DOI: 10.1515/jwld-2017-0009

JOURNAL OF WATER AND LAND DEVELOPMENT
2017, No. 32 (I–III): 79–86
PL ISSN 1429–7426

Available (PDF): http://www.itp.edu.pl/wydawnictwo/journal; http://www.degruyter.com/view/j/jwld

Received 11.07.2016
Reviewed 12.10.2016
Accepted 01.12.2016

A – study design
B – data collection
C – statistical analysis
D – data interpretation
E – manuscript preparation
F – literature search

Evapotranspiration data to determine agro-climatic zones in Egypt

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For citation: Ouda S.A.H., Norledin T.A. 2017. Evapotranspiration data to determine agro-climatic zones in Egypt. Journal of Water and Land Development. No. 32 p. 79–86. DOI: 10.1515/jwld-2017-0009.

Abstract

The objective of this paper was to compare between agro-climatic zones developed from 10-year interval of weather data from 2005–2014, 20-year interval of weather data from 1995–2014 and the zoning developed by [NORELDIN *et al.* 2016] using 30-year interval from 1985–2014 in the old cultivated land of Egypt in the Nile Delta and Valley. Monthly means of weather data were calculated for each year, and then monthly values for 10-year and 20-years were calculated for each governorate. Basic Irrigation scheduling model (BISm) was used to calculate reference evapotranspiration (*ETo*). Analysis of variance was used and the means was separated and ranked using least significant difference test ($LSD_{0.05}$). Our results showed that agro-climatic zoning using 20-year values of *ETo* was similar to the zones developed with 30-year values of *ETo*, with different values of average *ETo* in each zone. Furthermore, using 10-year values of *ETo* resulted in higher values of *ETo* in each zone, compared to 20-year and 30-year *ETo* values. However, the average value of *ETo* over the three classifications was close to each other. Thus, depending on the availability of weather data, either zoning can be sufficient to develop agro-climatic zones.

Key words: *10-year weather data, 20-year weather data, agro-climatic zoning, BISm model, reference evapotranspiration*

INTRODUCTION

Climatologists define climatic normals as the arithmetic average of a climate element over a 30-year interval. The 30-year interval was selected by international agreement, based on the recommendations of the International Meteorological Conference in Warsaw in 1933. The 30-year interval is sufficiently long to filter out many of the short-term inter-annual fluctuations and anomalies [NCDC 2002]. However, recently, variability in weather elements from year to year was observed worldwide, as well as in Egypt. Colder winters and hotter summers were prevailing in the past few years, which raise a question: what is the appropriate time interval to be use in developing agro-climatic zones in Egypt. One can argue that under the observed climate variability; a 30-year interval might be not suitable for such an assessment? Perhaps recent 10-year or 20-year interval will be more suitable or adequate to estimate reference evapotranspiration, which is the base for agro-climatic zoning.

Reference evapotranspiration (*ETo*) is an important agro-meteorological parameter for climatological and hydrological studies, as well as for irrigation planning and management [ŁABĘDZKI *et al.* 2011]. Several national and international studies were implemented using a 30-year interval (climate normals) in climatological and hydrological studies. McVicar *et al.* [2007], SONG *et al.* [2010], BUTTAFUOCO *et al.* [2010], and ŁABEDZKI *et al.* [2011] analyzed spatial distribution of *ETo*, internationally. In Egypt, there were several attempts to use *ETo* to develop agro-climatic zones [EID *et al.* 2006; KHALIL *et al.* 2011; MEDANY 2007; NORELDIN *et al.* 2016]. Each one of these national studies used different time interval, namely 10 or 30-year. The latest classification of agro-climatic zones by NORELDIN *et al*. [2016] indicated that 7 agro-climatic zones were distinguished using annual *ETo* values (Tab. 1, Fig. 1). Will the number of agro-climatic zones differ when 10 or 20-year *ETo* values used?

Table 1. Agro-climatic zones of Egypt as using 20-year *ETo* values

Zone number	Range of *ETo*, mm day^{-1}
Zone 1 (1 point)	4.520
Zone 2 (3 points)	4.677–4.700
Zone 3 (2 points)	5.063–5.084
Zone 4 (5 points)	5.176–5.548
Zone 5 (4 points)	5.681–5.881
Zone 6 (1 point)	6.002
Zone 7 (1 point)	6.167

Source: NORELDIN *et al*. [2016].

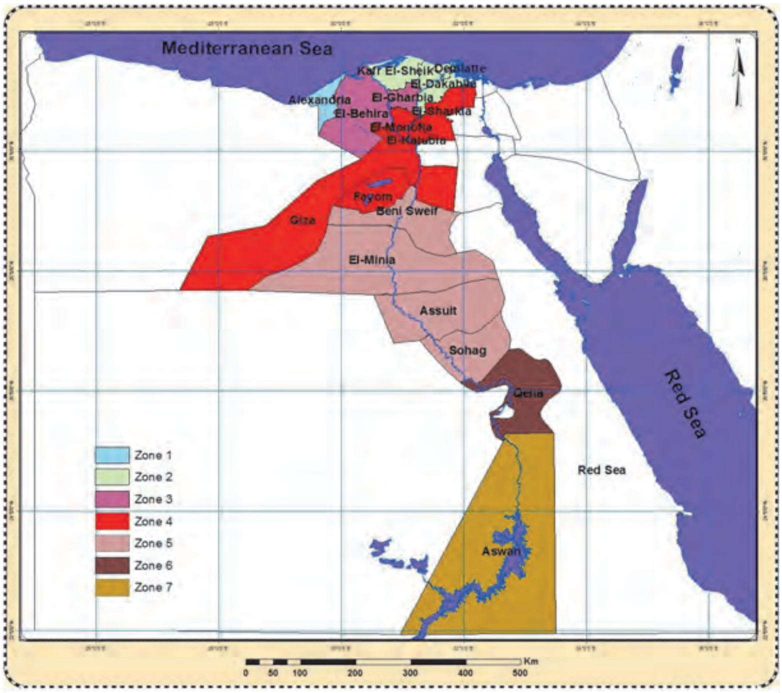

Fig. 1. Map of agro-climatic zones of Egypt; source: NORELDIN *et al*. [2016]

Thus, the objective of this paper was to compare between agro-climatic zones developed from 10-year interval of weather data from 2005–2014, 20-year interval of weather data from 1995–2014 and the zoning developed by NORELDIN *et al*. [2016] using 30-year interval from 1985–2014, in term of zones number and range of *ETo* values for each zone.

MATERIAL AND METHODS

SELECTED SITES

The Nile Delta and Valley is composed of 17 governorates and it is called the old cultivated lands. The soil of these governorates is mainly clay and it is under surface irrigation. Table 2 showed the latitude, longitude and elevation above sea level for the studied governorates.

CLIMATE DATA

Daily weather data for the selected governorates from 1995 to 2004 were collected. These data were solar radiation (MJ·m^{-2}·day^{-1}), maximum, minimum and mean temperature (°C), wind speed (m·s^{-1}) and dew point temperature (°C). Monthly means were calculated for each year, and then monthly values for 10-year (2005–2014) and 20-years (1995–2014) were calculated for each governorate.

USING BISM MODEL TO CALCULATE REFERENCE EVAPOTRANSPIRATION

BISm model (The Basic Irrigation Scheduling model, SNYDER *et al*. [2004]) was used to calculate (*ETo*). The model calculates (*ETo*) using the Penman–Monteith equation [MONTEITH 1965] as presented in the United Nations FAO Irrigation and Drainage Paper (FAO 56) by ALLEN *et al*. [1998]. The model requires to input station latitude and elevation. The model was used to calculate monthly *ETo* for each year in each governorate. Thus, we obtained values for *ETo* for 20 years for 17 governorates. Furthermore, these 20 years values were classified into 10-year and 20-year intervals. Using the data of 30-year *ETo* values presented in NORELDIN *et al*. [2016], a comparison between it and 10-year and 20-year intervals were done.

STATISTICAL ANALYSIS

Descriptive statistical analysis for the weather elements were performed to calculate the "mean", which is the total value divided by the number of observation), and the "range", which is the difference between highest and lowest values [SNEDECOR, COCHRAN 1980]. Furthermore, coefficient of determination (R^2) between each weather element and *ETo* was calculated for the two periods to test the strength of the relationship between them [DRAPER, SMITH 1988]. Analysis of variance [SNEDECOR, COCHRAN 1980] was done using one factor randomize complete block design (governorates), with replications number dependent on the number of studied years. Thus, the analysis was done for the 10-year and 20-year intervals. Then, the means were separated and ranked using least significant difference test ($LSD_{0.05}$). This ranking was the base for determination of agro-climatic zoning in Egypt.

RESULTS AND DISCUSSION

COMPARISON BETWEEN WEATHER DATA AND *ETo* VALUES IN THE THREE TIME PERIODS

The highest solar radiation could be found in Aswan governorate, where it located in high latitude, i.e. 24.02° (Tab. 2, Fig. 2). TRENBERTH *et al.* [2009] indicated that total energy received in a day depends on latitude. MORSY *et al.* [2016] indicated that, in general, solar radiation decreases gradually from south to north according to the apparent position of sun and reaches its maximum value in the south Egypt. Furthermore, Figure 2 showed that solar radiation values averaged over 10-years interval (2005–2014) have the highest values compared to the values averaged over 20-year period (1995–2014) or 30-year period (1985–2014).

Regarding to mean temperature, Figure 3 indicated that the highest values of mean temperature can be found in south Egypt and the lowest values are found in north Egypt. MORSY *et al.* [2016] indicated that there is a gradient of maximum temperature that intensifies during summer and spring seasons over northern part of Egypt and declines over the rest of Egypt. Figure 3 also showed that the mean temperature values averaged over 10 years (2005–2014) have the highest values, compared to the values averaged over 20 years (1995–2014) or 30 years (1985–2014), when a lower gradient existed from south to north. There was a strong relationship between mean temperature and solar radiation, where R^2 values were 0.60, 0.57 and 0.98 for the three time intervals, respectively.

Table 2. Latitude, longitude and elevation above sea level for the studied governorates in the Nile Delta and Valley

Governorate	Latitude	Longitude	Elevation above sea level, m
Nile Delta			
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-Behira	31.02°	30.28°	6.70
El-Gharbia	30.47°	32.14°	14.80
El-Minofia	30.36°	31.01°	17.90
El-Sharkia	30.35°	31.30°	13.00
El-Kalubia	30.28°	31.11°	14.00
Middle Egypt			
El-Giza	30.02°	31.13°	22.50
El-Fayom	29.18°	30.51°	30.00
Beni Sweif	29.04°	31.06°	30.40
El-Minia	28.05°	30.44°	40.00
Upper Egypt			
Assuit	27.11°	31.06°	71.00
Sohag	26.36°	31.38°	68.70
Qena	26.10°	32.43°	72.60
Aswan	24.02°	32.53°	108.30

Source: own study.

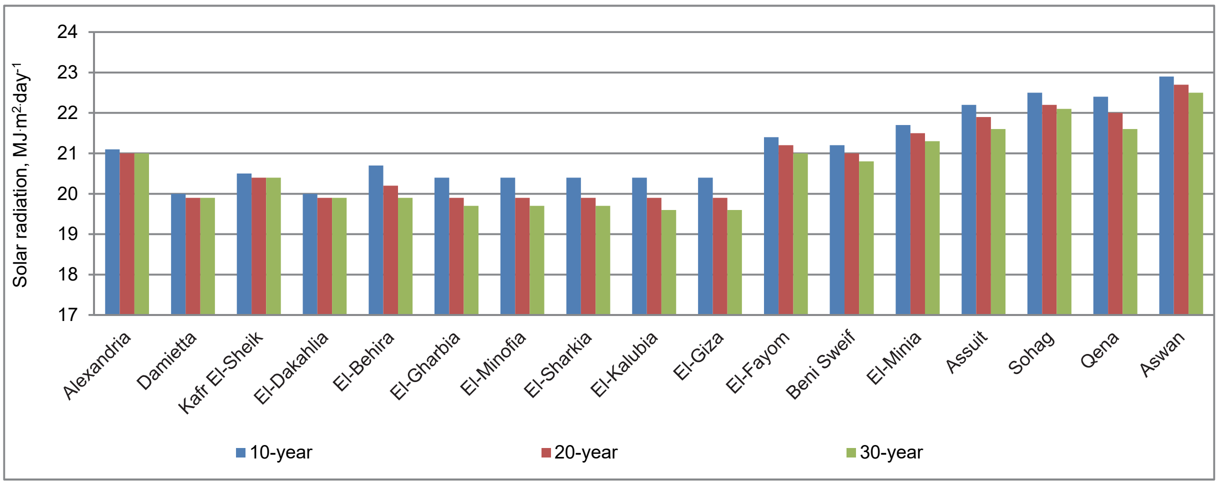

Fig. 2. Comparison between solar radiation values averaged over 10, 20 and 30 years; source: own study

The highest wind speed values exist in north Egypt, especially in governorates located on Mediterranean Sea (Alexandria, Damietta, Kafr El-Sheik, El--Dakahlia and El-Behira) (Fig. 4). MORSY *et al.* [2016] indicated that there is a strong gradient of wind over northern part of Egypt according to Mediterranean depression in winter season. The figure also indicated that the lowest values of wind speed existed in Middle Egypt. In general, wind speed values averaged over 10 years (2005–2014) have the highest values compared to the values averaged over 20 years (1995–2014) or 30 years (1985–2014) (Fig. 4).

Figure 5 showed dew point temperature in the three studied period. It is a common expression to indicate air humidity [ALLEN *et al.* 1989]. It is shown from the figure that the four governorates located on the Mediterranean Sea have the highest dew point temperature, as well as high wind speed. The figure also showed that over all the studied governorates, dew point temperature values averaged over 10 years (2005–014) have the highest values compared to the values averaged over 20 years (1995–2014) or 30 years (1985–2014). Furthermore, high value of R^2 between wind speed and dew point temperature was

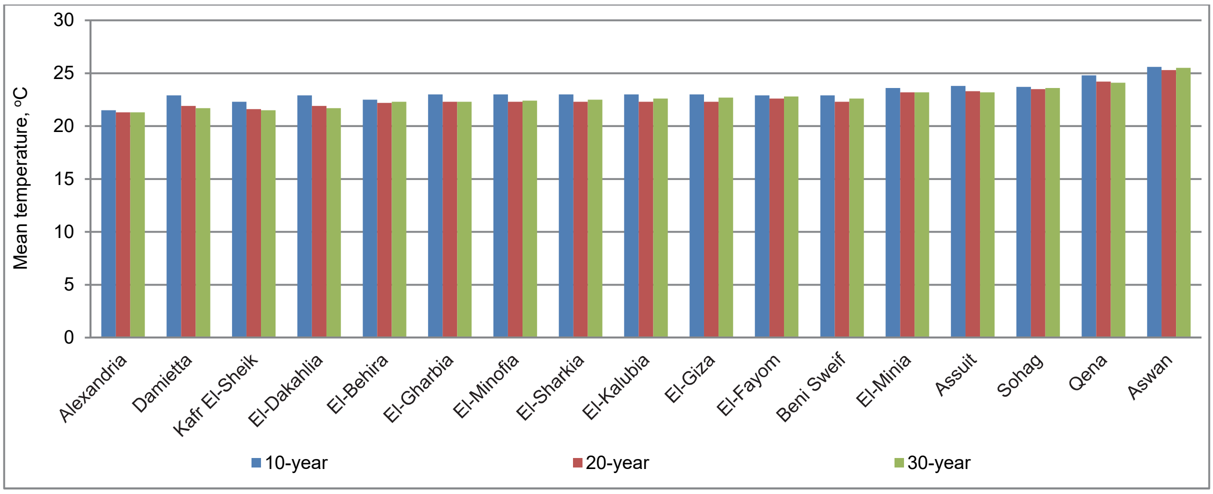

Fig. 3. Comparison between mean temperature values averaged over 10, 20 and 30 years; source: own study

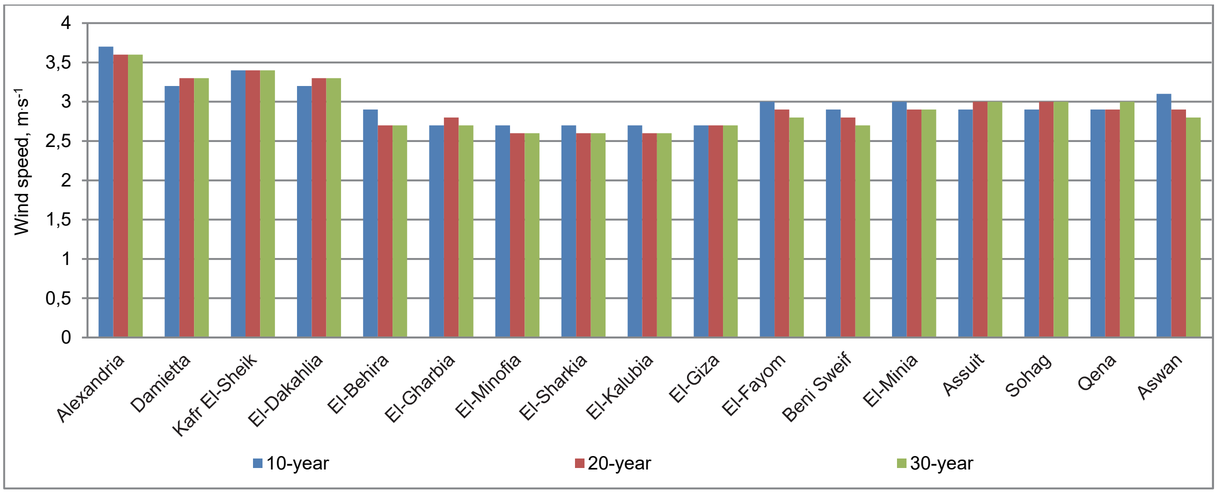

Fig. 4. Comparison between wind speed values averaged over 10, 20 and 30 years; source: own study

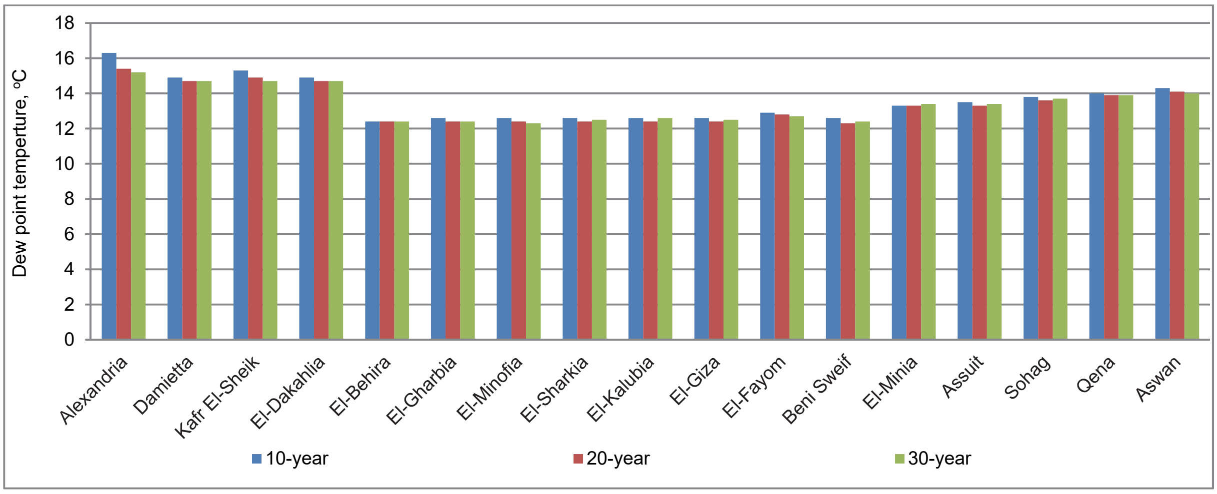

Fig. 5. Comparison between dew point temperature values averaged over 10, 20 and 30 years; source: own study

found in the three time period, namely 0.82, 0.74 and 0.91, respectively.

Figure 6 indicated that, in general, the lowest *ETo* values existed in the north Egypt and highest values existed in south Egypt. While, *ETo* values for 10-year time period (2005–2014) were the highest in all governorates, compared to the values obtained using 20-year (1995–2014) or 30-year time periods (1985–2014).

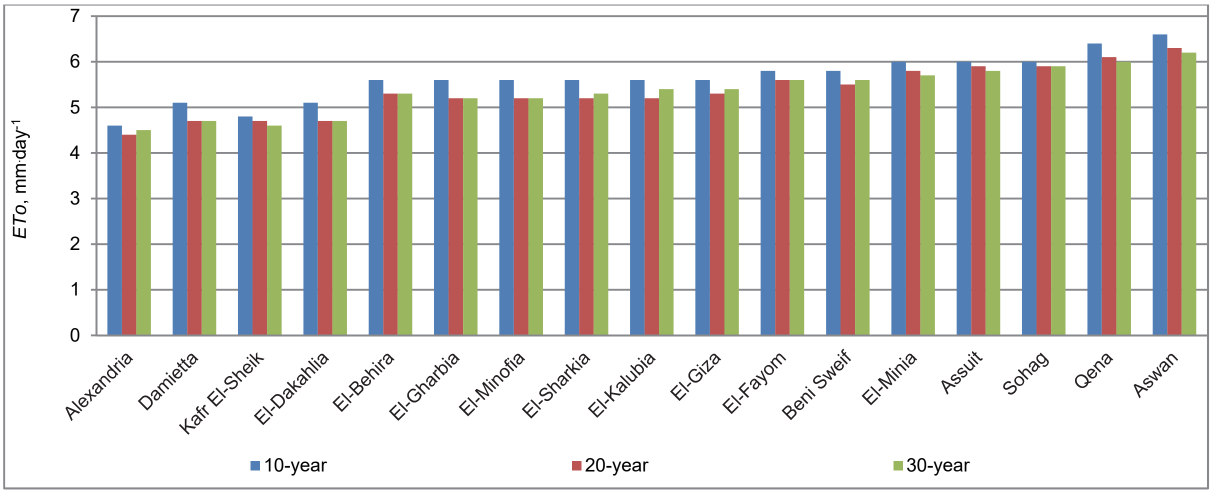

Fig. 6. Comparison between potential evapotranspiration (*ETo*) values averaged on 10, 20 and 30 years; source: own study

DESCRIPTIVE STATISTICS OF WEATHER DATA AND *ETo* IN THE THREE TIME PERIODS

The results in Table 3 indicated that the mean values for studied weather elements, as well as *ETo* were the highest for 10 years time period. The lowest value of the range (difference between the highest and the lowest values) for solar radiation, mean temperature and *ETo* was found for 20 years time period. The results in that table also showed that the highest R^2 value between solar radiation and *ETo* value was found for 10 or 20 years time period. Whereas, the highest R^2 value between mean temperature and *ETo* value was found for 20 or 30 years time period. Furthermore, the mean values of wind speed; as well as the range values were not changed in the three time periods, which implied that wind speed is not variable from year to year in the studied governorates. Similar trend was observed for dew point temperature in three studied time interval, where the mean and the range values were almost similar in the three time periods. However, R^2 values between dew point temperature and *ETo* values were the lowest in the three time periods, compared to other weather elements.

Table 3. Descriptive statistics for the studied weather elements and *ETo* values in the three studied time periods

Statistics	*SRAD* MJ·m^{-2}·day^{-1}	Tmean °C	*WS* m·s^{-1}	*Td* °C	*ETo* mm·day^{-1}
10-years data					
Mean	21.1	23.3	2.9	13.4	5.7
Range	2.9	3.3	1.0	3.9	1.8
R^2	0.58	0.79	0.37	0.21	–
20-years data					
Mean	20.8	22.5	2.9	13.4	5.4
Range	2.8	2.9	1.0	3.1	1.9
R^2	0.58	0.86	0.24	0.05	–
30-years data					
Mean	20.6	22.7	2.9	13.5	5.3
Range	3.0	4.2	1.0	3.0	1.7
R^2	0.42	0.86	0.32	0.03	–

Explanations: *SRAD* = solar radiation, *T*mean = mean temperature, *WS* = wind speed, *Td* = dew point temperature, *ETo* = reference evapotranspiration, R^2 = regression coefficient (between each weather element and *ETo*).
Source: own study.

AGRO-CLIMATIC ZONES USING 10-YEAR TIME PERIOD

Table 4 and Figure 7 revealed that Nile Delta and Valley can be distinguished into 5 agro-climatic zones using 10-year of *ETo* values, where $LSD_{0.05}$ value was 0.217 mm·day^{-1}. In this zoning, Giza and Fayom (Middle Egypt) joined three governorates in the Nile Delta to form zone 3. Zone 4 included Assuit and Sohag from Upper Egypt with the rest of Middle Egypt governorates. Zone 5 contained to governorates, i.e. Qena and Aswan. This result implied that the variation in *ETo* was low, using 10-year of *ETo* values, which resulted in only five agro-climatic zones.

Table 4. Agro-climatic zones of Egypt classification using 10-year time interval

Zone number	Governorate	*ETo*, mm·day^{-1}
Zone 1	Alexandria	4.279
	Kafr El-Sheik	4.852
Zone 2	Demiatte	5.123
	El-Dakahlia	5.344
	El-Behira	5.192
	El-Gharbia	5.125
Zone 3	El-Monofia	5.800
	El-Sharkia	5.869
	El-Kalubia	5.964
	Giza	5.701
	Fayom	5.587
Zone 4	Beni Sweif	6.139
	El-Minia	6.140
	Assuit	6.122
	Sohag	6.127
Zone 5	Qena	6.480
	Aswan	6.600
Average		5.673
Rang		2.321
$LSD_{0.05}$		0.217

Explanations: *LSD* – the least significant difference.
Source: own study.

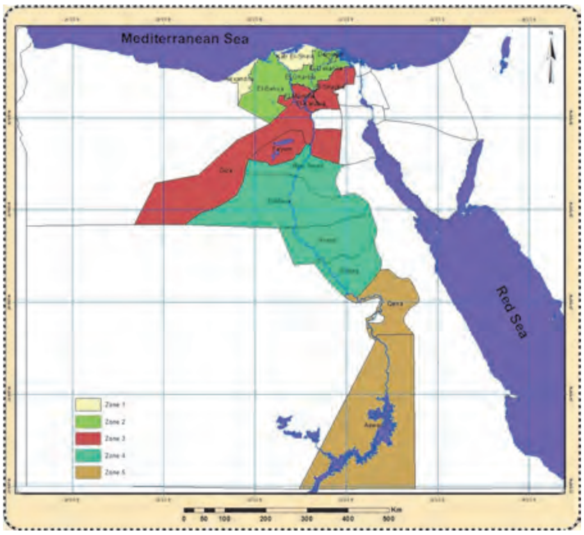

Fig. 7. Map of agro-climatic zones of Egypt using 10-year values of *ETo*; source: own study

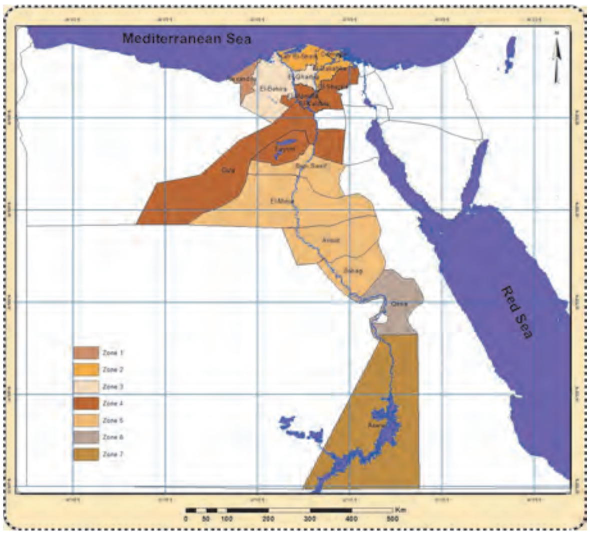

Fig. 8. Map of agro-climatic zones of Egypt using 20-year values of *ETo*; source: own study

AGRO-CLIMATIC ZONES USING 20-YEAR TIME PERIOD

Using 20-year of *ETo* values from 1995–2014 for agro-climatic zoning resulted in 7 agro-climatic zones with $LSD_{0.05}$ value equal to 0.142 mm·day^{-1}. In this zoning, Alexandria was in one zone, El-Behira and El-Gharbia joined together in one zone. Qena became in one zone and Aswan became in another zone (Tab. 5, Fig. 8).

Table 5. Agro-climatic zones of Egypt classification using 20-year time interval

Zone number	Governorate	*ETo*, mm·day^{-1}
Zone 1	Alexandria	4.444
Zone 2	Demiatte	4.701
	Kafr El-Sheik	4.767
	El-Dakahlia	4.769
Zone 3	El-Behira	5.104
	El-Gharbia	5.114
Zone 4	El-Monofia	5.267
	El-Sharkia	5.333
	El-Kalubia	5.460
	Giza	5.549
	Fayom	5.641
Zone 5	Beni Sweif	5.847
	El-Minia	5.851
	Assuit	5.913
	Sohag	5.951
Zone 6	Qena	6.142
Zone 7	Aswan	6.287
Average		5.420
Rang		1.843
$LSD_{0.05}$		0.142

Explanations: *LSD* – the least significant difference.
Source: own study.

COMPARISON BETWEEN THE DEVELOPED AGRO-CLIMATIC ZONES

NORELDIN *et al.* [2016] indicated that using 30-year values of *ETo* (1985–2014) resulted in 7 agro-climatic zones. Our results indicated that the distribution of the studied governorates in these zones were similar to what we obtained using 20-year values of *ETo* (Tab. 5, Fig. 8), with different values of average *ETo* in each zone (Tab. 5). This result implied that either 20-year values of *ETo* or 30-year values can be used in agro-climatic zoning in Egypt. Furthermore, using 10-year values of *ETo* resulted in higher values of *ETo* in each zone, compared to 20-year *ETo* values and 30-year *ETo* values. However, the average values of *ETo* over the three classifications of agro-climatic zones was close to each other, where it was 5.64, 5.43 and 5.36 mm day^{-1} for 10-year values of *ETo*, 20-year values of *ETo* and 30-year values of *ETo*, respectively (Tab. 6).

Table 6. Agro-climatic zones and its average *ETo* values using 10-year, 20-year and 30-years time intervals

Zone number	10-year *ETo* values	20-year *ETo* values	30-year *ETo* values
	mm·day^{-1}		
1	4.57	4.40	4.50
2	5.20	4.75	4.69
3	5.78	5.11	5.07
4	6.13	5.45	5.35
5	6.54	5.89	5.78
6	–	6.14	6.00
7	–	6.29	6.17
Average	5.64	5.43	5.36

Source: own study.

CONCLUSION

Agro-climatic zoning is very important for policy makers to prepare the appropriate developmental policies related to water management. Our assessment included comparison between three agro-climatic zoning approach using different time intervals, i.e. 10, 20 and 30 years of average values of *ETo*. Our results showed either 20-year values of *ETo* or 30-year values can be used in agro-climatic zoning in Egypt because the distribution of the studied governorates in the zones developed with 20-year values of *ETo* were similar to the zones developed with 30-year values of *ETo*, with different values of average *ETo* in each zone. In addition, number of zones was the same in both classifications.

Furthermore, zoning using 10-year values of *ETo* resulted in 5 agro-climatic zones only and higher values of *ETo* in each zone, compared to 20-year and 30-year *ETo* values. However, the average value of *ETo* over the three classifications was close to each other, with 0.21 mm·day^{-1} difference between classification using 10-year *ETo* values and 20-year *ETo* values. Similarly, the difference between classification using 10-year *ETo* values and 30-year *ETo* values was 0.28 mm·day^{-1}.

Thus, taking into account recommendation of 30-year weather data interval, the results showed that 20-year interval could give the same results with respect to agro-climatic zoning in Egypt, if the 30-year interval is not available.

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Wyznaczenie stref agro-klimatycznych w Egipcie na podstawie ewapotranspiracji obliczeniowej

STRESZCZENIE

Celem pracy było porównanie agro-klimatycznych stref wyznaczonych na podstawie dziesięcioletnich danych pogodowych z lat 2005–2014, dwudziestoletnich danych pogodowych z lat 1995–2014 i stref wyznaczonych przez NORELDINA i in. (2016) z trzydziestoletniego przedziału danych z lat 1985–2014 odnoszących się do terenów uprawnych w delcie i dolinie Nilu (Egipt). Dla każdego roku obliczono miesięczne średnie danych pogodowych, a następnie miesięczne wartości w 10- i 20-letnich przedziałach czasowych dla każdego gubernatorstwa. Wykorzystano model harmonogramu podstawowych nawodnień (BISm) do obliczenia ewapotranspiracji obliczeniowej (*ETo*). Użyto analizy wariancji, a różnice średnich określano za pomocą testu najmniejszej istotnej różnicy na poziomie $p < 0{,}05$. Uzyskane wyniki wskazują, że strefy agro-klimatyczne ustalone według dwudziestoletnich danych *ETo* były podobne do stref określonych na podstawie trzydziestoletnich danych *ETo* (różne średnie wartości *ETo* w każdej strefie). Wykorzystanie dziesięcioletnich danych *ETo* dało w efekcie wyższe wartości *ETo* w każdej strefie w porównaniu z uzyskanymi na podstawie dwudziesto- i trzydziestoletnich danych. Średnie wartości *ETo* w trzech systemach klasyfikacji były jednak zbliżone do siebie. Dlatego, w zależności od dostępności danych pogodowych, każdy ze sposobów ustalania stref będzie wystarczający, by wyznaczyć strefy agro-klimatyczne.

Słowa kluczowe: *dane pogodowe, ewapotranspiracja, model BISm, strefy agro-klimatyczne*