

## Integration Remote Sensing and Meteorological Data to Monitoring Plant Phenology and Estimation Crop Coefficient and Evapotranspiration

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### ABSTRACT

The water requirements of the wheat crop are represented by the actual evapotranspiration, which depends on the meteorological data of the study area and the amount of water consumed during the season. Estimation of crop coefficients ( $K_c$ ) and evapotranspiration ( $ET_c$ ) using remote sensing data is essential for decision-making regarding water management in irrigated areas in arid and semi-arid large-scale areas. This research aims to estimate the crop coefficient calculated from remote sensing data and the actual evapotranspiration values for the crop. The FAO Penman-Monteith equation has been used to estimate the reference evapotranspiration from meteorological data. Linear regression analysis was applied by developing prediction equations for the crop coefficient for different growth stages of comparing with the vegetation cover index (NDVI). The results showed that ( $R^2 = 0.98$ ) between field crop coefficient and crop coefficient predicted from ( $K_c = 2.0114 \text{ NDVI} - 0.147$ ) in addition to ( $\text{RMSE} = 0.92$  and ( $d = 0.97$ ).

**Keywords:** actual evapotranspiration; crop coefficient; remote sensing; vegetation index.

### INTRODUCTION

Estimating the water requirement of agricultural crops is important for calculating and scheduling the amount of water needed for irrigation. Thus, it is the cornerstone in managing and preserving water resources. The most widespread methods for determining the actual water needs of agricultural crops depend on the use of the reference evapotranspiration and the crop coefficient curve (Abdalkadhum et al., 2020, Acharya and Sharma, 2021). However, one of the most important disadvantages of this method is the difficulty of determining the yield coefficient curve and the lack of published data on this curve for all regions and for all agricultural crops. Remote sensing techniques have developed in the last decade were became used in various fields, the most important of which are agricultural applications, because they provide high accuracy in temporal

and spatial information about the wide cultivated areas, types of agricultural crops, and it also provides a real monitoring system for the crop and its stages of development during the growing season for plants, through vegetation indices like (NDVI, SAVI, RVI, and DVI) (Adamala et al., 2016; Al-Mansoori et al., 2021). Several researchers (Al-face et al. 2019; Allen et al., 1998) have indicated the possibility of using these vegetation indices to calculate the crop coefficient. In central Arizona in the United States of America, a study was conducted (Hunsaker et al., 2003) in which the relationship between the crop coefficient for cotton and NDVI) retrieved from remote sensing data was analyzed. The relationship was initially linear with a correlation coefficient ( $R^2 = 0.97$ ), later, it turned into a curve with a correlation coefficient ( $R^2 = 0.82$ ) at the value (0.80) of the vegetative index (NDVI) which represents the end of the full coverage phase.

The important challenges for agricultural horizontal extending policies and procedures in Iraq are limited water resources and water scarcity. At the same time, population growth is outpacing agricultural land availability. As a result, food quantity and quality diminish. To address this issue, policies of horizontal growth of agricultural fields and activities focused on saving irrigation water to agriculture in another region were implemented (Dingre, Gorantiwar and Kadam, 2021). Crop water requirements must be precisely assessed, irrigation efficiencies must be improved, and high-efficiency irrigation methods such as localized irrigation, scheduling irrigation, cultivating drought-tolerant crops, and cultivating short-term varieties must be used. For water resource planning and irrigation management, data on crop evapotranspiration or consumptive water usage is critical (Rawat and Singh, 2016).

Managing scarce water resources to meet rising demands is trouble in such a scenario. The precise quantification of ETc at regional and local scales can assist in the development of water resource-based decision making and policy, as well as helping in the management of our water resources. ETc is an energy-driven process that is a significant component of the water budget (Trenberth et al., 2007), as well as an important component of irrigation water, need estimation, irrigation planning, and design, soil, and flood management (Allen, Pereira, D Raes, et al., 1998; Abdalkadhum, Salih and Jasim, 2020), water usage efficiency (Yimam, Ochsner and Kakani, 2015; Hassan, Jafaar and Mohamm, 2019), and carbon flux (Yan et al., 2015; Ali, Hassan and Mohammed, 2021). Various highly accurate ETc measurement approaches have been proposed over time, each with its purpose, advantages, and limitations, the most widely used methods for measuring ETc are. Lysimeter (Evelt et al., 2012; Al-Mansoori, Abdalkadhum and Al-Husainy, 2020); the eddy of covariance (Moorhead et al., 2019); Bowen ratio water balance (Irmak, 2010); method of the crop coefficient (Allen et al., 1998 ; Hassan et al., 2021); the vegetation monitoring (sap flow) approach (Smith and Allen, 1996); the energy balance method (Allen et al., 2007; Aljanbi, Dibs and Alyasery, 2020); and the soil water balance method (Gibson, 2002) are some of the frequently utilized approaches. When extrapolating to a regional scale, the footprint of ETc measurement using the aforementioned methods is relatively smaller (Foken and Napo, 2008), which

might cause significant bias. As for Iraq, no previous study was carried out on the use of remote sensing techniques to determine the yield coefficient curve. Therefore, the main objectives of the study are as follows: (1) Using the vegetation cover indicators obtained from Landsat 8 satellite images, estimating the crop coefficient (Kc) Yield evaporation (ETc) of wheat crop in the study area during different growing ages; (2) For different growth stages, mapping of crop coefficient and crop transpiration evapotranspiration across the entire field of study area.

## MATERIALS AND METHODS

### Area of study

The research was carried out in the city of Al-Musayyib, which is located in the center of Iraq in the Babylon Governorate, between latitudes (32°30'–32°50' N) and longitudes (44°–44°20' E) at a height of (32) meters above sea level. The total area of the city is 48936.701 hectares and the cultivated area is 25916.896 hectares, Figure 1. The city of Al-Musayyib is located on the eastern and western banks of the Euphrates River, which is divided into Al-Hindiya and Al-Hilla branches south of the city.

### Climatic conditions

The average annual temperature in the city of Musayyib is (31°C), and temperatures reach their lowest values in January with an average of (-1 °C) and reach their highest values in August with an average of (48 °C), and the average annual rainfall is approximately (21 mm), and most of the precipitation occurs In the period between December and March, the relative humidity ranges between (36 %) in July to (88%) in February, and the wind speed in the city ranges between (1.6 m/s) in January and (3 m/s) in July, with an average of (2 m/s) (need reference).

### Data collection

Meteorological data were collected from meteorological stations to calculate the reference evapotranspiration. Five of Landsat-8 satellite images (path 168/row 37) were downloaded from <https://earthexplorer.usgs.gov/> around 10:30 a.m. local time with a resolution of 30 m.

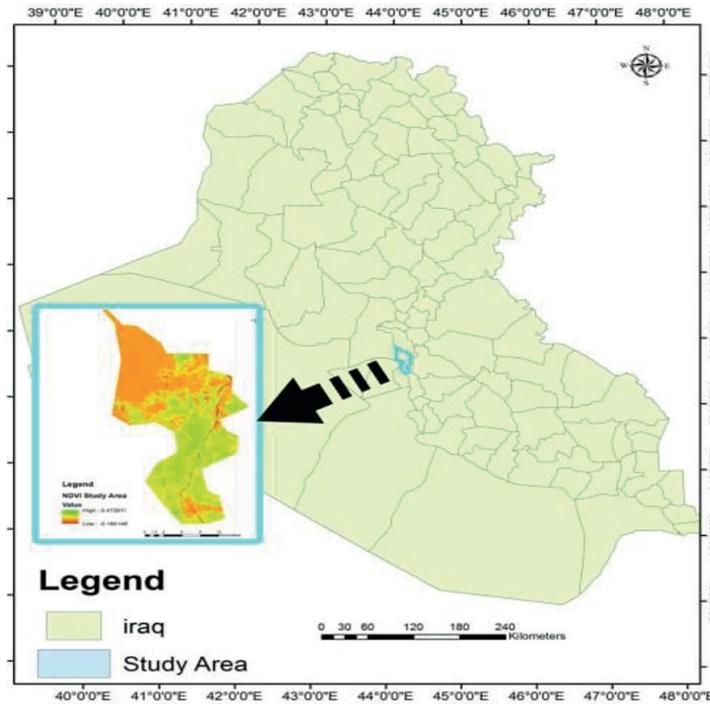


Figure 1. Area of study

during winter and spring seasons were used to calculate normalized difference vegetation index NDVI. The satellite imageries were acquired on Jan. 3<sup>th</sup>, 2020. Feb. 4<sup>th</sup>, 2020. Mar. 32<sup>th</sup>, 2020, Apr. 8<sup>th</sup>, 2020, and May. 10<sup>th</sup>, 2020.

### METHODOLOGY

The relationship for both NDVI and  $K_c$  is observable. The  $K_c$  curve's similarity to a satellite-derived vegetation index revealed the possibility of modeling  $K_c$  as a function of the vegetation index. As a result, the feasibility of determining  $K_c$  directly from a crop's satellite reflectance was studied (Hubbard, 2013). Bands 4 and 5 of Landsat-8 provide red and near-infrared measurements, therefore they can be utilized to generate NDVI data using the formula (Rouse J., Schell J.A., Deering D.W., 1973):

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

where:  $\rho_{Red}$  is the reflectance in the 4 bands (red band);

$\rho_{NIR}$  is the reflectance in the 5 bands (near-infrared band).

Crop coefficient values were determined based on the actual calculated evapotranspiration

( $ET_c$ ) and the reference evapotranspiration ( $ET_o$ ) using the relationship:

$$K_c = ET_c / ET_o \quad (2)$$

The actual evapotranspiration ( $ET_c$ ) was estimated from the following water balance equation:

$$I + P + CR = ET_c + R_0 + \Delta P + \Delta \theta Z \quad (3)$$

where:  $I$ : Amount of irrigation water (mm)

$P$ : Amount of precipitation (mm)

$CR$ : Water obtained by the plant by capillary action (mm)

$ET_c$ : Actual evapotranspiration (mm)

$R_0$ : Runoff (mm)

$\Delta P$ : deep deposition (mm)

$\Delta \theta$ : Moisture change during the period during which the evapotranspiration is to be calculated (%)

$Z$ : Effective depth of roots during the studied period (mm)

The values of each of the surface runoff and water obtained by the plant by capillary action were considered equal to zero (the land is flat and the groundwater is deep). The values of ( $ET_o$ ) were calculated using the equation (Penman-Monteith) (Allen, Pereira, Dirk Raes, et al., 1998; Acharya and Sharma, 2021) soil moisture, or groundwater. Over the years, various remote sensing-based surface energy balance (SEB based on the meteorological data at the

meteorological station in the city of Musayyib for the studied agricultural season.

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \left(\frac{900}{T+273}\right) u_2 (e_s - e_a)}{\Delta + \gamma(1+0.3\mu_2)} \quad (4)$$

In this study, shown in Figure (2), three stages were worked. The first stage was the field measurement of the crop coefficient and the calculation of ( $ET_o$ ) and ( $ET_c$ ) based on meteorological data and equation (2). In the second stage, finding a prediction equation between remote sensing data and crop coefficient data it was measured on the same day that the satellite images were acquired, and finally through the prediction equation and meteorological data ( $ET_c$ ) was calculated and compared with equation (3), then maps were made for each of the crop coefficient and ( $K_c$ ) and actual evapotranspiration ( $ET_c$ ) on the periods of plant growth.

## RESULTS AND DISCUSSIONS

### Normalized Difference Vegetation Index

Figure 3 shows the measured NDVI values of wheat during the growth stages. In general, the NDVI values were low in the early stages of plant growth, and the reason for the low value is that it is mainly related to the vegetative total of the plant (Gutman, 1991). Then the value increased with the growth stage of the plant and reaching the maximum vegetative growth during the flowering stage in April. Then it decreased at the end of the season to a lower value, that is, in the stage of maturity. NDVI values ranged between (0.29–0.62). These results were consistent agree with (Guan et al., 2019; Hassan et al., 2019; Thapa et al., 2019; Naser et al., 2020) as the phenological stages of

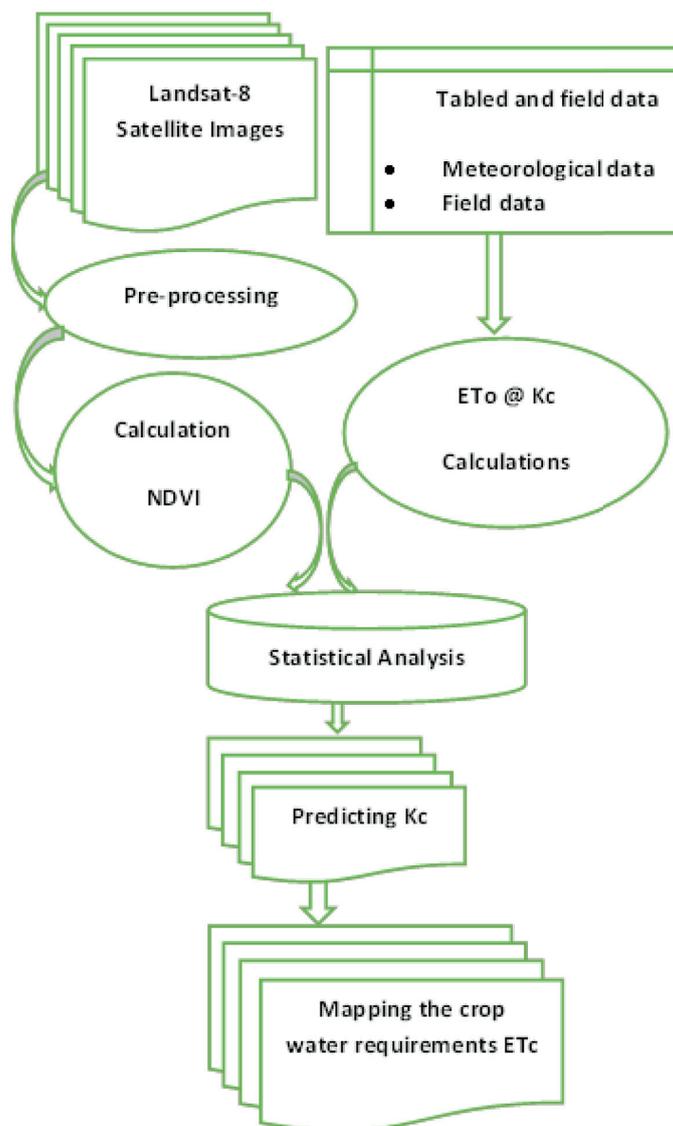


Figure 2. The flowchart of methodology

the wheat plant in the study area were (0.29) for the plant stage during January, then increased to reach (0.44) in March in the vegetative growth stage and reached (0.63) in April during the maturity stage during May. We note that the values are less than (0.2) due to the presence of desert areas as well as the Hilla River within the study area. The results of the NDVI in Figure 3 shows,

there is a variation in the density of vegetation cover during the study period, and the reason for this is due to the change in plant growth with time and the change in the prevailing climate in the study area, which has a significant impact on plant growth, as the basic principle on which the NDVI indicator is based on strong reflection of healthy plants based on chlorophyll at near-infrared

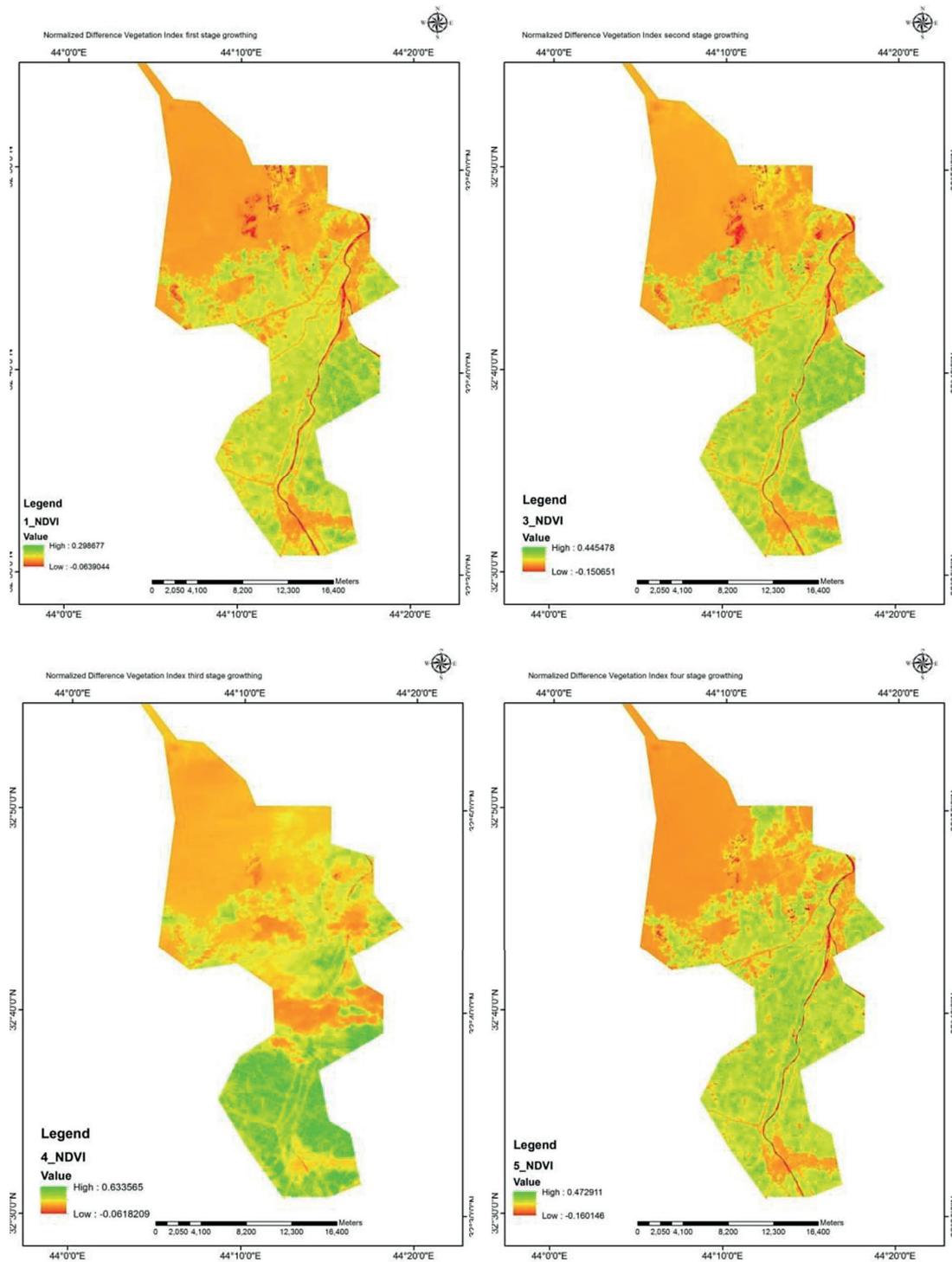


Figure 3. Growth stages for the normalized difference vegetation index (NDVI)

wavelengths and its relatively weak reflection in the visible red color. On the other hand shows the temporal variability in the average NDVI over the study period, as the red light is strongly absorbed by photosynthetic pigments (such as chlorophyll) present in green leaves, while near-infrared light passes or is reflected through leaving the tissue, regardless of its color. This means that the areas with bare soil in the early stages of plant growth that have little or no green space cover are similar in reflectance for both wavelengths. Figure 3 shows the NDVI maps for the period of the study area.

### Crop coefficient

Figure 4 shows the crop coefficient ( $K_c$ ) curve calculated from the equation based on the crop evapotranspiration ( $ET_c$ ) and the reference evapotranspiration ( $ET_o$ ) calculated from the Penman-Monteith equation. The crop coefficient calculated from the prediction equation for the study area was equation (2) and the crop coefficient was calculated from satellites. The lowest values of the crop coefficient were during the season in January, then this value started increasing until it reached the highest value during the flowering stage (1.13) and then decreased during the maturity stage to reach (0.72) When comparing the crop values extracted from remote sensing data and the values of the actually measured crop coefficient and the values taken from the FAO data, it was found that the crop coefficient is (0.3, 0.4, 0.42) for each of ( $Kc_{Fao}$ ,  $Kc_{sat}$ ,  $Kc_{cal}$ ) respectively at the germination stage, then the values increase to reach (0.6, 0.5, 0.65) for each of ( $Kc_{Fao}$ ,  $Kc_{sat}$ ,  $Kc_{cal}$ ) on successively at the stage of vegetative growth and continued

to rise to reach values of more than 1, a stage in which the value of the actual evapotranspiration increases over the value of the reference evapotranspiration, as it reached (1.15, 1.06, 1.13) for each of ( $Kc_{Fao}$ ,  $Kc_{sat}$ ,  $Kc_{cal}$ ) at the flowering stage, but at the maturity stage and because of cutting irrigation at this stage, the values of the crop coefficient will return It decreased as it reached (0.4, 0.74, 0.72) at the maturity stage for each of ( $Kc_{Fao}$ ,  $Kc_{sat}$ ,  $Kc_{cal}$ ) respectively. It is clear from the above data that there were no significant differences between the values of ( $Kc_{sat}$ ,  $Kc_{cal}$ ) and they differed slightly from the values of ( $Kc_{Fao}$ ).

It is clear from the above that this factor varies according to the different growth stages of the crop and climatic conditions, as it is affected by the factors that affect the plant density and the coverage ratio of the earth's surface, which are affected by the leaf area, the part of the land covered by vegetation cover, the age of the leaves, the opening and closing of the stomata, and the moisture of the soil surface, which were negatively affected by these characteristics. In irrigation, this was mentioned in the characteristics of vegetative growth that were affected under irrigation management. The FAO (1986) showed that the values of the wheat crop coefficient ranged from 0.3 to 1.87, depending on the climatic data of the agricultural season. The decrease in the values of the crop coefficient  $K_c$  at the stage of physiological maturity due to a decrease The crop's need for water due to the old age of the leaves and the low efficiency of the roots in absorbing water, while the values of the crop coefficient  $K_c$  increased in the early stages of plant growth due to the concentration of water

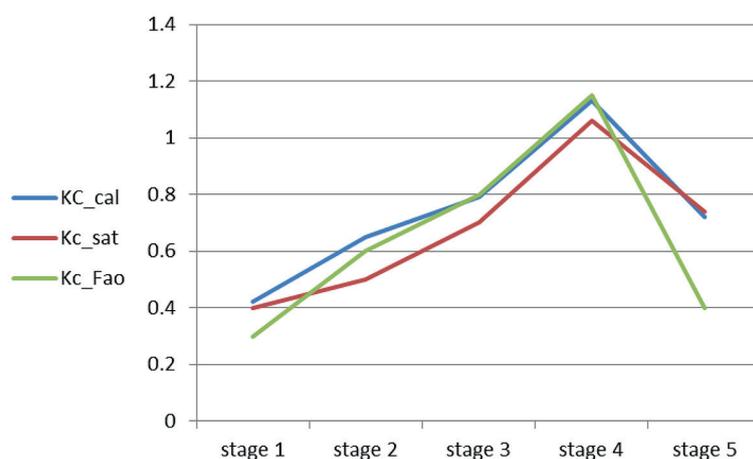


Figure 4. The trend of  $K_c$  and predicted  $K_c$  for the different growth stages

consumption through evaporation from the soil surface, which leads to an increase in the values of *E<sub>Tc</sub>* over the values of the reference evapotranspiration (Fraenkel, 1986).

### Study of the relationship between (*K<sub>c</sub>*) and (NDVI)

The relationship between the crop coefficient *K<sub>c</sub>* was field-measured and (NDVI) calculated from satellite images in the same period was studied. Figure 5 shows a great agreement between the *K<sub>c</sub>* and NDVI curves in terms of behavior during the growth stages, where the values of *K<sub>c</sub>* and NDVI were low in the germination stage, then these values increased to achieve their highest values in the flowering stage and then decreased to their lowest value before harvest. The correlation between the values of *K<sub>c</sub>* and NDVI

was also studied during the months from January to May, and the correlational relationship in the study area was ( $K_c = 2.0114NDVI - 0.147$ ) with a correlation coefficient ( $R^2=0.96$ ). This predictive equation is in agreement with (Er-Raki et al., 2007; Campos et al., 2010). The difference in the constants of the equation is due to the different types of crop and climatic conditions in the study areas (Figure 6).

### Crop Evapotranspiration (E<sub>Tc</sub>)

Figure 7 shows the daily crop evapotranspiration *E<sub>Tc</sub>* values measured by the water budget method, the crop evapotranspiration measured by remote sensing data, and the values extracted from the FAO data. Where the data were low at the beginning of the season to reach the highest value (8.5 mm/day), while the maximum values

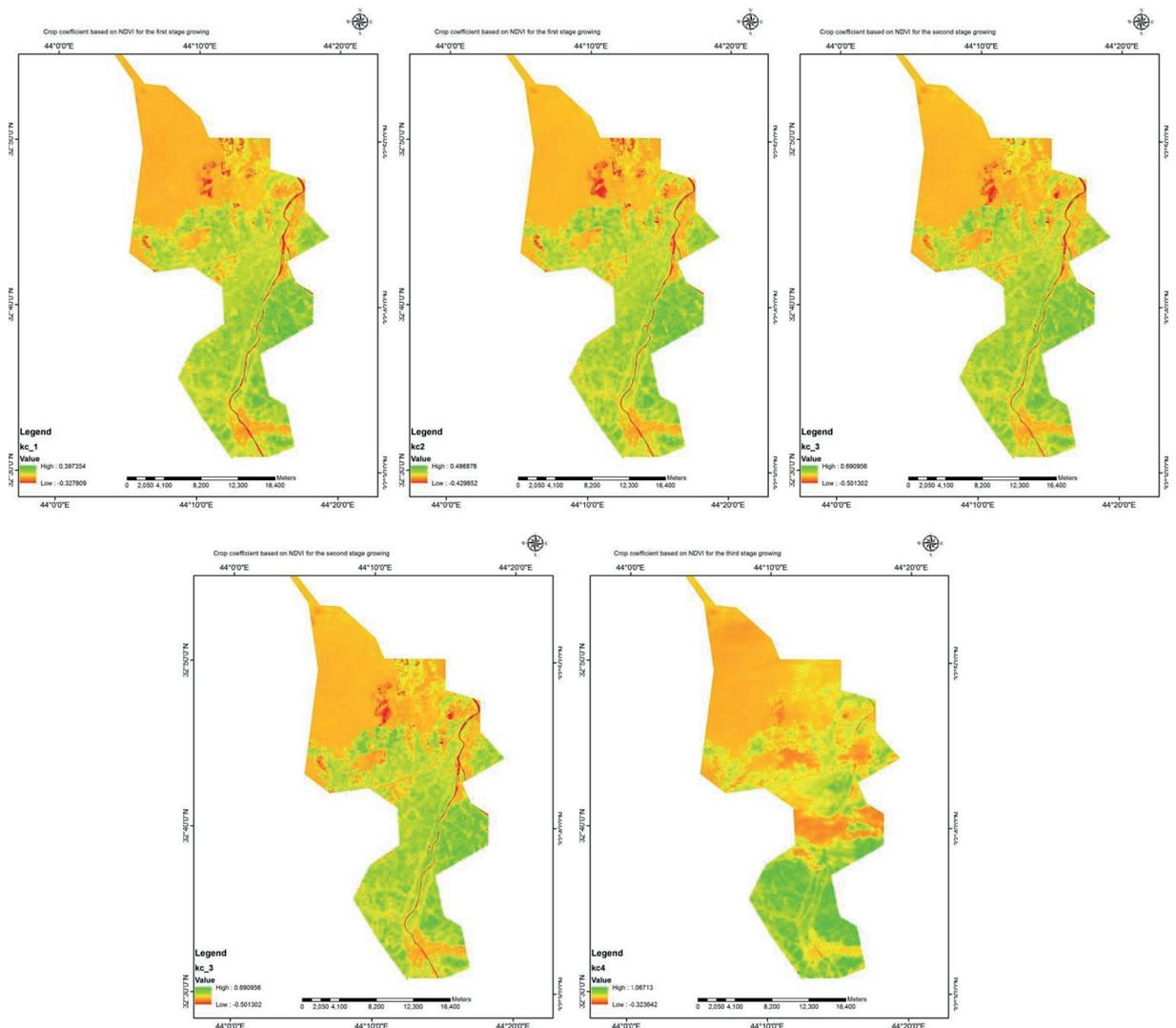


Figure 5. The predicted crop coefficient *K<sub>c</sub>* for growth stages

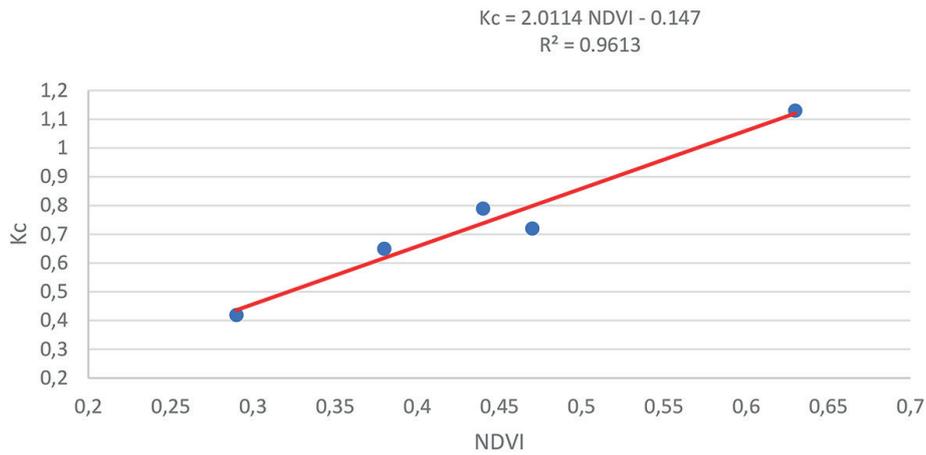


Figure 6. Relationship between ( $K_c$ ) and (NDVI)

of crop evapotranspiration in the days of capturing the satellite image in January, February, March, April, and May (1.21, 2.86, 5.61, 7.91, 8.5 mm/day) respectively, while the extracted from remote sensing data reached (1.15, 2.18, 4.9, 7.46, 8.8 mm/day) on Consecutively, there were significant, as its statistical criteria (RMSE, d) reached (0.98, 0.92, 0.97 ) when comparing between ( $ETc_{Satellite}$ ,  $ETc_{Calculat}$ ) while the values of ( $ETc_{Satellite}$ ,  $ETc_{FAO}$ ) reached (0.78, 1.89, 0.86) respectively during the study period. As for the statistical criteria when comparing ( $ETc_{Calculat}$ ,  $ETc_{FAO}$ ) were (0.64, 1.92, 0.83) respectively, and the difference between ( $ETc_{Satellite}$ ,  $ETc_{FAO}$ ) was very little. It is clear from the results that the statistical criteria were better when comparing between ( $ETc_{Satellite}$ ,  $ETc_{FAO}$ ) compared to the presence of FAO values, and the reason for this is the high drop in crop evapotranspiration at the maturity stage mentioned by FAO, while it was high at ( $ETc_{Calculat}$ ,

$ETc_{FAO}$ ) due to the different stages of maturity added to the changes climatic.

It can be seen from the results obtained, we can say that the actual crop evapotranspiration  $ETc$  of the crop varies according to the stages of growth, the number of days of the growth stage, the number of irrigations in it, and the increase in plant size, height and leaf area. The results show that the actual crop evapotranspiration values increased in the flowering stage, due to the increase in plant height, increase in leaf area, and almost complete vegetative growth stage, which caused an increase in evapotranspiration (Figure 8).

## CONCLUSIONS

The method of determining the crop coefficient ( $K_c$ ) based on (NDVI) is a good way to determine the crop coefficient. It is a simple method compared to other methods used

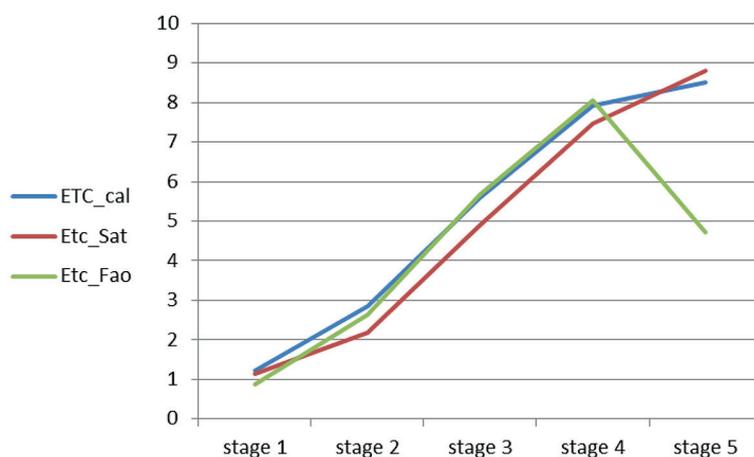


Figure 7. The trend of  $ETc$  and predicted  $ETc$  for the different growth stages

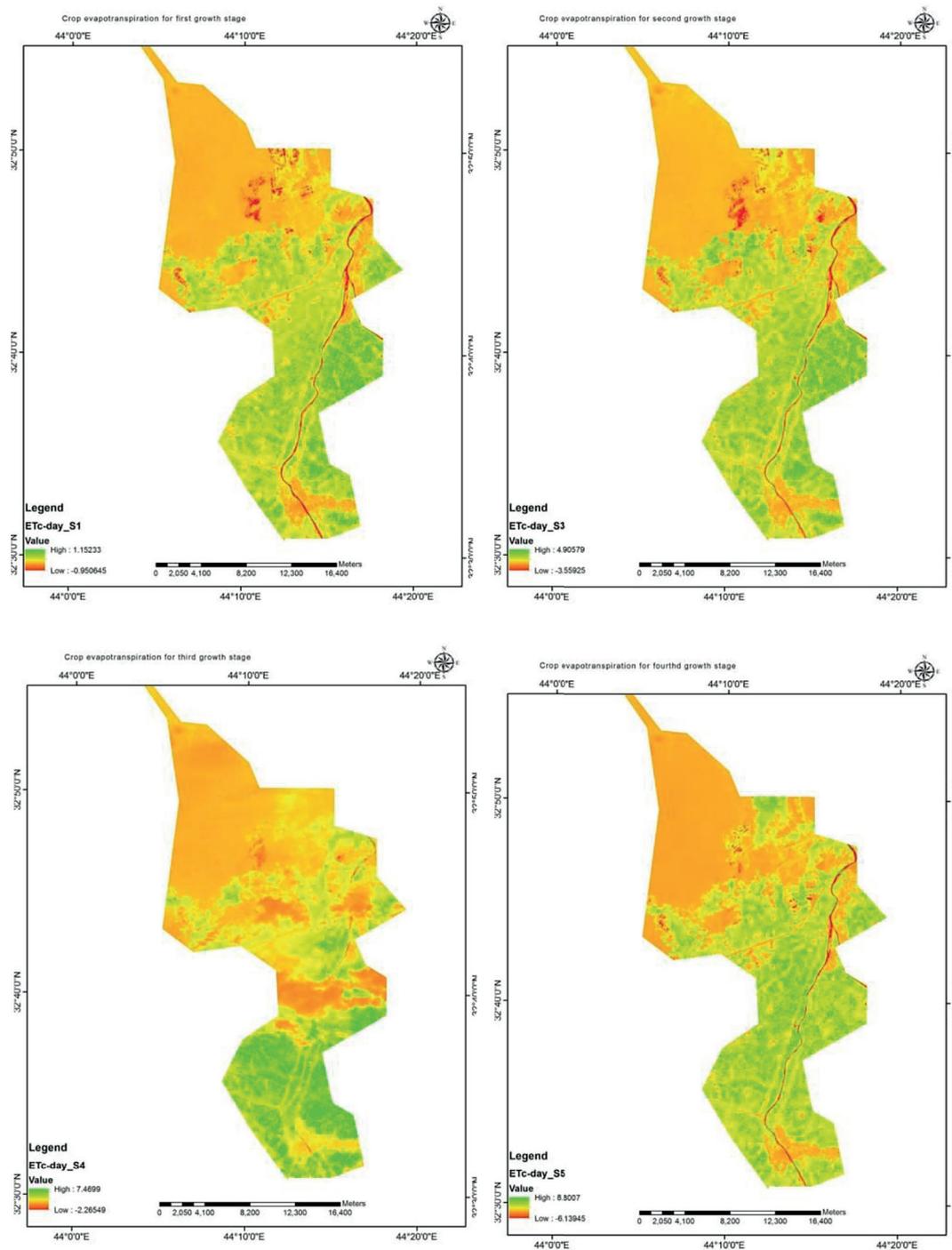


Figure 8. The predicted crop evapotranspiration ETc for growth stages

in determining (Kc) such as field methods, or relying on the publications of the FAO, and one of its most important features is the ease of obtaining (NDVI) values, whether through satellite images such as Landsat-8 images or measurement using terrestrial sensors. But it should be noted that equation (2) is valid for the conditions of the study area and the studied crop only, and other studies must be conducted in different areas on wheat or different crops.

## REFERENCES

1. Abdalkadhum A.J., Salih M.M., Jasim O.Z. 2020. Combination of visible and thermal remotely sensed data for enhancement of Land Cover Classification by using satellite imagery', in IOP Conference Series: Materials Science and Engineering. IOP Publishing, 12226.
2. Acharya B., Sharma V. 2021. Comparison of satellite driven surface energy balance models in

- estimating crop evapotranspiration in semi-arid to arid inter-mountain region. *Remote Sensing*. DOI: 10.3390/rs13091822
3. Adamala S., Rajwade Y.A., Reddy Y.V.K. 2016. Estimation of wheat crop evapotranspiration using NDVI vegetation index. *Journal of Applied and Natural Science*, 8(1), 159–166.
  4. Al-Mansoori T., Abdalkadhum A., Al-Husainy A.S. 2020. A GIS-Enhanced pavement management system: a case study in Iraq. *Journal of Engineering Science and Technology*, 15(4), 2639–2648.
  5. Alfaca A.B. et al. 2019. Sugarcane spatial-temporal monitoring and crop coefficient estimation through NDVI. *Revista Brasileira de Engenharia Agrícola e Ambiental*. *SciELO Brasil*, 23, 330–335.
  6. Ali Z.A., Hassan D.F., Mohammed R.J. 2021. Effect of irrigation level and nitrogen fertilizer on water consumption and faba bean growth', in *IOP Conference Series: Earth and Environmental Science*. IOP Publishing, 12043.
  7. Aljanbi A.J.A., Dibs H., Alyasery B.H. 2020. Interpolation and statistical analysis for evaluation of global earth gravity models based on GPS and orthometric heights in the middle of Iraq. *Iraqi Journal of Science*, 1823–1830.
  8. Allen R.G., Pereira L.S., Raes, Dirk, et al. 1998. Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. *Fao, Rome*, 300(9), D05109.
  9. Allen R.G. et al. 2007. Satellite-based energy balance for mapping evapotranspiration with internalized calibration (METRIC)—Applications. *Journal of irrigation and drainage engineering*. *American Society of Civil Engineers*, 133(4), 395–406.
  10. Campos I. et al. 2010. Assessing satellite-based basal crop coefficients for irrigated grapes (*Vitis vinifera* L.). *Agricultural Water Management*. Elsevier, 98(1), 45–54.
  11. Dingre S.K., Gorantiwar S.D., Kadam S.A. 2021. Correlating the field water balance derived crop coefficient (Kc) and canopy reflectance-based NDVI for irrigated sugarcane. *Precision Agriculture*. Springer, 1–20.
  12. Er-Raki S. et al. 2007. Combining FAO-56 model and ground-based remote sensing to estimate water consumptions of wheat crops in a semi-arid region', *Agricultural water management*. Elsevier, 87(1), 41–54.
  13. Evett S.R. et al. 2012. Can weighing lysimeter ET represent surrounding field ET well enough to test flux station measurements of daily and sub-daily ET? *Advances in Water Resources*. Elsevier, 50, 79–90.
  14. Foken T., Napo C.J. 2008. *Micrometeorology*, Springer.
  15. Fraenkel A.P. 1986. FAO irrigation and drainage paper 43: water lifting. *Food and Agriculture Organization of the United Nations, Rome*.
  16. Gibson J.J. 2002. Short-term evaporation and water budget comparisons in shallow Arctic lakes using non-steady isotope mass balance. *Journal of Hydrology*. Elsevier, 264(1–4), 242–261.
  17. Gilabert M.A. et al. 2002. A generalized soil-adjusted vegetation index. *Remote Sensing of environment*. Elsevier, 82(2–3), 303–310.
  18. Guan S. et al. 2019. Assessing correlation of high-resolution NDVI with fertilizer application level and yield of rice and wheat crops using small UAVs. *Remote Sensing*. *Multidisciplinary Digital Publishing Institute*, 11(2), 112.
  19. Gutman G.G. 1991. Vegetation indices from AVHRR: An update and future prospects', *Remote Sensing of environment*. Elsevier, 35(2–3), 121–136.
  20. Hassan D.F., Jafaar A.A., Mohamm R.J. 2019. Effect of irrigation water salinity and tillage systems on some physical soil properties. *Iraqi Journal of Agricultural Sciences*. *College of Agriculture, University of Baghdad*, 50(Special Issue), 42–47.
  21. Hassan D.F., Ati A.S., Neima A.S. 2021. Calibration and Evaluation of Aquacrop for Maize (*Zea Mays* L.) under Different Irrigation and Cultivation Methods. *Journal of Ecological Engineering*, 22(10), 192–204. <https://doi.org/10.12911/22998993/142123>
  22. Hassan M.A. et al. 2019. A rapid monitoring of NDVI across the wheat growth cycle for grain yield prediction using a multi-spectral UAV platform, *Plant science*. Elsevier, 282, 95–103.
  23. Hubbard B.K.A.K.K. 2013. Estimating Crop Coefficients Using Remote Sensing-Based Vegetation Index. *Remote Sensing*, 1588–1602. <https://doi.org/10.3390/rs5041588>
  24. Hunsaker D.J. et al. 2003. Estimating cotton evapotranspiration crop coefficients with a multispectral vegetation index. *Irrigation science*. Springer, 22(2), 95–104.
  25. Irmak S. 2010. Nebraska water and energy flux measurement, modeling, and research network (NEBFLUX)', *Transactions of the ASABE*. *American Society of Agricultural and Biological Engineers*, 53(4), 1097–1115.
  26. Lima J.G.A. et al. 2021. Water requirement and crop coefficients of sorghum in Apodi Plateau. *Revista Brasileira de Engenharia Agrícola e Ambiental*. *SciELO Brasil*, 25, 684–688.
  27. Moorhead J.E. et al. 2019. Evaluation of evapotranspiration from eddy covariance using large weighing lysimeters', *Agronomy*. *Multidisciplinary Digital Publishing Institute*, 9(2), 99.
  28. Naser M.A. et al. 2020. Using NDVI to differentiate wheat genotypes productivity under dryland and irrigated conditions. *Remote Sensing*. *Multidisciplinary Digital Publishing Institute*, 12(5), 824.

29. Niu H., Wang D., Chen Y. 2020. Estimating crop coefficients using linear and deep stochastic configuration networks models and UAV-based Normalized Difference Vegetation Index (NDVI). In: 2020 International Conference on Unmanned Aircraft Systems (ICUAS). IEEE, 1485–1490.
30. Rawat K.S., Singh S.K. 2016. Retrieval of Kc from SEBAL and comparison among NDVI and LAI based methods. *Bulletin of Environmental and Scientific Research*. *Bulletin of Environmental and Scientific Research (BESR)*, 5(2).
31. Rouse J., Schell J.A., Deering D.W.H.R.H. 1973. Monitoring vegetation systems in the great plains with ERTS. In: *Proceeding of the “3rd ETRS Symposium”*, NASA SP-351 1, US Government Printing Office, Washington, DC, USA, 309–317.
32. Smith D.M., Allen S.J. 1996. Measurement of sap flow in plant stems’, *Journal of Experimental Botany*. Oxford University Press, 47(12), 1833–1844.
33. Thapa S. et al. 2019. Use of NDVI for characterizing winter wheat response to water stress in a semi-arid environment’, *Journal of Crop Improvement*. Taylor & Francis, 33(5), 633–648.
34. Trenberth K.E. et al. 2007. Estimates of the global water budget and its annual cycle using observational and model data. *Journal of Hydrometeorology*. American Meteorological Society, 8(4), 758–769.
35. Yan H. et al. 2015. Improved global simulations of gross primary product based on a new definition of water stress factor and a separate treatment of C3 and C4 plants. *Ecological modelling*. Elsevier, 297, 42–59.
36. Yimam Y.T., Ochsner T.E., Kakani V.G. 2015. Evapotranspiration partitioning and water use efficiency of switchgrass and biomass sorghum managed for biofuel. *Agricultural Water Management*. Elsevier, 155, 40–47.
37. Zhang Y. et al. 2019. Maize crop coefficient estimated from UAV-measured multispectral vegetation indices. *Sensors*. Multidisciplinary Digital Publishing Institute, 19(23), 5250.