Kasetsart University, Nakhon Pathom, Thailand;
E-mail: fengvww@ku.ac.th*

ABSTRACT

Estimating and tracing actual crop water demands during the growing season are necessarily essential as it can be the basic and useful information for achievement of irrigation water management and reservoir operation practices. The crop water demand (ET_{crop}) is commonly determined by multiplying the crop coefficient (K_c) and reference crop evapotranspiration (ET_o) calculating from meteorological data at the nearby stations. In this study, the planting area and growth stage of crops in the Tortongdang, Wangbua, Wangyang and Nongkhwan Operation and Maintenance Projects, which are located in the Lower Ping River Basin, were tracked and crop coefficient was evaluated using weather based irrigation scheduling (IrriSAT) application for estimation of crop water requirement. IrriSAT provides the satellite images processing of Normalized Difference Vegetation Index (NDVI) of planting area of crop and uses empirical relationship to find K_c . K_c values of season and off-season crops planting in four irrigation area during 2000–2019 were traced by IrriSAT and the results were compared with average K_c -RID values which were calculated as a function of K_c from field observation for the different types of crop and accumulated area of crops monitored by the remote sensing. The results showed the similar patterns of average K_c over the growth stages of crops. However, the K_c values calculated by IrriSAT for four irrigation area were slightly deviated from K_c -RID values in some growing periods. Therefore, calibrating K_c values calculated by IrriSAT was then conducted in this study to estimate actual crop water use and benchmark with the filed observation data. This study also revealed that applying cloud-based IrriSAT could be greatly supportive for irrigators and reservoir operators to enhance the efficiency of irrigation water management.

Keywords: Crop coefficient, Reference crop evapotranspiration, Crop Water Demand, IrriSAT, ET_o calculator

1. INTRODUCTION

Thailand's economic development has been basically driven by agricultural sector. Improving the agricultural productivity plays a vital role to raise the livelihood and living standard of the local people in agricultural sector. Crop productivity depends not only on the farm inputs but also irrigation facilities. Therefore, estimating and

tracing crop water demands over the growth stage to monitor the dynamic crop water use are necessarily essential. Moreover, crop water demand has been considered as the basic and useful information for achievement of irrigation water management and reservoir operation practices.

Crop water demand is commonly defined as the depth of water needed to meet the water losses through evapotranspiration. Crop water demand (ET_c) mainly depends on climate factors, crop types and the growth stage of crops. In principle, crop water demand is determined by multiplying the crop coefficient (K_c) and reference crop evapotranspiration (ET_o) calculating from meteorological data at the nearby stations (Doorenbos et al., 1977).

The crop coefficient (K_c) is generally derived from the relationship between ET_o and ET_c from field observation. However, the innovative approach in remote sensing technique called Cloud-Based IrriSAT application has been introduced and developed recently to predict K_c , ET_o and ET_c . It is a useful decision support tool to support irrigators with irrigation water management which is proposed by Hornbuckle in 2016 (Hornbuckle et al., 2016). The K_c in IrriSAT is estimated by observing the crop growth using remote sensing and the strong relations between the Normalized Difference Vegetation Index (NDVI) of planting area and K_c will be then evaluated.

For reference crop evapotranspiration (ET_o), a number of empirical methods has been developed over the last 50 years by numerous scientists worldwide to estimate reference crop evapotranspiration (ET_o) from different climatic variables. Based on the available research results and recommendations of experts in 1971 and 1972, Food and Agriculture Organization of the United Nations (FAO) has recommended ET_o equations, namely the FAO modified Penman, FAO Radiation, FAO Blaney–Criddle, and pan evaporation methods (Doorenbos et al., 1977). Moreover, FAO Penman–Monteith formula was adopted by FAO as the worldwide standard method for computing potential evapotranspiration (or reference crop evapotranspiration) (Allen et al., 1998). This method was verified well for reference crop evapotranspiration calculation (Allen et al., 2006; Allen et al., 2011).

In this study, the cloud-based IrriSAT application is introduced to trace the dynamic values of K_c for estimating crop water demand in the Lower Ping Irrigation Project including Tortongdang (TTD), Wangbua (WB), Wangyang (WY) and Nongkhwan (NK) irrigation area. The dynamic values of K_c –IrriSAT are then compared with average K_c –RID values which were calculated as a function of K_c from field observation for the different types of crop and accumulated area of crops monitored by the satellite image from the Geo-Informatics and Space Technology Development Agency (GISTDA). The adjustment of K_c –IrriSAT was made to eventually use for the estimation of crop water demand in the study area.

2. MATERIAL AND METHOD

2.1 Study Area

There are four operation and maintenance projects in the Lower Ping River Basin namely; (1) Tortongdang (TTD), (2) Wangbua (WB), (3) Wangyang (WY), and (4) Nongkhwan (NK) which are located in Kamphaengphet, Nakhon Sawan, Sukhothai Provinces of Thailand. The total area of TD, WB, WY and NK are about 1,029, 714, 372 and 163 square kilometers, respectively. The irrigation water supplying for these 4 irrigation area are diverted from the Bhumibol Dam built across Ping River in Tak Province as shown in Figure 1.

2.2 Research Data Set

The climatological data during 2000–2019 from nearby climate stations were obtained from the Thai Meteorological Department (TMD) which provides average long-term monthly values of data such as pressure, temperature, relative humidity, wind speed as well as sunshine duration. These climatological data can be used for the calculation of the Reference Crop Evapotranspiration (ET_o). To verify the results of K_c from IrriSAT, K_c values from field observation which has been publicly provided by the Royal Irrigation Department for the different types of crop were also collected. In addition, the planting area of crops was monitored by the remote sensing technique of GISTDA in 2018. Consequently, the accumulated area of four main types of crops namely; (1) rice, (2) sugarcane, (3) corn, and (4) cassava are estimated from satellite image. The cropping patterns for the different crop types were also investigated.

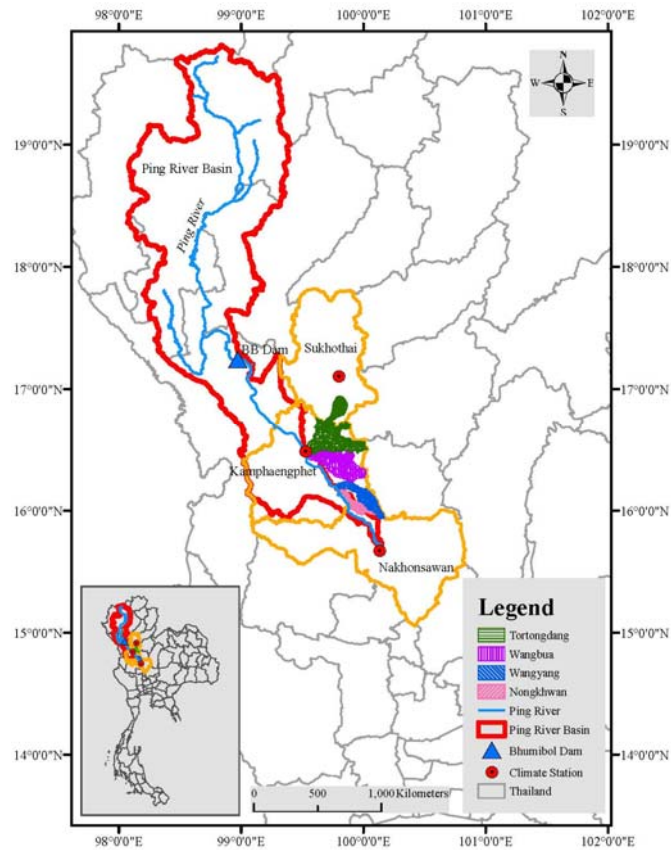


Figure 1. Study area map.

2.3 Cloud-Based IrrisAT Application

The Cloud-Based IrrisAT Application (IrrisAT) is a new approach of providing commonly appropriate tool for irrigation water management (Hornbuckle, 2014). It was created by the Cotton Research and Development Corporation (RDC) in Australia. IrrisAT is mainly created by using remote sensing to provide site specific information for crop water management. The calculation of the crop water requirements in IrrisAT are based on field observations and nearby climate observations. Moreover, IrrisAT undertakes the calculations of the crop coefficient data (K_c) based on the crop growth in the fields using remote sensing techniques which is useful information for irrigators. IrrisAT can also deliver the daily and seven-days crop water use forecasts to support and facilitate the decision making processes. IrrisAT requires only Keyhole Markup Language (KML) file of the crop growing area as an input data. Figure 2 illustrates the graphical display of study area imported in IrrisAT.

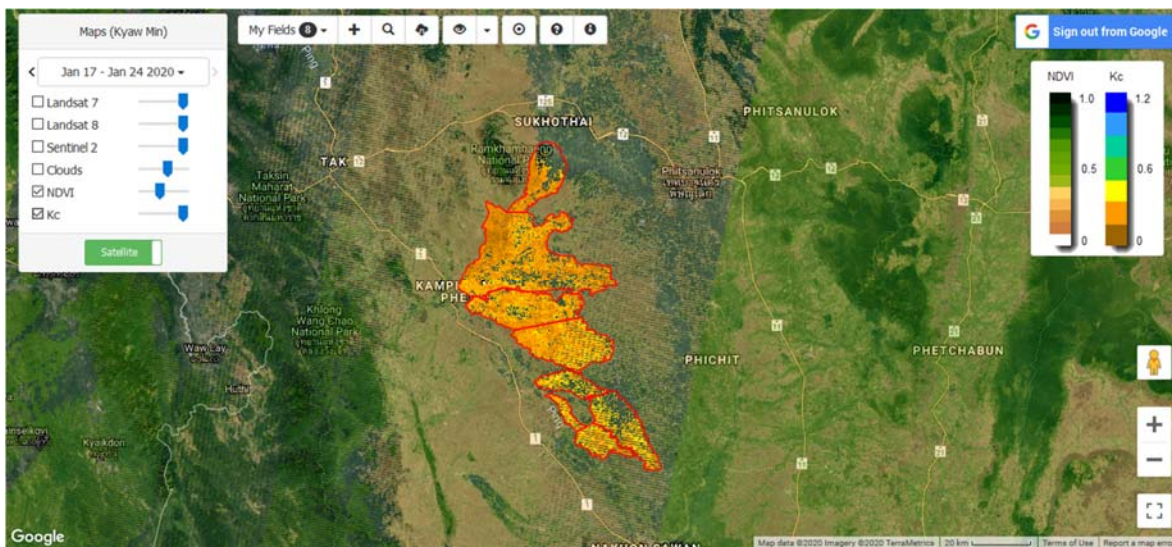


Figure 2. The study area displayed in IrrisAT.

Weekly K_c values of season and off-season crops in four irrigation area in the Lower Ping River Basin starting from 2000 to 2019 are computed on IrriSAT cloud-based platform. By importing the KML file of the study area into the IrriSAT application, the maximum, average and minimum crop coefficient (K_c) values can be achieved. It will automatically display time series of the crop coefficient according to the duration of the planting and harvesting dates of crops. In this study, the results of dynamic values of K_c –IrriSAT from October 2018 to September 2019 are verified and adjusted with average K_c –RID which were calculated as a function of K_c from field observation for the different types of crop and accumulated area of crops monitored by the remote sensing technique. However, crop water demand is not actually calculated by IrriSAT in this study due to the limits of global climate data from ground stations in Thailand on cloud platform.

Therefore, the crop water demand (ET_c) for each irrigation area is computed by using the observed climate data to estimate ET_o and adjusted K_c –IrriSAT instead of using the predicted ET_c values from IrriSAT. ET_o calculator is brought to estimate the reference crop evapotranspiration (ET_o). The crop coefficient chart can be generated from IrriSAT as shown the output of K_c –IrriSAT in Figure 3.

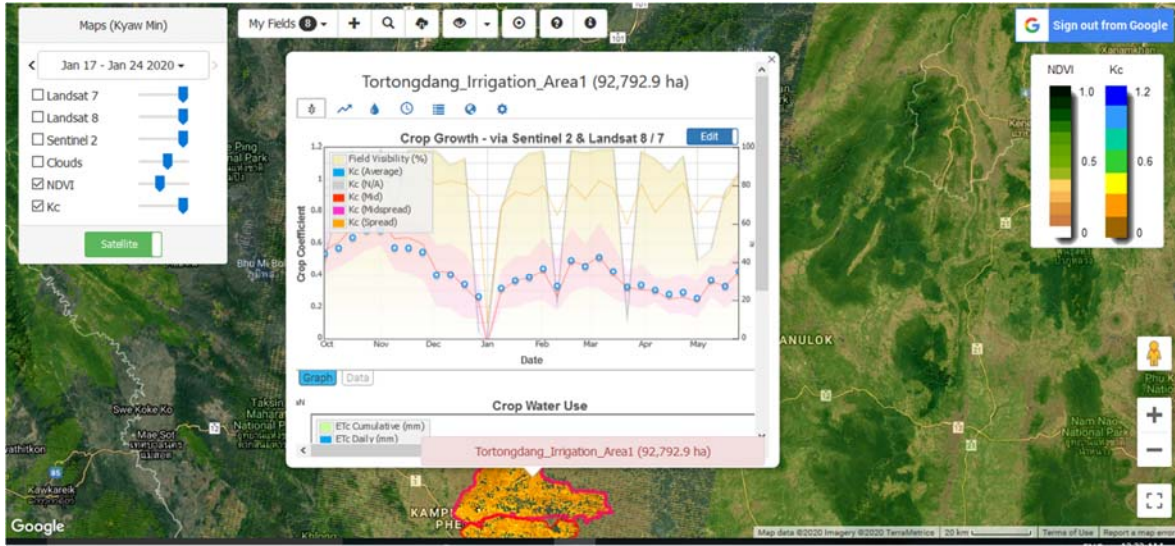


Figure 3. Crop coefficient charts performed by IrriSAT

2.4 Calculation of average crop coefficient (Average K_c –RID)

In fact, crop coefficient (K_c) is important factor that is used to estimate the amount of crop water demand (ET_c). The K_c values generally vary with crop characteristics and growth stages. In Thailand, the weekly K_c values of more than 40 types of economic crops have been derived from field observation by the Royal Irrigation Department, Thailand. To verify the results of K_c from IrriSAT, the average K_c –RID based upon 4 main types of crops namely; (1) rice, (2) sugarcane, (3) corn, and (4) cassava from October 2018 to September 2019 on the weekly scale are computed using Eq. (1).

$$\text{Average } K_c - \text{RID} = \frac{(K_{cri} \times \text{Areari}) + (K_{csu} \times \text{Areasu}) + (K_{cco} \times \text{Areaco}) + (K_{cca} \times \text{Areaca})}{\text{Total Area}} \quad (1)$$

where, K_{cri} , K_{csu} , K_{cco} , and K_{cca} are crop coefficient of rice, sugarcane, corn, and cassava, respectively and Areari , Areasu , Areaco , and Areaca are the accumulated planting area of rice, sugarcane, corn, and cassava, respectively.

2.5 Methods applied for the estimation of reference crop evapotranspiration

2.5.1 FAO Penman–Monteith equation

Smith and Allen et al., (1998) proposed the FAO Penman–Monteith equation to describe the reference crop evapotranspiration (ET_o). Reference crop evapotranspiration is defined as the rate of evapotranspiration from a hypothetical reference crop with the uniform height. The FAO Penman–Monteith equation can be used for daily ET_o calculation as expressed in Eq. (2).

$$ET_o = \frac{0.408\Delta(R_n - G) + r \frac{900}{T + 273} U_2 (e_s - e_a)}{\Delta + r(1 + 0.34U_2)} \quad (2)$$

where, ET_o is reference crop evapotranspiration [$mm\ day^{-1}$], R_n is net radiation at the crop surface [$MJ\ m^{-2}\ day^{-1}$], G is the soil heat flux density [$MJ\ m^{-2}\ day^{-1}$], T is the mean air temperature [$^{\circ}C$] measured at 2 m height, U_2 is the wind speed [$m\ s^{-1}$] measured at 2 m height, e_s is the saturation vapour pressure [kPa], e_a is the actual vapour pressure [kPa], $(e_s - e_a)$ is the saturation vapour pressure deficit [kPa], Δ is the slope of the vapour pressure curve [$kPa\ ^{\circ}C^{-1}$], and r is the psychrometric constant [$kPa\ ^{\circ}C^{-1}$].

2.5.2 ET_o calculator

The ET_o Calculator is a public domain software developed by the Land and Water Division of FAO (Raes, 2009). The ET_o Calculator version 3.2 issued in September 2012, is applied in this study. Its main function is to calculate the reference crop evapotranspiration (ET_o) according to FAO standards. Therefore, in this study ET_o Calculator is used as an analysis tool to estimate ET_o which can be later used in crop water demand studies.

3. RESULT AND DISCUSSION

3.1 Crop Coefficient Generated from IrriSAT Application (K_c -IrriSAT)

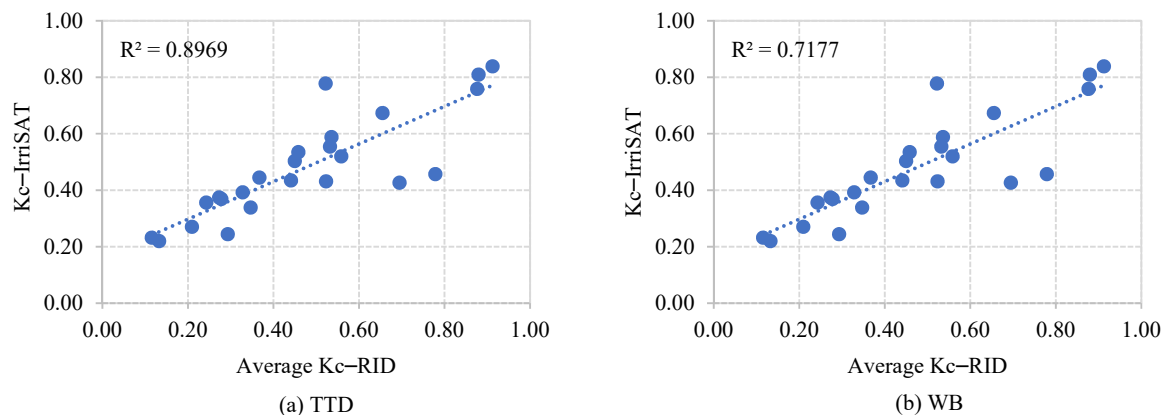
The dynamic values of K_c -IrriSAT of four irrigation area are computed during 2000–2019. The results are generated in almost one week timeframe including field visibility (%), and many forms of K_c such as; K_c (average), K_c (observed), K_c (override), K_c (stddev), K_c (min), K_c (Q1), K_c (median), K_c (Q3), and K_c (max). However, only K_c (average) is presented and used to compare the results with average K_c -RID. The maximum values of K_c (average)-IrriSAT are 0.77, 0.82, 0.78, and 0.81 for TTD, WB, WY, and NK irrigation area, respectively. The K_c (max) values obtained from IrriSAT for four irrigation area are relatively the same ranging between 1.10–1.14 as summarized in Table 1.

Table 1. Crop coefficient generated from IrriSAT application during 2000–2019.

IRRIGATION AREA	MAX. K_c (average)-IrriSAT	MAX. K_c (max)-IrriSAT
TTD	0.77	1.14
WB	0.82	1.11
WY	0.78	1.10
NK	0.81	1.11

3.2 Comparison of K_c -IrriSAT and average K_c -RID

The calculation of average K_c -RID of four irrigation area was made based upon four main types of crops namely; (1) rice, (2) sugarcane, (3) corn, and (4) cassava growing from October 2018 to September 2019 which cover 73.15%, 86.95%, 83.06%, and 74.40% of the total irrigation area, respectively. The results show the similar patterns of K_c -IrriSAT and average K_c -RID over the growth stages of crops. Correlations between K_c -IrriSAT and average K_c -RID for TTD, WB, WY, and NK irrigation area are relatively high namely; 0.8969, 0.7177, 0.8681, and 0.8307 as shown in Figure 4. However, the K_c values calculated by IrriSAT for 4 irrigation area are slightly deviated from average K_c -RID values in some growing periods in both season and off-season crops. It is found that the values of K_c -IrriSAT are lower than average K_c -RID from filed observation in initial and late stages of crop growth in dry and wet seasons for four irrigation area. Meanwhile, K_c values obtained from IrriSAT during the mid-stage of crop growth are higher than average K_c -RID as displayed in Figure 5. The reason might be that evaluating K_c by IrriSAT on cloud-based platform entails the entire planting area. However, calculating average K_c -RID is manipulated based upon some specific type of crops in some part of area size. Therefore, calibrating K_c values performed by IrriSAT is then conducted using least square criterion to see the good correlation to the average K_c -RID.



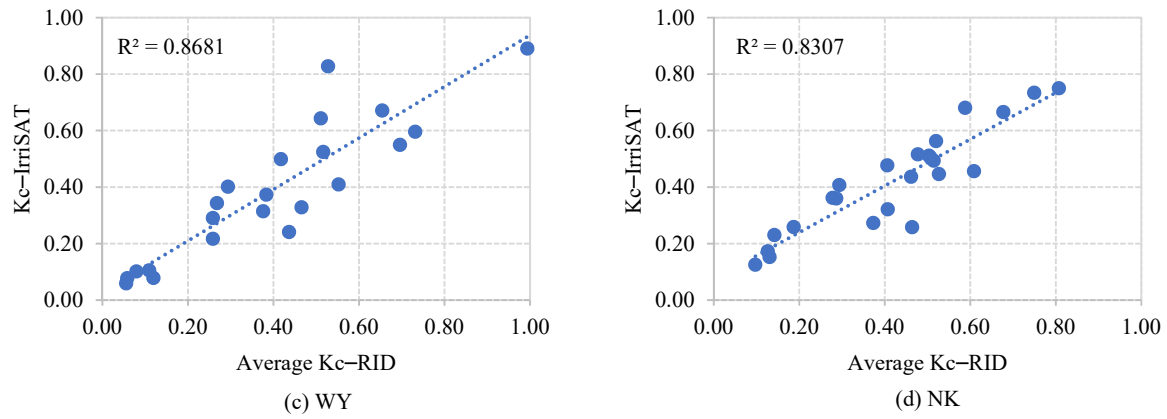


Figure 4. Correlations between K_c -IrriSAT and Average K_c -RID for four irrigation projects.

In this study, four different periods of in-season and off-season crops planting in the area are identified to compute the adjusted factors of K_c -IrriSAT. The adjusted factors and time periods identified are presented in Table 2. The comparison of K_c -IrriSAT before and after adjustments are shown in Figure 5.

Table 2. The adjusted factors of K_c -IrriSAT performed by the least square criterion.

STAGE	ADJUSTED FACTORS			
	OFF SEASON CROP	IN SEASON CROP		
	MID-END PERIOD	INITIAL	MID	END
TTD	1.1	0.6	1.3	0.7
WB	1.3	0.7	1.2	0.9
WY	1.3	0.3	1.4	0.6
NK	1.1	0.6	1.1	0.8

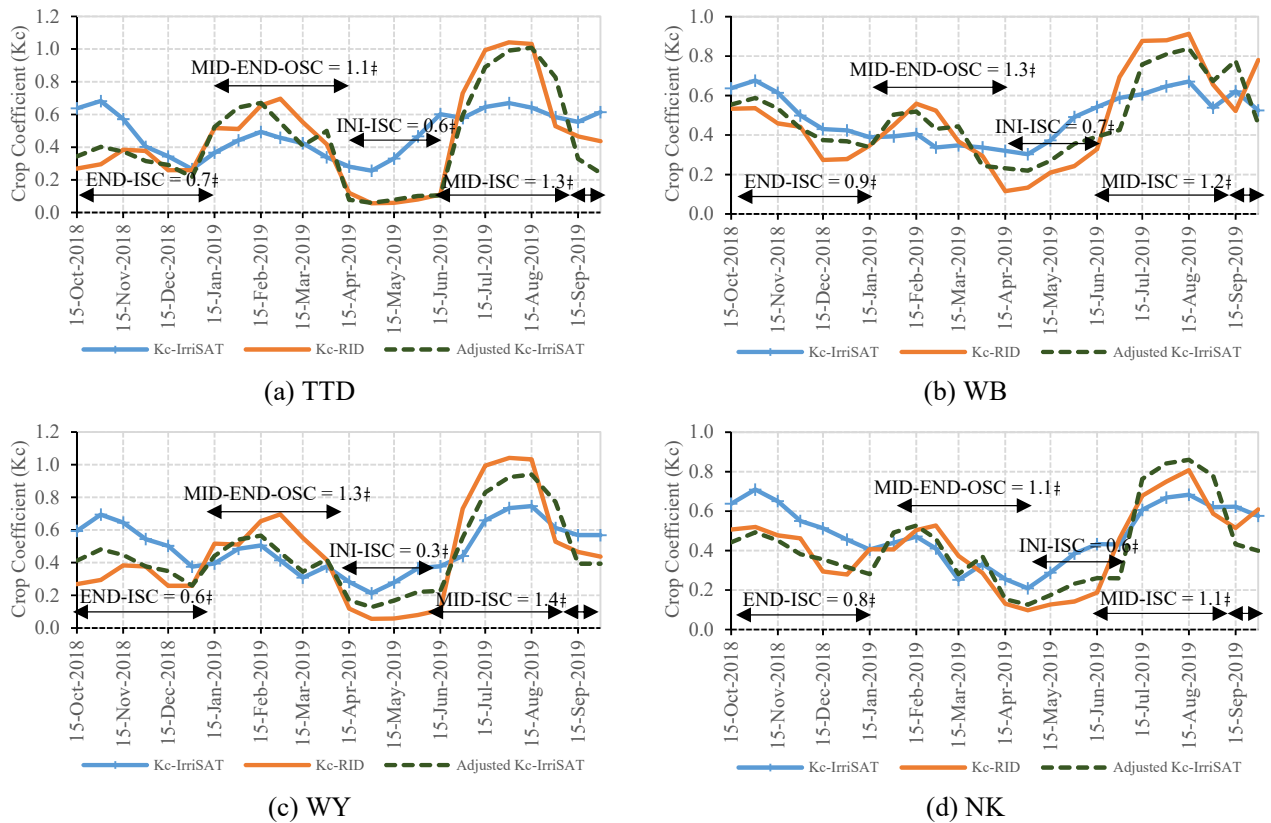


Figure 5. Comparison of K_c values and adjusted factors for four irrigation projects.

3.3 The results of reference crop evapotranspiration

To estimate the reference crop evapotranspiration (ET_o), the study area was positioned throughout three provinces of Thailand; (1) Kamphaengphet (KPP), (2) Nakhon Sawan (NSW), and (3) Sukhothai (SKT) Provinces. Therefore, the climate data such as the standard meteorological records of minimum, average and maximum daily temperature, solar radiation or sunshine duration, air humidity (preferably minimum and maximum relative humidity) and wind speed of these three provinces were used. The FAO Penman–Monteith equation in Eq.2 and ET_o calculator software were applied to estimate the reference crop evapotranspiration in this study. The results of ET_o calculation in Kamphaengphet, Nakhon Sawan and Sukhothai Provinces are illustrated in Figure 6. It is found that the values of ET_o in Nakhon Sawan are relatively closer to Sukhothai Province due to the similar physical circumstances. However, the ranges of ET_o in this region vary between 2.50–6.10 mm/day.

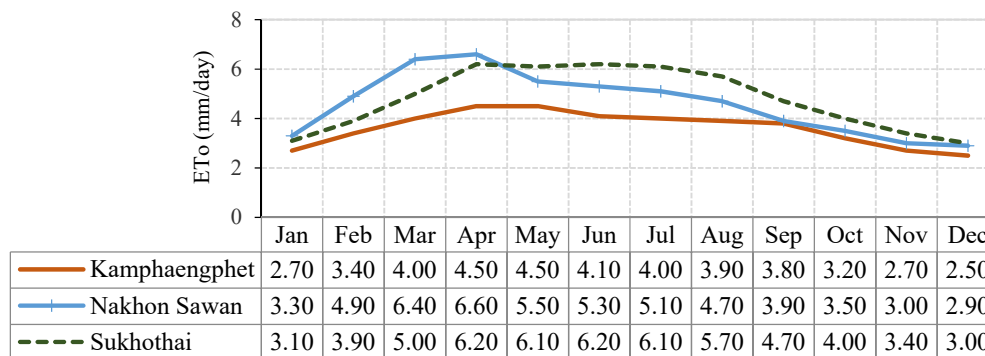


Figure 6. ET_o values used for crop water demand estimation.

3.4 Comparison of crop water demand calculated from the different types of K_c

Table 3 shows the calculated values of monthly and yearly crop water demands (ET_c) for four irrigation area using three kinds of K_c namely; (1) Average K_c -RID, (2) K_c -IrriSAT, and (3) K_c -IrriSAT adjusted. This calculation are done based upon the accumulated area monitored by GISTDA during 2018–2019 only and presented in million cubic meter (MCM). Among these three kinds of K_c , it is illustrated that the yearly crop water demands are quite the same with small percentage error for four irrigation area as presented in Table 3. All in all, after the adjustment of K_c -IrriSAT, the yearly crop water demands seem to be relatively closer to those received by using average K_c -RID (or filed observation). However, it shows the explicit variance on monthly crop water demand when K_c -IrriSAT and adjusted K_c -IrriSAT are employed.

Table 3. Monthly and yearly crop water demands in the study area.

MONTH	CROP WATER DEMAND (MCM) ^{1/}											
	TTD ^{2/}			WB ^{2/}			WY ^{2/}			NK ^{2/}		
	Avg. K_c -RID	K_c -IrriSAT	K_c -IrriSAT Adjusted	Avg. K_c -RID	K_c -IrriSAT	K_c -IrriSAT Adjusted	Avg. K_c -RID	K_c -IrriSAT	K_c -IrriSAT Adjusted	Avg. K_c -RID	K_c -IrriSAT	K_c -IrriSAT Adjusted
JAN	14.43	14.08	15.74	15.35	15.01	16.22	12.25	10.34	13.71	4.42	4.58	4.28
FEB	25.94	20.89	23.36	24.12	16.64	21.27	15.63	10.61	14.07	5.44	4.66	5.05
MAR	19.70	16.57	18.52	7.66	7.90	8.05	8.18	5.62	7.45	2.03	1.75	1.90
APR	3.47	7.30	6.65	1.92	4.78	3.46	0.62	1.63	0.45	0.42	0.85	0.51
MAY	8.95	15.44	9.31	4.72	9.02	6.53	0.24	1.13	0.31	0.41	1.03	0.61
JUN	40.71	36.25	36.87	17.04	17.22	12.46	7.03	4.77	5.75	1.65	1.90	1.13
JUL	69.35	53.35	67.16	34.83	24.88	31.09	23.79	16.31	22.02	5.36	4.79	5.25
AUG	57.07	50.22	63.23	26.90	20.74	25.92	16.93	14.79	19.97	5.23	4.91	5.39
SEP	34.54	39.70	27.53	20.46	17.42	18.32	7.64	8.45	4.88	4.08	4.35	3.44
OCT	17.82	29.83	20.69	14.40	17.69	15.38	3.06	7.03	4.06	3.49	4.58	3.63
NOV	11.63	17.42	12.08	15.56	19.29	16.77	8.30	13.01	7.52	4.79	6.13	4.86
DEC	4.37	7.02	4.87	9.24	14.31	12.44	5.02	8.57	4.95	2.81	4.77	3.78
YEARLY	307.98	308.07	306.02	192.21	184.89	187.92	108.70	102.26	105.14	40.15	44.30	39.85
%ERROR	-	-0.09	1.97	-	7.31	4.29	-	6.44	3.56	-	-4.15	0.29

Remark : ^{1/}Calculations of crop water demand are based on the accumulated area size of four main types of crop monitored by GISTDA during 2018–2019. ^{2/}Average values of $ET_{OKPP, SKT}$, ET_{OKPP} , $ET_{OKPP, NSW}$, $ET_{OKPP, NSW}$ are used for the calculations of crop water demands of TDD, WB, WY, and NK irrigation area, respectively.

4. CONCLUSIONS

This study revealed that applying IrriSAT could help support in estimating actual crop water demand promptly on cloud-based platform. It could deliver site specific crop water management information especially to the

irrigators and reservoir operators to enhance the efficiency of irrigation water management. However, the site and time specific adjustments of K_c -IrriSAT are essentially needed in order to get the closer results and similar patterns of crop water demands to field observation data.

ACKNOWLEDGMENTS

Authors would like to acknowledge the Thailand Science Research and Innovation (TSRI) for providing financial support. We are thankful to the Royal Irrigation Department (RID), Geo-Informatics and Space Technology Development Agency (GISTDA), and Thai Meteorological Department (TMD) for providing data for this study.

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