

ESTIMATION OF CROP COEFFICIENT VARIATION THROUGH SATELLITE VNIR SPECTRAL DATA

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ABSTRACT

Crop coefficient is a principle factor to estimate crop water consumption. Traditionally K_c estimated from $K_c = ET_c/ET_o$ or from the FAO table. The aim of this paper is to develop a simple model to estimate K_{cNDVI} using remote sensing technique. To develop such model this work was cared out in salhia area on three winter crops wheat, potato and sugar beet, on certain dates of their growing seasons of 2013-2014. Landsat 8 and Landsat7, the Enhanced Thematic Mapper Plus (ETM+) satellites were used to generate NDVI values on these dates. The values of NDVI and the K_c estimated from $K_c = ET_c/ET_o$ were used to established K_{cNDVI} equation. The following equation $K_{cNDVI} = 1.259 NDVI + 0.034$ is the developed model with $r = 0.92$. To validate this model the values of K_c predicted using it at six dates on wheat and potato crops raised on same site on 2014-2015 growing season was compared with estimated K_{cFAO} on same dates. The validation give a good results with $r = 0.98$ for the two crops.

Keywords: Normalized deference vegetation index (NDVI), landsat8, Landsat 7 ETM+; Crop coefficient (K_c).

INTRODUCTION

Egypt is facing and continues to face serious water shortage, which necessitate an optimum water management for various water uses. Agriculture depends mainly on irrigation. therefore the optimization of crop water consumption is a must. Crop evapotranspiration (ET_c) is used to estimate water needs. ET_c is a function of two parameters reference evapotranspiration (ET_o), and crop coefficient (K_c).

$$ET_c = ET_o \times K_c \quad (1)$$

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ET_0 have traditionally been derived from meteorological data. The reference crop is typically grass or alfalfa under well-watered conditions. The height of the grass reference should be at least 8 and no more than 15 cm (Allen et al., 2005). K_c values are specific to each crop. During the crop growing season, the value of K_c for most agricultural crops takes upward trend from a minimum value at germination, and expressed as a smooth continuous function in time until a maximum K_c is reached at about full canopy cover and then tends to decline at a point after reached the full cover in the growing season (Kamble et al., 2013).

The traditional method to calculate K_c by applying the eq.1 where K_c is the ratio of ET_c to ET_0 . The United Nations Food and Agriculture Organization (FAO) established tables of K_c for different crops which could be used in water management. Recently remote sensing technique is considered an important tool to estimate K_c . The researchers found that the relationships between vegetation indices (VI) and crop coefficients (K_{cs}) are usually observed for the single crop coefficient. VI was developed with the launch of the first satellites used for vegetation monitoring in the early 1970s (Rouse et al., 1973; Huete and Glenn, 2011). The relations (K_c -VI) have been developed for individual and mixed crops in agricultural regions starting nearly 30 years ago (Neale, 1983). Tasumi and Allen (2007) explained that satellite-based remote sensing is a robust, economic and efficient tool for estimating actual ET and developing K_c curves. This technique can cover large scale of fields at the same time so that large populations of ET_0 and K_c can be used to develop representative mean values. Normalized difference vegetation index (NDVI) one of the most common VI. It has been used extensively for crop yield assessment, vegetation monitoring and drought detection, Higher NDVI indicates a greater level of photosynthetic activity (Sellers 1985; Tucker 1979). The NDVI captures the sharp contrast in reflection of light from green leaves between the Red and NIR wavelengths. Red light is strongly absorbed by chlorophyll a and b in leaves, interacting mostly with the top layers of a dense canopy, but nearly all of the NIR is transmitted, reflected or scattered by the mesophyll structure in leaves, penetrating deep into the canopy and interacting with multiple leaf layers

(Glenn et al., 2008). This light is received by a downward-looking sensor sensitive to the NIR band. Most of the satellites have sensors that can measure in visible and near infrared region (El-Shirbeny et al., 2014). Many studies have shown a high correlation between NDVI and biophysical characteristics of plants, including fractional cover (f_c), leaf area index (LAI); chlorophyll content; and wet and dry biomass (Glenn et al., 2008). NDVI is also strongly correlated with physiological processes that depend on light absorption by the canopy, including ET, yield, or net and gross primary productivity. NDVI values fall between -1.0 and +1.0, tacking negative values with water, slightly positive values with soil, and vegetation having increasingly high values approaching 0.95 for very dense vegetation cover (Bannari et al., 1995). Many of researchers have used multispectral vegetation indices extracted from remote sensing to estimate K_c values at the field scale for maize, wheat, cotton (Hunsaker et al., 2005, Bausch and Neale 1989, El-Shirbeny et al., 2014), and beans (Irmak 2010). (Bausch and Neale 1989) produced application of ground based physical remote sensing technique to relate seasonal NDVI to K_c . The main aim of this study is a) to investigate the applicability of time-series Landsat8 and Landsat7 NDVI data to develop a simple model to calculate K_c values under the Egyptian conditions and b) to validate the results by comparing it with $K_{c\text{ FAO}}$ values which adjusted for local climate conditions.

MATERIALS AND METHODS:

Study Area

El-Salhia project was selected as a study area which is located at the eastern part from Nile Delta a. It is bounded by $30^{\circ} 22' 35''$ and $30^{\circ} 31' 19''$ latitudes and $31^{\circ} 55' 24''$ and $32^{\circ} 02' 38''$ longitudes as shown in Fig. 1. The whole area of the project is about 32857 Fed. Two irrigation systems are in use in the project; central pivots and drip irrigation. Pivot irrigation is used for field crops and drip irrigation is used for orchards trees. The project has about 100 pivots. Each pivot unit irrigates an area of about 151 Fed. The common pivots length in the project is about 450 meter.

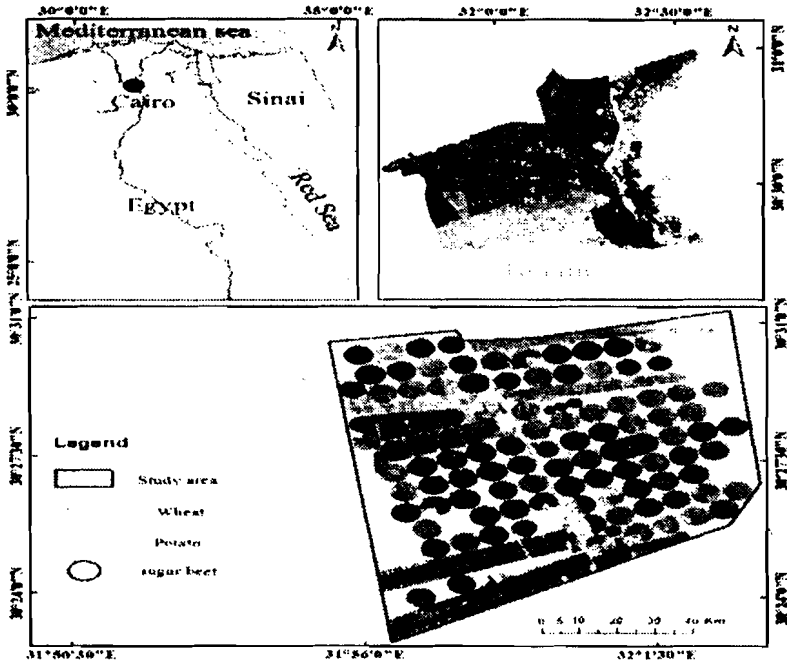


Fig. 1: Location map of the study area

Climate Conditions

In general, the climate in study area is a dry arid according to Köppen Climate Classification System, where precipitation is less than 50% of potential evapotranspiration. Annual average temperature is over 18°C. The average rainfall is approximately 20 mm/year. The maximum values of rainfall are registered in January with an average value of 6.9 mm. The average maximum value of temperature reach 34.6°C in June while January represents the coldest month 19.0 °C.

Remote Sensing Data Availability

A series of Landsat8 and Landsat 7 ETM+ data were collected from the U.S. geological survey earth explorer site (<http://earthexplorer.usgs.gov/>) to calculate NDVI and water deficit index (WDI). For model development satellite data of winter season 2013-2014 was used on Dec. 17th, 2013, Jan. 2nd, 2014, Feb. 11th, 2014, Mar. 15th, 2014, Mar. 31st,

2014, Apr. 16th, 2014 and May. 2nd, 2014. Three cultivated crops wheat, sugar beet, potato were raised and taken for this investigation.

For validating the results the same procedures was carried out for 2014-2015 winter season but only for two crops raised in this season wheat, potato. Satellite data for model validation were acquired on Dec. 4th, 2014, Dec. 12th, 2014, Dec. 28th, 2014, Jan. 29th, 2015, Feb. 6th, 2015, Mar. 2nd, 2015, Apr. 3rd, 2015, Apr. 19th, 2015 and May. 5th, 2015.

Model Development

Crop coefficient (K_c) estimation using traditional method:

K_c is a factor which indicates the ratio between the (ET_c) and the (ET_o). It depends on many parameters such as crop type, crop stage and crop management. So, the K_c can be estimated from the following equation:

$$K_c = \frac{ET_c}{ET_o} \quad (2)$$

WDI and ET_c Estimation:

ET_c was estimated by using the following relation between both of ET_c, ET_a and the Water Deficit Index (WDI) which account for soil moisture content and is an indicator for water shortage and stress effect on the crop.

$$WDI = 1 - \left(\frac{ET_a}{ET_c} \right) \quad (3)$$

Where: WDI is the water deficit index (dimensionless), ET_a, is the actual crop evapotranspiration (mm/day) and ET_c is the crop evapotranspiration (mm/day).

Remote sensing is a promising tool which introduces vital information about the surface and reflects the actual statue of the different surface features due to different conditions and heterogeneity. ET_c was estimated by using eq. 3 and produced in map format using remote sensing satellite data. ET_a was estimated using of the triangle method which was proposed by (Jiang and Islam 1999, 2001) and improved by (Jiang and Islam, 2003). This method is based on the P-T (Priestley-Taylor) equation and represents a simplified remote sensing model for ET_a estimation. This method was applied at this study area in the 2013/2014 winter season by (Baïoumy et al., 2016) and he got responsible results in estimating ET_a

using this method. Vegetation and water stress indexes calculated based on remotely sensed data can provide spatial and temporal information. When water becomes limited the ET_a rate will fall below the potential rate. (Moran et al., 1994). The WDI ranges from 0 (no stress) to 1 (maximum stress).

Reference evapotranspiration ET_o calculation:

Daily calculation of the ET_o is one of the most important tools used to determine the water requirements of different crops. Penman-Monteith equation adopted by the FAO as one of the methods used to estimate the ET_o , which can be globally applicable and it is based on meteorological data variables (wind speed, temperature, relative humidity and radiation), all the details have been mentioned in the Irrigation and Drainage Paper no. 56 (Allen et al., 1998). The formulation of the equation is as follows:

$$ET_o = \frac{[0.408 \Delta (R_n - G) + \gamma] \frac{900}{(T+273)} u_2 (e_s - e_a)}{\Delta + \gamma(1+0.34u_2)} \quad (4)$$

Where R_n is net radiation at crop surface MJ/m^2 day, G is soil heat flux density MJ/m^2 day, T is air temperature at 2 m height $^{\circ}C$, u_2 is wind speed at 2 m height m/s , $e_s - e_a$ is saturation vapor pressure deficit kPa , Δ is slope vapor pressure curve $kPa/^{\circ}C$, and γ is psychrometric constant $kPa/^{\circ}C$.

In devising Penman-Monteith equation is used a hypothetical green grass reference surface that is actively growing and is adequately watered with a surface resistance of $70s\ m^{-1}$, with an assumed height of 0.12 m, and an albedo of 0.23 (Allen et al., 1998).

NDVI and Kc relationship:

NDVI was derived from remote sensing data using two bands the red and near-infrared bands. It depends on reflectance of the plant in the red (R) and near-infrared (NIR) bands of the spectrum. This vegetation index is given by:

$$NDVI = \frac{(NIR-R)}{(NIR+R)} \quad (5)$$

Where: R is the reflectance in the red region and NIR is the reflectance in near infrared region of the spectrum. The researchers agreed that the

NDVI values are well correlated with vegetation parameters like net primary productivity, leaf area index and gross primary productivity (Gamon et al., 1995). For modeling the K_c -NDVI relationship we must calculate values of K_c , as well as NDVI from the same pixel, and adjusted K_{cFAO} values were used for validation purposes. K_c values as well as NDVI are available at different dates for the study area along the winter season. NDVI pixels used were located as close as possible to the center of the pivot, to avoid mixed pixel problems. Three winter crops are wheat, sugar beet and potato raised during the 2013/2014 winter season were used to generate values of both K_c and NDVI. Generated values is to be used in a Linear regression model to obtain the designed relationship in the form ($K_{c\ NDVI} = a \times NDVI \pm b$). The coefficient of determination of the above model is used to assess the degree of fit.

Model validation:

Adjusted K_{cFAO} Calculation for local climate conditions:

The values of the calculated $K_{c\ FAO}$ are used to compare it with $K_{c\ NDVI}$. The FAO procedure for adjusting K_c values uses mean daily minimum relative humidity and wind speed. For climates with RH_{min} greater than or less than 45% or with mean wind speeds at 2 m over grass (u_2) that are more than or less than 2.0 m/s, the standardized values for all K_c mid from FAO-56 and for K_c end are adjusted as:

$$K_{c\ mid/end} = K_{c\ mid/end(table)} + [0.04(u_2 - 2) - 0.004(RH_{min} - 45)] \left(\frac{h}{3}\right)^{0.3} \quad (6)$$

Where ($K_{c\ mid/end\ (table)}$) is the value for K_c mid and K_c end for the standardized climate and (h) is the mean maximum plant height (m) during the midseason period, or full cover period. The Previous equation is valid for $h < 20$ m (Allen et al. 1998 and 2005). The values for RH_{min} and u_2 need only be approximate values averaged over the mid-season and late-season periods. K_c ini for local climate conditions almost the same in table of the FAO, K_c ini is adjusted as:

$$K_{c\ ini} = fw \times K_{c\ ini\ (Tab)} \quad (7)$$

Where fw the fraction of surfaced wetted by irrigation or rain [0 - 1], $K_{c\ ini\ (Tab)}$ the value for K_c ini is the value for K_c ini for the standardized climate. In our case $fw = 1$.

RESULTS AND DISCUSSION:**Development of K_c $_{NDVI}$ model:**

In this section we develop the relationship between K_c and NDVI using three winter crops which are wheat, sugar beet and potato. Table 1 represents the average values of K_c and NDVI for the three winter crops during the season.

Table. 1: average values of K_c and NDVI for the three winter crops during the season.

Crop	Date	NDVI	K_c
Wheat	12/17/2013	0.56	0.62
	1/2/2014	0.68	1.0
	2/11/2014	0.81	1.16
	3/15/2014	0.75	1.07
	3/31/2014	0.50	0.77
	5/2/2014	0.23	0.20
Sugar beet	1/2/2014	0.74	0.89
	2/11/2014	0.83	1.03
	3/15/2014	0.78	0.96
	3/31/2014	0.74	1.02
	4/16/2014	0.77	1.10
	5/2/2014	0.75	0.84
Potato	2/11/2014	0.25	0.41
	3/15/2014	0.75	0.86
	3/31/2014	0.67	0.85
	4/16/2014	0.56	0.87

Fig. 2 shows the relationship between NDVI and the K_c for the crops in this investigation. There was a strong relation between NDVI and the K_c . The combined relationship between NDVI and the K_c is:

$$K_c_{NDVI} = 1.259 NDVI + 0.034 \quad (8)$$

The coefficient r is 0.92, which shows that there is a potential for established K_c $_{NDVI}$ model.

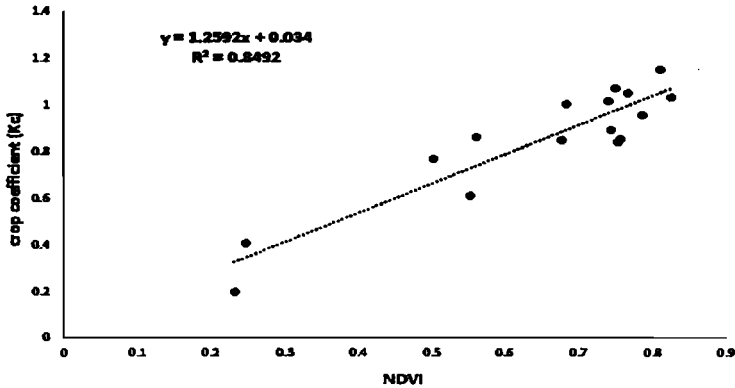


Fig. 2: Relationship between NDVI and K_{cs} for wheat, sugar beet and potato.

Validation of K_{cNDVI} model:

To validate the K_{cNDVI} model values of predicted K_{cNDVI} using eq. 8 is to be compared with calculated K_{cFAO} using eq. 7 for two crops raised on 2014-2015 season on el-Salhia area. For wheat dates were 12th, 2014, Dec. 28th, 2014, Jan. 29th, 2015, Mar. 2nd, 2015, Apr. 3rd, 2015, Apr. 19th, 2015 and May. 5th, 2015. For potato dates were Dec. 4th, 2014, 12th, 2014, Dec. 28th, 2014, Jan. 29th, 2015, Feb. 6th, 2015, Mar. 2nd, 2015.

Fig. 3 and 4 shows the K_{cNDVI} predicted values vs K_{cFAO} for wheat and potato respectively where r for the two crops was 0.988 and 0.989 respectively to indicate the relation between both methods.

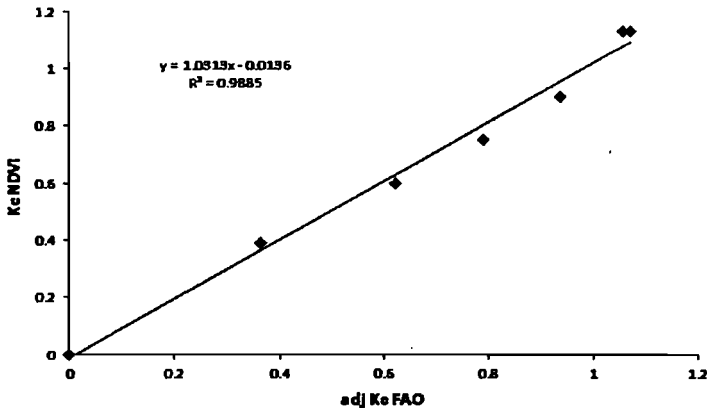


Fig. 3: Wheat regression scatter plots of adjusted K_{cFAO} and K_{cNDVI} .

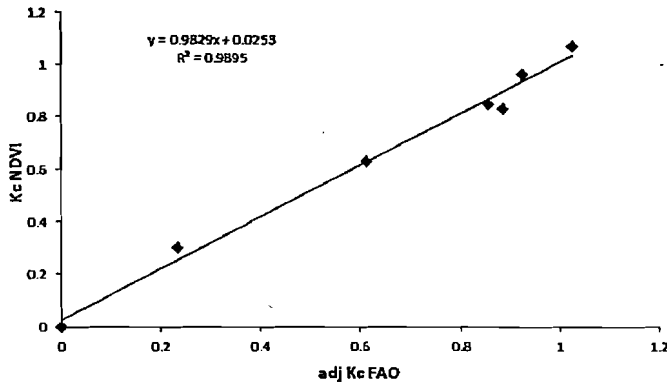


Fig. 4: potato regression scatter plots of adjusted $K_{c\text{FAO}}$ and $K_{c\text{NDVI}}$.

Therefore it may be concluded that the $K_{c\text{NDVI}}$ method could be used to predict K_c for various crops. These results agree with Hunsaker et al., 2005, Bausch and Neale 1989, El-Shirbeny et al., 2014, Irmak 2010 and Bausch and Neale 1989.

Conclusion:

The purpose of this work was to develop a model to estimate K_c using remote sensing technique. NDVI extracted from Landsat8 and Landsat 7 ETM+ satellite data for three winter crops wheat, sugar beet and potato and estimated K_c from ETC and ETo for same crops at same dates were used to develop the model during 7 dates through its growing season 2013-2014. The following equation $K_{c\text{NDVI}} = 1.259 \text{ NDVI} + 0.034$ is the developed model with $r = 0.92$. This model was validated with comparing the $K_{c\text{NDVI}}$ with the estimated $K_{c\text{FAO}}$ using two winter crops wheat and potato at season 2014-2015. The validation gave a good results with $r = 0.98$ for the two crops.

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الملخص العربي

تقدير التباين في معامل المحصول باستخدام بيانات الطيف المرئي وتحت الحمراء القريبة من الأقمار الصناعية

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معامل المحصول هو عامل رئيسي لتقدير الاستهلاك المائي للمحاصيل. تقليدياً يقدر معامل المحصول من العلاقة : معامل المحصول = البخرنتج للمحاصيل / البخرنتج المرجعي او من جداول معامل المحصول لمنظمة الفاو. الهدف من هذا البحث هو تطوير نموذج بسيط لتقدير معامل المحصول باستخدام تقنيات الاستشعار من البعد.

*الهيئة القومية للاستشعار من البعد وعلوم الفضاء- مصر
** قسم الهندسة الزراعية - كلية الزراعة بمشهر - جامعة بنها- مصر

لتطوير هذا النموذج تم اقامة هذا العمل في منطقة الصالحية على ثلاث محاصيل شتوية القمح، البطاطس وبنجر السكر في تواريخ مختلفة ممثلة لموسم نموهم ٢٠١٣-٢٠١٤ . الاقمار الصناعية Landsat 8 و Landsat 7 ETM+ تم استخدامهم لتوليد قيم دليل الاخضرار النباتي خلال هذه التواريخ. قيم كلا من دليل الاخضرار النباتي و معامل المحصول المقاس من العلاقة: معامل المحصول = البخرنتح للمحاصيل / البخرنتح المرجعي استخدمت لاستنباط معادلة معامل المحصول بدلالة دليل الاخضرار النباتي. المعادلة كانت على النحو التالي : $K_{CNDVI} = 1.259 NDVI + 0.034$ وكان $r = 0.92$. للتحقق من صحة النموذج تم مقارنة قيم معامل المحصول المتوقعة من النموذج المستنبط لمحصولي للقمح والبطاطس خلال ٦ تواريخ زرعت عام ٢٠١٤-٢٠١٥ بقيم معامل المحصول المتحصل عليها من جداول الفاو والمعدلة بالنسبة لمناخ المنطقة في التواريخ نفسها. المصادقة اعطت نتائج جيدة مع $r = 0.98$ لكلا من المحصولين.