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EVAPOTRANSPIRATION INTERVAL FOR PROPER IRRIGATION SCHEDULING IN EGYPT

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ABSTRACT

Due to unavailability of daily weather elements in many parts of Egypt, agricultural extension workers use weather data of the preceding year to calculate evapotranspiration (ETo) values, which might or might not be good representations of the current weather conditions. Thus, the objective of this research was to determine how many years of past weather data is required to develop an estimate of ETo to be use in irrigation scheduling for crops in the five agro-climatic zone of Egypt. Daily weather data was collected for 10 years (2007-2016). Statistical analysis was applied to study the spatial and temporal variability of weather elements, as well as ETo values (annual, winter and summer). The analysis revealed that in the first agro-climatic zone, the interval between 2013 and 2016 was suitable to be used to schedule irrigation for both winter and summer crops. In the second and third agro-climatic zones, the interval between 2012 and 2016 was suitable for winter crops and the interval between 2013 and 2016 was suitable for summer crops. For the fourth agro-climatic zone, the interval between 2013 and 2016 was suitable for winter between 2014 and 2016 was suitable for summer crops. Whereas, in the fifth agro-climatic zone, interval between 2013 and 2016 was suitable for winter crops and summer crops. Using the developed ETo-time intervals in calculating water requirements for the several crops resulted in1-3% saving in the applied water, compared to using 2016 weather data. Thus, the above results implied the suitability of the developed ETo-time intervals in irrigation scheduling for crops to improve irrigation water management on field level.

(Key words: Weather elements, spatial and temporal variability, annul and seasonal evapotranspiration values, agro-climatic zones of Egypt)

INTRODUCTION

Irrigation management is based upon delivery of water to a crop in the correct amount and time, and the crop's water need is determined by calculating evapotranspiration (ETo) using weather data (Mahan and Lascano, 2016).Irmak and Mutiibwa (2010) stated that "evapotranspiration in agro-ecosystems is the sum of two terms; (1) transpiration, in which water entering the plant roots is carried to stems and leaves for building plant tissue via photosynthesis and then passed through the leaves of the plant into the atmosphere, and (2) evaporation, which is water evaporating from soil, water surfaces, or from plant leaf surfaces holding water droplets from rain, irrigation, or dew formation". Thus, transpiration by the plant results in water moves from the roots to the surrounding atmosphere in the form of very small water vapor particles. This movement within or from a field is derived by climatic factors (Irmak and Mutiibwa, 2009).Air temperature, solar radiation, relative humidity of air, and wind speed are the primarily driver of ETo (Allen *et al*., 1998). ETo increases with increasing air temperature (maximum and minimum) and solar radiation (or sunshine duration), which are the two primary drivers of ETo (Allen *et al*., 1998). Decreasing relative humidity of the air surrounding the leaves results in higher ETo because the demand for water vapor by the atmosphere surrounding the leaf surface increases (Irmak and Irmak, 2008).Furthermore, high wind speed usually results in an increase in ETo value (Irmak and Mutiibwa, 2009).

Several investigations have been done in Egypt to study the strength of the relationship between each weather element and ETo. Khalil *et al*. (2011) found that a strong relation between ETo and mean temperature, sunshine duration, relative humidity, where correlation coefficient were 0.83, 0.79, and 0.70, respectively and weak relation between ETo and wind speed, i.e. 0.27. Their analysis was done using averaged weather data from 1997-2006 to calculate 10-year mean of ETo valued in 20 governorates in Egypt. Noreldin *et al*. (2016) analyzed 30-year averages of weather data from 1985-2014 in 17 governorates in the Nile Delta and Valley in Egypt and they found that the values of coefficient of determination (R^2) between ETo and maximum and minimum temperatures, solar radiation, as well as wind speed

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were 0.91, 0.86, 0.52 and 0.23, respectively. Ouda and Noreldin (2017) used averages of 10-year weather data from 2005-2014 to calculate ETo and they concluded thatR^2 values between ETo and mean temperature was 0.79. Moreover, R^2values was 0.58 and 0.37 between ETo values and solar radiation and wind speed, respectively. That analysis was done on 17 governorates in the Nile Delta and Valley in Egypt.

In Egypt, there is some evidence indicated an increasing trend in ETo values in the past 30-year time interval (1985-2014) (Ouda and Noreldin, 2017). Similar trends of increasing ETo values were reported around the world. An increasing trend in ETo values in Taiwan was observed when 48-year time interval of weather data was used in the analysis (Yue *et al*., 2002). In Northeast Brazil, (Da Silva, 2004) reported increase in ETo values, where 30-year time period was used. Burn and Hesch (2007) indicated that there was an increasing trend of ETo values in the northern regions of Canada. An increase by 28% in annual ETo values over Iran was reported during the period 1965–2005 (Dinpashoh *et al*., 2011). Lastly, there is an increasing trend in the annual ETo values in the agricultural areas of Sanjiang Plain, China between 1959 and 2013 (Song *et al*., 2017).

In Egypt, irrigated agriculture consumed 85% of water resources. Furthermore, irrigation application efficiency is low, which endure large losses of this valuable natural resource to the ground water. Thus, there is an extraordinary need for efficient water use in irrigated agriculture. Exact application of irrigation water amount and correct timing of application, or in another word irrigation scheduling, should be adopted to attain that. Irrigation scheduling has aimed to achieve an optimum water supply for better productivity, with soil water content maintained close to field capacity (Tariq and Usman, 2009). The aim of irrigation scheduling is to maximize yield, enhance irrigation efficiency, and improve crop quality by applying the exact amount of water needed by the crop, or to replenish the soil moisture to the desired level (Ali, 2010).

Knowledge of ETo values are necessary for irrigation scheduling. ETo-based irrigation scheduling is one of important method to apply irrigation water, where ETo losses are replaced in the root zone to meet plant water requirements (Mahan and Lascano, 2016). However, availability of weather elements to calculate ETo, sometimes, become an obstacle. Agricultural extension workers need monthly ETo values to guide farmers on when to apply irrigation and how much water needs to be applied. Thus, they use weather data of the preceding year to calculate ETo values, which might or might not be good representations of current weather conditions. Ouda and Noreldin (2017) detected variability in the weather elements, as well as ETo values in the past 10 years from 2005 to 2014, compared to the past 20-year or 30-year intervals, which imply obligation to determine the number of annual ETo data that contains less variability.

Thus, the objective of this research was to determine how many years of past weather data is required to develop an estimate of ETo to be use in irrigation scheduling for crops in the five agro-climatic zones of Egypt.

MATERIALS AND METHODS

Description of the agro-climatic zones of Egypt

The recent classification of Egypt to agro-climatic zones developed by Ouda and Noreldin (2017) was used in this analysis. This classification was done using 10-year averages of ETo (2005-2014). Their results revealed that there are five agro-climatic zones exist in Egypt (Table 1).

Statistical procedure

Weather data were collected for 10 years from 2007-2016 in each zone. These data were solar radiation, wind speed, as well as maximum, minimum and dew point temperatures. The mean value over 10 years of each of weather elements was calculated. ETo values were calculated with BISm model (Snyder *et al*., 2004) using Penman-Monteith equation, as presented in the United Nations FAO Irrigation and Drainage Paper (FAO 56) by (Allen *et al*., 1998).Annual and seasonal winter and seasonal summer values of ETo were calculated. In Egypt, the winter growing season starts in November to April, whereas the summer growing season is between May to October. The calculated annual weather elements and ETo values were individually analyzed to study its spatial and temporal variability and to check whether ETo values decreasing or increasing.

Descriptive statistical analysis for the weather elements, as well as, ETo (annual, winter and summer) in the five ago-climatic zones was performed to calculate maximum and minimum values, the range between them and the mean value of the studied values. Coefficient of variation (CV%) was also calculated, which is defined as the ratio of the standard deviation to the mean. Snedicor and Cochran, (1980) stated that the higher the coefficient of variation, the greater the level of dispersion around the mean. The deviation from the mean value of seasonal winter and summer ETo values was analyzed and graphed with its counterpart value. Furthermore, the analysis determined the suitable time-interval of ETo values to schedule irrigation in each agro-climatic zone.

Validation of the of the ETo time-interval

BISm model (Snyder *et al*., 2004) was used to schedule irrigation using the suitable time-interval of ETo values in each zone for the several winter and summer crops. Moreover, the calculated values of water requirements for these crops were compared to its counterpart values calculated using weather data in 2016.

Table 1. Agro-climatic zones classification in Egypt by using 10-years time interval

Zone number	Governorate	Latitude (º)	Longitude (º)	Elevation above sea level (m)	ETo (mm/day)
Zone 1	Alexandria	31.70º	29.00º	7.0	4.279
	Kafr El-Sheik	31.07º	30.57º	20.0	4.852
Zone 2	Demiatte	31.25º	31.49º	5.0	5.123
	El-Dakahlia	31.03º	31.23º	7.0	5.344
	El-Behira	31.02º	30.28º	6.7	5.192
	El-Gharbia	30.47º	32.14º	14.8	5.125
Zone 3	El-Monofia	30.36º	31.01º	17.9	5.800
	El-Sharkia	30.35º	31.30º	13.0	5.869
	El-Kalubia	30.28º	31.11º	14.0	5.964
	Giza	30.02º	31.13º	22.5	5.701
	Fayom	29.18º	30.51º	30.0	5.587
Zone 4	BeniSweif	29.04º	31.06º	30.4	6.139
	El-Minia	28.05º	30.44º	40.0	6.140
	Assuit	27.11º	31.06º	71.0	6.122
	Sohag	26.36º	31.38º	68.7	6.127
Zone 5	Qena	26.10º	32.43º	72.6	6.480
	Aswan	24.02º	32.53º	108.3	6.600
Mean					5.673
Rang					2.321
$LSD_{0.05}$					0.217

Source: Ouda and Noreldin (2017)

RESULTS AND DISCUSSION

Spatial and temporal variability of weather elements

1. Solar radiation

Figure (1) illustrated the spatial variability between zones and temporal variability between years for the annual solar radiation values in the five agro-climatic zones of Egypt. The figure showed a decreasing trend starting from 2013 in zone 4 and 5, and increasing trend started in 2015 in zone 1, 2, and 3. It worth noting that the differences between zone 1 and 2 in solar radiation are very low, both values almost identical.

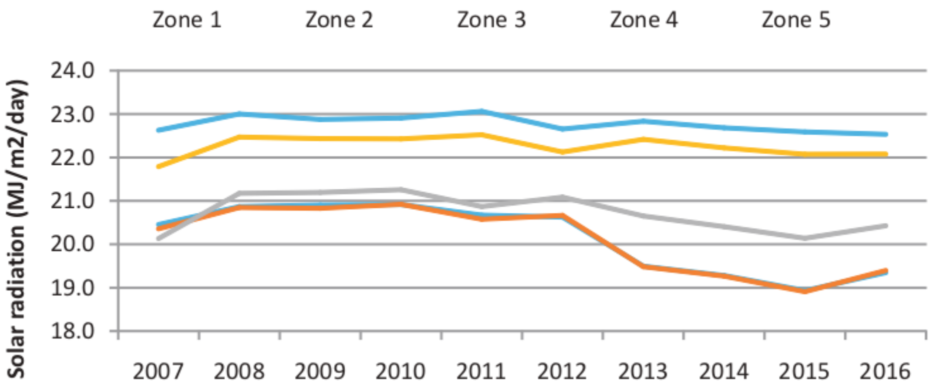

Figure 1. Spatial and temporal variability in the annual values of solar radiation in the studied time interval for the agro-climatic zones of Egypt

2. Maximum temperature

Spatial variability between the studied zones and temporal variability between the studied time intervals for maximum temperature are shown in Figure 2. In all zones, there was a stable trend stared from 2014 to 2016 (Figure 2).

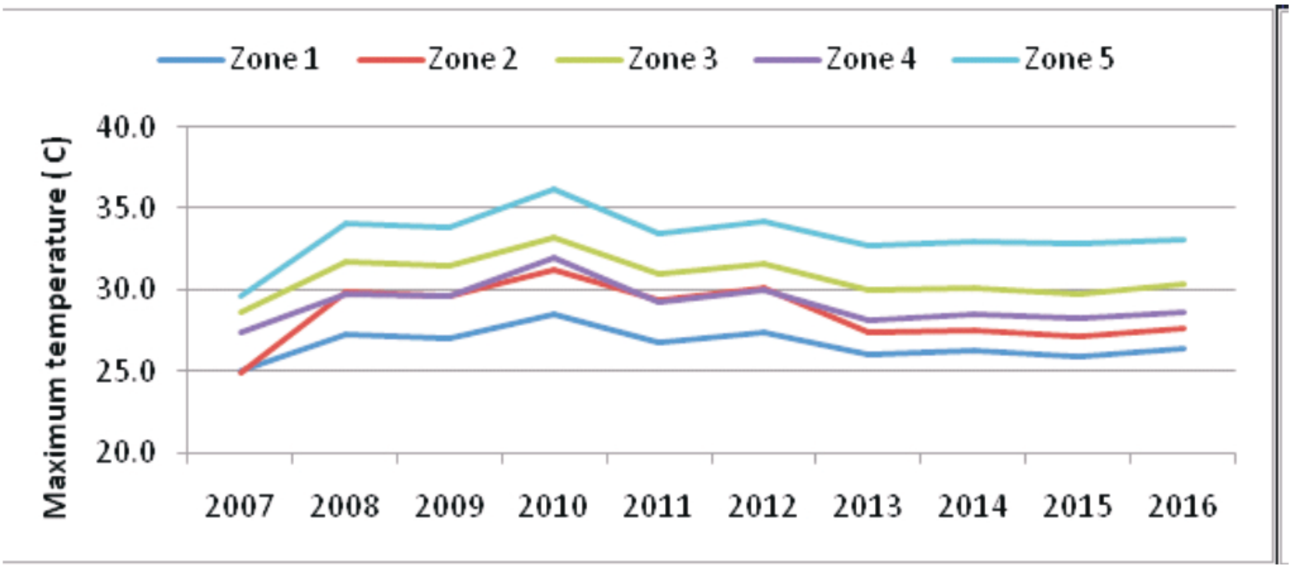

Figure 2. Spatial and temporal variability in annual values of maximum temperature in the studied time interval for the agro-climatic zones of Egypt

3. Minimum temperature

Lower temporal variability in annual minimum temperature values existed in the studied time interval. Starting from 2014 to 2016, a stable trend was found for annual minimum temperature values in the five agro climatic zones (Figure 3).

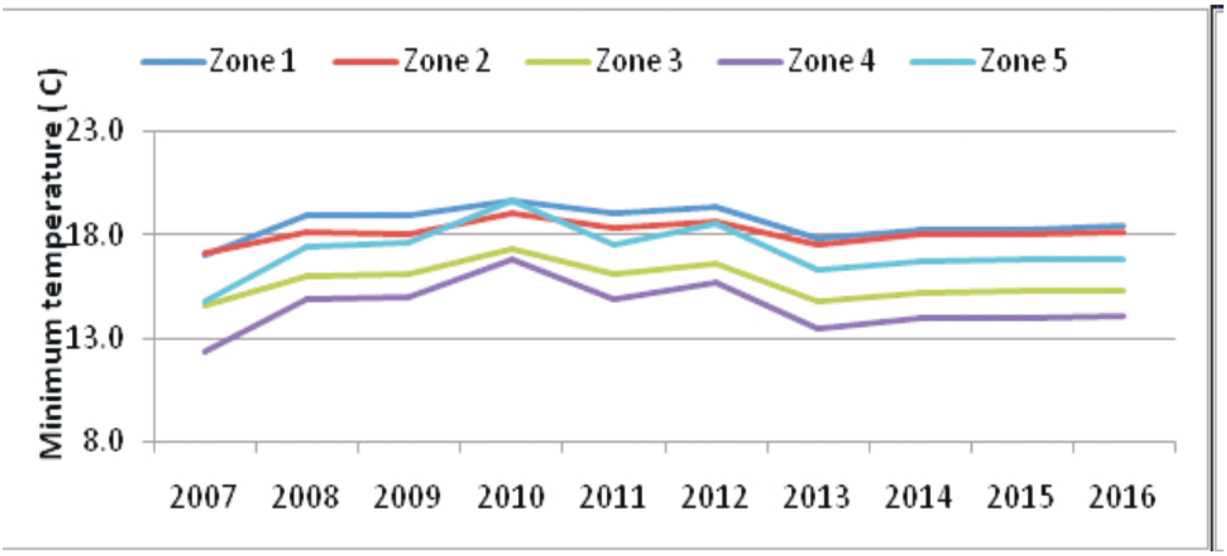

Figure 3. Spatial and temporal variability in annual values of minimum temperature in the studied time interval for the agro-climatic zones of Egypt

4. Wind speed

Figure 4 showed medium temporal variability in annual wind speed values in the five agro-climatic zones. The year of 2015 and 2016 witnessed stability in the annual wind speed values.

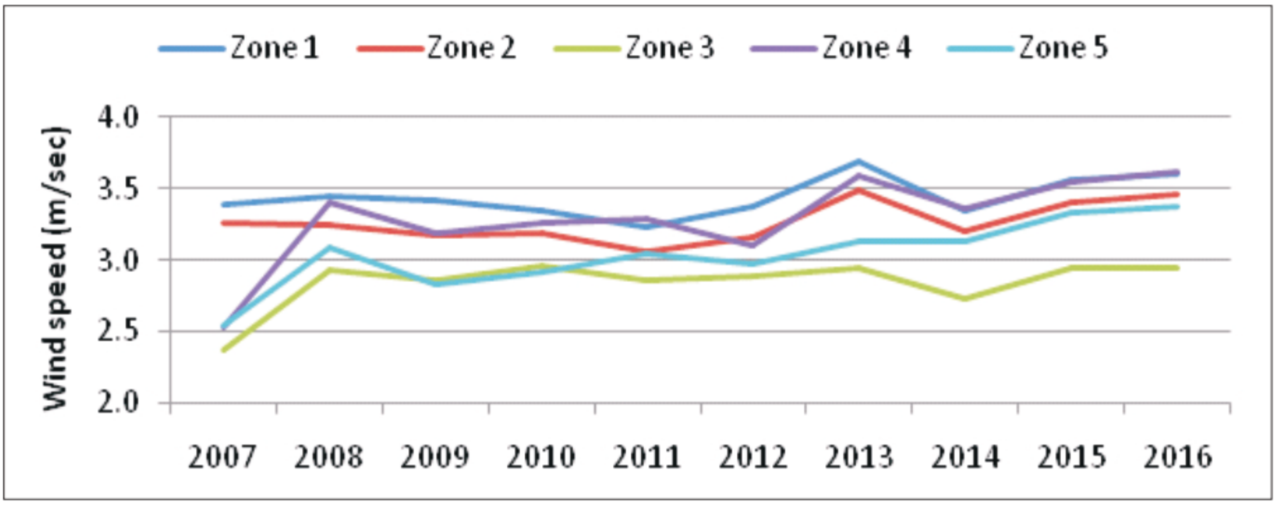

Figure 4. Spatial and temporal variability in annual values of wind speed in the studied time interval for the agro-climatic zones of Egypt

5. Dew point temperature

Figure 5 showed low temporal and spatial variability in the values of annual dew point temperature in the studied time interval in zone 1 and 2, medium variability in zone 3 and high variability in zone 1 and 5. The figure also showed that starting from 2014 until 2016, the value of dew point temperature became stable.

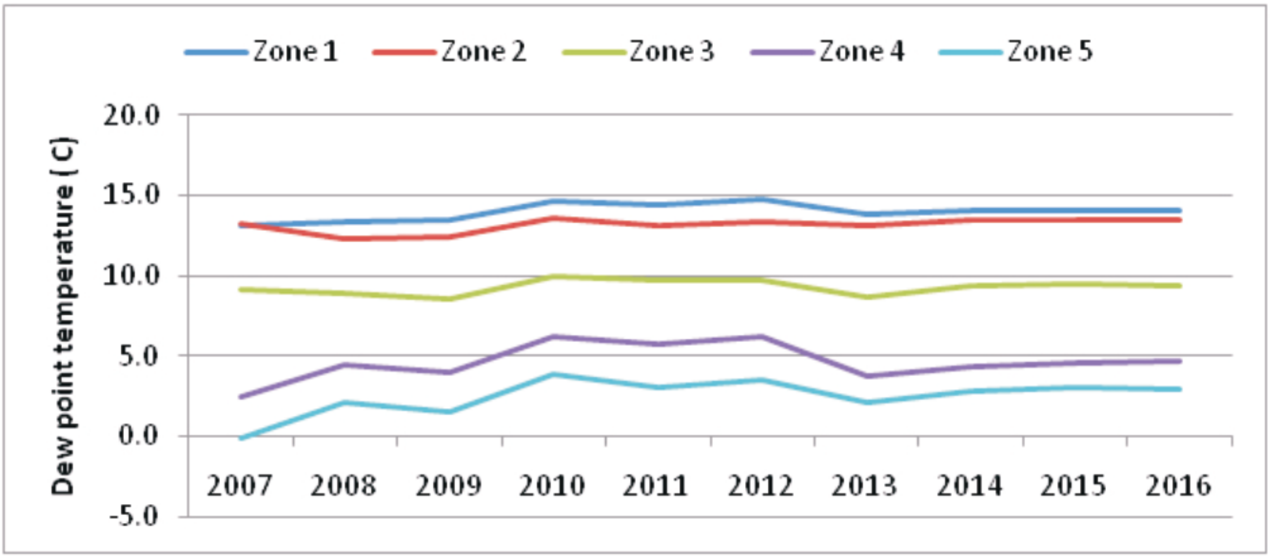

Figure 5. Spatial and temporal variability in annual values of dew point temperature in the studied time interval for the agro-climatic zones of Egypt

The above results indicated that the value of solar radiation was lower in 2016 than its counterpart value in 2007. Whereas, the values of the rest of the studied weather elements were higher in 2016, compared to its counterpart values in 2007. Furthermore, spatial variability between zones was expressed by lower value of solar radiation and maximum temperature in zone 1, as well as higher values of minimum temperature, wind speed and dew point temperature, compared to zone 5. Higher temporal variability in solar radiation, maximum temperature, as well as lower temporal variability in minimum temperature, wind speed and dew point temperature existed in zone 2, compared to zone 5.

6. Annual ETo values

Figure 6 showed comparison between annual values of ETo in the five agro- climatic zones. The figure showed that the lowest values existed in zone 1 and the highest value existed in zone 5. The figure also showed that there is a variable trend in the value of annual ETo from 2007 to 2013 in all zones. A steady trend in the value of annual ETo value from 2014 to 2016 was found in all zones, except for zone 1, ETo values increased in 2016.

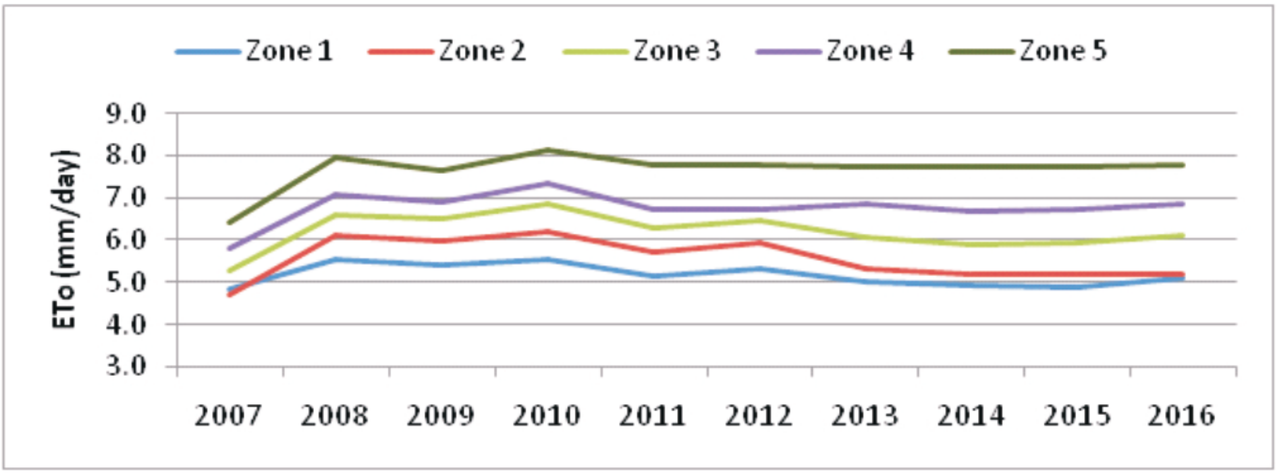

Figure 6. Comparison between annual values of ETo in the five agro-climatic zones of Egypt

Table 2 indicated that the highest mean value of solar radiation, maximum temperature, and ETo existed in zone 5. On the contrary, the lowest values existed in zone 1. Furthermore, the highest values of range and CV% for solar radiation were found in zone 1, whereas for maximum temperature and ETo it existed in zone 2. For minimum temperature and wind speed, the highest value of the mean was found in zone 1 and the highest value of the range was found in zone 5 and for minimum temperature and in zone 4 for wind speed. In addition, the highest values of the CV% for minimum temperature and wind speed were found in zone 4. The highest range value for ETo was found in zone 5 (Table 1). Dew point temperature.

In a study by Morsy *et al*., (2017) in Egypt, they indicated that solar radiation decreases gradually from south to north according to the apparent position of the sun and reaches its maximum value in the summer season and maximum temperature increases gradually southward in all seasons following the apparent position of the sun. They also reported that the lowest values of minimum temperature in all seasons existed in Middle Egypt, where zone 4 is located and there is a strong gradient of wind over northern part of Egypt, as a result of Mediterranean depression.

Table 2. Descriptive statistics of annual weather elements and ETo

	Year	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Solar radiation	Mean	20.2	20.1	20.7	22.3	22.8
	Range	2.0	2.0	1.1	0.7	0.5
	CV (%)	3.9	3.8	2.1	1.1	0.8
Maximum Temperature	Mean	26.6	28.5	30.8	30.9	33.3
	Range	3.5	6.4	4.6	4.6	6.6
	CV (%)	3.6	6.6	4.3	4.4	5.0
Minimum Temperature	Mean	18.6	18.1	15.7	14.5	17.2
	Range	2.6	1.8	2.8	4.4	4.9
	CV (%)	4.2	2.8	5.5	8.4	7.6
Wind Speed	Mean	3.4	3.3	2.8	3.3	3.0
	Range	0.4	0.4	0.6	1.1	0.8
	CV (%)	3.9	4.2	6.2	9.6	8.0
Dew point temperature	Mean	14	13.1	9.3	4.7	2.4
	Range	1.7	1.3	1.4	3.8	4.0
	CV (%)	4.0	3.5	5.3	24.9	47.6
ETo	Mean	5.2	5.6	6.2	6.8	7.7
	Range	0.7	1.5	1.6	1.5	1.7
	CV (%)	5.2	8.8	7.3	5.9	6.0

Deviation from the mean value of seasonal ETo

1. The first agro-climatic zone

Deviation from the mean value of seasonal ETo values of winter and summer in the first agro-climatic zone are presented in Figure (7a and 7b). The figures showed that positive deviation (above the value of the mean) for winter ETo values was observed starting from 2008-2010. It became negative (below the value of the mean) in 2011, then turned positive in 2012 then turned to negative again and continue to 2016 (Figure 9a). In the summer ETo, positive deviation was observed from 2008-2012, then the deviation turned negative until 2016 (Figure 9b).

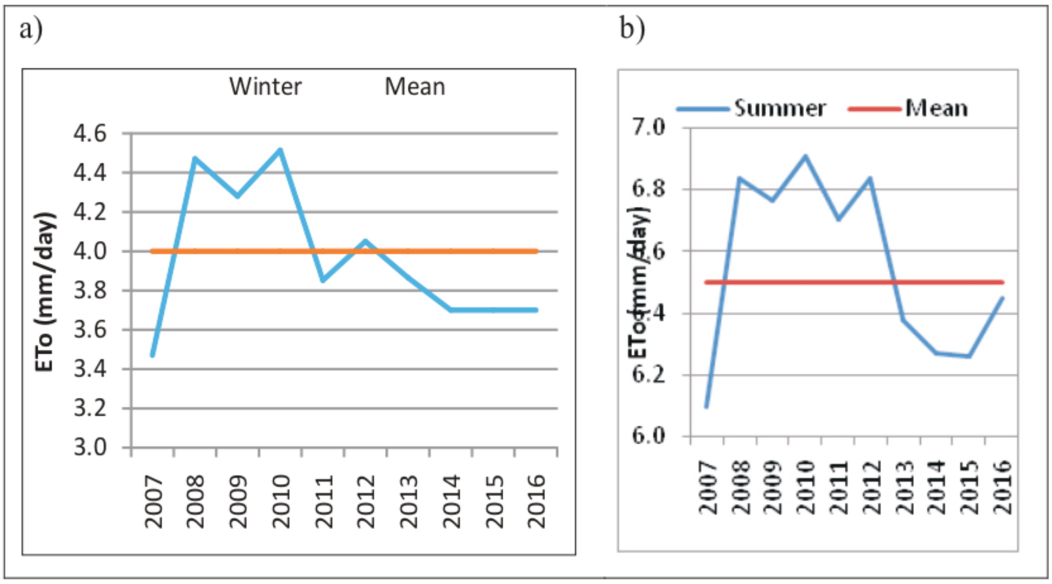

Figure 7. Deviation of the ETo values from the mean (a) winter seasons ETo and (b) summer seasons ETo in the first agro-climatic zone.

2. The second agro-climatic zone

Figure 8a showed that the negative deviations from the mean for winter values of ETo started from 2012 and continued to 2016. Negative deviations from the mean for the summer values of ETo started from 2013 and continued to 2016 (Figure 8b).

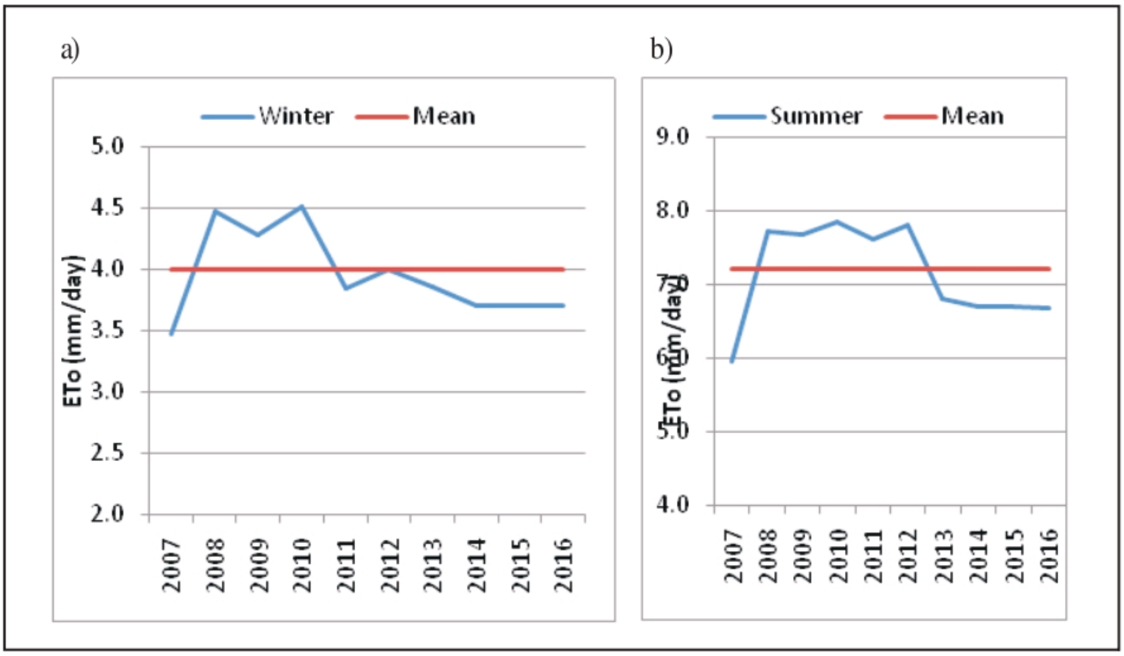

Figure 8. Deviation of the ETo values from the mean (a) winter seasons ETo and (b) summer seasons ETo in the second agro-climatic zone.

3. The third agro-climatic zone

Similar to the trend observed in the second agro-climatic zone, Figure 9 a showed a negative deviations from the mean for winter values of ETo started from 2012 and continued to 2016. Negative deviations from the mean for the summer values of ETo started from 2013 and continued to 2016 (Figure 9 b).

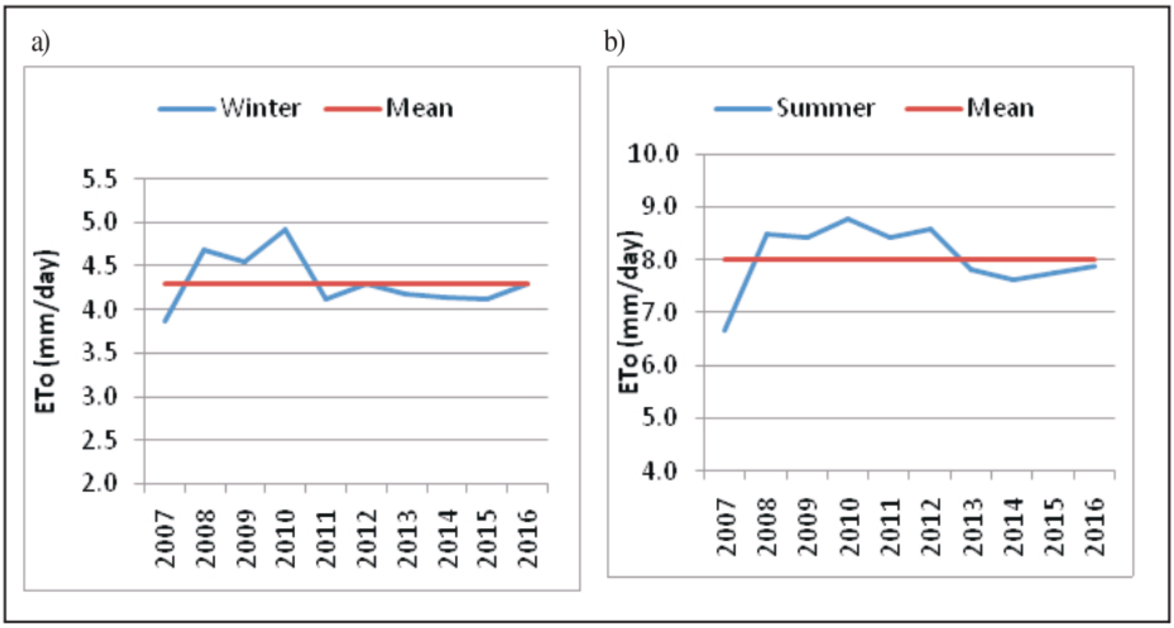

Figure 9. Deviation of the ETo values from the mean (a) winter seasons ETo and (b) summer seasons ETo in the third agro-climatic zone.

4. The Fourth Agro-climatic Zone

Figure 10 a showed that, in the fourth agro-climatic zone, the negative deviations from the mean for winter values of ETo started from 2013 and continued to 2016. Negative deviations from the mean for the summer values of ETo started from 2014 and continued to 2015 then became positive in 2016 (Figure 10 b).

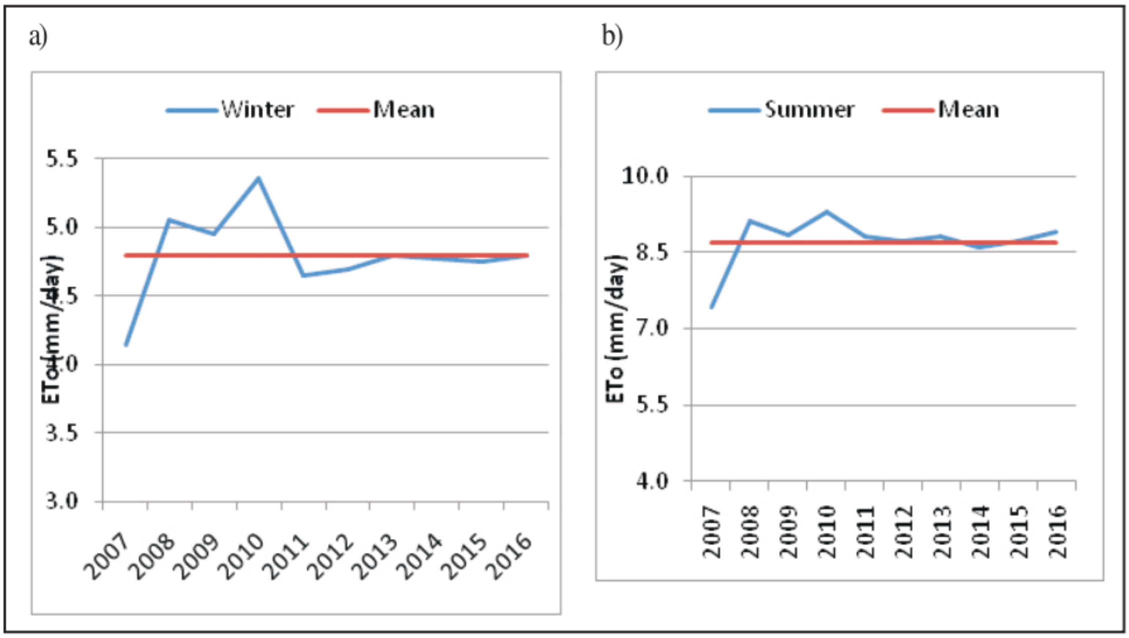

Figure 10. Deviation of the ETo values from the mean (a) winter seasons ETo and (b) summer seasons ETo in the fourth agro-climatic zone.

5. The fifth agro-climatic zone

In the fourth agro-climatic zone, Figure 11 a and 11 b showed negative deviations from the mean for both winter and summer values of ETo started from 2013 and continued to 2015 then became positive in 2016.

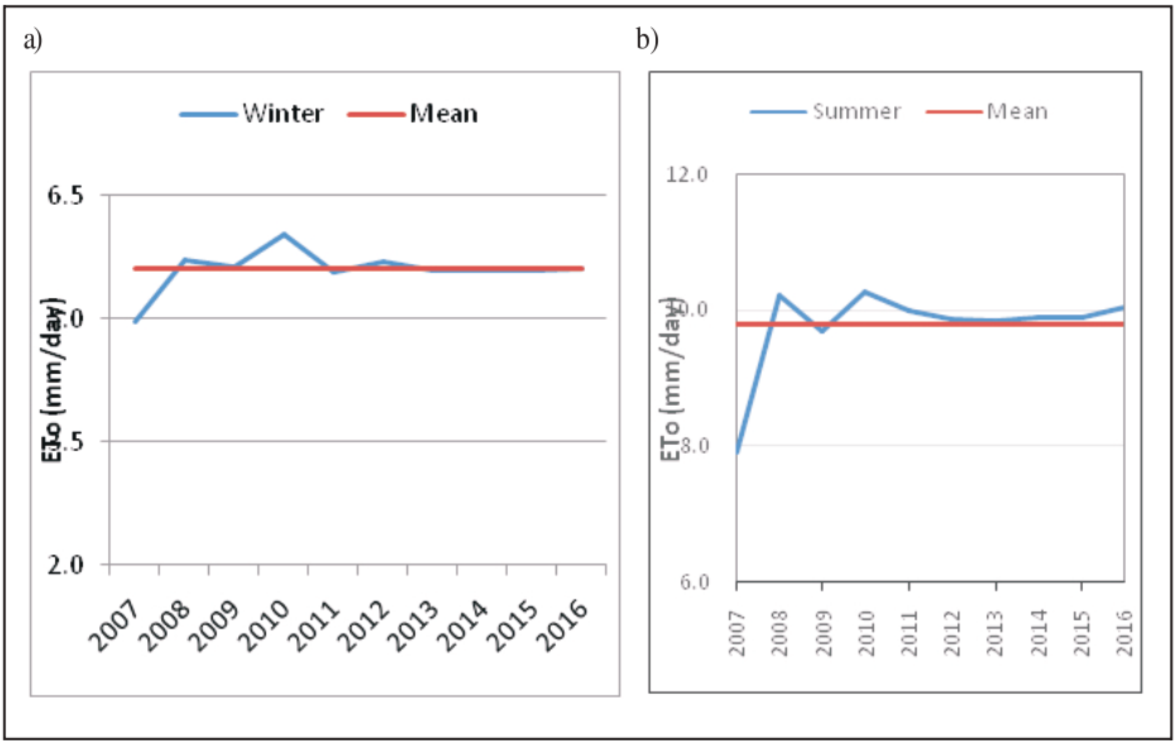

Figure 11. Deviation of the ETo values from the mean (a) winter seasons ETo and (b) summer seasons ETo in the fifth agro-climatic zone.

Appropriate values of ETo time-interval to schedule irrigation

According to the previous results, the appropriate interval of winter ETo values is different between the agro-climatic zones. In the first, the fourth, and the fifth agro-climatic zones, the interval of four years from 2013 to 2016 is the proper interval to be used in irrigation scheduling for winter crops. Regarding the second and the third agro-climatic zones, the interval between the years of 2012 to 2016 is the suitable interval to schedule irrigation (Table 3).

Table 3. Appropriate values of seasonal winter ETo to schedule irrigation in the five agro-climatic zones

Month	Zone 1 (2013-2016)	Zone 2 (2012-2016)	Zone 3 (2012-2016)	Zone 4 (2013-2016)	Zone 5 (2013-2016)
Nov	3.5	3.7	3.8	4.2	5.1
Dec	2.7	2.8	2.9	3.2	4.0
Jan	2.7	2.7	3.0	3.2	3.9
Feb	3.3	3.4	3.7	4.4	5.3
Mar	4.3	4.5	5.3	6.0	6.9
Apr	5.3	5.7	6.5	7.5	8.5
Mean	3.6	3.8	4.2	4.8	5.6

Similarly, Table (4) presents the mean values of summer ETo over a certain number of years. For summer crops, in the first, the second, the third and the fourth agro-climatic zones, is the suitable interval are between 2013 and 2016. For the fourth agro-climatic zone, the interval from 2014 to 2016 is the suitable interval.

Table 4. Appropriate values of seasonal summer ETo to schedule irrigation in the five agro-climatic zones

	Zone 1 (2013-2016)	Zone 2 (2013-2016)	Zone 3 (2013-2016)	Zone 4 (2014-2016)	Zone 5 (2013-2016)
May	6.3	6.8	8.3	9.0	10.1
Jun	7.1	7.6	9.1	10.0	11.2
Jul	7.1	7.7	9.0	9.9	11.0
Aug	6.8	7.3	8.5	9.5	10.7
Sep	6.0	6.3	7.3	8.1	9.4
Oct	4.7	4.9	5.4	6.1	7.1
Mean	6.3	6.8	7.9	8.8	9.9

Water requirements for crops grown in the agro-climatic zones of Egypt

In Egypt, wheat, maize, and clover are the main crops in all the agro-climatic zones. Moreover, sugar beet is cultivated in the first to the fourth agro-climatic zone. Rice is only cultivated in the Nile Delta, existed in first and second agro-climatic zones. The results in Table (5) showed that using the ETo time-interval can reduce the applied waterto the cultivated crops in all the agro-climatic zones. The percentage of saving were 1% in the first agro-climatic zone. It was between 2-3% in the second and third agro-climatic zones. Furthermore, it was between 1-2% in the fourth and fifth agro-climatic zones.

Crop (1)	Water requirements (mm) using: 2016 data (2)	Water requirements (mm) using: ETo time-interval (3)	Saved water (mm) (4)	Percentage of savings (5)
Zone 1				
Wheat	383	378	5	1
Clover	642	637	5	1
Sugar beet	556	550	6	1
Cotton	877	867	10	1
Peanut	565	559	6	1
Maize	550	542	8	1
Zone 2				
Wheat	399	390	9	2
Clover	658	648	10	2
Sugar beet	600	588	12	2
Rice	712	688	24	3
Soybean	582	569	13	2
Maize	590	581	9	2

(1)	(2)	(3)	(4)	(5)
Zone 3				
Wheat	448	434	14	3
Faba bean	375	367	8	2
Sugar beet	647	630	17	3
Soybean	592	572	20	3
Maize	597	585	12	2
Tomato	679	666	13	2
Zone 4				
Wheat	499	487	12	2
Sugar beet	743	733	10	1
Clover	756	745	11	1
Sunflower	725	711	14	2
Sorghum	725	710	15	2
Maize	643	633	10	2
Zone 5				
Wheat	509	499	10	2
Clover	804	790	14	2
Faba bean	510	502	8	2
Sesame	799	788	11	1
Maize	685	670	15	2
Sorghum	799	785	14	2

Our results indicated increasing trends in the past few years in all weather elements, except for solar radiation in the five agro-climatic zones. Solar radiation took a decreasing trend in the past few years.

Our results indicated that higher spatial variability between the first agro-climatic zone and the fifth agro-climatic zone expressed by higher CV% value of solar radiation and lower CV% value of maximum temperature, as well as higher values of minimum, minimum and dew temperatures, and wind speed were found. Furthermore, temporal variability within the first agro-climatic zone expressed by higher CV% value of solar radiation and lower CV% value of maximum temperature, as well as higher values of minimum, minimum and dew temperatures, and wind speed, compared to in the fifth agro-climatic zone were found.

Furthermore, the deviation of ETo values (winter and summer) from its mean value was the highest in the first agro-climatic zone. It was with medium degree in the second and third agro-climatic zones. Whereas, it was low in the fourth agro-climatic zone and it was very low in the fifth agro-climatic zone.

The analysis revealed that in the first agro-climatic zone, the interval between 2013 and 2016 is suitable to be used to schedule irrigation for both winter and summer crops. In the second and third agro-climatic zones, the interval between 2012 and 2016 is suitable for winter crops and the interval between 2013 and 2016 is suitable for summer crops. For the fourth agro-climatic zone, the interval between 2013 and 2016 is suitable for winter between 2014 and 2016 is suitable for summer crops. Whereas, in the fifth agro-climatic zone, interval between 2013 and 2016 is suitable for winter crops and summer crops.

The calculated water requirements of the cultivated crops in the five agro-climatic zones using ETo time-interval were lower than its counterpart values when 2016 weather data was used, by 1-3%.

The above results implied the suitability of the developed ETo time-intervals to be used in irrigation scheduling for the suggested crops to improve irrigation water management on the field level. It can rationalized the use of irrigation water in agriculture and reduced unnecessary losses.

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