

## EVAPOTRANSPIRATION ESTIMATION USING REMOTE SENSING DATA AND SOME CLIMATIC MODELS

Abdel Kader, M.H.<sup>1</sup>; H.E. Khalifa<sup>1</sup>; A.S. Sheta<sup>2</sup> and A.A. Ibrahim<sup>2</sup>



<sup>1</sup> Soils, Water and Environment Res. Institute, Agric. Res. Center, Egypt

<sup>2</sup> Soil Science Dept., Faculty of Agriculture, Ain Shams University, Egypt

### ABSTRACT

This study aims to assess the estimated values of evapotranspiration using the surface energy balance system (SEBS model) and four climatic models widely used including Penman-Monteith (FAO 56-PM), Penman (FAO 24-P), radiation (R) and Hargreaves-Samani (HS). Remote sensing model (SEBS) was used to estimate daily actual evapotranspiration values for wheat, Sugar beet and green onions crops using nine Landsat ETM+7 satellite images representing the 2012 / 2013 season. The selected site represents a private farm (6<sup>th</sup> October agricultural company) located in Ismailia governorate (between 31.92 and 32.62 E longitudes and 30.38 and 30.52 N latitudes).

Results indicated that there were clear differences between the estimated  $E_t$  values using any of the tested climatic or remote sensing models. The  $E_t$  values estimated by SEBS, P, R, and HS methods were lower than those estimated by PM method. Estimated  $E_t$  values using SEBS model were generally low compared with those estimated by the tested climatic models. The actual evapotranspiration values ( $E_t$ ) for the studied crops using SEBS, PM, P, R, and HS methods are 384, 574, 382, 450, and 329 for wheat, 491, 533, 331, 409 and 264 for sugar beet and 279, 614, 414, 508 and 360 mm/season for green onion crop respectively. Data suggested that, more studies and verification are needed to evaluate all the factors that might affect the quality of data affecting the surface energy balance under arid lands condition. Results concluded also that more verification through several consecutive seasons for various crops is recommended for estimating the actual evapotranspiration at the field level.

**Keywords:** Reference & actual crop evapotranspiration, FAO-56 Penman-Monteith method, (PM), Penman method (FAO 24 P), Radiation method (FAO R), Hargreaves-Samani method (HS), Remote sensing model (SEBS) model.

### INTRODUCTION

Water scarcity in Egypt and the other countries in the arid zone was the major factor that limits the ambitious hopes to expand the agricultural area and increase its productivity to meet the present gap between food production and consumption. The pressure of population growth and increasing domestic demand and other sectors for water as well as the negative impact of climate change represent additional challenges for the agricultural sector. To meet these challenges, good water governance which aims to reduce losses and increase benefits per unit of water should be adopted. For this reason, accurate estimation of crop water requirement was very important. The problem of over irrigation or under irrigation will be

minimized if we were able to accurately estimate crop water requirement or crop evapotranspiration (Sallam, 2014; Subedi & Chávez, 2015).

One of the most efficient ways to improve water use efficiency and optimize plant production is to provide crops only with the water they need based on the climate-plant-soil relationship. Therefore, the concept of evapotranspiration is the base for estimating the right amount of irrigation water that should be applied. As the measurement of ET from a crop surface is a very difficult and time consuming task, a large number of empirical methods have been developed over the last 50 years by numerous scientists and specialists worldwide to estimate evapotranspiration from different climatic variables like Thornthwaite method, Hargreaves method, Turc method, Blaney-Criddle method, Penman method, Penman-Monteith method etc. On the other hand, the scientific community has been interested in estimating evapotranspiration by remote sensing, since it is the unique way to retrieve ET at several temporal and spatial scales. For this reason, different methods have been developed to derive surface fluxes from remote sensing observations, such as: Surface Energy Balance Algorithm for Land (SEBAL), Bastiaanssen, 2000; Bastiaanssen *et al.*, 1998a,b; Jacob *et al.*, 2002), S-SEBI (Simplified Surface Energy Balance Index, Roerink *et al.* 2000), and SEBS (Surface Energy Balance System, Jia *et al.* 2003; Su, 2002).

Wahaj *et al.* (2007) studied crop water requirement as affected by climate change in some countries in Africa. They indicated that the reference crop evapotranspiration ( $E_{t_0}$ ) values of maize and dry bean crops were 678 and 189 mm, respectively for Kafr El-Shiekh governorate. They added that the  $E_{t_0}$  values for maize, dry bean, groundnut, and sorghum crops were 825, 310, 835, and 825 mm respectively for Giza governorate. In Egypt. Khalifa *et al.* (2011) used the CROPWAT model to assess the effects of different deficit irrigation scenarios on the yields of crops planted in field trials. They found that crop evapotranspiration values of wheat, peanut, and maize crops were 282, 543, and 524 mm seasons<sup>-1</sup> respectively. George *et al.* (2002) found that certain models, such as Hargreaves-Samani, perform best in situations where only maximum and minimum air temperature data were available. They concluded that the Hargreaves-Samani model fell within 1 percent of PM- FAO 56 method.

The Surface Energy Balance System (SEBS) model, developed by Su (2002), can be used to determine turbulent heat fluxes by employing satellite and meteorological data. It consists of: (1) an estimation of a series of land surface physical parameters, such as emissivity, albedo, vegetation coverage *etc.* based on spectral reflectance and radiance; (2) an extended model of roughness length estimation for heat transfer; and (3) an evaporative fraction estimation at limiting cases by energy balance. Weiqiang *et al.* (2013) used Surface Energy Balance System (SEBS) model based on ASTER images and field observations data for deriving  $E_{t_a}$  over the NamCo area in the southwest of China. They showed that the derived ET in different months over the study area was close to the field measurement; it is therefore concluded that the SEBS methodology is successful for the retrieval of  $E_{t_a}$  using the ASTER and in-situ data over the study area. Matinfar and Soorghali (2014) used SEBS model, spectral data and Landsat 5 (TM) thermal band to

estimate actual evapotranspiration rates. Results of the model were compared with the Penman Montieith method. Statistical analysis showed significant differences between the results of the two methods. They concluded that, the SEBS model can be a valuable alternative to traditional methods of estimating actual evapotranspiration.

Bansouleh *et al.* (2015) conducted a study to assess the accuracy of estimated  $E_t_a$  based on SEBS algorithm using LANDSAT TM images in Iran. The  $E_t_a$  of maize was calculated using four images of LANDSAT during the maize growing season in year 2010. At the same time, the actual ET of maize was measured in a Lysimeter in the same region. They observed a reasonable match between measured and calculated crop evapotranspiration by SEBS algorithm. The maximum difference between the calculated evapotranspiration by SEBS algorithm with measured values by Lysimeter was about 4.56% of measured ET.

In Egypt, few studies have applied remote sensing data at farmers' field level to estimate evapotranspiration. However, Elhag *et al.* (2011) used SEBS model to estimate daily evapotranspiration and evaporative fraction over the Nile Delta along with data acquired by the Advance along Track Scanning Radiometer (AATSR) and the Medium Spectral Resolution Imaging Spectrometer (MERIS), and six in situ meteorological stations. The simulated daily evapotranspiration values were compared against actual ground-truth data taken from 92 points uniformly distributed all over the study area. The derived maps and the correlation analysis showed strong agreement, demonstrating SEBS' applicability and accuracy in the estimation of daily evapotranspiration over agricultural areas.

The main objective of this study was to investigate the possibility of using the remote sensing model (SEBS) for in the estimation of actual evapotranspiration ( $E_t_a$ ) directly in the presence of three selected crops (wheat, Sugar beet, green onion) in comparison with four climatic models (Penman-Monteith (PM-FAO 56), Penman (P-FAO-24), Radiation method (R), and Hargreaves-Samani (HS) for used in estimating reference evapotranspiration indirectly or in absence of crop under Egyptian conditions.

## **MATERIALS AND METHODS**

### **Location and general description of the site:**

The selected site represents a 6<sup>th</sup> October farm that was located in Ismailia governorate between 31.92 and 32.62 E longitudes and 30.38 and 30.52 N latitudes (Figure 1).

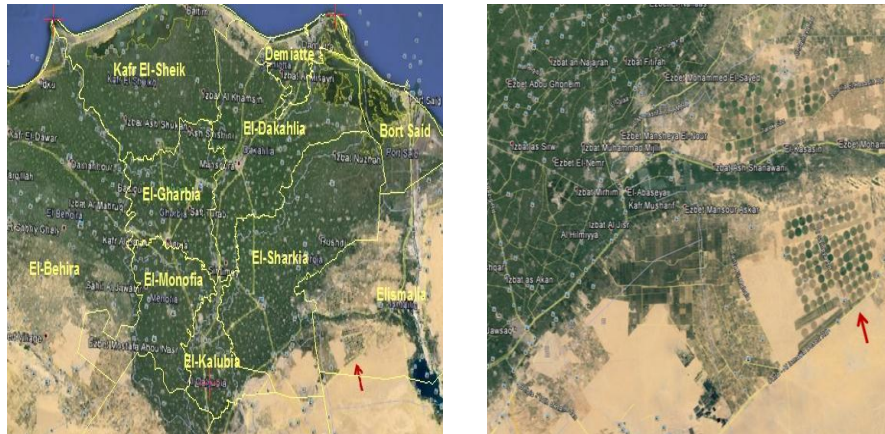


Fig. 1: Site location as illustrated on the administrative map and on satellite image.

**Data availability:**

**Satellite Data:**

Nine Landsat ETM+7 images (Table 1) acquired in October, November, and December 2012, Jan., February, March., April, May, and June 2013. Remote sensing and Meteorological data were used to estimate evapotranspiration at the day of images captured using the SEBS model. It is worthy to mention that the Landsat images were atmospherically and radiometrically corrected before using in the SEBS model.

**Table.1. Landsat ETM+7 satellite images specifications.**

Scene coverage area	185 x 185 km
Spatial Resolution	30 m Multispectral
	15 m Panchromatic
Blue-green	450 - 515 nm
Green	525 - 605 nm
Red	630 - 690 nm
Near-infrared	750 - 900 nm
Mid-infrared	1550 - 1750 nm
Far-infrared	10400 - 12500 nm
Mid-infrared	2090 - 2350 nm
Pan	520- 900 nm

**Meteorological data**

Meteorological data includes the maximum, minimum, and mean air temperatures and dew point temperatures ( $C^{\circ}$ ), wind speed ( $ms^{-1}$ ), relative humidity (%), and solar radiation ( $MJm^{-2}$ ) for Ismailia governorate during the period from Oct to Dec 2012 and from Jan to Dec 2013 were presented in Table 2. These data were required for calculating reference evapotranspiration values ( $Et_o$ ) using Penman-Monieth (PM), Penman (P),

radiation (R), and Hargreaves-Samani (HS) methods as well as actual evapotranspiration values at the day of image captured by the SEBS model.

**Table.2. Monthly average meteorological data for Ismailia governorate during the period from Oct 2012 to Dec 2013.**

Date	T <sub>max</sub> (C)	T <sub>min</sub> (C)	T <sub>mean</sub> (C)	T <sub>dew</sub> (C)	U <sub>2</sub> (ms <sup>-1</sup> )	RH (%)	R <sub>s</sub> (MJm <sup>-2</sup> )
Oct. 2012	32.6	20.3	26.5	14.6	3.3	51.5	18.1
Nov.	26.7	16.7	21.7	11.9	3.1	57.6	14.3
Dec.	21.1	11.6	16.4	6.8	3.1	56.7	12.5
Jan. 2013	19.1	8.1	13.6	4.1	3.9	55.6	13.1
Feb.	21.4	9.3	15.4	4.5	3.5	49.0	16.5
Mar.	26.6	11.7	19.1	4.7	4.5	41.0	21.2
Apr.	27.6	13.2	20.4	6.8	4.4	43.0	24.1
May	33.6	18.2	25.9	9.1	4.1	36.1	27.9
Jun.	35.2	20.3	27.8	11.5	4.0	38.3	30.0
Jul.	35.1	20.7	27.9	14.0	4.1	44.2	29.1
Aug.	36.2	21.6	28.9	14.8	3.5	44.0	27.0
Sep.	33.4	20.4	26.9	14.7	4.1	49.6	23.2
Oct.	28.8	16.4	22.6	11.5	4.4	52.7	19.0
Nov.	26.4	15.2	20.8	10.6	3.5	55.7	14.1
Dec.	19.5	9.3	14.4	4.4	3.8	53.5	11.5

**Crop Data:**

Three crops representing the major farming activity in the study area were selected to estimate the evapotranspiration using the selected four climatic models in addition to a remote sensing model (SEBS). The following is a brief description of each of these crops.

**1. Wheat crop:**

Wheat crop is one of the main cultivated winter crops in the study area under center pivot irrigation system. The variety was Misr-1, sowing dates ranged from 25<sup>th</sup> to 27<sup>th</sup> of November 2012 and the harvesting dates ranged from 23<sup>th</sup> to 30<sup>th</sup> of April 2013, The wheat crop was fertilized in this farm during growth season by 94, 13, 47, 11, and 10 kg/Fadden of N, P<sub>2</sub>O<sub>5</sub>, K<sub>2</sub>O, CaO and MgO, respectively, in addition to micronutrients injected through irrigation water using the fertigation system.

**2. Sugar beet crop:**

Few center pivots were cultivated with Sugar beet crop in winter season 2012/2013. The variety was *Giza*, sowing dates ranged from 10<sup>th</sup> to 12<sup>th</sup> of December 2012 and harvested from 10<sup>th</sup> to 15<sup>th</sup> of June 2013. The Sugar beet crop was fertilized in this farm during growth season by 72, 11, 67, 13, and 8 kg/Fadden of N, P<sub>2</sub>O<sub>5</sub>, K<sub>2</sub>O, CaO and MgO, respectively. in addition to micronutrients injected through irrigation water.

**3. Green onion crop:**

Green onion crop is one of the main winter vegetable crop cultivated in the study area under center pivot irrigation system mainly for export to UK. The variety was *Baja*, sowing dates ranged from 15<sup>st</sup> to 18<sup>st</sup> of September 2012 and the harvesting dates ranged from 6<sup>th</sup> to 13<sup>th</sup> of April 2013. The green onion crop was fertilized in this farm during growth season by 79, 12,

29, 9, and 9 kg/Fadden of N, P<sub>2</sub>O<sub>5</sub>, K<sub>2</sub>O, CaO and MgO, respectively, in addition to micronutrients injected through irrigation water.

**Irrigation system:**

The center pivot is the main irrigation system in the farm particularly for field and vegetable crops. The application efficiency of the system was about 75%. The pump station produces pressure of about 6 bars to maintain water flow of about 80 Lsec<sup>-1</sup> through nuzzle of a large center pivot. The pivot takes 12 hours to complete one cycle to apply 20 m<sup>3</sup>/Faddan of irrigation water.

**Evapotranspiration estimation models:**

The ET techniques were selected by considering the availability of meteorological data required by those models. In this study, the selected methods can be divided into two broad groups: I) climatic models, e.g. Penman-Monteith (PM-FAO 56), Penman, (P-FAO 24), Radiation-based method (R-FAO 24), temperature-based method (Hargreaves-Samani, HS), and II) remote sensing model based on surface energy balance method (SEBS). Ibrahim (2013) described a simple method using the Microsoft Excel to be a helpful tool in computation of evapotranspiration parameters using the different climatic models.

The performance efficiencies of these methods were determined using the appropriate statistical analysis such as the regression analysis and correlation coefficients.

**I. Climatic models:**

**1. Penman–Monteith method (Allen et al., 1998):**

This version PM model was recommended by FAO as a main method for estimating reference evapotranspiration (E<sub>t0</sub>) if the required data are available (Allen et al., 1998). The FAO 56 PM method is given as follows:

$$E_{t0} = \frac{0.409 \cdot \Delta \cdot (R_n - G_d) + \left( \gamma \cdot U_{2\text{mean}} \cdot (e_s - e_a) \cdot \frac{900}{T_{\text{mean}} + 273} \right)}{\Delta + \gamma \cdot (1 + 0.34 \cdot U_{2\text{mean}})} \quad \text{mm/day}$$

where Δ is the slope of the saturation vapor pressure/temperature relationship (kPa°C<sup>-1</sup>), R<sub>n</sub> is net radiation (MJm<sup>-2</sup> d<sup>-1</sup>), G<sub>d</sub> is soil heat flux (MJm<sup>-2</sup> d<sup>-1</sup>), γ is the psychrometric constant (kPa °C<sup>-1</sup>), T is mean daily air temperature at 2 m height (°C), U<sub>2mean</sub> is wind speed at 2 m height (m s<sup>-1</sup>), and (e<sub>s</sub> - e<sub>a</sub>) is the saturation vapor pressure deficit (kPa).

**2. Penman's method (Doorenbos and Pruitt, 1977):**

$$E_{t0} = C \times ((W \times R_n) + (1 - W) \times f(U) \times (e_a - e_d)) \quad \text{mmday}^{-1}$$

where W is temperature-related weighting factor, R<sub>n</sub> is the net solar radiation, f(U) is wind-related function, (e<sub>a</sub> - e<sub>d</sub>) is the difference between saturation vapor pressure at mean air temperature and mean actual vapor pressure of the air, and C is the adjustment factor to compensate for the effect of day and night weather conditions.

**3. Radiation method (Doorenbos and Pruitt, 1977):**

$$ET_o = C \times W \times R_s \quad \text{mmday}^{-1}$$

where  $R_s$  is the solar radiation,  $W$  is weighting factor which depends on temperature and altitude, and  $c$  is the adjustment factor which depends on mean humidity and daytime wind conditions.

**4. Hargreaves-Samani method:**

The Hargreaves and Samani (198 and 1985) equation is a temperature-based equation expressed as follows:

$$ET_o = 0.0135 \times KT \times R_a \times (TD)^{0.5} \times (T_{\text{mean}} + 17.8) \quad \text{mmday}^{-1}$$

where  $ET_o$  is the reference evapotranspiration (mm/day),  $KT=0.00185 \times (TD)^2 - 0.0433 \times TD + 0.4023$ ,  $T_{\text{mean}}$  is the mean air temperature ( $^{\circ}\text{C}$ ),  $TD$  is  $(T_{\text{max}} - T_{\text{min}})$  ( $^{\circ}\text{C}$ ), and  $R_a$  is the daily extraterrestrial radiation (mm/day).

**Actual evapotranspiration ( $ET_a$ ):**

Actual evapotranspiration values of the tested crops ( $ET_a$ ) were estimated simply by multiplying  $ET_o$  by the corrected crop coefficient ( $K_c$ ) according to the minimum relative humidity and wind speed as described by Ibrahim (2013) for different growth stages.

**II. Surface energy balance system model (SEBS):**

The surface energy balance system (SEBS) model derived by Su (2001) for the estimation of atmospheric turbulent fluxes using satellite earth observation data in combination with meteorological information as inputs to retrieve a set of geo-physical parameters, evaporative fraction, net radiation, and soil heat flux parameters etc. The equations used in the SEBS model were:

$$\lambda Et = R_n - G - H$$

where  $R_n$  is the net solar radiation,  $G$  is the soil heat flux,  $H$  is the turbulent sensible heat flux, and  $\lambda Et$  is the turbulent latent heat flux ( $\lambda$  is the latent heat of vaporization and  $Et$  is the evapotranspiration).

$$R_n = (1 - \alpha) (R_{s,\text{sun}} + R_{s,\text{sky}}) + R_{L,\text{sky}} - R_{L,\text{out}}$$

where  $\alpha$  is the albedo,  $R_s$  is the incoming and outgoing solar radiation,  $R_L$  is the incoming and outgoing longwave radiation.

$$G = R_n (\tau_c + (1 - f_c)(\tau_s - \tau_c))$$

where  $\tau_c = 0.05$  for full vegetation canopy,  $\tau_s = 0.315$  for bare soil, and  $f_c$  is fractional canopy cover.

$$H = (\rho C_p (T_s - T_a) / r_{ah})$$

where  $\rho$  is air density,  $C_p$  is air specific heat ( $1004 \text{ J kg}^{-1} \text{ K}^{-1}$ ),  $T_s$  is surface temperature,  $T_a$  is air temperature, and  $r_{ah}$  is the aerodynamic resistance to heat transport.

$$\lambda = (\lambda E / (R_n - G)) = (\lambda_r \lambda E_{\text{wet}} / (R_n - G))$$

where  $\lambda$  is the evaporative fraction,  $\lambda_r$  is the relative evaporation, and  $\lambda E_{\text{wet}}$  is the evaporation at potential rate under wet conditions.

$$E_{\text{daily}} = 8.64 \times 10^7 \times \lambda_0^{24} \times (R_n - G / \lambda \rho_w)$$

where  $E_{\text{daily}}$  is the daily actual ET ( $\text{mm day}^{-1}$ ),  $\lambda_0^{24}$  is the daily evaporative fraction, and  $\rho_w$  is the density of water.

**Statistical analysis:**

The correlation and linear regression analysis were applied to the computations of the different methodologies in order to observe the behavior of the methods. The quality of the fit between any two methodologies was presented in terms of the coefficient of determination,  $r^2$ .

**RESULTS AND DISCUSSION**

**Estimating reference evapotranspiration ( $E_{t_0}$ ):**

The estimated average  $E_{t_0}$  values ( $\text{mm day}^{-1}$ ) by Penman-Montieth (PM), Penman (P), radiation (R), and Hargreaves-Samani (HS) methods using the agrometeorological data of 2012/2013 were presented in Table 3. In general, results showed the same trend in  $E_{t_0}$  values calculated by the four climatic models. The lowest values were recorded in December, except for the PM method which recorded in January, while the highest values were recorded in June, except for the Radiation method which was recorded in July. The highest average  $E_{t_0}$  value was  $12.6 \text{ mmday}^{-1}$  for PM in June, while the lowest value was  $1.8 \text{ mmday}^{-1}$  for HS in December.

**Table.3. Average reference evapotranspiration values ( $\text{mmday}^{-1}$ ) Estimated using the models of Penman-Montieth (PM-FAO 56), Penman (P-FAO 24), Radiation (R), and Hargreaves-Samani (HS) with the agrometeorological data of 2012.**

Month	PM	P	R	HS
Jan.	3.8	2.4	3.1	1.9
Feb.	5.0	3.3	4.0	2.6
Mar.	6.3	4.6	5.2	4.3
Apr.	8.9	6.3	6.7	6.5
May	10.9	7.8	8.0	8.1
Jun.	12.6	8.8	8.6	9.1
Jul.	12.1	8.5	8.7	8.6
Aug.	11.3	8.0	8.7	7.8
Sep.	10.0	6.4	7.1	5.3
Oct.	7.7	4.7	5.3	3.6
Nov.	5.7	3.3	4.0	2.5
Dec.	3.9	2.3	3.0	1.8
Mean	8.2	5.5	6.0	5.2

Data reveal that the average values of  $E_{t_0}$  were 8.2 (100), 6.0 (73.2), 5.5 (67.1) and 5.2 (63.4) for PM, R, P and HS, respectively. The differences in  $E_{t_0}$  values obtained for the tested methods may attributed to the Lowest correlation found between  $E_{t_0}$  values estimated by HS and minimum temperature ( $T_{\min}$ ) and maximum temperature ( $T_{\max}$ ), minimum relative humidity ( $RH_{\min}$ ), solar radiation ( $R_s$ ) and sunshine hours ( $n$ ), which were 0.89, 0.74, -0.04, 0.9 and 0.88, respectively. in comparison with that found for the other tested climatic models. This result was in agreement with those reported by Droogers and Allen (2002) and Temesgen *et al.* (2005) who



stated that HS equation tends to underestimate  $E_{t_o}$  values in very dry and windy regions. The observed variations in the reference evapotranspiration values calculated for the tested crops using the different climatic models and even the remote sensing model (SEBS) may attributed to the variations in weather parameters values used in the calculations.

Since the Penman-Monteith method (FAO-56 PM) was recommended by the Food and Agriculture Organization of the United Nations (FAO) as the standard sole method to calculate  $E_{t_o}$  whenever the required input data are available (Allen *et al.* 1998; Droogers and Allen, 2002), therefore, a regression analysis was done to develop relationships between  $E_{t_o}$  values estimated by FAO-56 PM and the P, R, and HS methods. The obtained relationships were expressed as follows:

$$E_{t_o} \text{ PM (mm)} = 1.059 + 1.228 E_{t_o} \text{ P (mm)} \quad r^2 = 0.8869$$

$$E_{t_o} \text{ PM (mm)} = -0.049 + 1.304 E_{t_o} \text{ R (mm)} \quad r^2 = 0.8334$$

$$E_{t_o} \text{ PM (mm)} = 2.624 + 1.137 E_{t_o} \text{ HS (mm)} \quad r^2 = 0.7604$$

The high values of the coefficient of determination ( $r^2 = 0.76 - 0.89$ ) indicate that the given equations can be used within the range of the examined values to describe the relationship between  $E_{t_o}$  estimated by PM-FAO 56 and the P-FAO 24, R, and HS methods.

#### **Estimating daily evapotranspiration using SEBS Model:**

The temporal variation maps of daily  $E_{t_a}$  values generated by SEBS model on 9 Landsat7 ETM+ images acquired during the 2012/2013 winter season were illustrated in Figure 2. For wheat crop, the  $E_{t_a}$  values used in mapping actual evapotranspiration ( $E_{t_a}$ ) varied from 1.0 to 5.0  $\text{mmday}^{-1}$ , with the smaller and higher values observed on 30 December 2012 and 5 April 2013, respectively. For green onion crop,  $E_{t_a}$  values varied from 1.1 to 5.5  $\text{mmday}^{-1}$  for the same respective images. For Sugar beet crop, the  $E_{t_a}$  values varied from 1.45 to 4.2  $\text{mmday}^{-1}$  for 30 December 2012 and 5 April 2013 images, respectively. Larger values of  $E_{t_a}$  were the result of high temperature and low relative humidity conditions that were common in the study area during the growing season.

The temporal study for actual evapotranspiration values ( $E_{t_a}$ ) produced from this study showed that the highest values of  $E_{t_a}$  were associated with the highest rate of the growth of crop particularly during the stage of growth development, while the lowest values of  $E_{t_a}$  were related to the initial growth stage where the rate of growth and development was low. The produced maps showed also the spatial variation in the values of  $E_{t_a}$  for different cultivated areas as attributed to the differences in crop type.

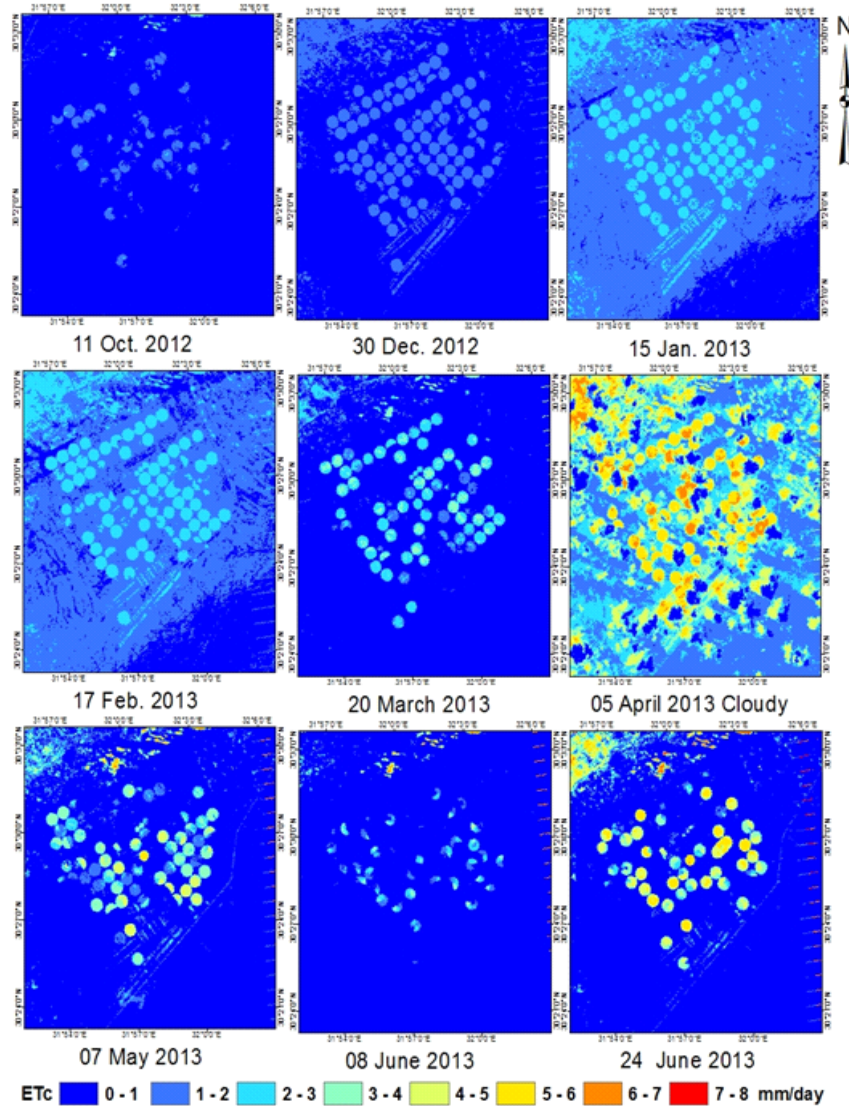
A regression analysis was done to express relationships between  $E_{t_a}$  values estimated by FAO-56 PM and the remote sensing model (SEBS) for the tested crops. The obtained relationships were shown as follows:

$$\text{For wheat crop, } E_{t_a} \text{ SEBS (mm)} = 3.019 + 0.395 E_{t_a} \text{ PM (mm)} \quad r^2 = 0.273$$

$$\text{For Sugar beet crop, } E_{t_a} \text{ SEBS (mm)} = 1.470 + 0.268 E_{t_a} \text{ PM (mm)} \quad r^2 = 0.712$$

$$\text{For green onion crop, } E_{t_a} \text{ SEBS (mm)} = 3.422 + 0.735 E_{t_a} \text{ PM (mm)} \quad r^2 = 0.348$$

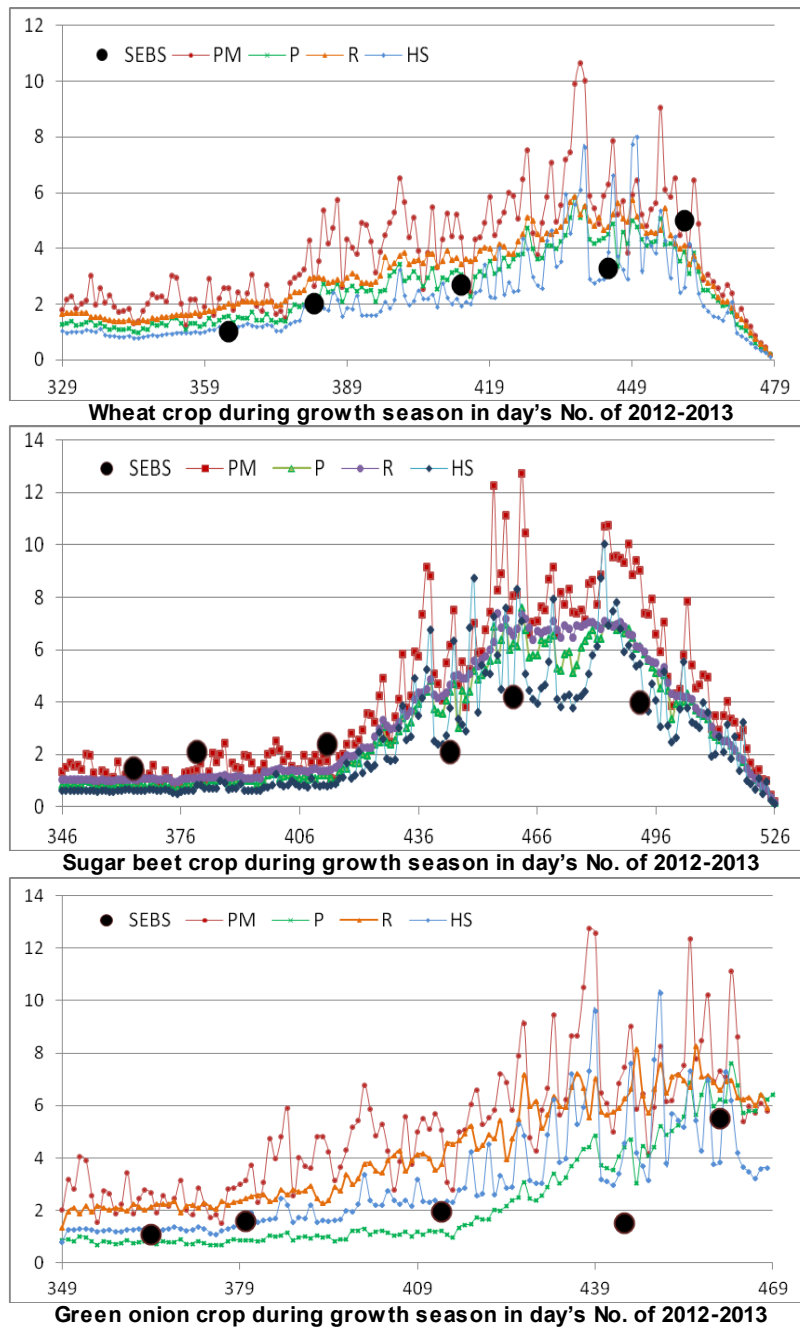
The low values of the determination coefficient ( $r^2 = 0.27-0.71$ ) indicate that the given equations can be carefully used within the range of the examined values to describe the relationship between  $E_{t_a}$  estimated by FAO-56 PM and by the SEBS methods.



**Fig.2. Daily actual evapotranspiration maps of the 2012/2013 winter season at the experimental site using Landsat 7 ETM+ images.**

**Estimating seasonal actual evapotranspiration (Et<sub>a</sub>)**

The average actual evapotranspiration values (Et<sub>a</sub>) as estimated by the four climatic models and the remote sensing model (SEBS) wheat, sugar beet, and green onion crops were illustrated in Figure (2). The average estimated Et<sub>a</sub> values using SEBS, PM, P, R, and HS methods were 2.80, 4.31, 3.00, 3.36, and 2.32 for wheat crop, 2.45, 4.51, 3.22, 3.53 and 2.43 for sugar beet crop and 2.33, 5.13, 3.61, 4.24 and 2.76 mmday<sup>-1</sup> for green onion crop respectively.



**Fig.3 Estimated actual evapotranspiration ( $E_t_a$ ) values in  $\text{mm day}^{-1}$  by the different climatic methods for the winter growing seasons of wheat, Sugar beet, and green onion crops.**

The seasonal values of the actual evapotranspiration ( $E_t$ ) may calculate based on the positive correlation (0.99) between the seasonal  $E_t$  and the average daily  $E_t$  determined using any of the climatic methods or the remote sensing (SEBS). Therefore, the calculated seasonal  $E_t$  values using SEBS, PM, P, R, and HS methods were 384, 574, 382, 450, and 329 for wheat crop, 423, 726, 497, 570 and 435 for Sugar beet crop and 306, 614, 414, 508 and 360  $\text{mmseason}^{-1}$  for green onion crop respectively. The obtained results were not comparable to those reported by Ali (2008) and Khalifa *et al.* (2011), who indicated that  $E_t$  of wheat crop was  $490 \text{ mmseason}^{-1}$ . However, The estimated  $E_t$  values For Sugar beet crop using PM is in agreement with that obtained by Ali (2008) using the same climatic model for Sugar beet crop, it was  $557 \text{ mmseason}^{-1}$ . This difference in  $E_t$  using the climatic or remote sensing methods may be attributed to the lack of similarity in the weather conditions, crop growth conditions and crop characteristics and consequently the crop production under which the reported values were estimated.

The comparison between daily evapotranspiration values as estimated by the SEBS remote sensing model and the PM, P, R, and HS climatic models was illustrated in Figure 3. Results indicated that SEBS model may estimate lower than actual ET values than those estimated using the tested climatic models except for the 5 April 2013 image for wheat and green onion crops and 30 Dec 2012 for Sugar beet crop. Results showed that, the daily actual evapotranspiration values estimated by SEBS model were close to those estimated by HS model, which could be due to that the HS model depends mainly on air temperature.

## CONCLUSIONS

From the aforementioned results it could be concluded that there were a clear differences between the estimated  $E_t$  values using the tested climatic and remote sensing models. In addition, the  $E_t$  values estimated by SEBS, P, R, and HS methods were lower than those estimated by PM method. Results indicated that SEBS model may estimate low actual ET values compared with those estimated using the tested climatic models,

The actual evapotranspiration values ( $E_t$ ) as estimated for the growing seasons of the tested crops using SEBS, PM, P, R, and HS methods were 384, 574, 382, 450, and 329 for wheat crop, 423, 726, 497, 570 and 435 for Sugar beet crop and 306, 614, 414, 508 and 360  $\text{mm/season}$  for green onion crop, respectively.

The substantial differences between actual evapotranspiration  $E_t$  for the same crop using different climatic models for estimating reference evapotranspiration  $E_t$  revealed the essential need to get accurate crop coefficients. However the remote sensing can help to overcome this problem by the direct measurements of the actual evapotranspiration which includes the actual crop coefficient values.

From the most important advantages of estimating evapotranspiration using the energy balance through satellite images were estimate the spatial and the possibility of producing maps reflect the water balance of the region under study which helps in improving water management not only in wide areas but also in small areas, as well as on tracking the time for water uses in the region under investigation by tracking the variability in evapotranspiration values. The remote sensing model (SEBS) needs more validation for multiple years and sites to be used as an alternative to traditional methods of estimating actual evapotranspiration at the field level.

## REFERENCES

- Ali, R.R. (2008). Digital soil mapping for optimum land uses in some newly reclaimed areas west of Nile delta, Egypt. *Australian Journal of Basic and Applied Sciences*. 2: 165-173.
- Allen, R.G., L.S. Pereira D. Raes and M. Smith (1998). *Crop evapotranspiration: Guidelines for computing crop water requirements*. FAO Irrigation and Drainage Paper 56, FAO, Rome.
- Bansouleh, B.F., A.R. Karimi and H. Hesadi (2015). Evaluation of SEBAL and SEBS Algorithms in the Estimation of Maize Evapotranspiration. *International Journal of Plant & Soil Science*. 6: 350-358.
- Bastiaanssen, W.G.M. (2000). SEBAL-based sensible and latent heat fluxes in the irrigated Gediz Basin, Turkey. *Journal of Hydrology*. 229: 87-100.
- Bastiaanssen, W.G.M., M. Menenti R.A. Feddes and A.A.M. Holtslag. (1998<sub>a</sub>). A remote sensing surface energy balance algorithm for land (SEBAL). Part 1: Formulation. *Journal of Hydrology*, v.212-213, p. 198-212.
- Bastiaanssen, W.G.M., H. Pelgrum J. Wang Y. Ma J.F. Moreno and G.J. Roerink (1998<sub>b</sub>). A remote sensing surface energy balance algorithm for land (SEBAL). Part 2: Validation. *Journal of Hydrology*, v.212-213, p.213-229.
- Doorenbos, J. and W.O. Pruitt (1977). *Guidelines for predicting crop water requirements*. FAO Irrigation and Drainage paper, 24.FAO Rome, Italy.
- Droogers, P., and R.G. Allen (2002). Estimating reference evapotranspiration under inaccurate data conditions. *Irrig. Drain. Syst.* 16: 33-45.
- Elhag, M., A. Psilovikos, I. Manakos and K. Perakis (2011). Application of the SEBS Water Balance Model in Estimating Daily Evapotranspiration and Evaporative Fraction from Remote Sensing Data over the Nile Delta. *Water Resource Management* 25: 2731-2742.
- George, B.A, B.R.S. Reddy N. S. Raghuvanshi and W.W. Wallender (2002). Decision support system for estimating reference evapotranspiration. *Journal of Irrigation and Drainage Engineering*. 128:1-10.
- Hargreaves, G.H. and Z.A. Samani (1982). Estimating potential evapotranspiration. *J. Irrig. and Drain Engr.*, 108:223-230.
- Hargreaves, G.H. and Z.A. Samani, (1985). Reference crop evapotranspiration from temperature. *Transaction of ASAE*. 1:96-99.
- Ibrahim, A. (2013). *Applications in irrigation and fertilization*. Part II: Water requirements for field and horticulture crops, Ain Shams Univ., Cairo, Egypt, (text book in Arabic) ISBN: 978-977-90-0327-6.
- Jacob, F., A. Olioso X.F. Gu Z. Su and N.B. Seguin (2002). Mapping surface fluxes using airborne visible, near infrared, thermal infrared remote sensing data and a spatialized surface energy balance model. *Agronomie*. 22: 669-680.
- Jia, L., Z. Su B. Van der Hurk M. Menenti A. Moene and H.A.R. De Bruin (2003). Estimation of sensible heat flux using the Surface Energy Balance System (SEBS) and ATSR measurements. *Physics and Chemistry of the Earth*. 28: 75-88.
- Khalifa, H., M.A.Sayed A.S. Ouda M. Karrou T. Oweis A. Bruggeman H. Farahani and B. Benli (2011). Chapter 4: Systems approach to water productivity assessment using cropping system Models, in the Karrou, M., T. Oweis, B. Benli, A. Swelam, A. (eds.) 2011, *Improving water and land productivities in irrigated systems*. Community-Based Optimization of the Management of Scarce Water Resources in Agriculture in CWANA. Report no. 10. International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria. vi + 195 pp.

- Matinfar, H.R., and M. Soorghali (2014). Estimate evapotranspiration (ET) using SEBS model based on LANDSAT 5 (TM) thermal data and GIS. Indian Journal of Fundamental and Applied Life Sciences. 4: 30-34.
- Roerink, G.J., Z. Su and M. Menenti. (2000). S-SEBI: A Simple Remote Sensing Algorithm to Estimate the Surface Energy Balance. Physics and Chemistry of the Earth. 25: 147-157.
- Sallam, A.A. (2014). Response of wheat crop to the amount and the quality of irrigation water in calcareous soils, under surface and sprinkler irrigation systems. PhD Thesis, Faculty of Agriculture, Moshtohor, Benha University, Egypt.
- Su, Z., (2001). A Surface Energy Balance System (SEBS) for estimation of turbulent heat fluxes from point to continental scale, In: *Advanced Earth Observation – Land Surface Climate*. Su and Jacobs, C. (Eds.). Publications of the National Remote Sensing Board (BCRS), USP-2, 01-02. 184pp.
- Su, Z. (2002). The surface energy balance system (SEBS) for estimation of turbulent heat fluxes. Hydrology and Earth System Sciences. 6: 85–99.
- Subedi, A. and J.L. Chávez (2015). Crop Evapotranspiration (ET) Estimation Models: A Review and Discussion of the Applicability and Limitations of ET Methods. Journal of Agricultural Science. 7: 50-68.
- Temesgen, B., S. Eching, B. Davidoff, and K. Frame. (2005). Comparison of some reference evapotranspiration equations for California. Journal of Irrigation and Drainage Engineering. 131: 73–84.
- Wahaj, R., F. Maraux and G. Munoz (2007). Actual crop water use in project countries: A synthesis at the regional level. Policy Research Working Paper. Vol. 4288. World Bank.
- Weiqliang M.A., M.A. Yaoming and H. Ishikawa (2013). Evaluation of the SEBS for up-scaling the evapotranspiration based on in-situ observations over the Tibetan Plateau. Atmospheric Research Journal. 1: 1-18.

**تقدير البخر - نتج باستخدام بيانات الاستشعار عن بعد وبعض النماذج المناخية**  
**محمد حسني حسن عبد القادر<sup>1</sup> ، حمدي الحسيني خليفة<sup>2</sup> ، عبد العزيز شتا<sup>3</sup> و**  
**أحمد إبراهيم<sup>4</sup>**  
**<sup>1</sup>معهد بحوث الأراضي والمياه والبيئة - مركز البحوث الزراعية**  
**<sup>2</sup>قسم الأراضي - كلية الزراعة - جامعة عين شمس - مصر**

يهدف هذا البحث إلى تقييم قيم البخر-نتج المقدر باستخدام نموذج نظام توازن طاقة السطح (SEBS) مع أربعة نماذج مناخية تستخدم على نطاق واسع في المنطقة هي: بنمان-مونثيث (PM) ، بنمان (P) ، الإشعاع (R) ، هارجريفز-سماني (HS). تم استخدام نموذج الاستشعار عن بعد (SEBS) لتقدير قيم البخر نتج الفعلية اليومية لزراعات القمح وبنجر السكر والبصل الأخضر باستخدام تسعة صور من القمر الصناعي لاندسات ETM7L+ لتتمثل الموسم الشتوي 2012/2013 (موقع الدراسة عبارة عن مزرعة خاصة) شركة السادس من أكتوبر الزراعية (بمحافظة الإسماعيلية) تقع بين خطي طول 31.92/32.62 شرقاً ودائرتي عرض 30.38/30.52 شمالاً.

وقد دلت النتائج المتحصل عليها أن هناك اختلافات واضحة بين قيم البخر-نتج الفعلي (Eta) المقدر باستخدام أي من النماذج المناخية أو الاستشعار عن بعد التي تم اختبارها. وكانت القيم المتحصل عليها من جميع النماذج المختبرة أقل من تلك المتحصل عليها عند استخدام نموذج PM. وأظهرت النتائج أن قيم البخر-نتج الفعلي المقدر من نموذج (SEBS) بصفة عامة أقل من نظيرتها المقدره بالنماذج المناخية الأخرى، وكانت قيم البخر نتج الفعلية المقدره على أساس موسمي باستخدام كل من SEBS ، PM ، P ، R ، HS هي 384 ، 574 ، 382 ، 450 ، 329 بالنسبة للقمح ، 423 ، 726 ، 497 ، 570 ، 435 لبنجر السكر و 614 ، 414 ، 508 و 360 م/م/موسم لمحصول البصل الأخضر على الترتيب. من نتائج هذا البحث، تتضح الحاجة لدراسات وتأكيدات أكثر لتقييم العوامل التي يمكن أن تؤثر على قيم نموذج (SEBS) تحت ظروف المناطق الجافة، كذلك المزيد من التحقق من خلال عدة مواسم متتالية لمحاصيل متنوعة في مناطق مختلفة حتى يمكن التوصية باستخدامه كأحد الطرق المعتمدة لتقدير البخر-نتج الفعلي بطريقة مباشرة في وجود المحصول على المستوى المحلي.