Alexandria Engineering Journal (2013) 52, 35–42

Alexandria University

Alexandria Engineering Journal

www.elsevier.com/locate/aej
www.sciencedirect.com

ORIGINAL ARTICLE

Estimating the potential evapo-transpiration and crop coefficient from climatic data in Middle Delta of Egypt

Walaa Y. El-Nashar *, Eman A. Hussien

Water Engineering and Water Structure Engineering Department, Faculty of Engineering, Zagazig University, Zagazig, Egypt

Received 28 March 2012; revised 28 November 2012; accepted 1 December 2012
Available online 3 January 2013

KEYWORDS

Evapo-transpiration;
Crop;
Climate;
Blaney–Criddle;
Middle Delta

Abstract There are many empirical and theoretical equations to estimate the value of the potential evapo-transpiration (PE_T) under certain weather conditions. The relation between PE_T and climatic factors has the greatest role in the development of such equations. The main goal of this study is to propose empirical equations for estimating the PE_T of climatic data for Middle Delta of Egypt and modify the Blaney–Criddle equation using data in the period from 1990 to 2006. The climatic data during the period from 1990 to 2000 is used to propose the empirical equation and modified Blaney–Criddle equation. The result of the proposed equation is more accurate in calculating PE_T. Monthly crop coefficient (K_{co}) for crops cultivated in this area is estimated for the proposed equation in the study area and is compared with the measured values. Sensitivity analysis is used to quantify the impact of climatic parameters on the potential evapo-transpiration and crop coefficient.

1. Introduction

Plans for increasing agricultural production in Egypt to overcome the problems of insufficient food should be mainly based on the irrigation resources and water requirements. Therefore, an intensive water budget program should be clearly known. One of the main items of water budget is the crop water requirements. Therefore the water requirements of the different crops should be well identified. The crop water requirements are depended on the potential evapo-transpiration (PE_T) and the crop coefficient (K_c). There are many empirical and theoretical equations to estimate the value of PE_T under certain weather conditions. The relation between PE_T and climatic factors has the greatest role in the development of such equations. These equations are applicable to regions that have similar climatic factors. Such equations include Blaney–Criddle, Thornthwaite, Penman, Solar Radiation equations, and others [1]. The choice of any of these equations depends on the availability of climatic data in the region, and the accuracy required. These equations are used to calculate PE_T in arid and semi arid regions. But these equations are not the best in terms of accuracy in the Delta of Egypt, because these equations are based on climate conditions which are different in Delta. The main objective of this study is to propose an empirical equation to estimate PET in this area. In this paper SPSS – computer program – was used to estimate potential

* Corresponding author. Tel.: +20 1005256658.
E-mail address: Walaanashar@yahoo.com (W.Y. El-Nashar).

Peer review under responsibility of Faculty of Engineering, Alexandria University.

ELSEVIER Production and hosting by Elsevier

1110-0168 © 2013 Faculty of Engineering, Alexandria University. Production and hosting by Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.aej.2012.12.001

evapo-transpiration in Middle Delta of Egypt by proposing an empirical equation from climate data. The potential evapo-transpiration for the total period (PE_{TE}) and the potential evapo-transpiration for each month (PE_{T0}) were proposed of climatic data such as temperature, relative humidity, and sun hours [2]. The accurate equation is used to estimate crop coefficient for different crops in the study area. Values of the accurate crop coefficient were estimated. The effects of climatic data on developed potential evapo-transpiration PE_{TE}, PE_{T0}, and accurate crop coefficient (K_{co}) were studied.

Many authors study potential evapo-transpiration, crop coefficient and the different methods to calculate it. Smajstral et al. [3] demonstrated the data requirements and sensitivity of the water budget approach to determine irrigation requirements of Florida nursery and agronomic crops. Semaika and Rady [4] calculated the monthly potential evapo-transpiration for Giza, Egypt by using the original Blaney–Criddle, the modified Blaney–Criddle the modified Penman, and the Radiation methods. Villalobos and Fereres [5] developed a water budget model based on long-term average potential and actual rainfall data. In their model, potential evapo-transpiration was assumed to be constant each year because long-term data were not available.

Cellier et al. [6], Olejnik et al. [7], Yanuso et al. [8] and Pauwels et al. [9] studied the effect of the configuration of the experimental field on the estimate of evapo-transpiration. The choice of the heights above the ground surface, at which the metrological variables are measured, is a key point not always considered with the necessary attention. Kraalingen and Stol [10] used water budget approach to develop a crop yield model and weather data are simulated if long-term climatic data were not available. He described three different methods: the Penman method, Makkink approaches, and Priestley–Taylor to be used in general crop growth models for water-limited conditions.

Nuberg [11] modified the aerodynamic and thermal components of the energy balance to reduce evapo-transpiration. Montero et al. [12] conducted several outdoor single-sprinkler and block irrigation tests to estimate drift and evaporation losses during the set sprinkler irrigation event. Gat and Molle [13] proposed a model describing the application pattern produced by a single sprinkler. Shah and Edling [14] used the water balance approach to determine daily evapo-transpiration from a flooded rice field based on measured values of water level, precipitation, irrigation, seepage, and tail water runoff. Droogers and Allen [15] estimated the reference evapo-transpiration by using a high-resolution monthly climatic database, and compared the results with Penman–Monteith and Hargreaves methods. Clemmens et al. [16] developed a two dimensional model of unsteady shallow water flow in surface irrigation to evaluate the influence of field grading precision irrigation performance.

Allen et al. [17] improved daily simulation of crop evapo-transpiration by considering separately the contribution of evaporation from soil. Izuka et al. [18] used data from nine widely distributed climate stations to assess the distribution of potential evapo-transpiration on the tropical South Pacific island of Tutuila, American Samoa. Campi et al. [19] improved the efficient use of water in a typical Mediterranean environment. Eric et al. [20] estimated the evapo-transpiration parameter using the more readily available normalized difference vegetation index satellite. Blanco-Gutierrez et al. [21] focused on 12 ICs, which covered an area of 136,000 ha (95% of the total irrigated surface) and presented very diverse characteristics regarding their year of foundation, surface area, geographical location, granted water allotments, source of water, and irrigation technology. Mazahrih et al. [22] determined the actual evapo-transpiration and crop coefficients for mature palm trees by depletion method using neutron scattering technique, then they drew production function curve and selected the optimum irrigation level. Igbadun [23] reported the use of weighing-type mini-lysimeters to estimate the crop water use of rain fed maize and groundnut. Majnooni-Heris et al. [24] determined some relationships, between K_c (crop coefficient), and days after planting, degree growing days, leaf area index and percentage of ground cover.

2. Methodology

To achieve the objectives of this research, the following steps are followed:

1. Study climatic data for Middle Delta of Egypt (from Tanta Climate Station) is collected.
2. SPSS program is used for examining homogeneity of the measured climatic data.
3. An empirical equation is developing to compute PE_T (from 1990 to 2000).
4. Blaney–Criddle equation is modified for Middle Delta by using measured data and SPSS program (from 1990 to 2000).
5. Validate the empirical and modified Blaney–Criddle equations with a new data set (from 2000 to 2006).
6. K_c for crops cultivated in this area is estimated for the proposed equation and is compared with the measured values.
7. Sensitivity analysis is used to quantify the impact of climatic parameters on PE_T and K_c.

2.1. Study data

Collected data included measured potential evapo-transpiration (PE_{Tm}), mean temperature (T), relative humidity (RH), and sun hours (S). These data were obtained from Tanta Climate Station. The homogeneity of such kind of measured data is examined by SPSS program. Descriptive statistics are calculated by SPSS for these data as shown in Table 1. This table shows that standard error is <0.5, which means that the measured data is homogeneous and can be used to estimate the potential evapo-transpiration. Linear correlation test is used to study the relationship between different variables. Table 1 shows a strong correlation between potential evapo-transpiration, mean temperature, humidity, and sun hours.

2.2. Consumptive use of water (Cu)

Consumptive use of water (Cu) in (mm/day) for irrigation purposes is related to the potential evapo-transpiration (PE_T) by the crop coefficient (K_c), which depends on the type and stage of plant growth as follows [25]:

$$\mathrm{Cu} = K_c * PE_T \tag{1}$$

where PE_T is the average daily potential evapo-transpiration for a particular month (mm).

Table 1 Descriptive Statistics of the Data-base.

	PE_{Tm}		T		RH		S	
	Statistic	Std. error	Statistic	Std. error	Statistic	Std. error	Statistic	Std. error
N	204		204		204		204	
Mean	6.0775	0.1583	19.4597	0.3607	67.2	0.4011	9.4176	0.1347
Variance	5.112	–	26.544	–	32.821	–	3.704	–
Sum	1239.8	–	3969.78	–	13.709	–	1921.2	–
Range	11.6	–	16.1	–	30	–	9.2	–
Skewness	0.656	0.17	−0.17	0.17	−0.521	0.17	0.006	0.17
Kurtosis	0.217	0.399	−1.472	0.399	−0.161	0.399	−1.079	0.399

2.3. Empirical methods to estimate PE_T

There are many empirical and theoretical equations to estimate the value of PE_T under certain weather conditions. The relation between PE_T and climatic factors has the greatest role in the development of such equations.

A relationship between measured potential evapo-transpiration (PE_{Tm}) and the climatic variables in the study area was evaluated. The linear correlation between PE_T and other climatic data were examined and used to develop such relationship. Data for the period 1990–2000 were used in such analysis. The general form of the equation relating PE_T with climatic variables is:

$$PE_T = C + B_1 \times T + B_2 \times RH + B_3 \times S \tag{2}$$

where PE_T is the average daily potential evapo-transpiration for a particular month (mm), T is the average temperature (°C), RH is the average relative humidity (%), and S is the average number of hours of sunshine. A general equation is developed to calculate PE_{TE} (for the total period), depending on the measured climatic data as a continuous time series. The SPSS program is used to calculate the factors C, B_1, B_2, and B_3 for the total period as shown in Table 2.

$$PE_{TE} = 6.525 - 0.018 \times T - 0.125 \times RH + 0.88 \times S \tag{3}$$

The (SPSS) program is used to calculate the factors C, B_1, B_2, and B_3 for each month as shown:

$$PE_{T1} = 6.73 + 0.098 \times T_1 - 0.09 \times RH_1 + 0.28 \times S_1 \tag{4}$$
$$PE_{T2} = 6.75 - 0.096 \times T_2 - 0.093 \times RH_2 + 0.7 \times S_2 \tag{5}$$
$$PE_{T3} = 6.1 + 0.245 \times T_3 - 0.113 \times RH_3 + 0.361 \times S_3 \tag{6}$$
$$PE_{T4} = -12.5 + 0.62 \times T_4 + 0.07 \times RH_4 + 0.4 \times S_4 \tag{7}$$
$$PE_{T5} = -10.2 + 0.252 \times T_5 - 0.002 \times RH_5 + 1.25 \times S_5 \tag{8}$$
$$PE_{T6} = -19.4 + 0.202 \times T_6 + 0.136 \times RH_6 + 1.31 \times S_6 \tag{9}$$
$$PE_{T7} = -16.61 - 0.018 \times T_7 + 0.0325 \times RH_7 + 1.93 \times S_7 \tag{10}$$
$$PE_{T8} = 0.234 - 0.416 \times T_8 + 0.07 \times RH_8 + 1.07 \times S_8 \tag{11}$$
$$PE_{T9} = -0.003 - 0.006 \times T_9 - 0.088 \times RH_9 + 1.22 \times S_9 \tag{12}$$
$$PE_{T10} = 9.71 + 0.044 \times T_{10} - 0.131 \times RH_{10} + 0.459 \times S_{10} \tag{13}$$
$$PE_{T11} = 1.2 + 0.247 \times T_{11} - 0.062 \times RH_{11} + 0.415 \times S_{11} \tag{14}$$
$$PE_{T12} = 3.312 - 0.052 \times T_{12} - 0.04 \times RH_{12} + 0.508 \times S_{12} \tag{15}$$

2.4. Middle Delta Blaney–Criddle equation

Blaney–Criddle equation [26] is used to calculate the average value of PE_T for a period of month or longer. Although this equation is not the best in terms of accuracy, but it is the most common and widely used one, especially in arid and semi arid regions for its simplicity and ease of application. It needs only to measure the temperature in the region required. The general form of Blaney–Criddle is:

$$PE_T = a_1 * f + a_2 \tag{16}$$
$$f = p(0.46T + 8) \tag{17}$$

where a_1 and a_2 are constants depend on the average values during the month of lowest relative humidity during the day, p is the percentage of the average number of daylight hours in the day for the specified month to the total of daylight hours in the year, and T is the average temperature for a full day during the month in Celsius.

The percentage of the average number of daylight hours in the day for the specified month to the total of daylight hours in the year (p) depends on the latitude of the area under study, and the month required. In order to apply the Middle Delta Blaney–Criddle equation put to the study area the values of the constants a_1 and a_2 must be determined according to climatic conditions in this area. Eq. (16) presents a linear relationship between PE_T and the function f, and to determine the values of a_1 and a_2, following procedure was proposed:

1. The values of the function (f) are calculated for each month through the year, based on measured values of T, and the values of p.
2. Using linear regression analysis by the aid of SPSS, values of a_1 and a_2 can be determined.

The results of linear regression analysis in the period from 1990 to 2000 are shown in Table 3. The obtained values of a_1 and a_2 are 1.63 and 1.615 respectively, and the Middle Delta Blaney–Criddle equation can be applied to estimate PE_T in Tanta Station and take the form:

Table 2 Values of coefficient in Eq. (2) for the total period.

Model	Un-standardized coefficients		Standardized coefficients	t	Sig.
	B	Std. error	Beta		
Constant	6.525	1.144	–	5.705	0
T	−1.8E−02	0.025	−0.041	−0.713	0.475
RH	−0.125	0.013	−0.316	−9.308	0
S	0.88	0.073	0.749	12.011	0

Table 3 Values of a_1 and a_2 calculated using the program (SPSS).

Model	Un-standardized coefficients		Standardized coefficients	t	Sig.
	B	Std. error	Beta		
a_2	−1.615	0.424	–	−3.807	0
a_1	1.63	0.088	0.795	18.621	0

$$PE_{TWD} = 1.63[p * (0.46T + 8)] - 1.615 \quad (18)$$

To investigate the validity of the Middle Delta Blaney–Criddle equation, values of PE_T were calculated using Eq. (18), and the results were compared with the measured one.

2.5. Validation of PE_{TE}, PE_{T0} and PE_{TWD} equations

Comparing Middle Delta measured values (PE_{Tm}), PE_{TE} for the total period and PE_{T0} for each month with the climatic data from 2000 to 2006, by using T-test, it was found that Pearson correlation is 0.95, and P factor (two-tail) is 0.69 for PE_{TE}, and Pearson correlation is 0.98, and P factor (two-tail) was 0.32 for PE_{T0}. It was clear that the values of potential evapo-transpiration calculated on basis of each month (PE_{T0}) were more accurate and closer to a large extent to the measured values. The developed equations for each month can be accurately used to calculate potential evapo-transpiration and the consumptive use of water in Middle Delta of Egypt.

To valid the results of Middle Delta Blaney–Criddle, a comparison between PE_{Tm} and PE_{TWD} for Middle Delta with the climatic data from 2000 to 2006 was made, by using T-test, it was found that Pearson correlation is 0.8, and P factor (two-tail) was 0.86 for PE_{TWD}. It was clear that the values of potential evapo-transpiration calculated on basis of each month (PE_{T0}) were more accurate and closer to a large extent to the measured values.

2.6. Selection of crop coefficient

The values of actual consumptive use of different crops (Cu) were obtained from Irrigation Ministry [27]. The values of PE_T are measured on Tanta station and calculated values from empirical equation for each month. Crop coefficient (K_c) is calculated from Eq. (1),

$$K_c = Cu/PE_T \quad (19)$$

K_c in Eq. (19) will be replaced by the measured crop coefficient (K_{cm}), or crop coefficient (K_{co}) calculated from empirical potential evapo-transpiration for each month. Rice, maize, wheat, cotton, vegetables, and berseem crops are cultivated in this study area. The crop coefficients for these crops are shown in Tables 4 and 5.

2.7. Sensitivity analysis

Sensitivity analysis is used to quantify the impact of input parameters on the equations results. It is likely that errors will be made in estimating one or more of measured climatic parameters (T, RH, S), to illustrate their individual impacts on potential evapo-transpiration PE_T, assuming T, RH and S can vary between −20% and +20% of their measured values. The effects of the climatic parameters (T, RH, S) on PE_{T0} which calculated from empirical equations for each month are shown in Figs. 1–3. Meanwhile the effects of the climatic parameters (T, RH, S) on K_{co} for the main crop in this study area (rice) are shown in Figs. 4–6.

3. Results and discussion

A general equation for the total period is developed by using SPSS to calculate the potential evapo-transpiration depending on the measured climatic data on the study area as a continuous time series. General equations for each month are developed also by using SPSS. The results from the equation for the total period and from the equation for each month were compared with the measured values. It was found that the developed equations for each month could be accurately used to calculate potential evapo-transpiration and the consumptive use of water in Middle Delta of Egypt.

Blaney–Criddle equation for Middle Delta of Egypt is investigated to calculate the potential evapo-transpiration. By the results of this equation, a correspondence between measured and modified values of PE_T is evident. But the proposed

Table 4 K_c and Cu for rice, maize, and cotton crops.

Crop	Rice			Maize			Cotton		
Month	Cu	K_{cm}	K_{co}	Cu	K_{cm}	K_{co}	Cu	K_{cm}	K_{co}
April	8.2	1.12	1.12	5.1	0.7	0.7	4.27	0.58	0.58
May	11.7	1.27	1.28	6.8	0.74	0.74	5.75	0.63	0.63
June	14.8	1.54	1.54	7.33	0.76	0.77	6.56	0.68	0.68
July	12.4	1.65	1.64	6.48	0.86	0.86	6.0	0.8	0.79
August	10.1	1.57	1.58	5.4	0.84	0.84	4.4	0.68	0.69
September	8.68	1.39	1.4	4.5	0.72	0.72	3.6	0.58	0.58
October	6.8	1.15	1.15	3.75	0.64	0.63	3.12	0.53	0.53
November	N/A	N/A	N/A	N/A	N/A	N/A	2.11	0.49	0.49
December	N/A	N/A	N/A	N/A	N/A	N/A	1.34	0.41	0.41

Table 5 K_c and Cu for wheat, vegetables, and berseem crops.

Crop	Wheat			Vegetables			Berseem		
Month	Cu	K_{cm}	K_{co}	Cu	K_{cm}	K_{co}	Cu	K_{cm}	K_{co}
January	1.53	0.44	0.45	1.64	0.47	0.48	1.12	0.32	0.33
February	1.98	0.45	0.45	2.15	0.49	0.49	1.52	0.35	0.34
March	2.4	0.45	0.45	2.8	0.53	0.53	2.07	0.39	0.39
April	3.4	0.47	0.47	4	0.55	0.55	3.16	0.43	0.43
May	N/A	N/A	N/A	5.3	0.58	0.58	4.67	0.51	0.51
June	N/A	N/A	N/A	5.81	0.6	0.61	N/A	N/A	N/A
July	N/A	N/A	N/A	5.23	0.7	0.69	N/A	N/A	N/A
August	N/A	N/A	N/A	4.42	0.69	0.69	N/A	N/A	N/A
September	N/A	N/A	N/A	3.89	0.62	0.63	2.04	0.29	0.33
October	N/A	N/A	N/A	3.45	0.58	0.58	2.57	0.43	0.43
November	2.13	0.49	0.5	2.31	0.53	0.54	2.05	0.44	0.48
December	1.68	0.52	0.52	1.58	0.48	0.49	1.38	0.38	0.42

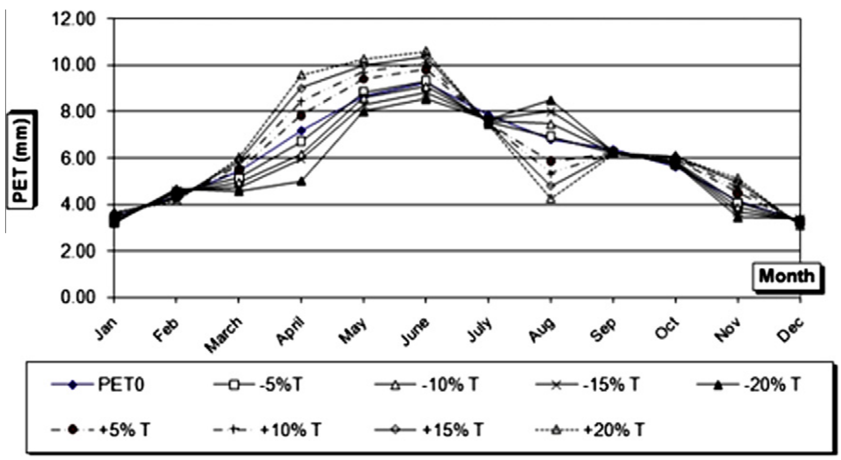

Figure 1 Sensitivity analysis of T on PE_{T0}.

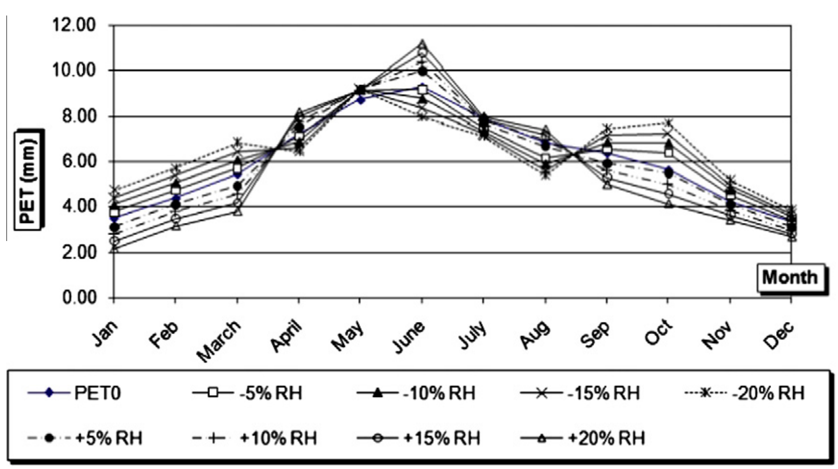

Figure 2 Sensitivity analysis of RH on PE_{T0}.

equation for each month is more accurate than Middle Delta Blaney–Criddle equation. The crop coefficient (K_c) was calculated from the equation (K_c = consumptive use (Cu)/potential evapo-transpiration (PE_T)) for the different crops which cultivated in this area, the actual values of Cu of these crops were obtained from Irrigation Ministry [27], the values of PE_T were

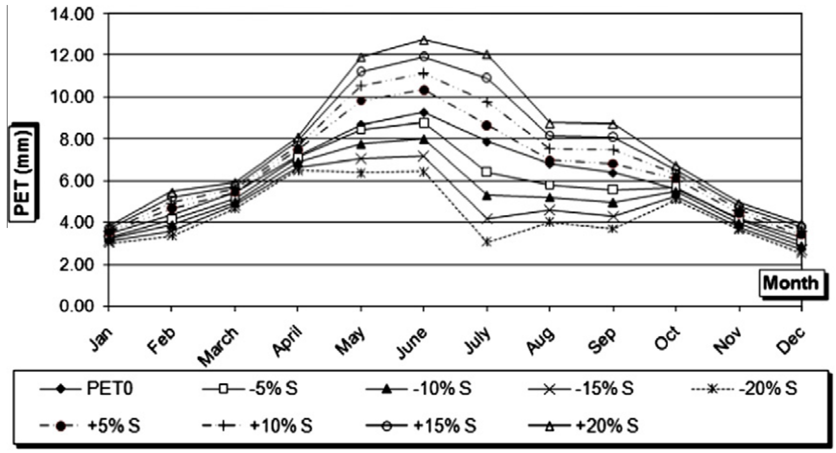

Figure 3 Sensitivity analysis of S on PE_{T0}.

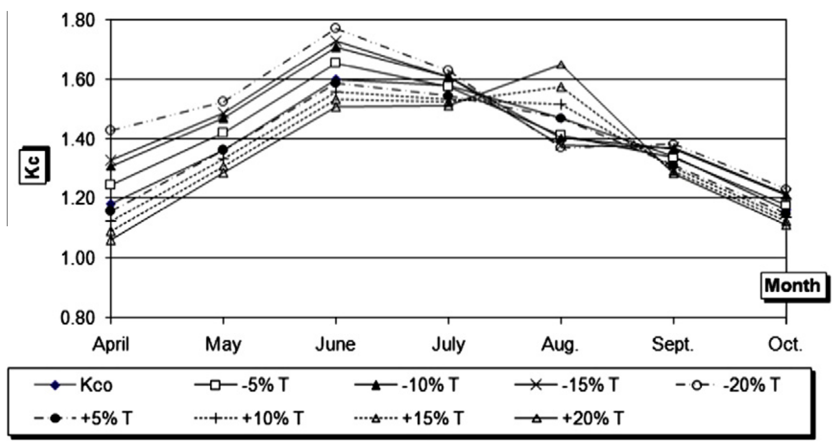

Figure 4 Sensitivity analysis of T on K_{co} of rice crop.

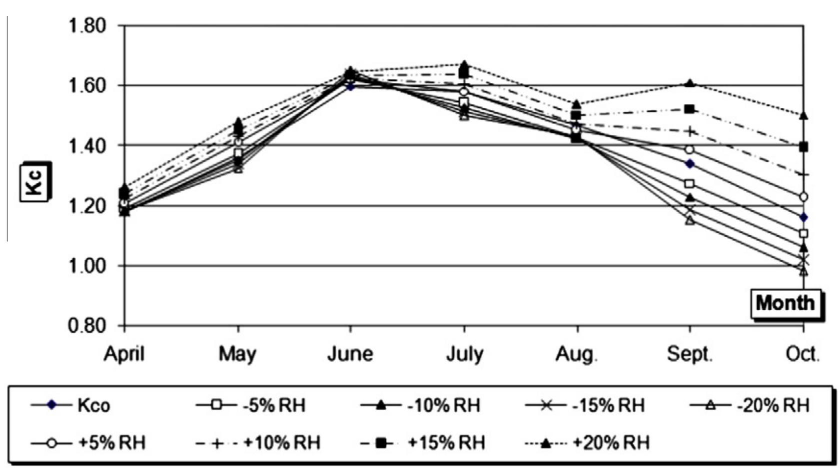

Figure 5 Sensitivity analysis of RH on K_{co} of rice crop.

obtained from measured values, and empirical equations for each month (PE_{T0}). The values of K_{co} which are calculated from [Cu/PE_{T0}] could be used to calculate crop coefficient. It was found that the values of K_{co} were closed to measured values. Thus K_{co} was the accurate crop coefficient for these crops in this study area.

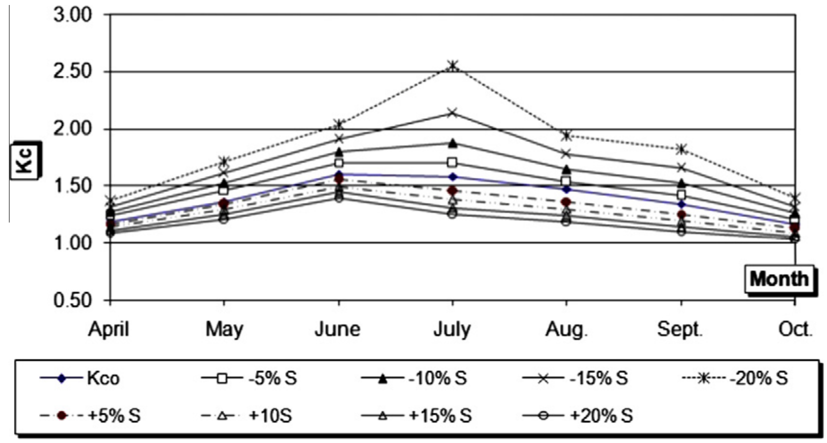

Figure 6 Sensitivity analysis of S on K_{co} of rice crop.

Sensitivity analysis was used for climatic parameters (T, RH, S) to illustrate their individual impacts on potential evapo-transpiration and crop coefficient. The effect of T on the evapo-transpiration was not noticeable from January to March and from September to December, but its effect was noticeable from April to August. The effect for rice T on K_{co}, was significant from January to July, but its effect was negligible from August to October. For cotton, the effect was noticeable from April to July, but was negligible from August to December. The effect of RH on the evapo-transpiration was not noticeable from January to December. The effect of RH on K_{co}, for rice was significant from August to October. For cotton, the effect of RH was noticeable from September to December. The effect of S on the evapo-transpiration was noticed from April to November. The effect of S on K_{co}, for rice was noticed from May to September, but its effect was not noticeable from August to December. For cotton, meanwhile the effect was notice from May to September.

4. Conclusion

The main goal of this study is to compute the potential evapo-transpiration for Middle Delta of Egypt proposed empirical equations for this area by using climatic data collected during the period 1990–2006, for the total period and for each month. SPSS is used to compute these equations. Blaney–Criddle equation for Middle Delta of Egypt is investigated to calculate the potential evapo-transpiration. The proposed equations for each month could be accurately used to calculate potential evapo-transpiration and the consumptive use of water in Middle Delta of Egypt. The climatic data during the period from 1990 to 2000 is used to propose the empirical equation and modified Blaney–Criddle equation, and data for Middle Delta of Egypt during the Period from2000 to 2006 is used to validate the proposed equation. The crop coefficient (K_c) is calculated for the different crops which cultivated in this area, the actual values of Cu of these crops are obtained from Irrigation Ministry, and the values of PE_T are obtained from empirical equations for each month. The values of K_{co} which are calculated from PE_{T0} could be accurate values of crop coefficient in Middle Delta of Egypt. Sensitivity analysis is used for climatic parameters (T, RH, S) to illustrate their individual impacts on potential evapo-transpiration, and crop coefficient.

References

[1] R. Allen, L. Pireira, D. Raes, M. Smith, Crop Evapo-Transpiration – Guidelines for Computing Crop Water Requirements, FAO, Rome, Italy, 1998, 56.
[2] W. Shuttleworth, Towards one-step estimation of crop water requirements, Trans. ASABE 49 (4) (2006) 925–935.
[3] A. Smajstral, G. Zazueta, D.S. Parsons, K.C. Stone, Trickle Irrigation Scheduling for Florida Citrus, IFAS, Univ. of Florida, Gainesville, FL, 1987.
[4] M. Semaika, M. Rady, On the calculation of crop coefficient when estimating crop water requirements, Water Sci. Egypt 3 (1987) 76–90.
[5] F.J. Villalobos, E. Fereres, A simulation model for irrigation scheduling under variable rainfall, Trans. ASAE 32 (1) (1989) 181–188.
[6] P. Cellier, A. Olioso, A simple system for automated long-term Bowen ratio measurements, Agric. Forest Meteorol. 66 (1993) 81–92.
[7] J. Olejnik, F. Eulenstein, A. Kedziora, A. Werner, Evaluation of water balance model using data for bare soil and crop surfaces in Middle Europe, Agric. Forest Meteorol. 106 (2001) 105–116.
[8] I.A. Yanusa, R.R. Walker, Potential evapo-transpiration components from energy balance, sap-flow and micro-lysimetry techniques for an irrigated vineyard in Inland Australia, Agric. Forest Meteorol. 127 (2004) 93–107.
[9] V. Pauwels, R. Samson, Comparison of different methods to measure and model actual evapo-transpiration rates for wet sloping grassland, Agric. Water Manage. 82 (2006) 1–24.
[10] D.W.G. Kraalingen, W. Stol, Evapo-transpiration modules for crop growth simulation, Quant. Approaches Syst. Anal. (1997) 11.
[11] I. Nuberg, Effect of shelter on temperature crops: a review to define research for Australian conditions, Agroforest. Syst. 41 (1998) 3–34.
[12] J. Montero, J.M. Tarjuelo, J. Ortega, J.A. Juan, Discharge efficiency in sprinkler irrigation: analysis of the evaporation and drift losses in semi-arid areas, Int. Comm. Agric. Eng. (CIGR), E-J. 2 (2000).
[13] Y. Gat, B. Molle, Model of water application under pivot sprinkler, J. Irrig. Drain. Eng. – ASCE 126 (6) (2000) 343–347.
[14] S.B. Shah, R.J. Edling, Daily evapo-transpiration prediction from Louisiana flooded rice field, J. Irrig. Drain. Eng. – ASCE 126 (1) (2000) 8–13.

[15] P. Droogers, R. Allen, Estimating reference evapo-transpiration under inaccurate data conditions, Irrig. Drain. Syst. 16 (2002) 33–45.
[16] A. Clemmens, T. Strelkoff, E. Playan, Field verification of two-dimensional surface irrigation model, J. Irrig. Drain. Eng. – ASCE 129 (6) (2003) 402–411.
[17] R. Allen, L. Pereira, M. Smith, D. Raes, J. Wright, FAO-56 dual crop coefficient method for estimating evaporation from soil and application extensions, J. Irrig. Drain. Eng. – ASCE 13 (1) (2005) 2–13.
[18] S. Izuka, T. Giambelluca, M. Nulletto, Potential evapo-transpiration on Tutuila, American Samoa. U.S. Geological Survey Scientific Investigations Report 2005-5200, 40 p.
[19] Campi P, Palumbo A, Mastrorilli M. The evapo-transpiration of crop protected by windbreak. Irrigation in Mediterranean Agriculture: Challenges and Innovation for the Next Decades Options Mediterranean, 2008, Series A (84).
[20] B. Eric, C. Bryce, P. Daniel, Evaluation of a method for estimating irrigated crop-evapo-transpiration coefficients from remotely sensed data in Idaho, J. Irrig. Drain. Eng. – ASCE 134 (6) (2008) 722–730.
[21] I. Blanco-Gutierrez, C. Varela-Ortega, D. Purkey, Integrated economic–hydrologic analysis of policy responses to promote sustainable water use under changing climatic conditions, EAAE, Congress, 2011.
[22] N. Mazahrih, Y. AL-Zu'bi, H. Ghnaim, L. Lababdeh, M. Mona Ghananeem, H. AbuAhmadeh, Determination actual evapo-transpiration and crop coefficients of date palm trees (phoenix dactylifera) in the Jordan valley, Am-Euras. J. Agric. Environ. Sci. 12 (4) (2012) 434–443.
[23] H. Igbadun, Estimation of crop water use of rain-fed maize and groundnut using mini-lysimeters, J. Sci. Technol. 13 (1) (2012) 527–535.
[24] A. Majnooni-Heris, A. Sadraddini, A. Nazemi, M. Shakiba, M. Neyshaburi, I. Tuzel, Determination of single and dual crop coefficients and ratio of transpiration to evapo-transpiration for canola, Ann. Biol. Res. 3 (4) (2012) 1885–1894.
[25] J. Doorenbos, W. Pruitt, Guidelines for Predicting Crop Water Requirements. FAO Irrigation and Drainage, FAO, Rome, Italy, 1977, 24.
[26] H. Blaney, Monthly consumptive use requirements of irrigated crops, J. Irrig. Drain. Eng. DID. Proc. ASCE (1959).
[27] Ministry of State for Environmental Affairs Egyptian Environmental Affairs Agency. Irrigation and crop management plan. Report No. 25 LIFE Integrated Water Resources Management, Task Order No. 802, Report No. 25, 2006.