

Crop Water Requirement Estimation of Maize Using Remote Sensing in Mae Chaem District in Chiang Mai Province

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Abstract

Maize is widely produced because it is the essential raw material for animal feed industries. Maize is one of the drought-tolerant plants; however, it needs to consume water for cultivation like Crop Water Requirement (CWR). In fact, CWR estimation is used to investigate sufficient agricultural water consumption. In addition, CWR estimation can presently calculate from the global crop coefficient from the FAO Penman-Monteith. On the other hand, when this crop coefficient of maize in each area is not similar under local conditions, the global crop coefficient is inconsistent with the specific area. Therefore, this study aims to estimate the crop coefficient of maize under local conditions under the study area. The crop coefficient (K_c) of maize is calculated by using remote sensing technique in the maize crop through image processing for the Normalized Difference Vegetation Index (NDVI) as $NDVI-K_c$ to estimate the CWR and then CWR using $NDVI-K_c$ is compared with CWR from Royal Irrigation Department. The study area is Mae Chaem district in Chiang Mai Province because this area is a steep slope and lack access to irrigation. Results reveal the amount of CWR through $NDVI-K_c$ in this study area is $471.50 \text{ m}^3/\text{rai}$, which is similar to CWR of the Royal Irrigation Department around $550 \text{ m}^3/\text{rai}$. In other words, the accuracy assessment of this result is 86 % as percent accuracy. $NDVI-K_c$ can assess CWR to plan water management for maize in the steep slope which is difficult to access water source.

Keywords: Crop Water Requirement (CWR), Remote Sensing, Normalized Difference Vegetation Index (NDVI), Maize, Crop Coefficient

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1. Introduction

Water is the main component of the earth. About 71 percent of the Earth's surface is water-covered, only 3 percent is freshwater which is important for human activities such as agriculture, industry, and livestock. Around 70 percent of global freshwater is used in agriculture (Hannah, R. and Max, R., 2017) for agricultural activity in food production. Irrigation is a significant contributor to the agricultural activity that has long been around to control freshwater to crop areas. On the other hand, irrigation is not suitable for all areas because there are many factors in decision making such as slope, land use, soil and rainfall (Abeyou, W., et.al., 2017). Especially, a slope above 30 percent as plateau and mountain is classified as not suitable for irrigation in water management (FAO and Agriculture Organization of the United Nations, 1999). When farmers on the plateau and mountain cannot access irrigation, water use in plateau and mountain is insufficient in agriculture. Eventually, rainfall is the main water source on plateau and mountains. On the other hand, the demand for food is not decreased especially, since maize is the principal material used in chicken feed production. Hence, the higher demand for maize cultivation results in the increasing maize area as well.

Maize is one of the economic field crops of Thailand and is important for animal feed industries.

Also, the return for maize cultivation is high. As a result, maize is widely cultivated in Thailand. Moreover, farmers in mountain areas favor this crop as maize is drought tolerant plant. So, maize crops on the sloping area under the rainfed condition without irrigation. Although maize is a drought-tolerant plant, the amount of rainfall is insufficient for the growing season. As a result, water consumption is not enough for plant growth and lack access to irrigation. Therefore, Crop Water Requirement (CWR) calculation is important in water management in high plain. Generally, maize in Thailand is planted around two times per year. In addition, the starting day of the growing season is different. Furthermore, the growing season of maize cultivation is not always in accordance with the crop calendar. Moreover, the amount of rainfall in the growing season can lead to K_c values. As the daily rainfall variability characteristics contributed to the CWR difference. As a result, the starting day of the growing season can bring about CWR estimation.

Today the CWR has been used for various purposes in agriculture, for instance, CWR is the total amount of water required by the crop during the growing season (Memon A.V., 2018). Also, CWR is used for the estimation of irrigation water requirements and irrigation scheduling. Moreover, crop coefficient is used to estimate CWR. Besides, CWR is used to calculate water footprint as well (Thippapa S. et al., 2013). The component of CWR estimation consists of crop coefficient (K_c) and reference crop evapotranspiration (ET_o). Crop coefficient (K_c) depends on crop type and growing season while reference crop evapotranspiration (ET_o) is determined by using the Penman-Monteith equation as a standard method based on meteorological information. CWR evaluation relies on several input data which is difficult to collect historical data such as the amount of rainfall because K_c estimation depends on effective rainfall. So, CWR calculation is difficult to estimate the specific K_c on the specific area.

Satellite remote sensing is widely used to be a tool for K_c estimation as the ability of satellite image can coverage overview area and identify growing season (Arturo, R., et.al., 2018). Whilst Normalized Difference Vegetation Index (NDVI) is one of the popular vegetation indexes, in which NDVI is strongly absorbed by chlorophyll and is reflected by mesophyll structure in leaves of the canopy (Arturo, R, et.al., 2018). NDVI is related to healthy and dense vegetation. In addition, NDVI time series are used to define the crop coefficient curve. Many previous researchers apply remote sensing techniques through image processing to analyze the relationship between NDVI and crop coefficient (K_c) using linear regression calculation. For example, Arturo Reyes-González et al. (2018) improved a simple linear regression model between NDVI from Landsat 7 images and K_c from ASCE Manual 70. In addition, Reyes-Gonzalez, A (2015) developed the relationship between NDVI from Landsat 5 images and K_c from FAO-56 for corn and alfalfa, including Célia, T., et al. (2017). Kamble B., et al. (2013) developed the relationship between NDVI from MODIS images and K_c as well. So, NDVI can be used to determine K_c which is one of the parameters to estimate CWR. In addition, a Geographic Information System (GIS) is used to determine CWR estimation. For example, land use, rainfall, meteorological data including crop information are used to estimate CWR in the Gaza Strip approach model builder in ArcMap (Said M Ghabayen, Ali A Salha, 2013). GIS can show the spatial distribution of the monthly crop water requirement. Many researchers attempt to apply technologies both GIS and remote sensing to define K_c in a specific area.

The objective of this research aims to estimate CWR on maize crop in Changkerng sub-district, Mae Chaem district in Chiang Mai province, where is a steep slope and difficult to access water consumption. NDVI is calculated by remote sensing based on satellite image processing to estimate K_c using the linear regression equation between NDVI and K_c based on the above literature reviews as NDVI- K_c in the growing season (Kamble et al., 2013; Arturo Reyes-Gonzalez et al., 2015; Célia Toureiro et al., 2017). Likewise, NDVI- K_c is K_c estimation from the functions of the relationship between NDVI and K_c using a simple linear regression model. All above methodology is processed in the Model builder tool in ArcGIS software. And, CWR estimation for this study is processed by using NDVI- K_c and ET_o .

2. Material and methods

In this study, crop water requirement estimation using NDVI based on remote sensing technique in Changkerng sub-district, Mae Chaem district in Chiang Mai province. There are three main procedures. First, NDVI calculation is processed by using image processing in a remote sensing technique. Second, NDVI- K_c values are estimated by using the functions of the relationship between NDVI and K_c using a simple linear regression model. Both procedures are developed in the Model Builder tool in ArcGIS software. Then, this study calculates the mean NDVI- K_c from NDVI- K_c values from the result of the above procedure to be representative of the maize area in this study. Next, the mean NDVI- K_c value in this study only is used to estimate K_c in other days using polynomial regression including ETo as well in order to calculate CWR estimation along maize growing season. Finally, CWR estimation using NDVI- K_c and ETo is revealed along the growing season. Figure 1 demonstrates the overall structure of the methodology.

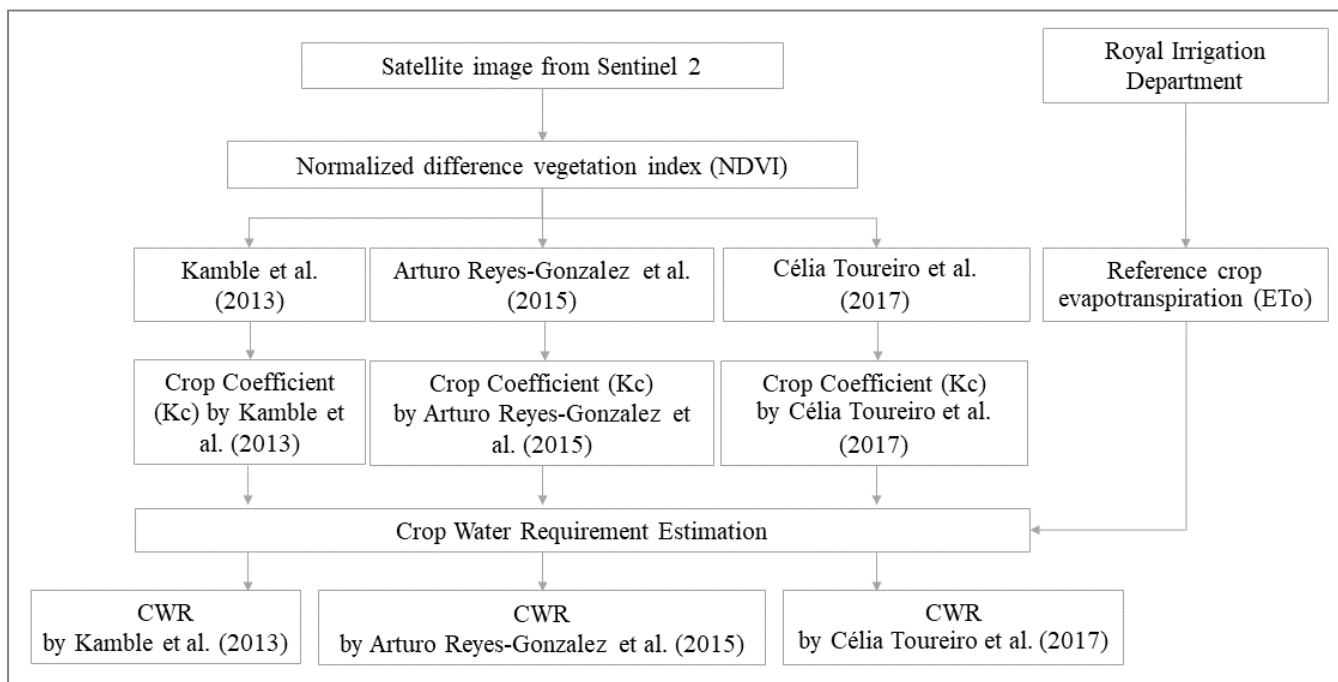


Figure 1 Overall structure of the methodology for crop water requirement estimation

2.1 Study area

The study area is the Changkerng sub-district, Mae Chaem district in Chiang Mai province, which is located in northern Thailand. Changkerng sub-district has maize cropped area around 13.4 % of the sub-district area, which is the largest maize cropped area comparing with other sub-districts. The study area with maize cropped area based on land use data in 2018 from Land Development Department is shown in Figure 2. The mean annual temperature is between 20–34 °C. In addition, a rainy season is between May and October (Arunrat, N., et.al., 2018), which is the maize growing season.

Changkerng sub district, Mae Chaem district in Chiang Mai province

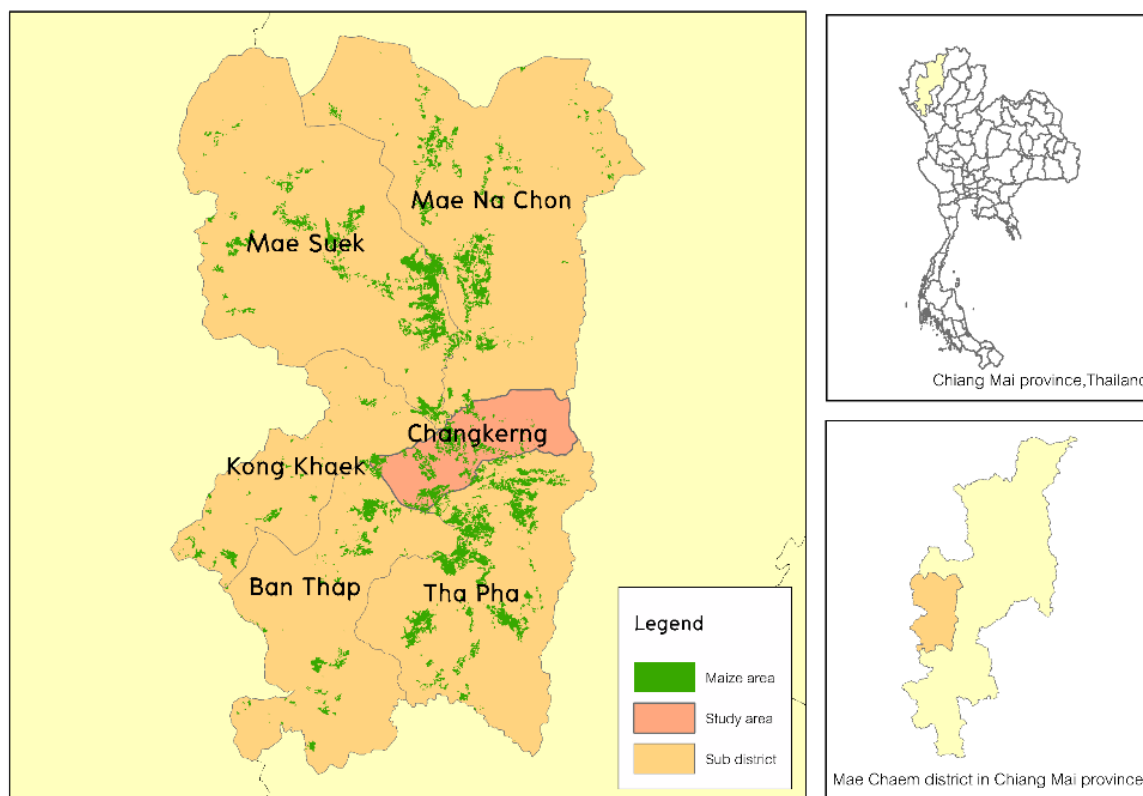


Figure 2 Study area

2.2 Satellite image

Satellite images from Sentinel 2 Multispectral Imager (MSI). Sentinel 2 MSI cover 13 spectral bands with a swath width of 290 km and a spatial resolution of 10 m (Band 2-4 and 8) 20 m (Band 5-7, Band 8a and Band 12) and 60 m (Band 1, Band 9-10) (ESA., 2021). For satellite image application, band 4 as a red band and band 8 as near-infrared band is useful for land cover classification and leaf chlorophyll content. In addition, the temporal resolution is 10 days (ESA, 2021).

In this study, only Band 8 (Near-Infrared bands) and Band 4 (Red) with a spatial resolution of 10 m area since used to calculate NDVI to estimate K_c . Also, this study selects path 131 and row 47 of satellite images which are Worldwide Reference System (WRS) covering the study area as following Figure 3. Satellite images from Sentinel-2 satellite are downloaded from the United States Geological Survey (USGS) EROS Datacenter (<https://earthexplorer.usgs.gov/>) and acquired for 2020.

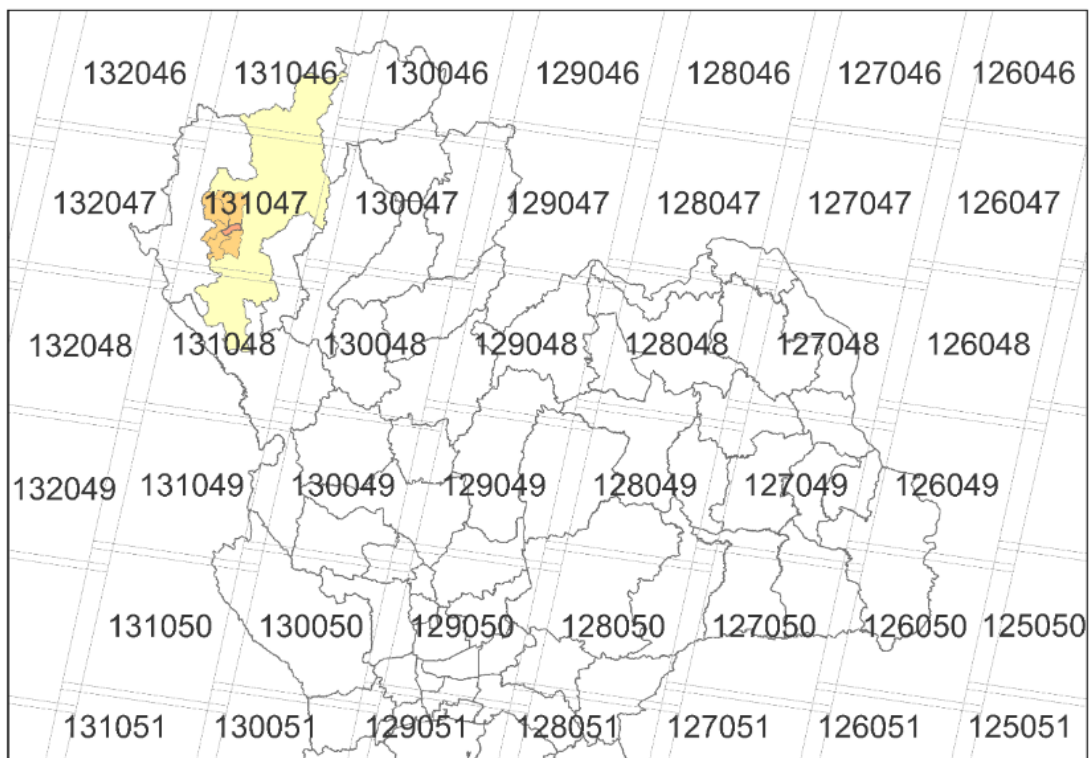


Figure 3 path 131 and row 47 of satellite images covering the study area

2.3 Normalized difference vegetation index (NDVI) calculation

The NDVI can measure the density of leaves in a vegetated area. The NDVI value is between -1 to 1. High NDVI values are healthy vegetation while low NDVI values are unhealthy vegetation or die. The NDVI range of more than 0.14 is considered to identify the agricultural area because this range is suitable NDVI ranges identified for the land cover classes (Akbar, T.A, 2019). This study selects Band 8 and Band 4 from Sentinel-2 satellite images to represent the visible and near-infrared, respectively. NDVI is calculated as following Eq. (1):

$$NDVI = \frac{NIR - Red}{NIR + Red} \quad (1)$$

where NIR is the surface reflectance in the near-infrared band as band 8.

Red is the surface reflectance in the red band as band 4.

2.4 Crop Coefficient (K_c) estimation

Crop Coefficient (K_c) estimation as NDVI- K_c is calculated based on a NDVI simple linear regression model for the maize crop from these works of literature as following Table 1. However, the resolution of Sentinel-2 satellite images in this study is higher than the mentioned literature. As a result, the NDVI value is suitable for this study area which has a small area. On the contrary, K_c is estimated through the Penman-Monteith method of FAO. Table 1 shows several correlation equations from works of literature based on NDVI input to reveal specific K_c values. In addition, coefficient of determination (R^2) is used to measure the strength of the relationship between the regression model and the dependent variable as NDVI values. Clearly, the larger the R^2 , the better the regression model fits observations. (Ben, D., 2021) obtained around 0.5 which is a significant relationship.

Table 1 Correlation equations between NDVI and K_c for the maize crop

Correlation equations	R^2 *	Reference
$K_{c1} = 1.457 \text{ NDVI} - 0.1725$	0.90	Kamble et al. (2013)
$K_{c2} = 1.62 \text{ NDVI} - 0.1471$	0.97	Arturo Reyes-Gonzalez et al. (2015)
$K_{c3} = 0.918 \text{ NDVI} + 0.303$	0.82	Célia Toureiro et al. (2017)

* R^2 is Coefficient of Determination

Crop Coefficient (K_c) value referred Penman-Monteith method from Royal Irrigation Department (RID) based on meteorology data of Thailand (RID- K_c) as following Table 2. K_c values are compared with NDVI- K_c .

Table 2 Crop Coefficient (K_c) value for the maize crop from RID (RID, 2011)

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
K_c	0.63	0.72	0.86	1.13	1.35	1.52	1.61	1.63	1.58	1.5	1.38	1.15	0.9	0.67

2.5 Reference crop evapotranspiration (ET_o)

Reference crop evapotranspiration (ET_o) values are another parameter in the CWR calculation. This study refers ET_o values based on Chiang Mai province in 2011 (RID, 2011). The values are calculated based on the FAO Penman-monteith method by RID that has shown in Table 3. FAO Penman-monteith method requires location, temperature, humidity, radiation and wind speed for daily calculations (Jiabing C., et al, 2007).

Table 3 Reference crop evapotranspiration (ET_o) (mm/day) (RID, 2011)

Month											
Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul	Aug.	Sep.	Oct.	Nov.	Dec.
3.21	4.09	5.26	6.12	4.97	4.3	3.8	3.62	3.67	3.74	3.35	3.03

2.6 Crop Water Requirement (CWR) calculation

CWR is the total amount of daily water required, which can calculate from the multiply K_c by ET_o . Then, the daily water required is summed along the growing season.

This study considers 98 days for maize growing season as ET_o consists of 14 weeks following K_c value for the maize crop from RID. CWR of maize is calculated by using the NDVI- K_c values. The CWR equation is showed as Eq. (2).

$$CWR = (\text{NDVI-}K_c * ET_o) * \text{No. day} * \text{size} \quad (2)$$

where CWR is Crop Water Requirement (m^3)

NDVI- K_c is Crop Coefficient based on NDVI

ET_o is Reference crop evapotranspiration (mm/day)

No. day is the number of maize cultivation days (days)

Size is the size of the field (m^2)

2.7 Accuracy assessment

This study considers accuracy assessment between CWR estimations of maize using NDVI- K_c and K_c from RID (RID- K_c) as following Eq. (3).

$$\% \text{Accuracy} = \left(1 - \left| \frac{X_m - X_t}{X_t} \right| \right) * 100 \quad (3)$$

where X_m is the amount of CWR using NDVI- K_c as simulated values.

X_t is the amount of CWR using RID- K_c as observed values.

3. Results and Discussion

This study develops the NDVI- K_c values estimation model using the Model builder tool in ArcGIS software, which can process satellite image processing based on remote sensing. For the NDVI- K_c values estimation model on the Model builder tool, the input data is satellite images which consist of red band and near-infrared band to calculate crop coefficient (K_c) based on a NDVI simple linear regression model for the maize crop. This model consists of 4 parts which are NDVI calculation, vegetation range identification, raster extraction by specific area and NDVI- K_c model from three references as Kamble et al. (2013) (K_{c1}), Arturo Reyes-Gonzalez et al. (2015) (K_{c2}) and Célia Toureiro et al. (2017) (K_{c3}). Finally, this model obtains NDVI- K_c values. The methodology of the NDVI- K_c values estimation model using the Model builder is shown in Figure 4.

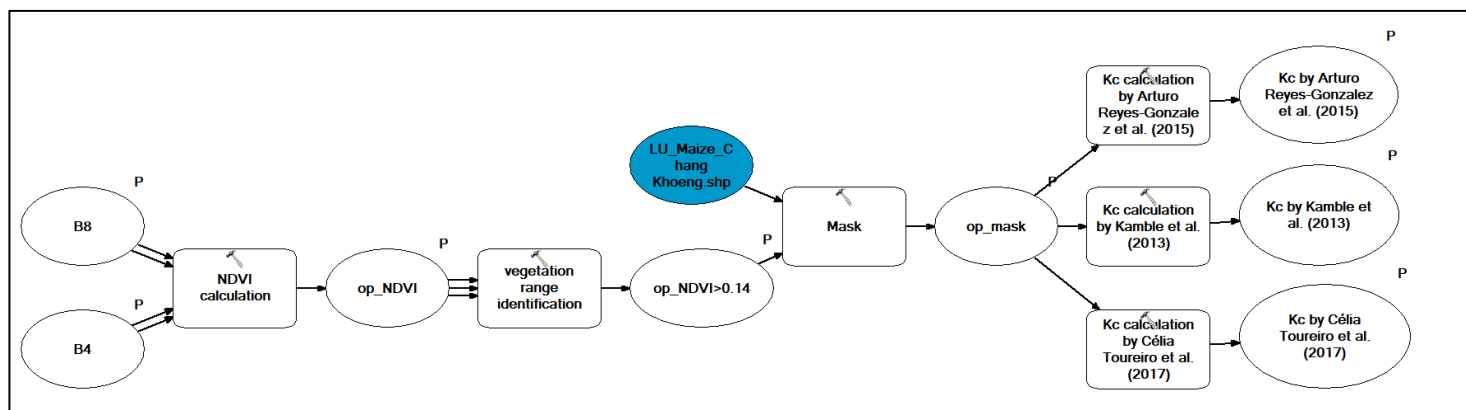
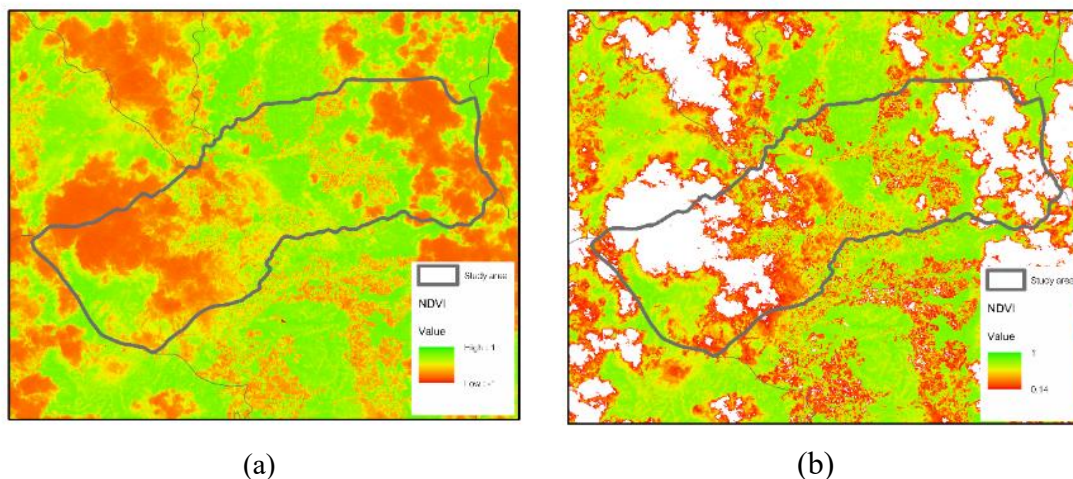


Figure 4 NDVI- K_c values estimation model using Model builder tool in ArcGIS software

The results of the NDVI- K_c values estimation model which is spatial NDVI- K_c values on 13 June 2020 only like the starting day of the planting date were presented in Figure 5. For the result of the first step, NDVI values on 13 June 2020 is calculated as following Figure 5 (a), which shows unhealthy vegetation area as water, cloud and bare land. Figure 5 (b) shows the range of vegetable extraction to consider only vegetation area. For the result of Figure 5 (c), it shows maize raster extraction by land use for maize area which NDVI in maize area between 0.14-0.83. Next, NDVI- K_c values from Kamble et al. (2013) (K_{c1}) are 0.43-1. Also, NDVI- K_c values from Arturo Reyes-Gonzalez et al. (2015) (K_{c2}) are 0.03-1.03. In addition, NDVI- K_c values from Célia Toureiro et al. (2017) (K_{c3}) are 0.08-1.20. From the results, the mean NDVI- K_c values are considered to be representative of K_c in the growth period.



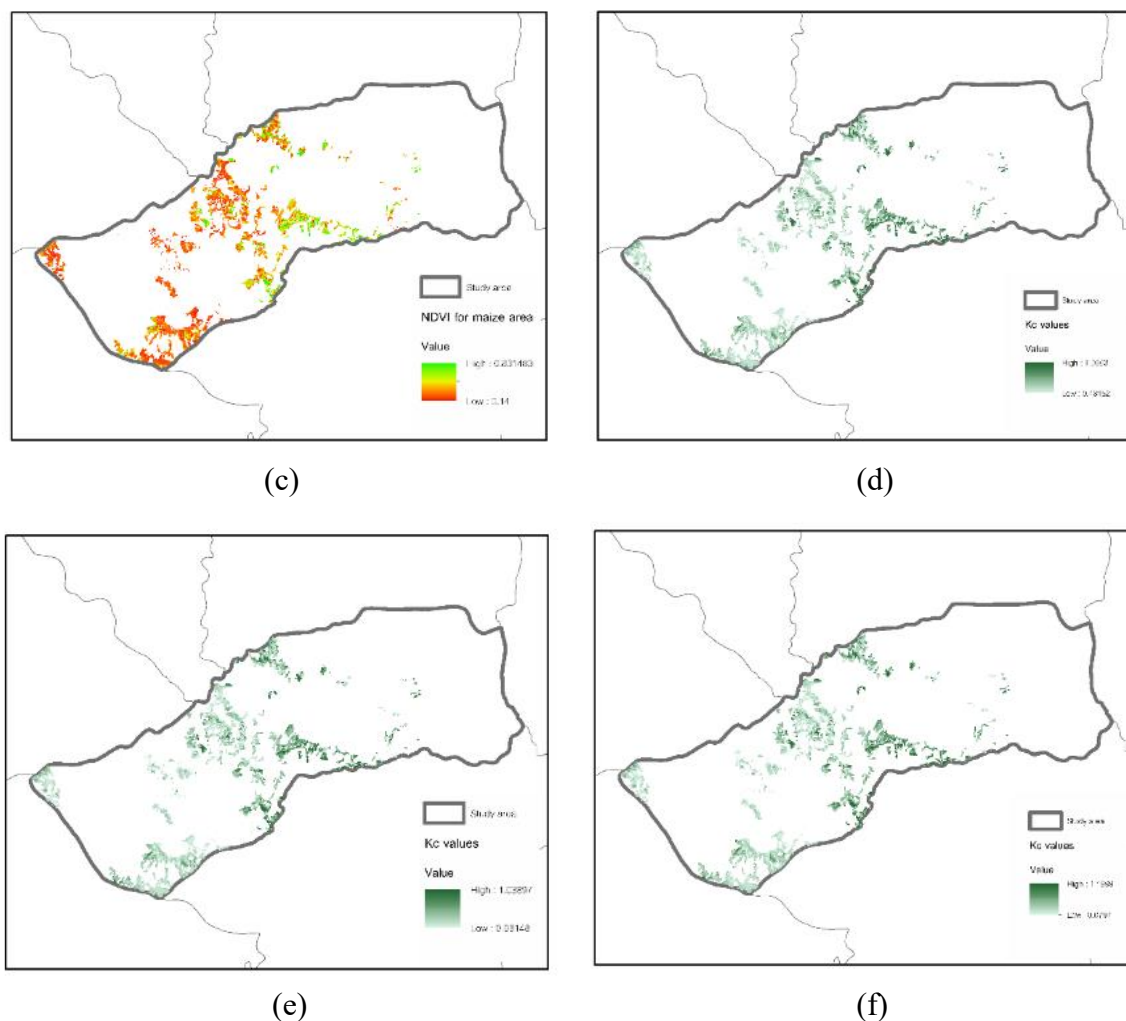


Figure 5 The results of the NDVI- K_c values estimation model on 13 June 2020
 (a) NDVI calculation, (b) Vegetation range identification, (c) raster extraction by maize area,
 (d) NDVI- K_c values by using regression model refer Kamble et al. (2013), (e) NDVI- K_c values by
 using regression model refer Arturo Reyes-Gonzalez et al. (2015), (f) NDVI- K_c values by using
 regression model refer Célia Toureiro et al. (2017)

Maize crop coefficient values are estimated by NDVI (NDVI- K_c) simple linear regression model refer Kamble et al. (2013) (K_{c1}), Arturo Reyes-Gonzalez et al. (2015) (K_{c2}) and Célia Toureiro et al. (2017) (K_{c3}). Crop coefficient (RID- K_c) values along the maize cultivation calendar in Mae Chaem district in Chiang Mai province are between the middle of May and December. NDVI- K_c values are shown in Figure 6, which reveals the curve of K_c values along with the maize cultivation calendar. However, the NDVI- K_c curves during 13 June 2020 – 16 September 2020 are similar to the standard growth stage of the maize crop coefficient curve. In other words, NDVI- K_c curves have a connection during growth stages. So, this study assumed 13 June 2020 is the starting day of the planting date because the NDVI- K_c value of this day is the start point ahead of a steep increase like an early season. Time series of NDVI- K_c values can reveal the trend of K_c along with the maize cultivation calendar. Thus, this result of NDVI- K_c curves from those literature reviews can reveal the starting day of planting date of maize growing season based on the characteristic of the standard growth stage of maize crop coefficient curve.

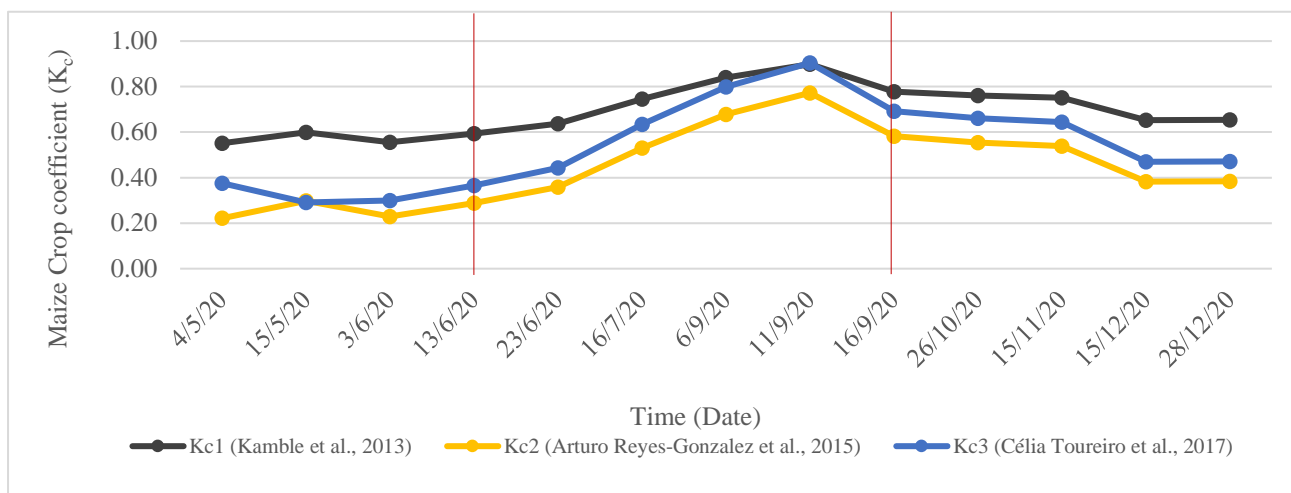


Figure 6 K_c on date of Sentinel-2 satellite image along with maize cultivation calendar in Mae Chaem district in Chiang Mai province.

This part considers the comparison between NDVI- K_c values and RID- K_c as shown in Figure 6. Certainly, the temporal resolution of sentinel-2 images is 10 days. However, the NDVI- K_c values cannot represent the trend of the flowing formation stage because this study lacks satellite images in August. Thus, NDVI- K_c values in this stage are not close to RID- K_c . As a result of the satellite images on some days in the maize, the growing season is affected by cloud cover and this cultivation period is the rainy season. Hence, clouds and rain represent natural obstacles for optical satellite imagery. Many satellite images are not selected to process NDVI- K_c values estimation because values on satellite imagery are not clear and unworkable. Therefore, this study provides the mean NDVI- K_c values from six days by using satellite images in the maize growing season. So, Figure 7 reveal that the NDVI- K_c curve is similar to the RID- K_c curve like a RID line. Alternatively, the NDVI- K_c values in August are missing, the flowing formation stages and grain formation stage is not clear in the NDVI- K_c curve.

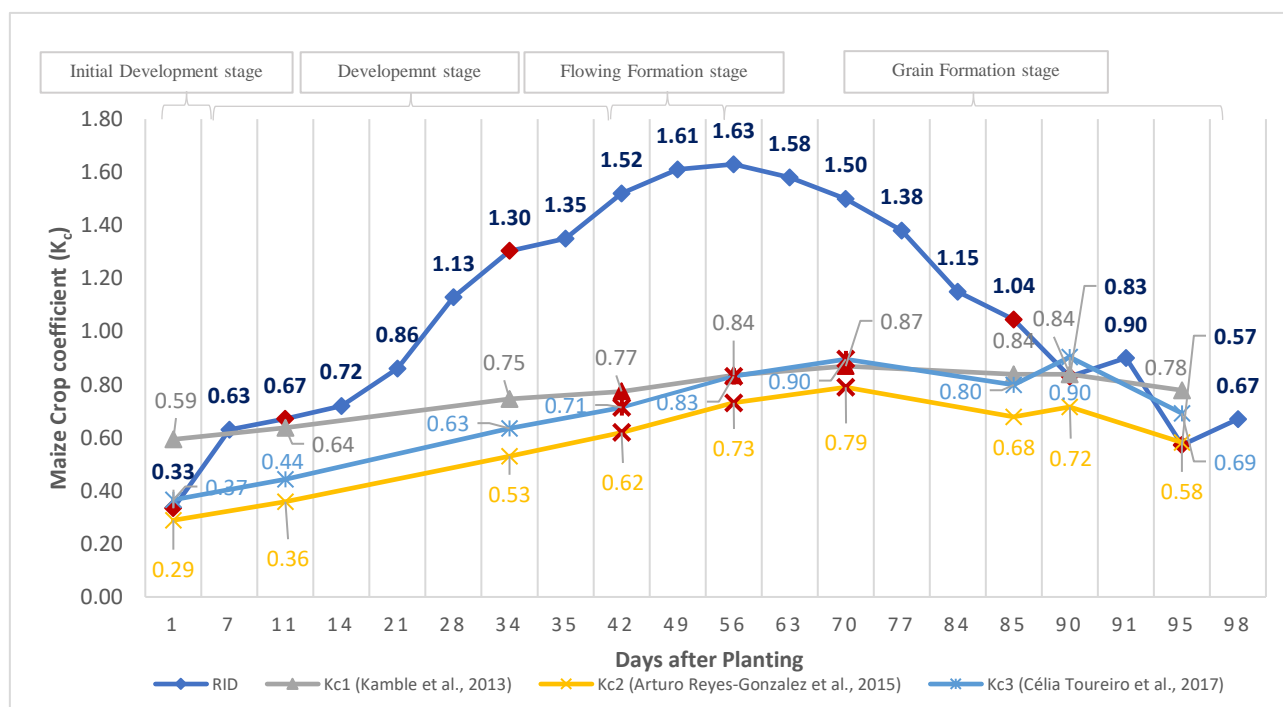


Figure 7 The comparison between NDVI- K_c values and RID- K_c values

From the result of Figure 7, this study improves the functions of the day after planting using third-order polynomial regression from NDVI- K_c values as gray, yellow and light blue light and RID- K_c values as following blue line to estimate K_c of other days in maize growing season. Abedinpour, M. (2015) use a third-order polynomial regression to determine growth stage to specific K_c as well. The missing values of NDVI- K_c and RID- K_c that from a K_c estimation are handled by applying a third-order polynomial regression, the substituted values are shown in the red point in Figure 7. Clearly, the NDVI- K_c curves are likely to RID- K_c curve, which can be applied to calculate CWR. The NDVI- K_c values of 98 days of the growing season are used to estimate CWR for maize cultivation based on maize size area in this study area.

Crop Water Requirement (CWR) according to Eq. (2) is calculated by the sum of the amount of daily water required along with maize cultivation, which NDVI- K_c refer to K_{c1} , K_{c2} and K_{c3} line according to Figure 6. Also, RID- K_c is estimated as following the blue line. The amount CWR of maize cultivation in Changkerng sub-district, Mae Chaem district in Chiang Mai province is shown in Table 4.

Table 4 Crop Water Requirement (CWR) estimation by using NDVI- K_c linear regression from references

References for K_c estimation		Crop Water Requirement		%Accuracy
		m^3	m^3 / rai	
K_{c1}	Kamble et al. (2013)	6,742,113.07	457.46	83%
K_{c2}	Arturo Reyes-Gonzalez et al. (2015)	6,015,910.73	408.19	74%
K_{c3}	Célia Toureiro et al. (2017)	6,948,926.17	471.50	86%

From Table 4, the amount of CWR in 2020 using the NDVI- K_c as K_{c3} linear regression model from Célia Toureiro et al. (2017) is the most as 6,948,926.17 m^3 in Changkerng sub-district area or 471.50 m^3 / rai . Moreover, the result of CWR estimation in this study as simulated values is investigated accuracy assessment with the amount of CWR in Chiang Mai province from RID as observed values as well. The amount of CWR in Chiang Mai province from RID is 550 m^3 / rai , which evapotranspiration in this CWR from the experiment using lysimeter in a maize field. Percent accuracy of CWR using the NDVI- K_c linear regression from Célia Toureiro et al. (2017) is 86 %, which is the most precise.

In addition, the amount of CWR using NDVI- K_c linear regression model from Célia Toureiro et al. (2017) and Kamble et al. (2013) are similar to CWR of RID as both research measure K_c from up-to-date meteorological data. As a result, a linear regression model of both pieces of research is a strong equation to adapt to other areas.

4. Conclusions

This study proposed a remote sensing technique based on the satellite image to develop the NDVI- K_c values model in Changkerng sub-district, Mae Chaem district in Chiang Mai province. The result of this study finds that CWR estimation from NDVI- K_c value using linear regression model from Célia Toureiro et al. (2017) is similar to CWR from RID based on the Chiang Mai province, which percent accuracy is 86 %. So, the crop water requirement of maize cultivated in the Changkerng sub-district is around 471.50 m^3 / rai . NDVI- K_c can assess CWR for maize in the steep slope which is difficult to access water source. Related agencies can use this method proposed in this study to calculated CWR in order to determine water consumption in other agricultural areas. Generally, K_c value from RID is the standard value that is widely used all over the country. In fact, K_c value is a specific value for each area. Hence, the proposed method in this study can estimate specific K_c values based on area. In other words, related agencies can apply satellite imagery to CWR estimation with other areas or other plants. In addition, this method can help related agencies to assess the total losses outside irrigation areas to

support water management in a steep slope.

For limitation of this study, using satellite images do not cover all growing stages. As a result, K_c values do not close to true K_c values on some growing stages. On the other hand, NDVI can help specific K_c estimation for any area using the NDVI- K_c regression model.

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