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EVALUATION OF HARGREAVES BASED ON REMOTE SENSING METHOD TO ESTIMATE POTENTIAL CROP EVAPOTRANSPIRATION

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ABSTRACT: In arid and semi-arid regions, agricultural water consumption information is very important to managing and developing water resources. Potential crop evapotranspiration (ET_c) is the major parameter in agricultural water resources management. Remote sensing techniques were involved in this work to evaluate Hargreaves method for estimating ET_c depending on satellite data. The difference between air temperature (T_{air}) and Land Surface Temperature (*LST*) varies particularly by surface water status. Normalized Difference Vegetation Index (*NDVI*) was extracted from *NOAA/AVHRR* and landsat8 satellite data to calculate emissivity as an intermediate step for producing *LST*. Linear relation between T_{air} and *LST* was established and R^2 was 0.93. Reference evapotranspiration (ET_o) was estimated using agro-meteorological data through FAO-Penman-Monteith (*FPM*) which used as standard method and Hargreaves (*Har*) method. To calibrate $ET_{o\text{-}Har}$, the $ET_{o\text{-}FPM}$ was used under the same conditions. Landsat8 data acquired on 13th of Aug. and 08th of Aug. 2014 and were used to calculate Crop coefficient (K_c) based on satellite data ($K_{c\text{-}Sat}$). *LST* was used to predict T_{air} (ºC) in Aug. 2014. ET_o estimated using *Har* method and was used with $K_{c\text{-}Sat}$ to estimate $ET_{c\text{-}Har}$. $ET_{o\text{-}FPM}$ combined with $K_{c\text{-}Sat}$ to estimate $ET_{c\text{-}FPM}$. $ET_{c\text{-}FPM}$ used to evaluate $ET_{c\text{-}Har}$. The relation between $ET_{c\text{-}FPM}$ and $ET_{c\text{-}Har}$ was very strong where R^2 as high as 0.99.

Keywords: Land Surface Temperature (LST), Reference Evapotranspiration (ET_o), Normalized Deference Vegetation Index (NDVI), Crop Coefficient (K_c), and Landsat8.

1. INTRODUCTION

Low ground data availability is a serious problem in Egypt and developing counties. Free satellite data may be used as alternative method if it is used after calibration and evaluation especially in Agricultural field. In last years, remotely sensed data and techniques were evaluated and used effectively in estimating ET_a and ET_c for irrigation water management [1] – [8].

ET_o mainly depends on water availability and incoming solar radiation which reflects the interactions between surface water status and climate [9]. Many models were used and developed to calculate ET_o to improve irrigation water conservation [10], [11]. FAO-penman-monteith (*FPM*) model is the most accurate method in both humid and arid climatic conditions [12]. FAO organization recommended Hargreaves method in case of low data availability. This method uses minimum data; maximum, minimum and average Temperature, number of the day and latitude [13].

Determination of ET_c depends on two steps approach. *ETo* is first estimated and semi-empirical coefficient (k_c) is then applied to take into account all other crop and environmental factors [13] – [16]. Similarities between K_c curve and a satellite-derived vegetation index showed potential for modeling a K_c as a function of the vegetation index [16]. Therefore, the possibility of directly estimating K_c from satellite data was investigated [3], [13], [17].

The main objective of this paper is to evaluate Hargreaves method to estimate potential crop evapotranspiration (ET_c) depending on satellite data.

2. MATERIALS AND METHODS

2.1 Study Area

The target areas chosen for the implementation of this paper is located in three regions which are Alexandria, El-Minya and Aswan Governorates as shown in figure (1).

2.2 Remote Sensing Data

Satellite images from *NASA* database which available on web were used to cover the study area. *NOAA/ AVHRR* (advanced very high resolution radiometric) was used from the 1st of Aug. to 30th of Aug. 2014 with 1100 m ground resolution. Landsat8 data acquired on 13th of Aug. and 08th of Aug. 2014 which used to calculate K_c and $ET_{o\text{-}Har}$ (Table, 1)

Table 1. Satellite data discretion (location and time)

NO	Path	Raw	Date
1	177	039	13 Aug 2014
2	177	040	13 Aug 2014
3	174	043	08 Aug 2014

Fig. 1 shows the study area location.

2.3 Extracting *LST* and *NDVI*

NOAA data were considered by the following steps:- a) Clear-sky satellite overpasses selection; b) Georeferencing data; c) 10 days average *NDVI* data generation; d) Computing of the 9 pixels mean *LST* over the ground-based stations position. The [18] (equation 1) use the retrieved emissivity computed by [19] (eq. 2, 3 and 4) algorithm, by means of the *NDVI* as representative of the emissive characteristics. The emissivity factor was retrieved as follows:-

$LST = T4+[0.53+0.62(T4-T5)](T4-T5)+64(1-\varepsilon)$ (1)

Where; T4 and T5 = brightness temperature for channels 4 and 5 of *AVHRR*, and ε = mean emissivity for channels 4 and 5, (ε4 + ε5)/2.

$\varepsilon = 0.985Pv + 0.96(1-Pv) + 0.06Pv(1-Pv)$ (2)

Thus:

$$Pv = \frac{(1-{}^{i}/_{ig})}{(1-{}^{i}/_{ig})-k(1-{}^{i}/_{iv})} \quad (3)$$

And k is:

$$k = \frac{\rho 2v-\rho 1v}{\rho 2g-\rho 1g} \quad (4)$$

Where; i, ig and iv are *NDVI*, *NDVI* bare soil, and *NDVI* vegetated surface, ρ1 and ρ2 are channels 1 and 2 reflectance's of *AVHRR*, and v and g are indexes for vegetation and bare soil.

For landsat8 data, the recorded digital numbers (*DN*) and converted to radiance units (*Rad*) using the calibration coefficients specific for each band. Band 10 used to extract *LST* as follow:-

Radiance = 0.0003342* *DN*+ 0.10000 (5)

Surface emissivity (*Eo*) was estimated from the *NDVI* using the empirical equation developed from raw data on *NDVI* and thermal emissivity [19].

Eo = 0.9932 + 0.0194 ln *NDVI* (6)

The radiant temperature (*To*) can be calculated from band 10 radiance (*Rad10*) using calibration constants K1=774.89 and K2=1321.08.

To = K2/ ln((K1/Rad10) +1) (7)

The resulting temperature (Kelvin) is satellite radiant temperature of the viewed Earth atmosphere system, which is correlated with, but not the same as, the surface (kinetic) temperature. The atmospheric effects and surface thermal emissivity have to be considered in order to obtain the accurate estimate of surface temperature from satellite thermal data [20]. *LST* is calculated from the top of atmosphere radiant temperature (*To*) and estimated surface emissivity (*Eo*) as:

LST = *To*/*Eo* (8)

2.4 Reference Evapotranspiration Estimation

ET_o was calculated from meteorological data using FAO-Penman-Montieth method equation (9) prepared by [13].

$$ETo = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1+0.34u_2)} \quad (9)$$

Where; *ETo*, reference evapotranspiration [mm day-1], Rn, net radiation at the crop surface [MJ m-2 day-1], G, soil heat flux density [MJ m-2 day-1], T, mean daily air temperature at 2 m height [°C], u2 ,wind speed at 2 m height [m s-1], es, saturation vapour pressure [kPa], ea ,actual vapour pressure [kPa], es - ea, saturation vapour pressure deficit [kPa], Δ , slope vapour pressure curve [kPa °C-1], *y*, psychrometric constant [kPa °C-1].

Hargreaves method used to estimate ET_o from predicted T_{air} equation (10). Then, it calibrated with *FPM* under the same conditions. The meteorological parameters used in this equation were considered from predicted data from Landsat8 satellite data.

$ETo = 0.0023(Tmean+17.8)(Tmax-Tmin)^{0.5} * Ra$ (10)

Where; Tmean is average of daily temperature (°C), Tmax is maximum temperature (°C), Tmin is minimum temperature (°C), and Ra is the extraterrestrial radiation, for each day of the year and for different latitudes could be estimated from the solar constant.

Ra is the extraterrestrial radiation, for each day of the year and for different latitudes could be estimated from the solar constant, the solar declination and the time of the year by:-

$$R_a = \frac{24(60)}{\pi} G_{so} d_r [\omega_s \sin(\varphi)\sin(\sigma) + \cos(\varphi)\cos(\sigma)\sin(\omega_s)] \quad (11)$$

Where; *Ra* is extraterrestrial radiation ($MJ/m^2/day^1$), *Gsc* is solar constant (0.0820 $MJ/m^2/min^1$), *dr* is inverse relative distance Earth-Sun, *Ѡs* is sunset hour angle (*rad*), *j* is latitude (*rad*) , *d* is solar decimation (*rad*). *Ra* is expressed in the above equation in ($MJ/m^2/day^1$). The corresponding equivalent evaporation in (*mm /day*) is obtained by multiplying *Ra* by 0.408. The latitude (*j*) expressed in radians is positive for the northern hemisphere and negative for the southern hemisphere. The conversion from decimal degrees to radians is given by:

Radians = Л/180*(decimal degrees) (12)

The inverse relative distance Earth-Sun (*dr*) and the solar declination (δ) are given by:

dr = 1+0.033*cos (2 ЛJ/365) (13)

δ = o.409*sin((2* Л*J/365)-139) (14)

Where; J is number of the day in the year between 1 (1 January) and 365 or 366 (31 December). J Values for all days of the year.

The sunset hour angle, Ѡ*s*, is given by:

Ѡ*s* = *arccos* [-*tan* (*j*) *tan* (*d*)] (15)

As the *arccos* function is not available in all computer languages, the sunset hour angle can also be computed using the arctan function:

Ѡ*s* = (Л/2)-*arctan*[-*tan*(φ)***tan*(δ)/X0.5] (16)

Where:-

X = 1 - [*tan*(*j*)]2 [*tan*(*d*)]^2 (17)

and X = 0.00001 if X £ 0

2.5 Crop Coefficient

Kc is a dimensionless number (usually between 0.1 and 1.2) which used to calculate (*ETc*). The resulting *ETc* helps in irrigation scheduling; timing of irrigation and quantity of water should be applied. The relation between *Kc* and *NDVI* represented by equation (18) which used by [17] and evaluated by [4] for wheat.

$$Kc = \frac{1.2}{NDVI_{dv}}(NDVI - NDVI_{mv}) \quad (18)$$

Where; 1.2 is the maximum K_c under Egyptian conditions, $NDVI_{dv}$ is difference between minimum and maximum *NDVI* value for vegetation and $NDVI_{mv}$ is the minimum *NDVI* value for vegetation.

3. Results and Discussion

3.1 The Relation between *LST* and T_{air}

The difference between T_{air} and *LST* varies particularly with the surface water status, the roughness length and wind speed. *LST* was lower than T_{air} at night but at day it was the opposite, because of the surface energy emitted during the day more than during the night and T_{air} affected by wind speed and air humidity. Quantities of data during night were lower than during day especially in Alexandria because of clouds. Figure (2) shows the relation between T_{air} (°C) and *LST* (°C) derived from *NOAA/AVHRR* in regions under investigation. This relation used to predict T_{air} from *LST*.

3.2 ET_O Estimation

[21] used *FPM*, Hargreaves and Radiation methods to estimate ET_o based on satellite and ground data. ET_o calculated according to *FPM* for Alex, El-Minya and Aswan (Table, 2). The ET_o values for August 2014 were 7.12, 9.45 and 15.37 (*mm/day*) in Alex., El-Minya and Aswan respectively.

ET_o extracted form Landsat8 data according to Hargreaves after calibration with *FPM*. Figure (3) shows ET_o estimated by Hargreaves after calibration. It varies from 6.7 to 25 *mm/day*. Non-vegetative areas had a very high ET_o because of *LST* and T_{air} of non-vegetative areas are very high and ET_o depend completely on weather parameters.

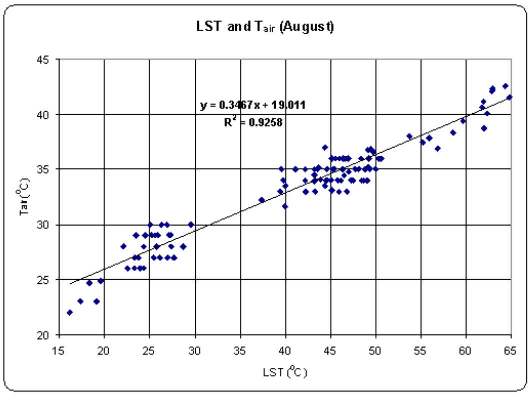

Fig. 2 shows the relation between T_{air} (°C) and *LST* (°C) in study areas.

Table 2. ET_o estimated using *FPM* method according to meteorological data (2014).

Month	*ETo (mm/day) Alexandria*	*ETo (mm/day) El-Minya*	*ETo (mm/day) Aswan*
Jan.	2.25	2.91	5.82
Feb.	3.1	4.31	7.72
Mar.	4.34	5.78	10.34
Apr.	5.2	8	12.36
May	6.68	10.03	14.42
Jun.	7.05	10.62	14.94
Jul.	7.11	9.69	15.18
Aug.	7.12	9.45	15.37
Sep.	6.29	9.34	12.57
Oct.	5.23	6.08	9.85
Nov.	4.16	4.05	7.02
Dec.	3.12	2.87	5.88

3.3 K_C Estimation Using Satellite Data

K_c depends on stage of canopy height, crop growth, architecture and cover [13]. The relation between K_c and *NDVI* is highly correlated. *NDVI* calculated from Red and NIR bands in Landsat8 data. The *NDVI* equation produces values in the range of -1.0 to 1.0, where vegetated areas typically have values greater than 0.2 and less values indicate non-vegetated surface features such as water, barren, ice, snow, or clouds. *NDVI* vary according to crop age, planting density and chlorophyll activity. It seems like K_c varying from planting to senescence. Figure (4) illustrates K_c values variation in study area according to Landsat8 data. K_c in study area varied from 0 to 1.2.

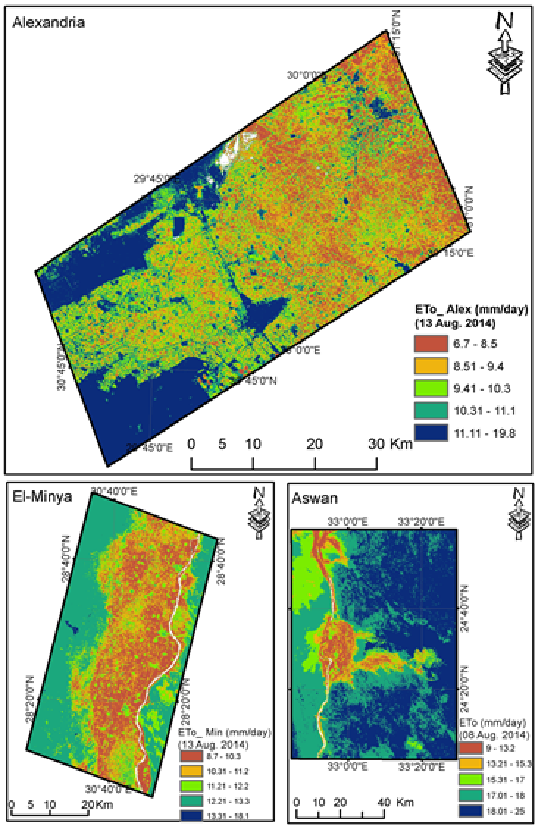

Fig. 3 ET_o estimated by Hargreaves after calibration with *FPM*.

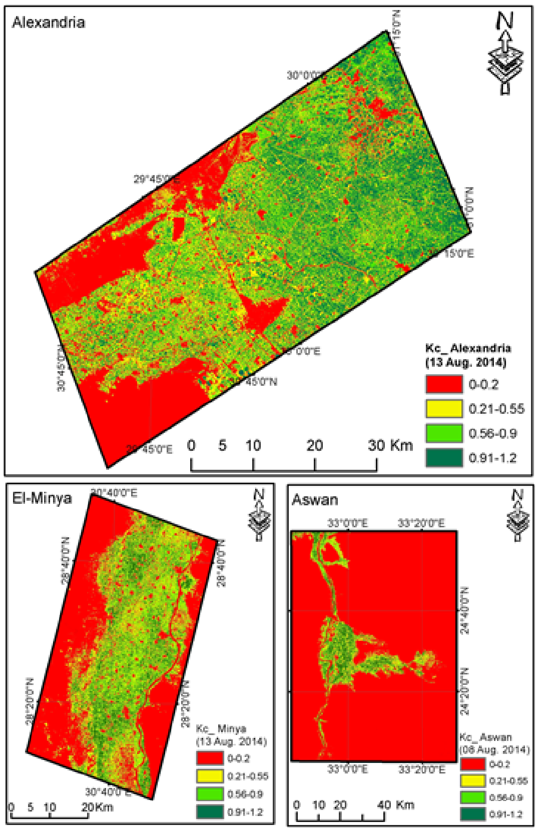

Fig. 4 K_c extracted from Landsat8 according to equation NO (18)

3.4 ET_c estimation

In arid and semi-arid regions ET_c is a good index for irrigation water requirements calculation. ET_o and K_c used to estimate ET_c.

$ET_{c\text{-}Har}$ values varied from 0 to 13 (*mm/day*) in Alexandria and from 0 to 15.4 in El-Minya but in Aswan the $ET_{c\text{-}Har}$ values varied from 0 to 25 (*mm/day*). Figure (5) shows $ET_{c\text{-}Har}$ distribution in study areas. On the other side, $ET_{c\text{-}FPM}$ values varied from 0 to 11.3 (*mm/day*) in Alexandria and from 0 to 14.5 (mm/day) in El-Minya. On the other hand, $ET_{c\text{-}Har}$ values varied from 0 to 23.5 *mm/day* in Aswan. Figure (6) shows $ET_{c\text{-}Har}$ distribution in study areas.

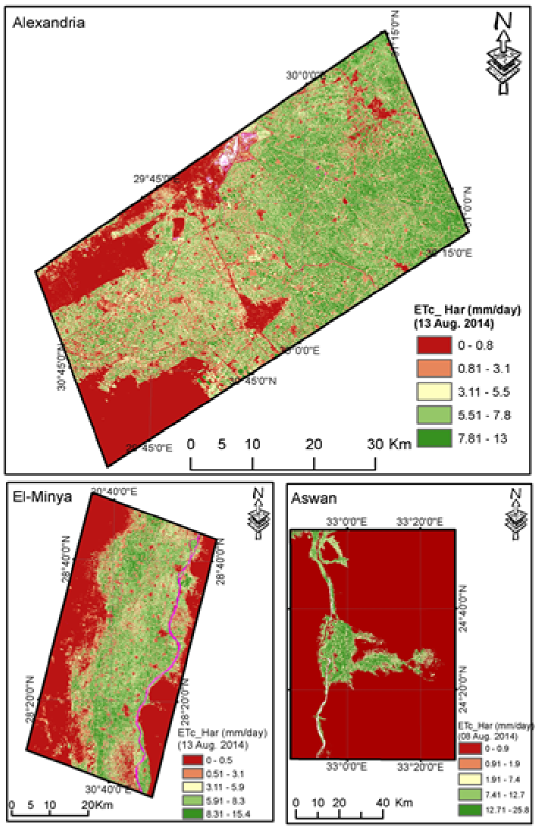

Fig. 5 $ET_{c\text{-}Har}$ distribution in areas under investigation

3.5 Hargreaves Method Compared with *FPM*

ET_o estimated using agro-meteorological data according to Hargreaves and *FPM* methods under the same conditions. Most of ET_o values calculated using Hargreaves were overestimated because of Hargreaves method depends on few parameters, so it must be calibrated with a standard method like *FPM* or Lysimeter. [22] evaluated popular forms of the penman equation, and general relationships for estimating ET_o. They did a relationship between FAO-24 corrected penman equation and Lysimeter. They also did a relation between 1982 Kimberly-Penman and Penman-Monteith vs.

Lysimeter. All methods used in the daily analysis, besides the Penman-Monteith, were adjusted for Lysimeter vegetation type using the 1.15 multiplier. Compatibility with [22] and FAO56 paper recommendations, ET_o estimated by Hargreaves method should be calibrated with *FPM* method under the same conditions and time. Figures (7, 8, and 9) show the relation between ET_c by Hargreaves method and *FPM* method. It gave a well distributions and good correlation where R^2 as high as 0.99.

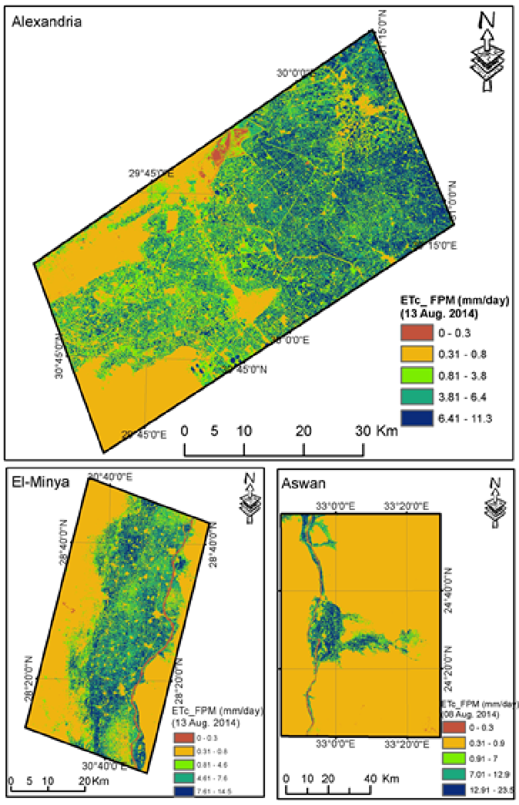

Fig. 6 $ET_{c\text{-}FPM}$ distribution in areas under investigation.

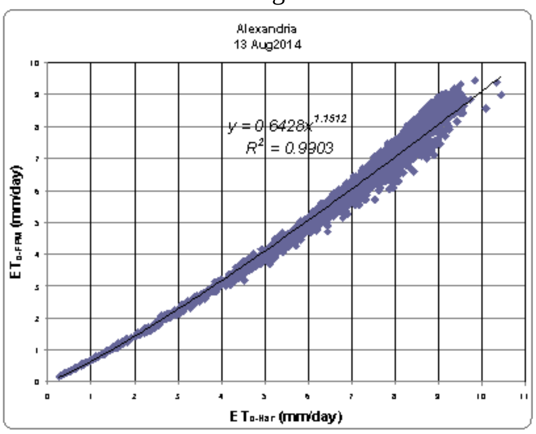

Fig. 7 shows the relation between $ET_{c\text{-}Har}$ and $ET_{c\text{-}FPM}$ in Alex.

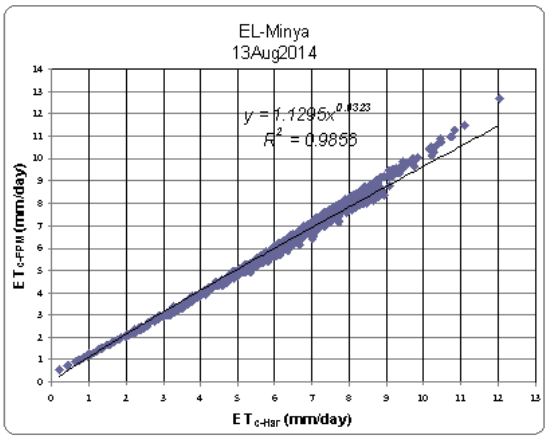

Fig. 8. shows the relation between $ET_{c\text{-}Har}$ and $ET_{c\text{-}FPM}$ in El-Minya.

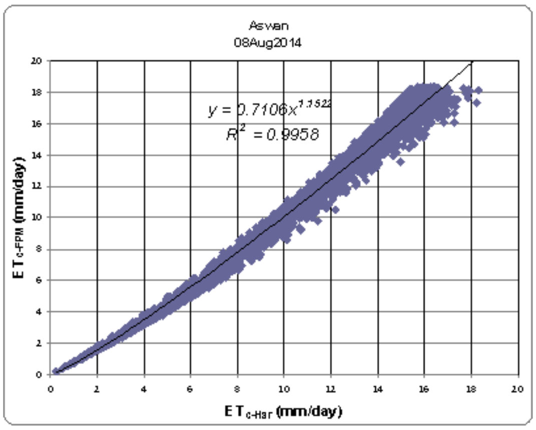

Figure 9. shows the relation between $ET_{c\text{-}Har}$ and $ET_{c\text{-}FPM}$ in Aswan.

4. CONCLUSION

ET_o can be estimated by many models which vary in complexity but the accuracy of ET_o estimation is proportional to the degree of calibration and validation of the used model. Low ground data availability is a serious problem in Egypt and developing counties. Free satellite data may be used as alternative method if it is used after calibration and evaluation especially in Agricultural field. Hargreaves after calibration with *FPM* is good method to calculate ET_o in low availability data regions. $ET_{o\text{-}Har}$ which calculated by Hargreaves based on remotely sensed data was overestimated compared with $ET_{o\text{-}FPM}$ method. The planning of irrigation strategies will be useful and low cost method for estimating crop water requirements and enhancing water resources management.

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