ET_0 Estimation Using Satellite Meteorological Data and Exploratory Regression Tool

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Abstract

Evapotranspiration is an important component of the hydrological cycle and its accurate quantification is crucial for the design, operation and management of irrigation systems. The aim of the present work is to investigate satellite-sensed meteorological data in estimating reference evapotranspiration (ET_0) for some Egyptian governorates, for the months between 1998 and 2000; and to assess the order of the meteorological factors affecting ET_0 value. Besides estimating the best empirical models for ET_0 as an output from least square analysis that comprises the most influence climatic variables. Air temperature, relative humidity, and wind speed were daily collected from MERRA 2 from NASA. Daily Solar Irradiance was collected from Meteosat satellite images which processed using Heliosat-2 method. Reference evapotranspiration (ET_0) were calculated monthly based on: 1. agro-meteorological stations and 2. satellite data using FAO-Penman- Monteith (FPM). Exploratory Regression based Ordinary Least Square (OLS) was applied to analyze all possible combinations of the input climatic variables to evaluate the most significant parameters in ET_0 estimated models for Kafr El Shikh, El Sharkia, El Mnofia, El Behira, Damiata and El Fayoum Governorates. The results indicate 1- strong correlation (R^2) between calculated ET_0 based satellite data and ET_0 based climate station, which ranged between (0.90 - 0.97). 2- The order of the meteorological factors affecting ET_0 from strong to weak is temperature (95%), radiation (95%), relative humidity (32%) and finally the wind speed (18%). The resulted R^2 between ET_0 estimated based on OLS empirical model applying satellite parameters and ET_0 based (P-M) applying climatic station parameters is almost equal to R^2 between ET_0 based (P-M) applying satellite parameters and ET_0 based (P-M) applying climatic station parameters, being on average 0.93.

Keywords: Reference evapotranspiration (ET_0) ; Exploratory Regression ; Satellite Meteorological Data ; Penman –Monteith

1. INTRODUCTION

Reference evapotranspiration (ET_0) is an agro meteorological variable widely used in hydrology and agriculture. Together with precipitation, it is a major input in soil water balance models. Several of these models require daily or hourly evapotranspiration data to provide acceptable estimate of plants water requirements (Brisson et al., 1992; Guyot, 1997; Lebon et al., 2003). Penman-Monteith (P-M) combination method is one of the most accurate methods to evaluate ET_0 at different time steps. A standardization of this method has been proposed by the Food and Agriculture Organization (Allen et al., 1998). It is known as FAO- 56 Penman-Monteith application, and it can be considered as a worldwide standard. However it requires numerous weather variables, which are seldom available in basic meteorological records. Consequently, reference evapotranspiration is often estimated by means of empirical equations based on air temperature, relative humidity, extraterrestrial radiation and/or precipitation (Droogers and Allen, 2002; Hargreaves et al., 1985; Popova et al., 2005; Turc, 1961). The number of meteorological stations where all of these parameters are observed is limited in many areas of the globe. The number of stations where reliable data for these weather variables exist is even smaller, especially in developing countries (Droogers P, Allen RG, 2002). Several authors proposed modifications of existing empirical methods (Droogers and Allen, 2002; Gavilan et al., 2006; Pereira, 2004; Pereira and Pruitt, 2004; Popova et al., 2005; Xu and Singh, 2002). The accuracy of these methods remains acceptable when applied at large time and space scales. However, empirical formulae are limited by their inherent characteristics. The lack of one, or more, climate variable physically related to evaporation and transpiration processes inescapably reduces the accuracy of evapotranspiration estimation. Even if recalibration of empirical factors may improve locally the precision of these methods, considerable estimation errors will remain as time variations.

New method was proposed to assess ET0 by means of satellite data, such as remotely sensed solar radiation, air temperature derived from infrared images and weather station measurements(Choudhury ,1997). This method provides good evapotranspiration estimates for low-resolution applications such as worldwide scale and monthly time step. In Egypt: different assessments of mapping Evapotranspiration using satellite data were carried out (Khalil et al., 2015; Mohammed A. El-Shirbeny et al.,2016).

The Modern-Era Retrospective Analysis for Research and Application (MERRA) (Lefèvre et al., 2007) was stimulated by the recognition that various aspects of the hydrologic cycle represented in previous generations of re-analyses were not adequate for climate and weather studies. MERRA pro- posed to improve upon the water cycle as a contribution to the science community and to reanalysis research. MERRA's span of most of the satellite era is also intended to place observations from NASA's Earth Observing System (EOS) satellites, particularly those available since October 2002 from EOS/Aqua, into a climate context. Several methods have been recently proposed to estimate solar radiation (Struzik, 2001). Amongst them, the Heliosat-2 method (Rigollier et al., 2004) has been proved to be reasonably reliable for estimating daily irradiation over Europe and Africa. This method has been used to elaborate a database, HelioClim-1, available at http://www.soda-is.org (Lefèvre et al., 2007).

The aim of the present work is to investigate satellite-sensed meteorological data in estimating reference evapotranspiration (ET_0) for some Egyptian governorates, for the months between 1998 and 2000; and to assess the order of the meteorological factors affecting ET_0 value. Besides estimating the best empirical models for ET_0 as an output from least square analysis that comprises the most influence minimum climatic variables.

2. STUDY AREA

The study area comprises six governorates that reflect different agro meteorological conditions as possible i.e. Kafr El Shikh, El Sharkia, El Mnofia, El Behira, Damiata, and El Fayoum . And these governorates were selected based on data availability (**Figure1**).

Figure1: Study Areas for Some Egyptian Governorates

3. DATA

3.1. Ground Station Data

Meteorological Data were collected by Water Management Research Institute (WMRI) from weather stations at geographic coordinates relevant to the study governorates. The Data include minimum and maximum temperature, minimum and maximum relative humidity, solar irradiation and wind speed at 2 meters height above ground surface at a monthly time step. The data were collected for years (1998-2001) for availability reason. Reference evapotranspiration (ET_0) were calculated based on FAO Penman-Monteith (P-M) expression (**1**) using ET_0 calculator software.

$$E_{PM} = \frac{0.408\Delta(R_n) + \gamma \frac{900}{(T+273)} u_2(e_s - e_a)}{\Delta + \gamma(1 + .34u_2)} \qquad \mathbf{1}$$

3.2. Satellite Sensed Solar Radiation And Meteorological Data

Remotely sensed solar irradiation was collected from the HelioClim-1 database available at http://www.soda-is.org. This database has been obtained by the application of the Heliosat-2 method to Meteosat satellite images. The Heliosat-2 method is based on the principle of the construction of a cloud index for each given pixel of satellite images (Rigollier et al., 2004).
This index is obtained by calculating ground and cloud albedo from time-series of images acquired in a broadband channel spanning visible and near-infrared bands. The HelioClim-1 database provides daily irradiation data for Europe and Africa (**Figure2**).

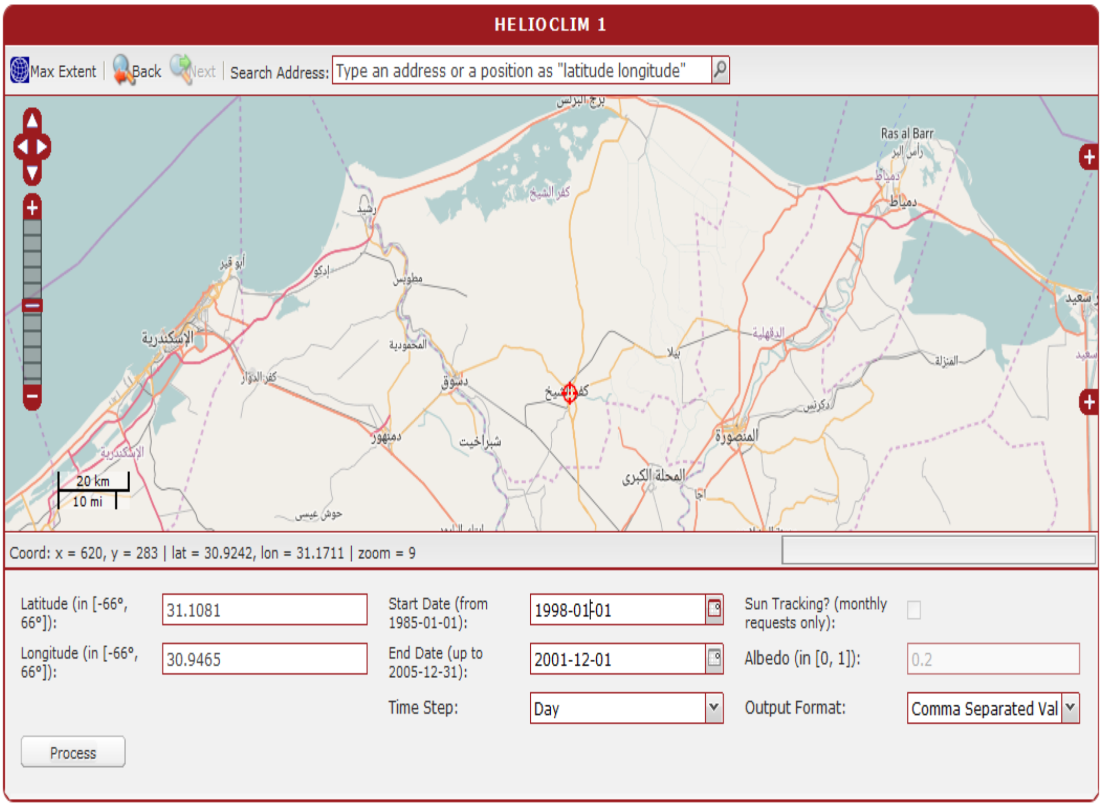


Figure2: Snapshot of Web Site of HelioClim-1 Database for Kafr El Shikh at The Same Geographic Coordinates of the Weather Station

Remotely sensed Meteorological data at the same geographic coordinates of weather stations that is relevant to the study governorates were downloaded from the Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2). This web service, delivers time series of temperature (at 2 m above ground in K), relative humidity (at 2 m above ground in %), pressure (at 2 m above ground), wind speed (at 10 m above ground in m/s) and direction at daily and monthly time step.

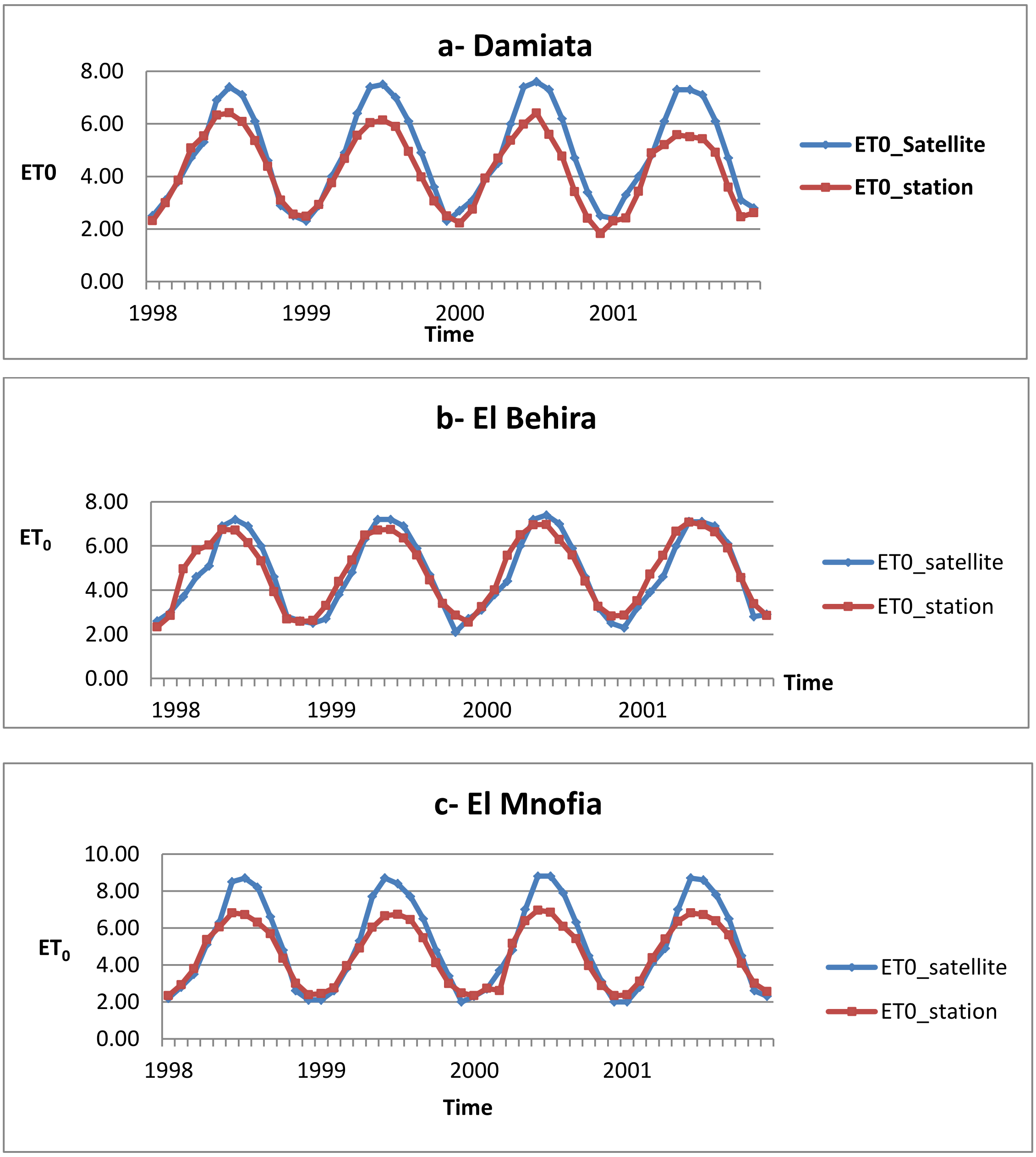
4. METHODOLOGY

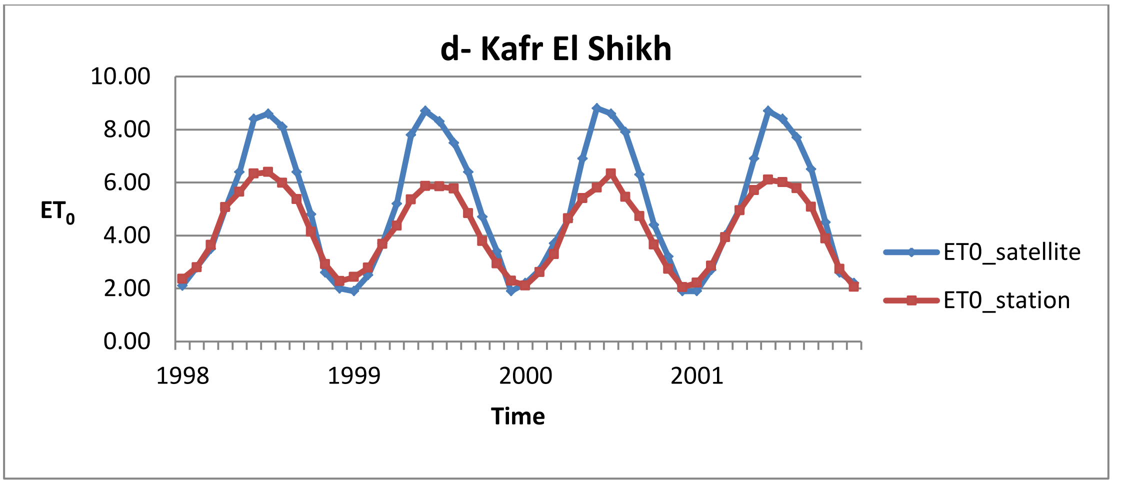
- Reference evapotranspiration was calculated based on climate satellite data from MERRA-2 and HelioClim-1 database using ET_0 calculator software at monthly and seasonally time steps for some Egyptian governorates at the same location of ground climate station.
- Exploratory Regression (ER) was applied to assess the influence of satellite climate parameters on ET_0 values for some Egyptian governorates. All possible combinations of the input independent variables looking for ET_0 models that pass all of the necessary OLS diagnostics were evaluated. Threshold criteria were specified as :Adjusted R^2, Coefficient of Probability (P), Variance Inflation Factor (VIF) which measures redundancy among explanatory variables, The Jarque-Bera to asses model bias, and a measure of residual spatial autocorrelation (the Global Moran's I p-value) - SA.
- The output of this analysis are groups of Empirical models relate the most effective satellite climate parameters (few number of climate parameters) that influence on ET_0 seasonally, and on epoch time (1998-2001), beside determination of Least square coefficients.

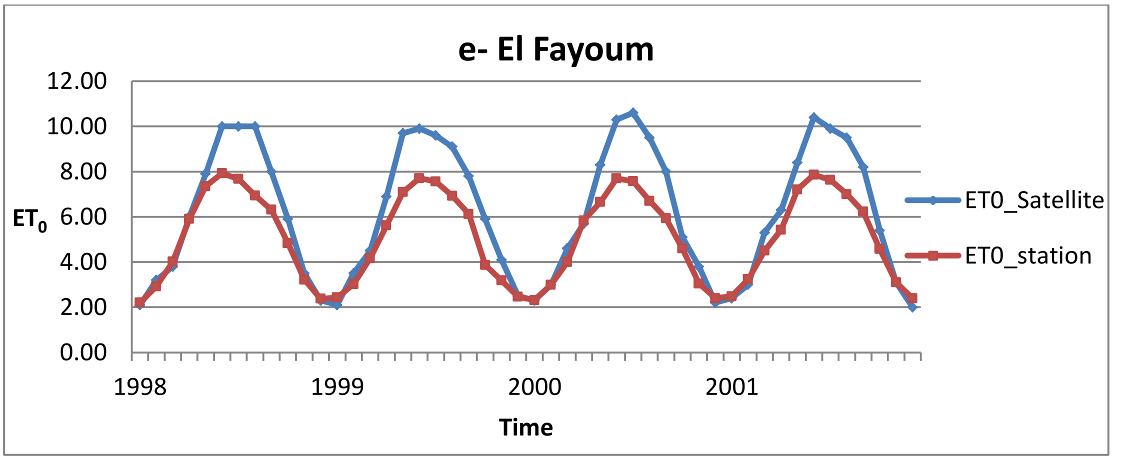
- Evaluation of ET_0 based satellite climate data using PM equation was carried out by comparing with those based climate ground station data. Also resulted ET_0 based OLS models were compared with ET_0 based climate station data for the study time.

5. RESULTS AND DISCUSSIONS

ET_0 values were studied for some Delta governorates and El Fayoum that represent different geographic locations with different climatic conditions i.e. north, south, east and west of Delta. ET_0 values were calculated based on satellite data and climate (weather) stations data at the same geographic locations for time epoch (1998-2001) and seasonally, using Penman- Monteith method (**Figure 3**).







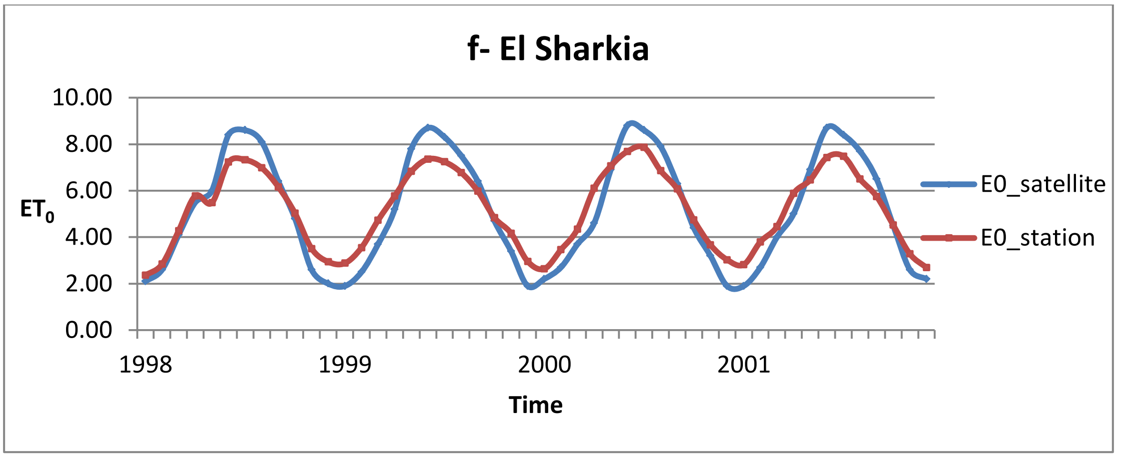


Figure 3: Comparison Between ET_0 Values Based Satellite Data and ET_0 Values Based Climate Stations for Some Egyptian Governorates (a-f).

It was clear from the above figures that there are peak period differences between ET_0 values based satellite data and ET_0 values based climate stations for almost all study governorates except for El Behira . The difference between these beaks for ElBehira is little , due to it consider as the most rainy governorate ,as better radiation results(using Heliosat-2 for deriving shortwave solar radiation from satellite images) are observed during the rainy season and location than during the dry season and location as mentioned by Isabelle Marie-Joseph et al.(2013).
Determination coefficient R^2 were calculated for ET_0 values and demonstrated in **Table 1**. It was noticed that for epoch (1998- 2001): R^2 for ET_0 ranged from 0.91 and 0.97. In summer season R^2 was between 0.63 and 0.86, while in winter season it was between 0.72 and 0.9.

Table 1: Determination Coefficient R^2 Between ET_0 Based Satellite and Climate Station Data

Governorate	Duration (1998 -2001)	Coefficient of determination (R^2) between ET_0_ based satellite data and ET_0_ based climate stations
Damiata	All months	0.91
	Summer months	0.63
	Winter months	0.72
El Behira	All months	0.91
	Summer months	0.63
	Winter months	0.72
El_Fayoum	All months	0.96
	Summer months	0.76
	Winter months	0.88
El_Mnofia	All months	0.95
	Summer months	0.86
	Winter months	0.83
El Sharkia	All months	0.97
	Summer months	0.75
	Winter months	0.87
Kafr El Shikh	All months	0.95
	Summer months	0.75
	Winter months	0.9

The Exploratory Regression analysis under ArcGIS environment was carried out and all possible combinations for a list of climate variables (temperature, relative humidity, wind speed and radiation) were assessed to select the best models of ET_0 which pass the necessary OLS checks (lowest Adjusted R-Squared value is 0.5, Maximum_ Coefficient_ value_ Cutoff default p-value is 0.05, maximum Variance Inflation Factor (VIF) value is 7.5, minimum_acceptable_Jarque_Bera_p_value is 0.1, and minimum acceptable Spatial Autocorrelation p_value is 0.1).

The best models were chosen from the output summary reports of Exploratory Regression Analysis based on the lowest AICc value and the highest adjusted R^2. The resulted significant variables for the best models were used to create the final empirical models, and their relevant coefficients were computed by linear regression tool. These final models were deuced for the study governorates at different time seasons and in all months during 1998-2000. **Table 2** demonstrates the output statistical report of the best models for the governorates being studied .

Table 2: The Output Statistical Report of the Best Models With Its Relevant Variables Combinations

Governorate/time seasons(1998-2001)	AdjR2	AICc	Jarque_Bera JB	K_BP	MaxVIF	Variable:X1	Variable:X2	Variable:X3
Damiata _all months	0.94	39.17	0.68	0.91	2.08			
Damiata _summer	0.65	21.26	0.54	0.77	1.07	Temperature		
Damiata _winter	0.74	24.38	0.71	0.85	1.09		Irradiation	
El Behira_all months	0.97	22.61	0.13	0.32	3.42	Temperature	Relative Humidity	Irradiation
El Behira _summer	0.86	0.24	0.93	0.18	1.05			
El Behira _Winter	0.79	26.94	0.97	1.00	1.10	Wind_Speed	Irradiation	
El Fayoum_all months	0.98	21.49	0.00	0.56	3.17			
El Fayoum_summer	0.89	9.89	0.00	0.84	1.16		Irradiation	
El Fayoum_winter	0.89	16.42	0.65	0.02	2.64	Temperature	Wind_Speed	Irradiation
El Mnofia_all months	0.98	6.41	0.03	0.20	3.12		Irradiation	
El_Mnofia_summer	0.91	-5.24	0.93	0.06	3.25	Temperature	Relative Humidity	Irradiation
El_Mnofia_winter	0.87	8.85	0.04	0.22	1.20		Irradiation	
El Sharkia_all months	0.97	27.54	0.10	0.56	5.01			Wind_Speed
El Sharkia_summer	0.85	15.64	0.00	0.81	2.89	Temperature	Relative Humidity	
El Sharkia_winter	0.88	16.27	0.58	0.45	3.13			Irradiation
Kafr_Elshikh_all months	0.97	4.39	0.04	0.21	6.89		Relative Humidity	
Kafr Elshikh_summer	0.76	15.73	0.25	0.62	3.37			Irradiation
Kafr Elshikh_winter	0.94	-13.81	0.46	0.66	1.15	Temperature	Irradiation	

The best models obtained from Exploratory Regression Analysis illustrate that for these specific governorates and time duration, temperature and radiation together are the most effective parameters for estimating ET_0 followed by relative humidity, then comes wind speed which shows the least effect.

ET_0 were estimated for the best models for these study governorates (empirical ET_0 formula obtained by applying OLS) . These models comprise the most effective climate variables. Coefficient of determination R^2 was calculated between ET_0_estimated from OLS models based satellite data and ET_0 deduced from climate stations for all months between 1998 and 2001. **Figure 4** below illustrates that the resulted R^2 between ET_0 estimated based on OLS model applying satellite parameters and ET_0 based (P-M) applying Climate _station parameters is almost equal to R^2 between ET_0 based (P-M) applying satellite parameters and ET_0 based (P-M) applying Climate _station parameters.

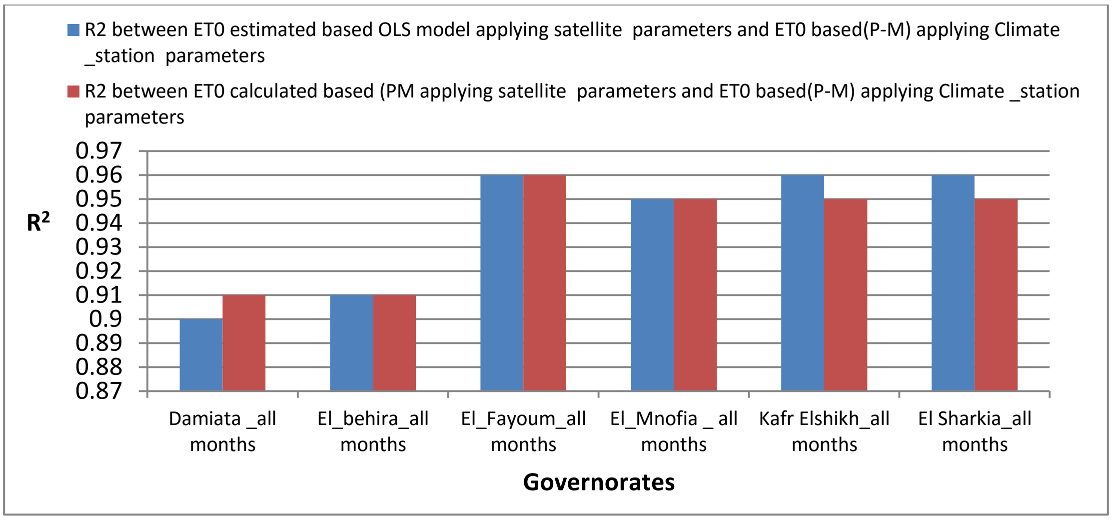
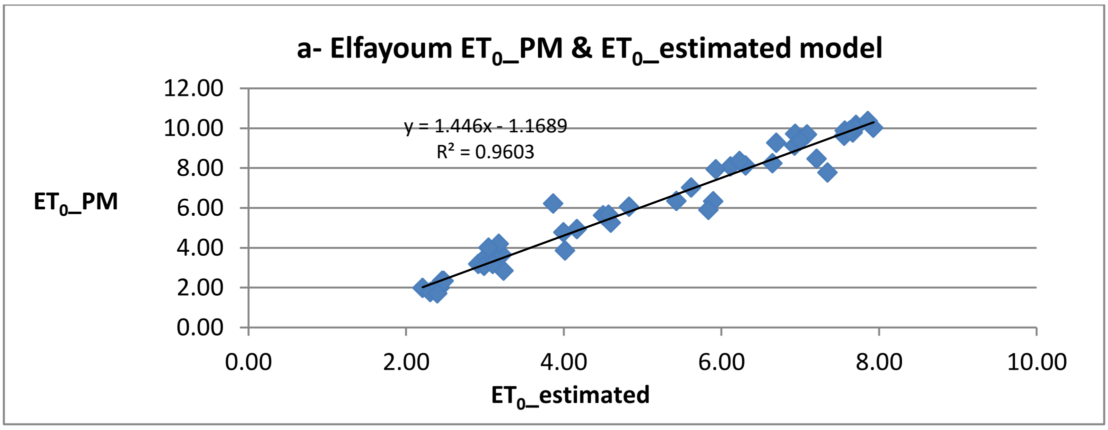
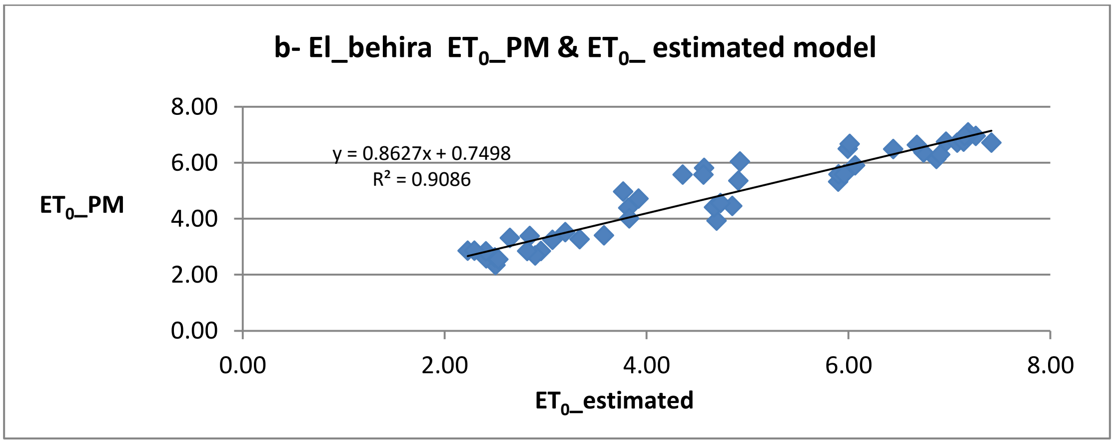


Figure 4: R^2 Values for ET_0 Relations for Some Egyptian Governorates

Relations between estimated ET_0 models based on satellite climate parameters (as demonstrated in **Table 2**) , and ET_0 based on satellite parameters data with applying P-M formula were demonstrated below in **Figure 5** (a-f) for some Egyptian governorates.





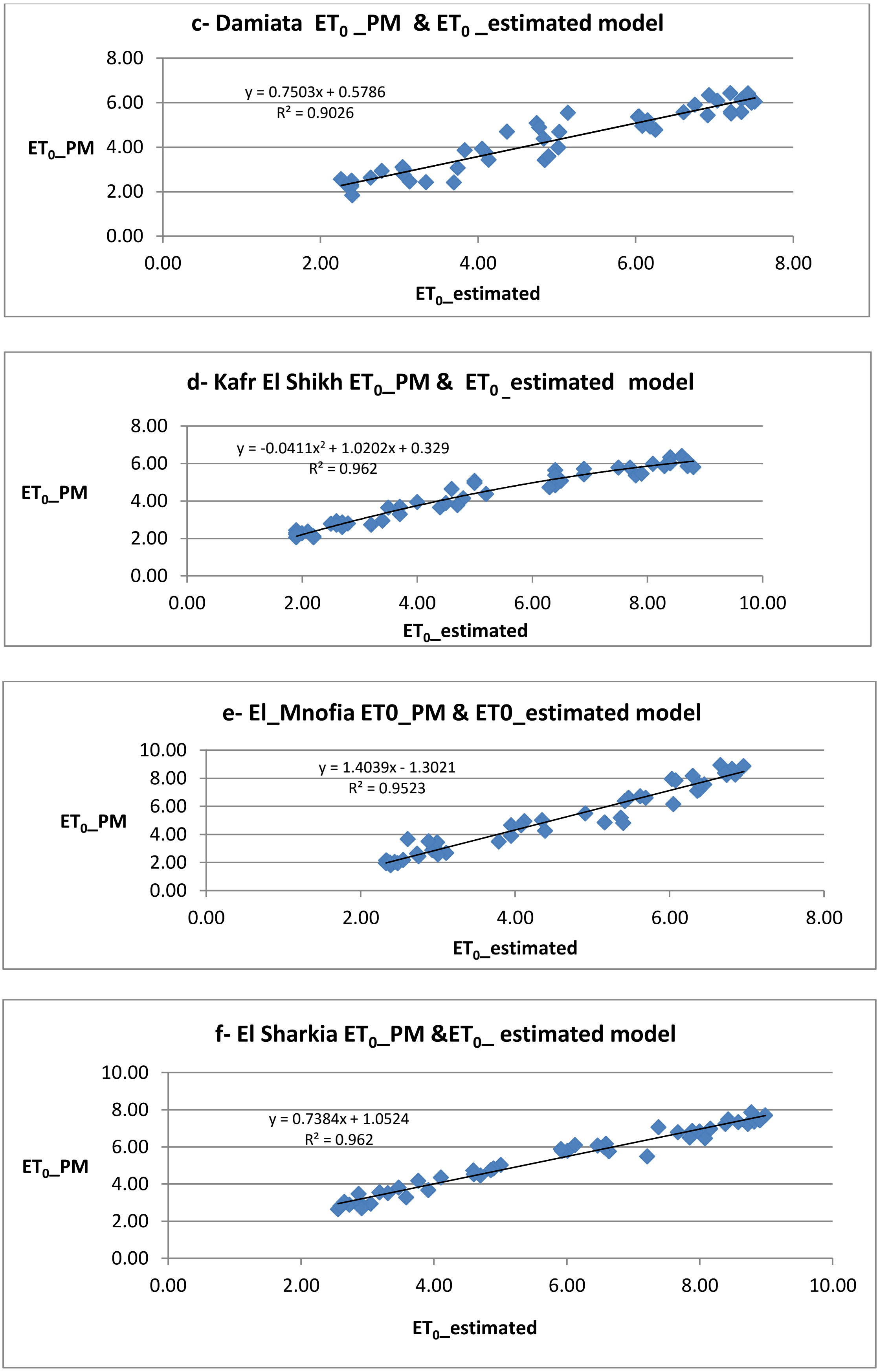


Figure 5: Estimated Model of ET_0 Based Satellite Data for Some Egyptian Governorates

The study area was selected due to data availability (Governorates climate stations data) and as possible it reflects different agro meteorological conditions. As to the 16 year old satellite records it was used to be compared and evaluated with the available old ET_0 station data. Nevertheless ,the available ET_0 values based climate station was only limited for 4 years , and in order to obtain more reliable results for mapping the OLS ET_0 based satellite data ,more extended calibration and evaluation should be undertaken with respect to ET_0 values obtained for longer period of time .Hence it is not recommended to be soon applied .

6. CONCLUSIONS

Influence of four major climatic variables on reference evapotranspiration was studied in some Egyptian governorates using satellite MERRA 2 and Meteosat datasets during months between 1998 and 2001. Exploratory regression and OLS were applied on these climatic variables to estimate the best models that describe ET_0 seasonally and in all months of the year. The study showed that air temperature and radiation were the most sensitive variables in general for these specific governorates, followed by relative humidity while wind speed has the least impact. The results indicate strong Correlation (R^2) between calculated ET_0 based satellite data and ET_0 based climate station for all months of the year, which ranged between (0.9- 0.97). The resulted R^2 between ET_0 estimated based on OLS model applying satellite parameters and ET_0 based (P-M) applying Climate _station parameters is almost equal to R^2 between ET_0 based (P-M) applying satellite parameters and ET_0 based (P-M) applying Climate _station parameters, being on average 0.93. The results of this work can be used as a theoretical basis for future research on the response of reference evapotranspiration to meteorological parameters. Also resulted equations based OLS model need more data for long time to make more calibration processing and more investigation .

7. REFERENCES

1. Brisson, N., Seguin, B. and Bertuzzi, P., 1992., *Agrometeorological soil water balance for crop simulation models*. Agricultural and Forest Meteorology, 59(3-4): 267-287.
2. Droogers, P. and Allen, R.G., 2002., *Estimating reference evapotranspiration under inaccurate data conditions.* Irrigation and Drainage Systems, 16(1): 33-45.
3. Gavilan, P., Lorite, I.J., Tornero, S. and Berengena, J., 2006., *Regional calibration of Hargreaves equation for estimating reference ET in a semiarid environment*.Agricultural Water Management, 81(3): 257-281.
4. Guyot, G., 1997., *Climatologie de l'environnement*. De la plante aux ecosystèmes. Masson, Paris, 505 pp.
5. Hargreaves, G.L., Hargreaves, G.H. and Riley, J.P., 1985., *Agricultural benefits for Senegal River Basin*. Journal of Irrigation and Drainage Engineering, 111: 111- 124.
6. Isabelle Marie-Joseph, Laurent Linguet, Marie-Line Gobinddass, Lucien Wald. *On the applicability of the Heliosat-2 method to assess surface solar irradiance in the Intertropical Convergence Zone, French Guiana*. International Journal of Remote Sensing, Taylor & Francis, 2013, 34 (8), pp.3012-3027.
7. Khalil A.A.1, Y.H. Essa1 and M.M. Abdel-Wahab,2015., *Evapotranspiration mapping over Egypt using MODIS / Terra satellite data* . International Journal of Advanced Research, 3(12): 512 – 522.
8. Lebon, E., Dumas, V., Pieri, P. and Schultz, H.R., 2003., *Modelling the seasonal dynamics of the soil water balance of vineyards*. Functional Plant Biology, 30(6): 699-710.
9. Mohammed A. El -Shirbeny , Bassam Abdellatif, Abd -Elraouf M. Ali , Nasser H. Saleh,2016., *Evaluation of hargreaves based on remote sensing method to estimate potential crop evapotranspiration* .International Journal of GEOMATE, (2016), 11(23), 2143-2149
10. Pereira, A.R., 2004., *The Priestley-Taylor parameter and the decoupling factor for estimating reference evapotranspiration*. Agricultural and Forest Meteorology, 125(3/4): 305-313.
11. Pereira, A.R. and Pruitt, W.O., 2004., *Adaptation of the Thornthwaite scheme for estimating daily reference evapotranspiration*. Agricultural Water Management, 66(3): 251-257.
12. Popova, Z., Kercheva, M. and Pereira, L.S., 2005., *Validation of the FAO methodology for computing ET0 with limited data*., ICID 21st European Regional Conference, Frankfurt and Slubice, 13pp.

13. Rigollier, C., Lefevre, M. and Wald, L., 2004., *The method Heliosat-2 for deriving shortwave solar radiation from satellite images*. Solar Energy, 77(2): 159-169.
14. Turc, L., 1961., *Evaluation des besoins en eau d'irrigation, évapotranspiration potentielle. Annales Agronomiques*, 12(1): 13-49.
15. Xu, C.Y. and Singh, V.P., 2002., *Cross comparison of empirical equations for calculating potential evapotranspiration with data from Switzerland.* Water Resources Management, 16(3): 197-219