



LONG-TERM ESTIMATION OF ACTUAL CROP EVAPOTRANSPIRATION BASED ON SATELLITE DATA ANALYSIS

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Received 2 December, 2019

Accepted 26 December, 2019

ABSTRACT

Arid regions conditions are overwhelmed with various water scarcities problems, however, one of the reasons of this problems may be due to climate change effect. Moreover, under these conditions, water is a crucial key for any agricultural development processes. Therefore, the aim of this study was to estimate the actual evapotranspiration of different crop pattern under climate change conditions based on satellite data analysis for long time effect (1985 – 2019).

The study area is considered active agricultural area, the percentage of bare soil and vegetation cover were (86.9%) and (12.7) in 1985 while in 2019 the percentage of bare soil sharply decrease so it was reached to (34.1%) but the percentage of d vegetation cover was (64.2%).

Satellite images have been gathered and analyzed from Landsat TM, Landsat ETM+ and Landsat OLI, through the studied period. However, Normalized Difference Vegetation Index (NDVI) had been obtained for estimating the actual evapotranspiration under the studied area conditions. Planning and management of water use by irrigation agriculture are especially important in an arid and semiarid areas like the study area so the understanding of the Actual Evapotranspiration (AET) prerequisite for better management and conservation of agriculture water, By determine the area of every crop pattern, actual evapotranspiration (AET) was estimated by $m^3/ha/day$ and $m^3/total\ cultivated\ area/day$.

Data analysis indicate that the minimum and maximum NDVI values had been ranged from 0.7 and 0.9 for mango trees from 1985 and 2019, 0.5 and 0.8 for olive trees, 0.4 and 0.8 for forests and 0.7 for annual crops within the studied period from

1985 to 2019. The minimum and maximum actual evapotranspiration under different crop pattern from 1985 to 2019 ranged from 2.6 and 4.9 mm/day, 1.7 and 4 mm/day, 1 to 4.4 mm/day and 2.7 mm/day for the same crop pattern respectively. This study can assist in water management practices for better irrigation management.

Keywords: Reference Evapotranspiration (ET_0), Crop Coefficient (K_c), Remote Sensing (RS) and land Surface Temperature (LST).

1. INTRODUCTION

Agricultural sectors are facing many environmental challenges, such climate change and reduction of water resource. Agricultural water use and cropping patterns are closely related to each other, with both linked to the regional climate (**Daliakopoulos et al 2017**). Remote sensing has been beneficial tool for water resources management studding, especially when we look at regional scale. Planning and management of water use by irrigation agriculture are especially important in an arid and semiarid areas like the study area so the understanding of the Actual Evapotranspiration (AET) prerequisite for better management and conservation of agriculture water (**Agdasi, 2010**).

Normalized Difference Vegetation Index (NDVI) is the main vegetation indices. NDVI considers the reflected wavebands in red and near-infrared, where red wave band is substantially absorbed by chlorophyll in the top layers of leaves, nevertheless near-infrared wave bands are reflected by the mesophyll structure in leaves in the healthy and density vegetation (**Romero Trigueros et al 2017**). High values of NDVI are considered as healthy and density vegetation, which presents

rising reflectance values in NIR waveband and depressed reflectance values in the red waveband (Toureiro et al 2017).

Estimation of K_c based on NDVI on account of the high correlation NDVI with K_c (Abuzar et al 2013, Campos et al 2017, Reyes-González et al 2018, Mahmoud and Gan 2019). Because of this high relationship between NDVI and K_c , NDVI has been broadly used for vegetation monitoring, crop yield estimating and drought detection (Justice and Townshend 2002). Crop coefficients created from vegetation indices to determine ET_c was realistic than a tabulated K_c because it represents the actual crop developing conditions and capture the spatial variability within different fields (Reyes-Gonzalez et al 2018). Estimation of ET can be the basic process to determine (ACWR) (Hasan et al 2018). basically, ET has been difficult and costly to estimate (Rozenstein et al 2018). ET_c can be estimated at macro / micro scale in less time by utilizing remote sensing (Kjaersgaard et al 2011).

In this study satellite remote sensing (RS) will be used to quantify Actual Evapotranspiration (AET), which plays a key role in the conservation and management of water resources.

2. Materials and Methods

2.1. Description of the studied area

The study area is located at 32°10'58.46"E to 32°18'31.784"E longitude and 30°26'32.11"N to 30°31'8.204"N latitude in the Northern East of Egypt, the distance between the east border of the study area and the Suez Canal is 2.25 km at the North and 4 km at the south. The study area covers approximately 102.6 km² (10260 ha) illustrated in (Fig. 1A). The vegetation cover area increased from 1299.2 ha (12.7%) in 1985 to 6591.5 ha (64.2%) in 2019 see (Table 1) and (Fig. 1B). The study area is considered active agricultural area and were selected because of the rapid increase in cultivated area during the past few years which make it good area for monitoring, mapping and analyzing the interaction dynamic between vegetation and climate change.

The mean annual maximum temperature is 29.1°C, minimum 15.3°C and mean 21.7°C. The mean annual relative humidity is about 48.8%, mean annual solar radiation is 19.8 (MJ/m²/day) and the mean annual wind speed is 3.5 (m/s) and

The average ET_o is 5.9 (mm/day) for duration of 33 years (1985 to 2017) Mean elevation from Sea surface is 3m to 86m.

The crop patterns in the study area divided into three categories showed in (Fig. 1A), the first one is orchard such as mango and olive trees. Mango trees located north east part and irrigated with surface water by surface irrigation system. Parallel with the north west part that were majority cultivated with olive trees, but these trees irrigated with aquifer wells. The second category are forest that located in the middle of study area approximately and irrigated with treated sewage water since 1997 by surface drip irrigation system. The third category are crops that located in the south part of the study area. Its cultivated under center pivots irrigation system and the water source from aquifer since 2016.

Based on GPS tool lot of point were observed and recorded. (Fig. 1A) illustrated the important points of these records. Point (1) show the parts that majority cultivated with mango trees. Point (2) display the site that cultivated with olive trees. Point (3) illustrate the area that cultivated with combination of trees such as mango, olive and orange. Point (4) show the Serapeum forest that cultivated with wooden trees, Point (5) illustrated the part that cultivated under center pivots. Point (6), Ismailia sewage water were collected and treatment in this part after that utilized these treatment water to irrigate the Serapeum forest. Point (7) show the surface water that infiltrated from Suez Canal.

2.2. Initial data sources

2.2.1. Meteorological data

Meteorological data were directly recorded from the available weather station that located at 31°57'39.6"longitude, 30°31'37.2"latitude and that belong to Central Laboratory for Agriculture Climate (CLAC). The distance between study area and that station about 21.5km distance this distance is not significant according to (EL-Shirbeny et al 2013). The reference evapotranspiration (ET_o) calculated by ET_o calculator version 3.2. ET_o calculator is software developed by FAO. The prime function of this calculator is to estimate ET_o based on FAO standards (Zahid and Rasul, 2011). Result in (Fig. 2) indicate that the maximum.

Table 1. The crop pattern percent

Crop pattern	Year							
	1985	1990	1995	2000	2005	2010	2015	2019
Orchard trees	12.9%	19.3%	22.0%	38.1%	41.3%	46.5%	49.8%	56.9%
Forest trees	0%	0%	0%	0.2%	1.6%	1.6%	1.6%	1.6%
Annual crops	0%	0%	0%	0%	0%	0%	0%	5.8%

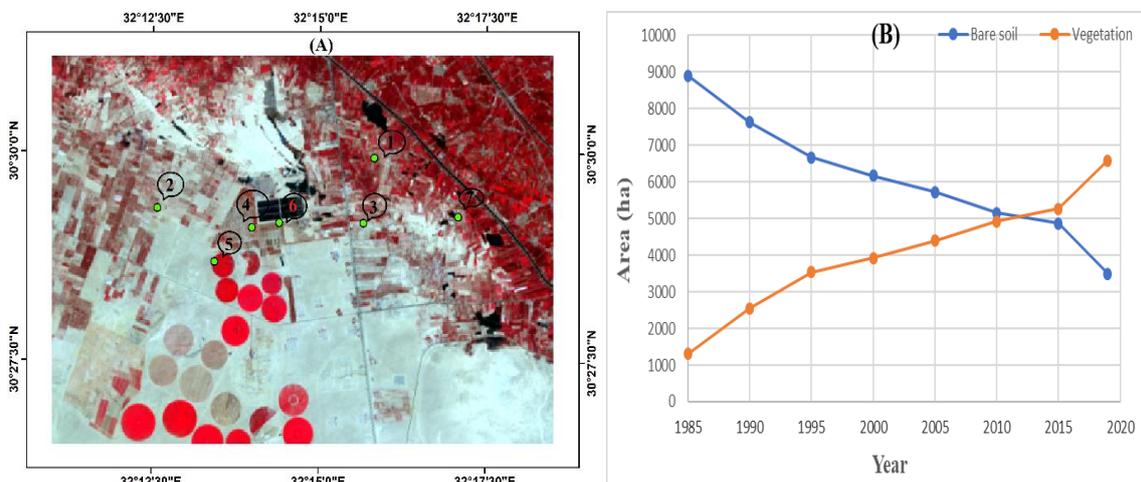


Fig. 1. (A) Location of the study area, (B) Accumulative analysis of agricultural development processes versus bare soils within the studied period.

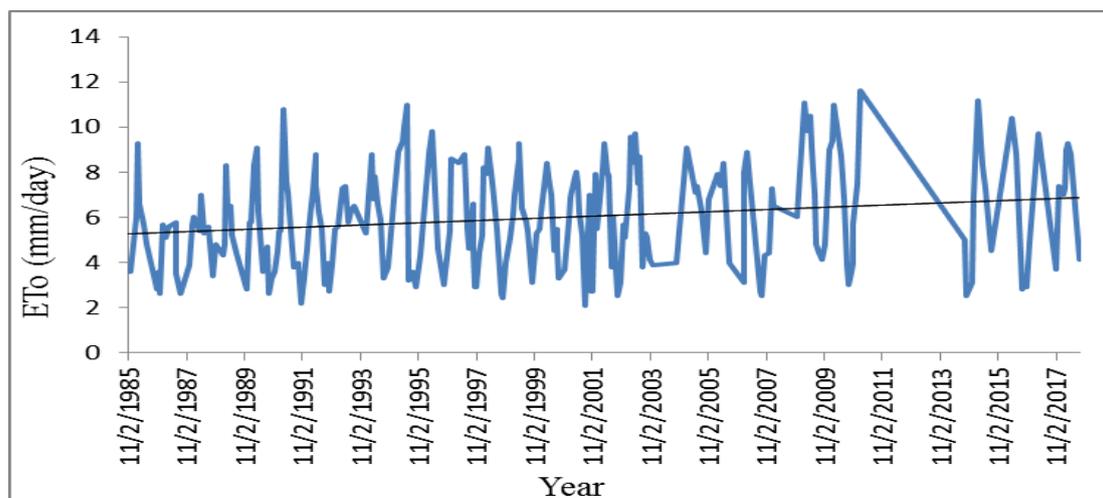


Fig. 2. ETo (mm/day) values from 1985 to 2017

2.2.2. Satellite data gathering and processing

Data from remote sensing were the primary input data in study. The satellite data sets were downloaded for the Landsat satellite. These images were gained from the [USGS] website (<http://earthexplorer.usgs.gov/>) from the year 1985 to 2019. The data processing for TM, ETM+ & OLI data mainly includes radiometric correction and atmospheric correction. All utilized images were free cloud during image acquisition. All images processing steps were performed utilizing ENVI software 5.1.

A combination of Landsat-5 Thematic Mapper (TM), Landsat-7 (ETM+) and Landsat-8 (OLI) imagery were employed in study. Landsat 5 is the most important satellite for this study because of utilizing 200 images from it from 1985 to 2010, In 13 images utilized from Landsat 7 from 2001 to 2003 only because the problem in this sensor and Utilized 25 images from Landsat 8, 23 images from the period 2013 to 2017 and two imaged in 2019. All data registered into UTM projection system (UTM-WGS84) and zone 36, north. The details of satellites data are showed at (Table 2).

2.3. Data analysis and calculations

2.3.1. Normalized Difference Vegetation Index (NDVI)

NDVI was introduced by (Rouse et al 1973) to monitor the vegetation using satellite images, it takes into account the reflectance of red (0.61 - 0.68 μm) and near infrared NIR (0.79 - 0.89 μm) wavebands and was computed as the ratio of target radiance to time interpolated values of solar radiance. NDVI is calculated from the Red and NIR bands from TM, ETM+ and OLI images using the following Equation.

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

Where, NIR and Red are the spectral reflectance red and near-infrared bands in the TM, ETM+ and OLI. Estimation of NDVI for a given pixel evermore valid results fall between ranges from -1 to +1; where positive values signify more green vegetation and negative values indicate non vegetated surface features.

2.3.2. Crop coefficient ($K_{c \text{ sat}}$)

K_c is approximately between 0.1 and 1.2. Relation between $K_{c \text{ sat}}$ and NDVI performed by following Equation which established by (El-Shirbeny, et al 2014).

$$K_{c \text{ sat}} = \frac{1.2}{\text{NDVI}_{dv}} (\text{NDVI} - \text{NDVI}_{\text{min}})$$

Where 1.2 presented the maximum K_c under Egyptian conditions, NDVI_{dv} is the difference maximum and minimum NDVI values for vegetation and NDVI_{min} is the minimum NDVI value for vegetation.

2.3.3. Crop Evapotranspiration (ET_c)

$K_{c \text{ sat}}$ utilized with ET_o to estimate ET_c according to following Equation.

$$ET_c = ET_o * K_{c \text{ sat}} \quad (3)$$

Where; ET_c is crop evapotranspiration (mm/day), ET_o is reference evapotranspiration (mm/day), $K_{c \text{ sat}}$ is crop coefficient by satellite data. Based on the area of every crop pattern actual evapotranspiration (AET) was estimated by $\text{m}^3/\text{ha}/\text{day}$ and $\text{m}^3/\text{total cultivated area}/\text{day}$.

2.3.4. Land Surface Temperature (LST)

For Landsat data, the recorded digital numbers (DN) were transformed to radiance units (Rad) utilizing the calibration coefficient certain for each band.

$$\text{Radiance} = \text{Gain} * \text{DN} + \text{offset} \quad (4)$$

Surface emissivity (E_o) generated from the NDVI. NDVI utilizing the empirical equation that developed from row data on thermal emissivity and NDVI thermal emissivity according to (Valor and Caselles, 1996).

$$E_o = 0.9932 + 0.0194 \ln \text{NDVI} \quad (5)$$

The radiant temperature (T_o) can be calculated from band 6, 6.1 and 10 (Rad) based on (Goetz et al 1995), however the thermal Band Calibration Constants could be described as Table (2).

$$T_o = K2 / \ln((K1 / \text{Rad}6) + 1) \quad \text{Landsat 5 (6a)}$$

$$T_o = K2 / \ln((K1 / \text{Rad}6.1) + 1) \quad \text{Landsat 7 (6b)}$$

$$T_o = K2 / \ln((K1 / \text{Rad}10) + 1) \quad \text{Landsat 8 (6c)}$$

Table 2. Technical specification of satellites

Sensors	Path/Row	Bands	K1 ($Wm^{-2}sr^{-1}\mu m^{-1}$)	K2 (Kelvin)	Source
Landsat 5 TM	176/39	3,4 6	1260.56	607.76	earthexplorer.usgs.gov
Landsat 7 ETM+	176/39	3,4 6.1	1282.71	666.09	earthexplorer.usgs.gov
Landsat 8 OLI	176/39	4,5 10	1321.08	774.89	earthexplorer.usgs.gov

The effects of atmospheric and emissivity of thermal surface have to be count for reach the accurate surface temperature data from satellite thermal (Norman et al 1995). The surface temperature was studied from the top of atmosphere radiant temperature (T_o) and estimated surface emissivity (E_o) as:

$$T = T_o/E_o \quad (7)$$

The temperature in Kelvin were converted to Celsius degrees using the following Equation

$$LST(^{\circ}C) = T - 273.13 \quad (8)$$

2.3.5. Predicted Crop Evapotranspiration (ET_c)

Either LST and NDVI indices had been combined with metrological parameters data for estimating the actual evapotranspiration of different crops pattern of the studied area.

3. Result and Discussion

The study area divided into three category of crop pattern, NDVI and ET_c were estimated under mango, olive, forest and annual crops. By determine the area of every crop pattern, actual evapotranspiration (AET) was estimated by $m^3/ha/day$ and $m^3/ha/total$ cultivated area. Result in (Table 3) illustrated the NDVI and ET_c under different crop pattern from 1985 to 2019. The number of zero demonstrated that this crop pattern not cultivated in this year. Result in (Table 4) indicate the actual evapotranspiration (AET) $m^3/ha/day$ and total actual evapotranspiration $m^3/cultivated\ area/day$ under different crop pattern from 1985 to 2019. The

number of zero demonstrated that this crop pattern not cultivated in this year.

3.1. Data analysis of observed NDVI

Data analysis of the NDVI indicate that NDVI values had been high significant increase. The NDVI increasing due to plant density and vegetation area, as presented in (Fig. 4). According to cultivation a new region under center pivots, its affected that on NDVI values, so the NDVI values were sharply increasing. Data analysis indicate that the NDVI values had been ranged from 0.7 up to 0.9 for mango trees, 0.5 to 0.8 for olive trees, 0.4 up to 0.8 for forests and 0.7 for annual crops within the studied period. The NDVI values under different crop pattern showed in (Table 3).

3.2. Data analysis of observed $K_c\ sat$

K_c dependence on crop pattern was estimated based on satellite data. K_c values utilized to estimate actual evapotranspiration.

3.3. Actual Evapotranspiration

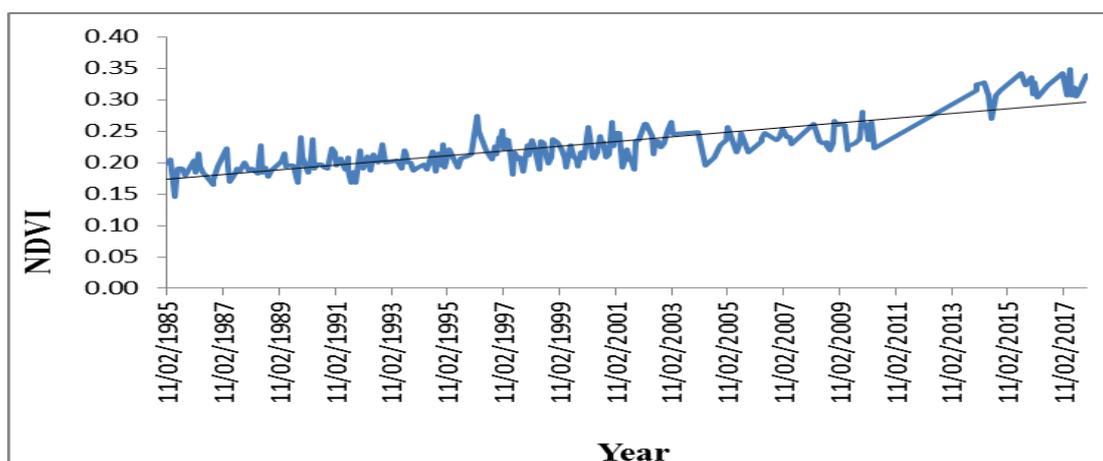
Data analysis in (Fig. 4) presents ET_c maps (mm/day) on (11th Feb 1985, 24th Jan 1990, 06th Jan 1995, 19th Nov 2000, 01st Nov 2005, 15th Jan 2010, 15th Dec 2015 and 25th Feb 2019). These images were selected to be an indicator of minimum mean ET_c . The range of ET_c is divided from (0: 5 mm/day). It is better to assessment the vegetation covers every 5 years to monitor changing in cultivated areas which affects the agricultural sector especially in arid and semi-arid regions.

Table 3. NDVI, $K_{c,sat}$ and ET_c under different crop pattern

Years	Mango trees		Olive trees		Forest trees		Annual crops	
	NDVI	ET_c	NDVI	ET_c	NDVI	ET_c	NDVI	ET_c
1985	0.7	3.1	0.5	2.4	0	0	0	0
1990	0.7	2.6	0.6	2.0	0	0	0	0
1995	0.7	2.7	0.5	1.7	0	0	0	0
2000	0.7	3.1	0.7	2.9	0.4	1.0	0	0
2005	0.7	4.9	0.6	4.0	0.7	4.4	0	0
2010	0.7	4.7	0.6	3.0	0.6	3.6	0	0
2015	0.8	3.1	0.8	2.5	0.8	3.2	0	0
2019	0.9	3.5	0.7	2.2	0.6	2.5	0.7	2.7

Table 4. Actual crop water requirements per ha and all crop pattern cultivated area

Year	Orchard trees			Forest			Crops		
	AET $m^3/ha/day$	Area (ha)	TAET $m^3/cultivated\ area/day$	AET $m^3/ha/day$	Area (ha)	TAET $m^3/cultivated\ area/day$	AET $m^3/ha/day$	Area (ha)	TAET $m^3/cultivated\ area/day$
1985	27.5	1299	35723	0	0	0	0	0	0
1990	23	2557	58811	0	0	0	0	0	0
1995	22	3538	77836	0	0	0	0	0	0
2000	30	3905	117150	10	25	250	0	0	0
2005	44.5	4237	188547	44	162	7128	0	0	0
2010	38.5	4768	183568	36	162	5832	0	0	0
2015	28	5112	143136	32	162	5184	0	0	0
2019	28.5	5840	166440	25	162	4050	27	590	15930

**Fig. 3.** Mean NDVI values during the period (1985 – 2017)

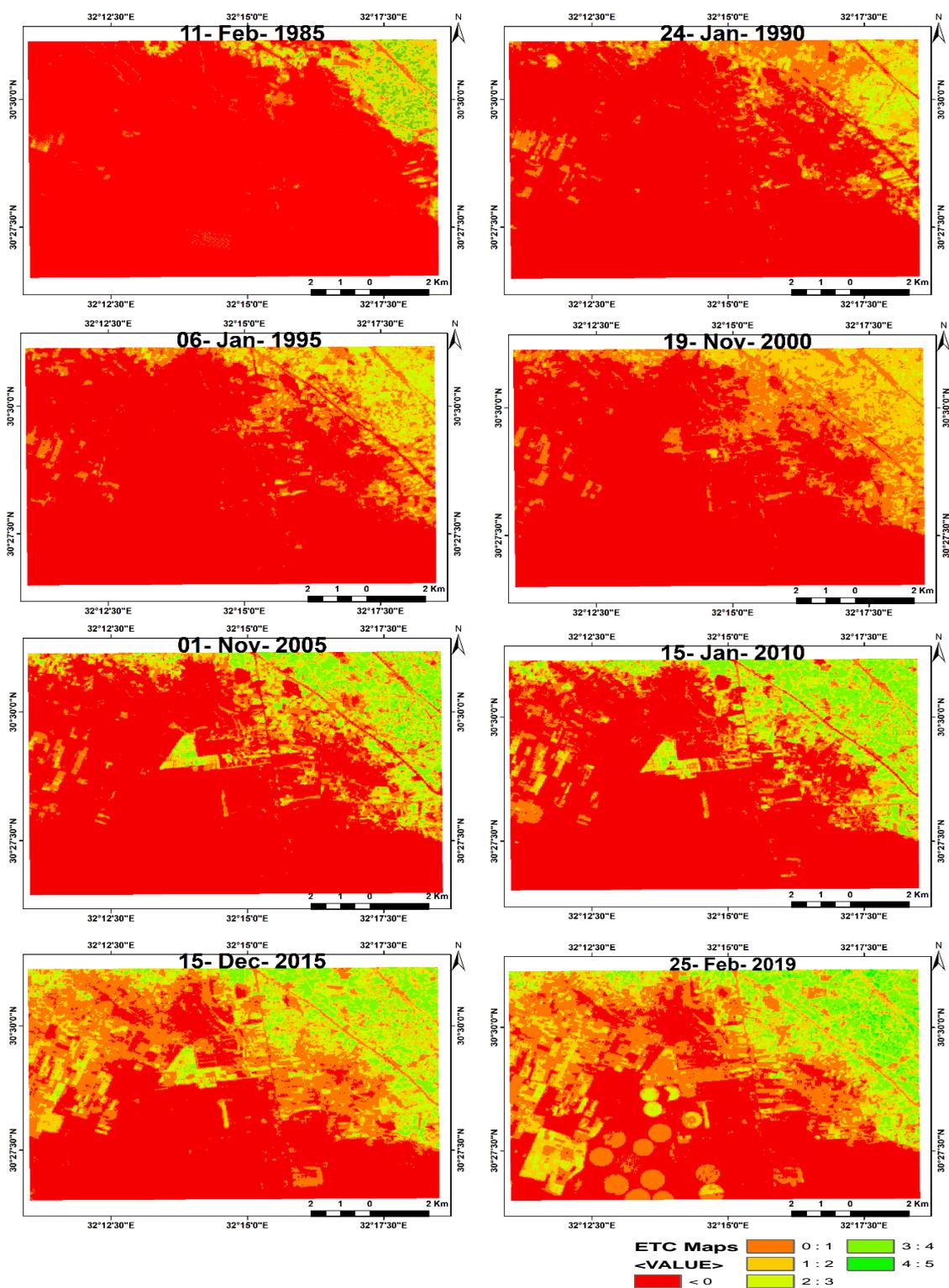


Fig. 4. Minimum mean of ETc maps (mm/day) for study area on (11th Feb 1985, 24th Jan 1990, 06th Jan. 1995, 19th Nov. 2000, 01st Nov. 2005, 15th Jan. 2010, 15th Dec. 2015 and 25th Feb. 2019).

The ET_c values were low at the beginning of cultivating area regarding to the cause of low K_c after that the results show increasing in values of ET_c . The case study work on 239 images there are clear from clouds from 1985 up to 2019. According to ET_c values that estimated from all available images, after that selected the minimum values in investigated years (1985, 1990, 1995, 2000, 2005, 2010, 2015 and 2019). Regardless about month. The maps illustrated that the ET_c values were increased with time and with rising in vegetation cover. With comparison (2005, 2010, 2015 and 2019) the ET_c values under forest regions approximately stabled. Moreover, ET_c values under center pivots variation between center pivots.

ET_c maps (mm/day) on (05th Jul 1985, 19th Jul 1990, 2nd Aug 1995, 22nd Jul 2000, 13th Aug 2005, 07th Jul 2010, 09th Aug 2015 and 04th Aug 2019) presented in (Fig. 5). These images were selected to be an indicator of maximum mean ET_c . The range of ET_c is divided from (0: 10 mm/day). According to ET_c values that estimated from all available images, after that selected the maximum values in investigated years (1985, 1990, 1995, 2000, 2005, 2010, 2015 and 2019). In 1985 and 1990, the ET_c was depressed because the trees in forest was small and the vegetation cover per pixel was lower. After that the vegetation cover became high so the ET_c was raised according to both pixel and all study area. The mean ET_c of crop pattern were illustrated in (Table 3).

3.4. Actual Evapotranspiration (AET)

The data that illustrated in (Table 4) indicate the AET in the study area under different crop pattern the smallest AET under orchard trees (mango and olive) was 22 m³/ha/day in 1995 largest AET was recorded in 2005 by 44.5 m³/ha. Regardless, forest was recorded lowest AET by 10 m³/ha in 2019 and the largest AET was 44 m³/ha/day in

2005. On the other hand, AET under annual crops was 27 m³/ha/day. Based on the area of every crop pattern total actual evapotranspiration was estimated. 166440, 4050 and 15930 m³/day for orchard trees, forest trees and annual crops.

3.5. LST and mean air temperature (T mean)

LST is an essential parameter of land surface energy budget and climate systems to monitor long-term environmental changes. The result in (Fig. 6) demonstrated that were decrease in LST and T mean (-0.5^oc and -1.2^oc) respectively through the period of study but this decreasing is insignificant at 5%.

3.6. Practical equation for estimation crop evapotranspiration (ET_c)

Under the investigated study estimated ET_c not to specific crop or tree but under crop patterns, so we need equation we can used it when it's difficult to determine the crop cultivated. So, calculated ET_c values from this equation could obtained regardless the cultivated plant. To predicted ET_c , calculated ET_c by following equation. By using 2015, 2016 and 2017 data to validate ET_c , statistical analysis of RMSE used to insure of predicted ET_c . The regression factors $R^2 = 0.80$ and RMSE is 0.6mm/ day that is showed in (Fig. 7).

$$ET_c = -1.256 + (0.484*ET_o) - (0.004*LST) + (7.193*NDVI) - (0.042*T \text{ mean}) - (0.006*SR) + (0.002*RH) - (0.019*WS) \quad (9)$$

ET_c : Crop Evapotranspiration [mm/day].

ET_o : Reference Evapotranspiration [mm/day].

LST: Land Surface Temperature [^oc].

NDVI: Normalized Deference Vegetation Index.

T mean: Mean air temperature [^oc].

SR: Solar radiation [MJ/ m²/ day].

RH: Relative humidity [%].

WS: Wind speed [m/s].

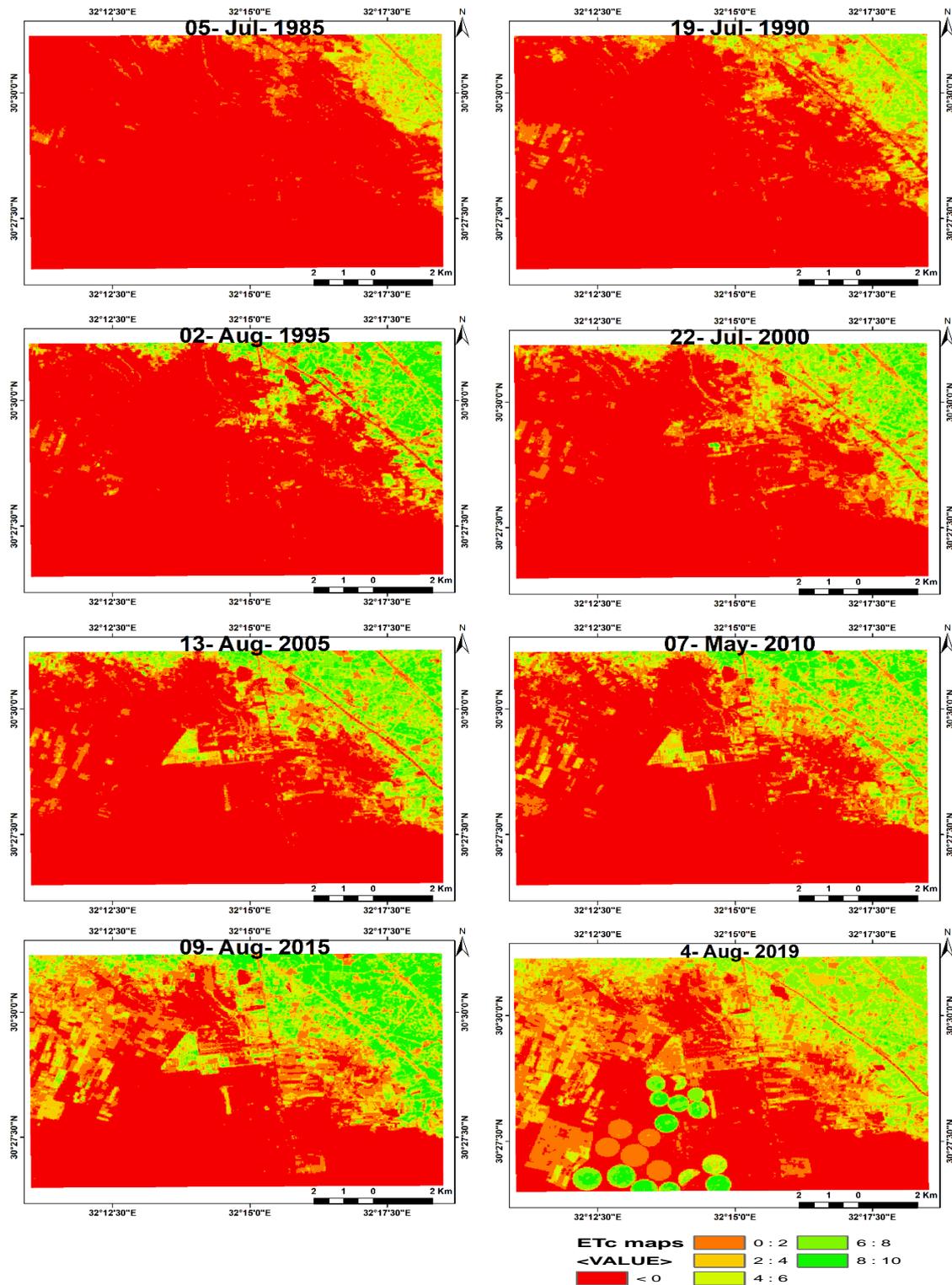


Fig. 5. Maximum mean of ETc maps (mm/day) for study area on (05th Jul. 1985, 19th Jul. 1990, 2nd Aug. 1995, 22nd Jul. 2000, 13th Aug. 2005, 07th Jul. 2010, 09th Aug. 2015 and 04th Aug. 2019).

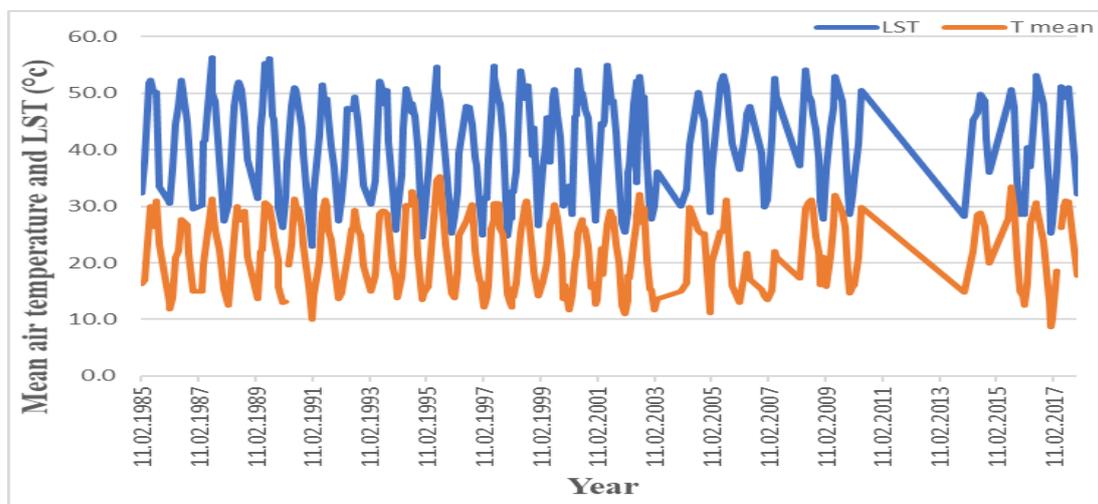


Fig. 6. LST and mean air temperature (°C) from 1985 to 2017

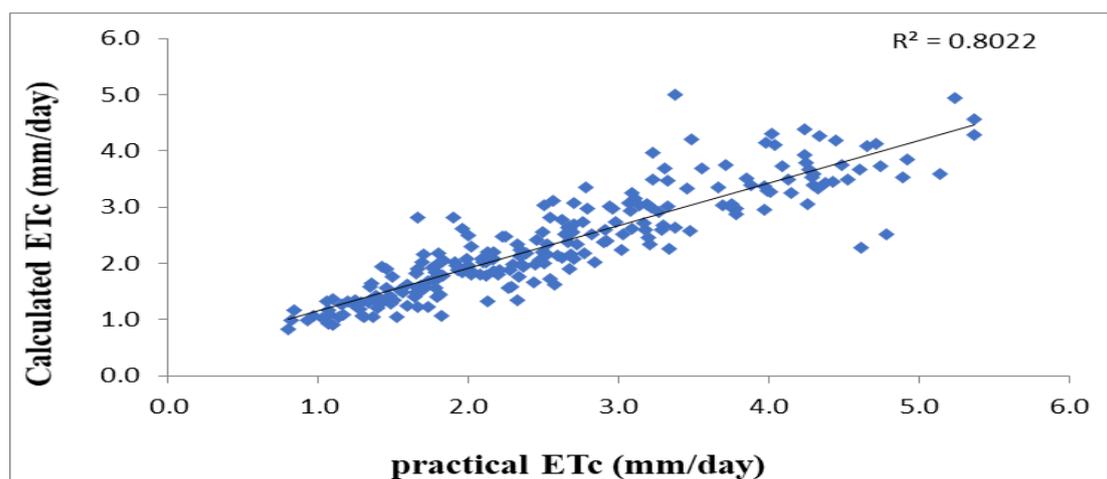


Fig. 7. Practical ET_c (mm/day)

4. CONCLUSION

This study confirms the usefulness of utilizing remote sensing as a tool for actual crop evapotranspiration estimation. Landsat 5, 7 and 8 utilized to estimate NDVI under different crop pattern. $K_c \text{ sat} = (1.7 * \text{NDVI} - 0.2)$ represent the relation between K_c and NDVI. ET_o was calculated from ET_o calculator software based on the Penman-Montieth formula. $K_c \text{ sat}$ and ET_o utilized to estimate actual crop evapotranspiration. Metrological data, ET_o and LST used to predicted ET_c . Actual crop evapotraspiration were estimated under different crop pattern. Based on the results concluded that ET_c estimated from remote sensed based on vegetation indices are a useful method for quantifying accurate ET_c at macro / micro scales.

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التنبؤ بعيد المدى بالبحر نتج الفعلي للمحاصيل إعتاماداً علي تحليل بيانات الأقمار الصناعية

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Received 2 December, 2019

Accepted 26 December, 2019

الموجز

كذلك أوضحت نتائج الدراسة أن القيم الصغرى والعظمى لدليل الـ NDVI لمختلف التراكيب المحصولية هي 0.7 و 0.9، 0.5 و 0.8، 0.4 و 0.8 لأشجار المانجو والزيتون وللغابات الشجرية علي التوالي خلال الفترة من 1985 إلي 2019، وكان متوسط دليل الـ NDVI للمحاصيل السنوية بـ 0.7. بينما أوضحت النتائج أن القيم الصغرى والعظمى للبحر نتج الفعلي تحت مختلف التراكيب المحصولية هي 2.6 و 4.9 مم/يوم، 1.7 و 4 مم/يوم، 1 و 4.4 مم/يوم لأشجار المانجو والزيتون وللغابات الشجرية علي التوالي خلال الفترة من 1985 إلي 2019، بينما كان متوسط البحر نتج الفعلي للمحاصيل السنوية بـ 2.7 مم/يوم. خلصت الدراسة إلى أنه يمكن الإستعانة بنتائج هذه الدراسة في تحسين إدارة الري.

تعاني المناطق القاحلة من العديد من مشاكل ندرة المياه، ويعزى العديد من هذه المشاكل للتغيرات المناخية حيث تعتبر المياه المحرك الأساسي للتنمية الزراعية تحت ظروف المناطق القاحلة. تهدف الدراسة إلي التنبؤ بالبحر نتج الفعلي تحت مختلف التراكيب المحصولية في ظل التغيرات المناخية إعتاماداً علي تحليل بيانات الأقمار الصناعية خلال الفترة من 1985 إلي 2019. تم تجميع وتحليل صور الأقمار الصناعية وهي تتمثل في لاندسات 5 ولاندسات 7 ولاندسات 8. استخدمت هذه البيانات في تقدير البحر نتج المحصولي الفعلي إعتاماداً علي دليل التغير في الغطاء النباتي الـ NDVI.

أوضحت النتائج زيادة كبيرة في الرقعة الزراعية في منطقة الدراسة حيث كانت تمثل 12.7% في عام 1985 إلي أن وصلت هذه النسبة إلي 64.2% عام 2019 من المساحة الأجمالية لمنطقة الدراسة.

الكلمات الدالة: البحر نتج المرجعي، معامل المحصول، الإستشعار عن بعد، درجة حرارة السطح