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"ET-CALCULATOR" A NEW MODEL TO ROBUSTLY CALCULATE EVAPOTRANSPIRATION IN EGYPT

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ABSTRACT

The Penman-Monteith (P-M) equation is widely recommended to calculate evapotranspiration (ET) because of its detailed theoretical base and its accommodation of small time periods. Thus, there is a need to develop a model to easily calculate ET and can be used by extension workers. The objective of this research is to use evaluate the MS Excel sheet capability to develop a program to calculate ET values in the Governorates of the Nile Delta and Valley. A model was developed called "ET-Calculator". The model uses P-M equation to calculate ET. Weather parameters of 17 governorates in the Nile Delta and Valley were input (maximum and minimum temperature, mean of relative humidity, wind speed and solar radiation), as well as the elevation above sea level in order to calculate ET values. To test the validity of the model, the estimated ET values by ET-Calculator model were compared to the estimated ET values by BISm model. Closeness of both estimated ET values to each other was tested by Root Mean Square Error per observation (RMSE/obs) and Willmott index of agreement (*d)*. The results indicated that ET-Calculator model estimated monthly and annual ET values in all governorates similar to the ET values estimated by BISm model, where RMSE/obs values were low and *d* values were high. These results implied that the presence of friendly and easy use program to calculate ET, such as ET-Calculator facilitate the calculation of water requirements for crops by extension workers and could improve the current situation of agricultural water management in Egypt.

Keywords: BISm model; Nile Delta and Valley governorates; Penman-Monteith equation and weather parameters.

INTRODUCTION

Climate plays an important role in crop production. Crops growth periods, crop water requirements and scheduling irrigation for crops are dependent on weather conditions and physical properties of the soil in each site. Agriculture water demand is one of the serious pressures on water sector in Egypt, since 85% of total available water is consumed in agriculture and most of the prevailing on-farm irrigation systems are less efficient coupled with poor irrigation management (Abou Zeid, 2002). Irrigation water management becomes increasingly important in the presence of low water supplies and expected water scarcity conditions.

In order to avoid underestimation or overestimation of crop water consumption, knowledge of the exact water loss through actual evapotranspiration is necessary for sustainable development and environmentally sound water management (Shideed *et al.* 1995), which cause both waste of water and negative impacts on economic, social and environmental levels (Katerji and Rana 2008). Further, efficient irrigation requires knowledge of soil water supplies and of water capacity (Gerakis and Zalidis 1998). Irrigation would help maintain optimal soil moisture during the growing period, thereby ensuring more stable and higher agricultural production. Irrigation and its planning are demanding tasks, which involve a multidisciplinary approach to define and calculate all the relevant factors and parameters (Abou Zeid, 2002).

Evapotranspiration (ET) is a key component in hydrological studies. It is used for agricultural and urban planning, irrigation scheduling, regional water balance studies and agro-climatological zoning (Khalil, 2011). The calculation of the ET values includes all the weather parameters prevailed in a specific area. ET is a combination of two processes water evaporation from soil surface and transpiration from the growing plants (Gardner *et al.* 1985). Direct solar radiation and, to a lesser extent, the ambient temperature of the air provide energy for evaporation. Whereas, solar radiation, air temperature, air humidity and wind terms should be considered when assessing transpiration (Allen *et al.* 1998). Various equations are available for estimating ET. The Penman-Monteith equation is widely recommended because of its detailed theoretical base and its accommodation of small time periods. For instance, this approach provided the optimal estimates on the daily and monthly scales and was the most consistent across all locations (Sentelhas *et al.* 2010). It was also indicated that the Penman-Monteith method exhibited excellent performance in both arid and humid climates (Jensen *et al.* 1990).

Penman-Monteith equation is included in two well known models, i.e. CROPWAT (Smith *et al.* 2000) and BISm (Snyder *et al.* 2004). These two models are easy to be used by researchers. However, for extension workers, it requires training to facilitate its use. Thus, there is a need to develop a model to easily calculate ET to be used by extension workers. Such model can improve irrigation water management for cultivated crops and reduce water losses through deep percolation resulting from overirrigation.

The objective of this research is to evaluate the use MS Excel sheet capability to develop an easily and reliable program to calculate ET values under the Egyptian governorates of the Nile Delta and Valley conditions.

MATERIALS AND METHODS

ET-Calculator model description

The ET-Calculator model is a MS Excel sheet uses Penman-Monteith equation to calculate ET. Monthly weather parameters of a certain governorate are used as input, as well as the elevation above sea level. These weather data are maximum and minimum temperature (°C), mean of relative humidity (%), wind speed (msec^{-1}) and solar radiation (MJm^{-2}day^{-1}). The weather data were obtained from Water Requirements and Field Irrigation Research Department; Soils; Water and Environment Research Institute; Agricultural Research Center. These data were monthly averaged from 2003-2013 for the above parameters. Penman-Monteith (P-M) equation (Allen *et al.* 1998) was used to calculate ET as follows:

$$ET_0\,(mm\,day^{-1}) = \frac{0.408\,\Delta\,R_n + \gamma\,\dfrac{900}{T_a + 273}\,u_2\,(e_a^{+} - e_a)}{\Delta + \gamma\,\left(1 + 0{,}34\,u_2\right)}$$

ET_0 = Reference evapotranspiration (mm day^{-1}).
R_n = Net radiation at the crop surface (MJ m^{-2} per day).
G = Soil heat flux density (MJ m^{-2} per day).
T = Mean daily air temperature at 2 m height (°C).
u_2 = Wind speed at 2 m height (m sec^{-1}).
es = Saturation vapor pressure (kPa).
ea = Actual vapor pressure (kPa).
es - ea = Saturation vapor pressure deficit (kPa).
Δ = Slope of saturation vapor pressure curve at temperature T (kPa/°C).
γ = Psychrometric constant (kPa/°C).

The model calculates each component in P-M equation using weather data for 17 governorates in the Nile Delta and Valley, Table 1 and Figure 1.

Table 1: Latitude, longitude and elevation above sea level for Nile Delta and Valley Governorates

Governorate	Latitude	Longitude	Elevation above sea level (m)
Alexandria	31.70°	29.00°	7.00
Damietta	31.25°	31.49°	5.00
Kafr El-Sheik	31.07°	30.57°	20.0
El-Dakahlia	31.03°	31.23°	7.00
El-Beheira	31.02°	30.28°	6.70
El-Gharbia	30.47°	32.14°	14.80
El-Monuofia	30.36°	31.01°	17.90
El-Sharkia	30.35°	31.30°	13.00
El- Kalubia	30.28°	31.11°	14.00
El-Giza	30.02°	31.13°	22.50
El-Faiyoum	29.18°	30.51°	30.00
Beni Suweif	29.04°	31.06°	30.40
El-Minia	28.05°	30.44°	40.00
Assuit	27.11°	31.06°	71.00
Suhag	26.36°	31.38°	68.70
Qena	26.10°	32.43°	72.60
Aswan	24.02°	32.53°	108.30

Validation of ET-Calculator model

The estimated ET values by ET-Calculator model were compared to the estimated ET values by BISm model. The Basic Irrigation Scheduling application (BISm, Snyder *et al.* 2004) was used to calculate monthly and annual ET values. The BISm application calculates ET using the Penman-Monteith (P-M) equation (Monteith, 1965) as presented in the United Nations

FAO Irrigation and Drainage Paper (FAO, 56) by Allen *et al.* (1998). Closeness of both estimated ET values by the two models was tested by root mean square error per observation (RMSE/obs) and Willmott index of agreement (*d*).

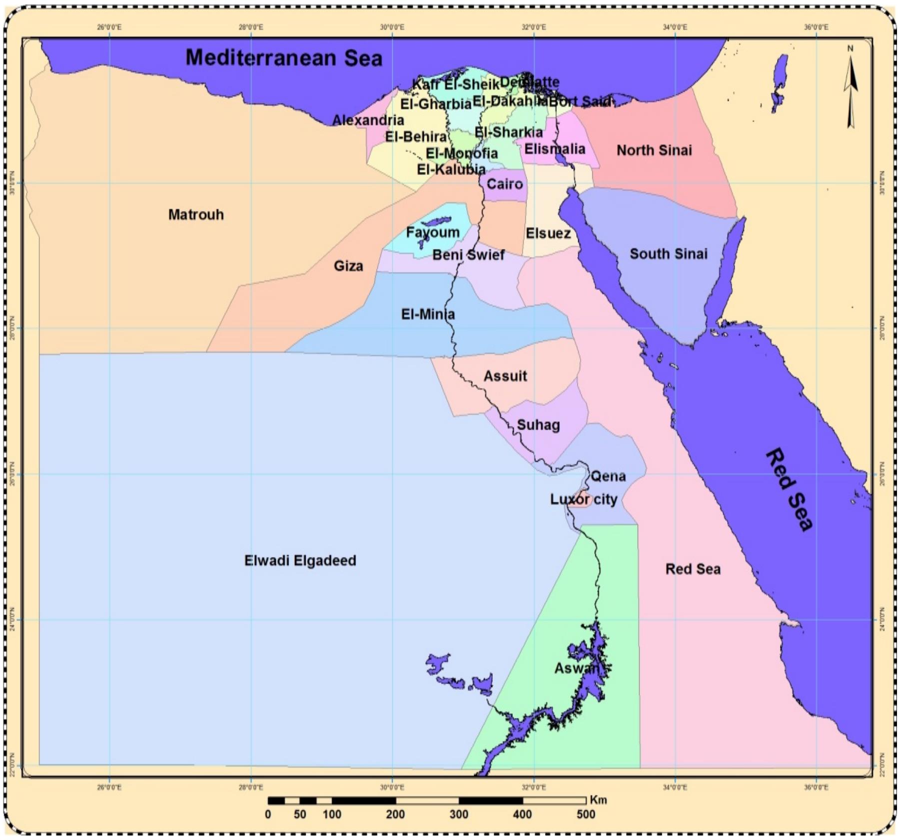

Figure 1: Map of Nile Delta and Valley of Egypt

RESULTS AND DISCUSSION

Monthly ET values in North Nile Delta

North Nile Delta is composed of five Governorates, i.e. Alexandria, Demiatte, Kafr El-Sheik, El-Dakahlia and El-Behira Table 2. These Governorates have one common characteristic: they are located on the Mediterranean Sea, thus they have relatively similar weather conditions. ET-Calculator model calculated ET values in these five Governorates similar to the ET values estimated by BISm model Table 2. RMSE/obs was between 0.039 - 0.065 mm day^{-1} and *d* was between 0.995 - 0.987. These results reflect the accuracy of ET-Calculator model in estimating ET values in these Governorates.

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Monthly ET values in South Nile Delta

Regarding to south Nile Delta Governorates, i.e. El-Gharbia, El-Monofia, El-Sharkia and El-Kalubia, there was good agreement between ET values obtained from ET-Calculator model and BISm model. RMSE/obs ranged between 0.021- 0.051 mm day^{-1} and *d* was between 0.995 and 0.999 Table 3.

Monthly ET Values in Middle Egypt

In Middle Egypt, El-Giza, El-Fayoum, Beni Sweif and El-Minia, the estimated values of ET by ET-Calculator and BISm models were close to each other. RMSE/obs was between 0.025 - 0.041 mm day^{-1} and *d* was between 0.997- 0.999 Table 4.

Table 4: Comparison between ET (mm day^{-1}) values calculated by ET-Calculator model and its counterpart calculated by BISm model in Middle Egypt governorates.

Month		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	RMSE/obs	*d*
Giza	ET (ET-Calculator)	3.4	4.2	5.5	7.3	8.7	9.5	9.4	8.8	7.5	5.8	4.2	3.5	0.032	0.998
	ET (BISm)	3.4	4.3	5.8	7.6	8.8	9.8	9.7	8.9	7.7	6.0	4.3	3.5		
	PD %*	0	2	6	4	1	3	3	1	3	3	2	0		
El-Fayoum	ET (ET-Calculator)	3.6	4.7	6.1	8.2	9.6	10.4	10.1	9.7	8.3	6.4	4.5	3.7	0.041	0.997
	ET (BISm)	3.6	4.6	6.4	8.3	9.9	10.9	10.6	9.9	8.7	6.7	4.7	3.7		
	PD %*	0	2	5	1	3	5	5	2	5	4	4	0		
Beni Sweif	ET (ET-Calculator)	3.7	4.6	6.1	8.2	9.6	10.4	10.2	9.7	8.3	6.4	4.6	3.7	0.028	0.999
	ET (BISm)	3.5	4.5	6.4	8.3	9.7	10.8	10.4	9.7	8.5	6.6	4.7	3.6		
	PD %*	6	2	5	1	1	4	2	0	2	3	2	3		
El-Minia	ET (ET-Calculator)	4.0	5.1	6.7	8.9	10.4	11.2	10.9	10.4	9.1	7.1	5.0	4.0	0.025	0.999
	ET (BISm)	3.8	4.9	6.9	8.9	10.5	11.6	11.1	10.4	9.3	7.4	5.1	3.9		
	PD %*	5	4	2	0	1	3	2	0	2	4	2	3		

***PD (%): percentage of difference between calculated value of ET by ET-Calculator model and BISm model**

Table 5: Comparison between ET (mm day^{-1}) values calculated by ET-Calculator model and its counterpart calculated by BISm model in Upper Egypt governorates

Month		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	RMSE/obs	*d*
Assuit	ET (ET-Calculator)	4.1	5.4	7.1	9.4	10.8	11.6	11.3	10.9	9.6	7.6	5.3	4.2	0.023	0.999
	ET (BISm)	3.8	5.1	7.2	9.1	10.7	11.8	11.3	10.7	9.7	7.6	5.4	4.0		
	PD %*	8	6	1	3	1	2	0	2	0	0	2	5		
Suhag	ET (ET-Calculator)	4.3	5.5	7.3	9.6	10.9	11.7	11.4	11.1	9.9	7.9	5.5	4.3	0.041	0.997
	ET (BISm)	4.0	5.2	7.3	9.2	10.6	11.8	11.2	10.8	9.9	7.8	5.5	4.1		
	PD %*	7	6	0	4	3	1	2	6	0	1	0	5		
Qena	ET (ET-Calculator)	4.5	5.8	7.6	9.6	11.1	12.3	11.9	11.6	10.4	8.2	5.8	4.6	0.029	0.998
	ET (BISm)	4.2	5.6	7.6	9.6	11.1	12.3	11.6	11.3	10.2	8.0	5.7	4.5		
	PD %*	7	4	0	0	0	0	3	3	2	3	2	2		
Aswan	ET (ET-Calculator)	5.0	6.4	8.1	10.6	11.9	12.6	12.2	12.0	11.0	8.9	6.2	5.0	0.038	0.996
	ET (BISm)	4.8	6.2	8.2	10.0	11.2	12.3	11.8	11.6	10.7	8.6	6.3	5.0		
	PD %*	4	3	1	6	6	2	3	3	3	3	2	0		

***PD (%): percentage of difference between calculated value of ET by ET-Calculator model and BISm model**

Similarly, in Assuit, Suhag, Qena and Aswan (Upper Egypt governorates), RMSE/obs was low and ranged from 0.023 to 0.041 mmday^{-1} and *d* was close to the unit i.e. between 0.997and 0.999 Table 5.

Annual ET values

The annual ET values calculated by both models were close to each other in all the studied Governorates (Table 6). Percentage of difference between the two values ranged between 0 and 6%. Furthermore, RMSE and *d* values were 0.026 and 0.996 mm day^{-1}, respectively, (Table 6).

Table 6: Comparison between annual ET (mm day^{-1}) values calculated by ET-Calculator model and its counterpart calculated by BISm model in the selected governorates.

Governorate	Nile Delta									Middle Egypt				Upper Egypt				RMSE/obs	*d*
	Alexandria	Demiatte	Kafr El-Sheik	El-Dakahlia	El-Behira	El-Gharbia	El-Monofia	El-Sharkia	El-Kalubia	Giza	El-Fayoum	Beni Sweif	El-Minia	Assuit	Suhag	Qena	Assiut		
ET(ET-calculator) (mm day^{-1})	4.9	5.9	5.5	5.9	5.5	6.6	6.9	6.6	6.5	7.1	7.2	7.2	7.7	8.1	8.3	8.7	9.1	0.026	0.996
ET (BISm) (mm day^{-1})	5.1	5.9	5.6	5.9	5.6	6.6	6.6	6.6	6.6	7.3	7.3	7.2	7.8	8.0	8.1	8.5	8.9		
PD (%)*	4	0	2	0	2	0	4	·	2	3	1	·	1	1	2	2	2		

***PD (%): percentage of difference between calculated value of ET by ET-Calculator model and BISm model**

The above results implied that ET-Calculator model could be capable to estimate ET values with high degree of accuracy.

Instructions to use ET-Calculator model

The model inputs are maximum and minimum temperature (°C), mean relative humidity (%), wind speed (m sec^{-1}) and solar radiation (MJ m^{-2}day^{-1}), in addition to elevation above sea level. Figure 2 represents an example of the data sheet exists for each of the studied governorate, where its weather data should be input.

Figure 2: Example of data sheet required to run ET-Calculator model

Month	TMAX (ºC)	TMIN (ºC)	TMEAN (ºC)	RH (%)	WS (m sec^{-1})	SRAD (MJ m^{-2} day^{-1})	Elevation (m)	ET* (mm day^{-1})
January	17.8	13.6	15.7	63.2	5.4	11.5	7	3.1
February	17.9	12.9	15.4	60.8	5.6	14.7	7	3.5
March	19.5	13.9	16.7	60.7	5.3	20.4	7	4.1
April	22.1	15.8	19.0	61.3	5.1	24.6	7	5.0
May	24.9	18.6	21.7	62.6	4.5	27.8	7	5.6
June	27.8	21.8	24.8	65.9	4.7	30.2	7	6.3
July	29.7	24.1	26.9	67.2	5.0	29.8	7	6.7
August	30.3	25.0	27.6	66.7	4.6	27.4	7	6.6
September	28.7	24.0	26.4	64.2	4.6	23.4	7	5.9
October	26.0	21.6	23.8	63.8	4.4	18.0	7	4.6
November	22.4	18.6	20.5	65.0	4.5	13.2	7	3.6
December	19.3	15.4	17.3	63.8	5.1	10.8	7	3.2

***automatically calculated**

ET-Calculator model can be obtained from the corresponding author Prof. Samiha Ouda: samihaouda@yahoo.com.

CONCLUSION

Evapotranspiration (ET) is an important factor affecting crop growth and yield. Its accurate estimation is an essential path to accomplish efficient management of irrigation water. Inaccurate estimates of ET can lead to poor assessment of crop stress and yield and consequently inefficient use of water. Penman-Monteith method is by far the most recognized among all evapotranspiration models, as reported in numerous investigations worldwide. Thus, using P-M equation to calculate ET values is highly recommended.

The results of this research trial proved that ET-Calculator model is capable of calculating monthly and annual values of ET very close to the values calculated by BISm model. The presence of friendly and easy use program to calculate ET, such as ET-Calculator will facilitate the calculation of water requirements for crops by extension workers and will improve the current situation of agricultural water management in Egypt.

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"ET-Calculator"نموذج جديد لحساب البخر نتح بدقه فى مصر

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*** قسم بحوث المقننات المائية و الرى الحقلى – معهد بحوث الأراضي و المياه و البيئة – مركز البحوث الزراعية**

****المعمل المركزى للمناخ الزراعى - مركز البحوث الزراعية**

تستخدم معادلة بنمان- مونتيث على نطاق واسع لحساب البخر نتح لأن الاساس النظرى لها دقيق حيث لها القدرة على حساب قيم البخر نتح لفتره زمنيه صغيره . ولذلك كان هناك حاجة لعمل برنامج يحسب بسهولة قيم البخر نتح ويمكن استخدامه من قبل العاملين فى مجال الإرشاد الزراعى. والهدف من هذا البحث هو استخدام قدرة Microsoft Excel لوضع برنامج لحساب قيم البخر نتح فى محافظات الدلتا والوادى. وهذا النموذج يسمى ET-Calculator وهو يستخدم معادلة بنمان-مونتيث لحساب قيم البخر نتح. وكانت بيانات الارصاد الجوية من ال ١٧ محافظة فى الوادى والدلتا هى المدخلات للنموذج (درجة الحرارة العظمى والصغرى، ومتوسط الرطوبة النسبية وسرعة الرياح والإشعاع الشمسي) بالإضافة الى الارتفاع فوق مستوى سطح البحر . لاختبار دقة نموذج ET-Calculator فى حساب قيم البخر نتح تم مقارنتها بقيم البخر نتح محسوبة باستخدام نموذج BISm وحسب الجذر التربيعى لمجموع مربعات الخطأ التجريبي لكل قراءه وكذا معامل ويلمت للتطابق. أشارت النتائج الى ان قيم البخر نتح المقدرة شهرياً وسنوياً باستخدام ET-Calculator فى جميع المحافظات متقاربه من قيم البخر نتح المقدرة من نموذج BISm حيث كانت قيم الجذر التربيعى لمجموع مربعات الخطأ التجريبى لكل قراءه منخفضة وقيم معامل ويلمت للتطابق عالية . وهذا يؤكد دقة النموذج بالإضافة الى سهولة استخدام برنامج ET-Calculator لحساب البخر نتح وتسهيل حساب الاحتياجات المائية للمحاصيل من قبل العاملين فى مجال الإرشاد الزراعى لتحسين الوضع الحالى لإدارة المياه الزراعية فى مصر.

Table 2: Comparison between ET (mm day^{-1}) values calculated by ET-Calculator model And its counterpart calculated by BISm model in North Nile Delta governorates

Month		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	RMSE/obs	*d*
Alexandria	ET (ET-Calculator)	3.1	3.5	4.1	5.0	5.6	6.3	6.7	6.6	5.9	4.6	3.6	3.2	0.065	0.987
	ET (BISm)	3.3	3.8	4.5	5.3	6.0	6.8	7.1	6.9	6.2	4.9	3.7	3.3		
	PD %*	6	8	9	6	7	7	6	4	5	6	3	3		
Demiatte	ET (ET-Calculator)	3.3	3.7	4.7	6.2	7.2	8.9	8.9	8.4	7.0	5.1	4.1	3.5	0.046	0.996
	ET (BISm)	3.3	3.9	5.0	6.4	7.4	8.4	8.6	8.0	6.9	5.4	4.1	3.4		
	PD %*	0	5	6	6	3	6	3	5	1	6	0	3		
Kafr El-Shiekh	ET (ET-Calculator)	3.1	3.6	4.5	5.7	6.6	7.8	8.0	7.7	6.5	4.9	3.8	3.3	0.039	0.996
	ET (BISm)	3.3	3.8	4.7	6.0	6.9	7.7	7.8	7.5	6.6	5.3	3.8	3.3		
	PD %*	6	5	4	5	4	1	2	3	3	7	0	0		
El-Dakahlia	ET (ET-Calculator)	3.2	3.7	4.6	6.1	7.2	8.8	9.2	8.6	6.9	5.1	4.0	3.4	0.043	0.995
	ET (BISm)	3.3	4.0	5.0	6.4	7.4	8.4	8.6	8.0	6.9	5.5	4.1	3.4		
	PD %*	3	8	8	5	3	5	7	7	0	7	2	0		
El-Behira	ET (ET-Calculator)	3.1	3.6	4.4	5.7	6.6	7.8	8.0	7.7	6.5	4.9	3.9	3.3	0.043	0.996
	ET (BISm)	3.3	3.9	4.8	6.0	6.9	7.7	7.9	7.5	6.6	5.3	3.9	3.4		
	PD %*	6	8	8	5	4	1	1	3	2	7	0	3		

***PD (%): percentage of difference between calculated value of ET by ET-Calculator model and BISm model**

Table 3: Comparison between ET values(mm day^{-1}) calculated by ET-Calculator model and its counterpart calculated by BISm model in South Nile Delta governorates.

Month		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	RMSE/obs	*d*
El-Gharbia	ET (ET-Calculator)	3.3	4.2	5.7	7.6	8.9	9.8	9.3	8.8	7.6	6.0	4.2	3.4	0.021	0.999
	ET (BISm)	3.4	4.2	5.8	7.6	8.8	9.8	9.3	8.9	7.7	6.0	4.3	3.5		
	PD %*	3	0	2	0	1	0	0	1	1	0	2	3		
El-Monofia	ET (ET-Calculator)	3.4	4.4	5.9	7.8	9.3	10.4	10.0	9.5	8.0	6.2	4.4	3.6	0.051	0.995
	ET (BISm)	3.4	4.2	6.0	7.7	8.9	9.8	9.7	9.0	7.7	6.0	4.3	3.5		
	PD %*	0	5	2	1	4	6	3	6	4	3	2	3		
El-Sharkia	ET (ET-Calculator)	3.4	4.2	5.5	7.4	8.7	9.5	9.4	8.8	7.5	5.8	4.2	3.5	0.032	0.998
	ET (BISm)	3.4	4.4	5.8	7.6	8.5	9.8	9.7	8.8	7.7	6.0	4.3	3.5		
	PD %*	0	5	5	3	2	3	3	0	3	3	2	0		
El-Kalubia	ET (ET-Calculator)	3.4	4.2	5.5	7.4	8.7	9.5	9.4	8.8	7.5	5.8	4.2	3.5	0.031	0.998
	ET (BISm)	3.4	4.3	5.8	7.6	8.8	9.8	9.7	8.9	7.7	6.0	4.2	3.4		
	PD %*	0	2	5	3	1	3	3	1	2	3	0	3		

***PD (%): percentage of difference between calculated value of ET by ET-Calculator model and BISm model**