DETERMINATION OF AGRO-CLIMATIC ZONES IN EGYPT USING A ROBUST STATISTICAL PROCEDURE

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ABSTRACT

The agricultural land area is determined by climate and water availability. It is important to develop scientific method to determine agro-climatic zones in Egypt to be use as the basis for agriculture development. The pervious zoning was more administrative than ecological. Therefore, a statistical procedure was developed to determine the number of agro-climatic zones in Egypt. CROPWAT model was used to calculate reference evapotranspiration (ETo) using 10-years weather data for 20 agricultural governorates. After calculation, analysis of variance was done using one factor randomize complete block design, with number of years as replicates. Furthermore, the simple correlation coefficients and multiple regression analysis were done to test the strength of the relationship between ETo and weather parameters. The means of ETo for each governorate was separated and ranked in ascending order using least significant difference test ($LSD_{0.05}$). The results identified 8 agro-climatic zones ($LSD_{0.05}$ = 0.131). These zones were: (1) Alexandria and Demiatte; (2) Dakhlia and North Sinai; (3) Kafr El-Sheikh and El-Gharbia; (4) Ismalia, El-Sharkia and El-Monofia; (5) El-Kalubia, Beni Sweif and El-Minia (6) Giza, Qena, Sohage and El-Wadi El-Gedid; (7) El-Behira and El-Fayoum and (8) Assuite and Aswan. This classification clearly implied that water requirements are similar within each zone and different between zones. Such zoning will increase the ability of the Egyptian policy makers to prepare the appropriate developmental policies as a result of the availability of proper information on each zone.

Key words: weather data, Egypt agricultural governorates, agro-climatic zones.

INTRODUCTION

Egypt lies in the northeastern corner of the African continent and has a total area of about 1 million km^2. Hot dry summers and mild winters characterize Egypt's climate, where rainfall is very low, irregular and unpredictable. The Nile River is the main source for irrigation, with an annual allocated flow of 55.5 km^3/year. The total actual renewable surface water resources estimated at 56 km^3/year. Internal renewable groundwater resources are estimated at 1.3 km^3/year. In Egypt the total actual renewable water resources of the country are estimated by 57.3 km^3/year (http://www.fao.org/nr/water/aquastat/main/index.stm [1]).

The agricultural area in Egypt is composed of two parts: Nile Delta and Valley, which is the main contributor to food production, trading activities and national economy. It is also the most densely populated area in Egypt. Through the last four decades vast areas at the desert fringes of the Nile Valley and Delta were reclaimed using mostly Nile water to add greater economic assets and relocate a significant portion of the population (El-Bagouri, 2008 [2]).

Climate plays an important role in crop production. Crops growth periods, water requirements and scheduling irrigation for crops are dependent on weather conditions. The agricultural land area is determined by climate and water availability. Agro-climatic zone is a land unit in terms of major climate, superimposed on length of growing period i.e. moisture availability period (FAO, 1983 [3]). This classification is done using reference evapotranspiration (ETo). The calculation of the ETo includes all the weather parameters prevailed in a specific area. Evapotranspiration is a combination of two processes water evaporation from soil surface and transpiration from the growing plants (Gardner et al., 1985[4]). Direct solar radiation and, to a lesser extent, the ambient temperature of the air provide energy for evaporation. Whereas, solar radiation, air temperature, air humidity and wind terms should be considered when assessing transpiration (Allen et al., 1998 [5]). In Egypt, evapotranspiration is relatively high during the summer (about 8 mm/day in June) and relatively low in winter (about 2 mm/day in December) (Eid et al., 2006 [6]).

In the past, Egypt was divided into three main agro-climatic zones, i.e. Delta (Lower Egypt), Middle Egypt and Upper Egypt. The previous zoning was more administrative than ecological. Further zoning for Egypt divided the country into 9 agro-zones: (1) Coastal zone; (2) Central Delta; (3) East and West Delta; (4) Giza; (5) Menia; (6) Asuitt and Sohag; (7) North Qena; (8) South Qena and (9) Aswan (Eid et al., 2006). The previous classification depended on the calculation of annual reference evapotranspiration (ETo) for each governorate. When the difference between the ETo of several governorates was less than 5%, they grouped together in one zone (Eid et al., 2006 [6]). In 2007, a report published by Central Laboratory of Agricultural Climate (Agricultural Research Center), where another classification for agro-ecological zones were developed (Medany, 2007 [7]). Regression equations were used in this report to predict reference evapotranspiration for each zone using average temperature and month. These zones were: (1) North Delta (Dakhlia, Gharbia, Damietta and Kafr El-Sheikh); (2) West Delta (Alexandria and Behira governorates); (3) Middle Delta, (Ismailia, Kalubia, Minofia, Port-Said, Sharkia governorates); (4) South Delta (Giza, Cairo, Beni Suef and Fayom governorates); (5) Middle Egypt (Sohag, Qena, Asyout and Minia governorates) and (6) Upper Egypt region (Aswan governorate). Thus, determination of agro-climatic zones should be done using scientific method to be use as a basis for agricultural development. Yield potentialities, crop suitability and crop rotation in each zone should be assessed to formulate future plan of action involving crop production (Velayutham et al., 1999 [8]).

The objectives of this work were: (i) to provide an analytical description of 20 agricultural governorates in Egypt; (ii) to use a robust statistical procedure to divide the agricultural governorates in Egypt into agro-climatic zones.

MATERIALS AND METHODS

1. Total area and cultivated area for the studied governorates

The area of each of the 20 governorate was obtained from the following web site: http://en.wikipedia.org/wiki/Egypt_governorates [9]. The cultivated and cropped areas at each governorate were obtained from Central Administration for Agricultural Economics 2nd volume (2008) [10].

Percentage of the cultivated area to the total area was calculated for each governorate to decide if there a potentiality to increase total cultivated area through reclamation of new lands. The studied governorates were clustered in groups according to percentage of cultivated area to the total area.
Moreover, after the development of the agro-climatic zones, percent of the cultivated area to the total area was calculated to determine the possibility of adding new land to the total cultivated area. The annual ETo values and the total cropped area values were used to calculate an abstract value for the annual total irrigation water needed to support the crops grown in each zone.

2. Weather data

Weather data sets of monthly means of maximum and minimum temperature, relative humidity, wind speed and potential sunshine hours for the 20 agricultural governorates in Egypt were obtained from Water Requirements and Field Irrigation Research Department; Soil, Water and Environment Research Institute; Agricultural Research Center. These governorates were: North Sinia, Alexandria, Demiatte, Kafr El-Sheik, El-Dakahlia, El-Beheira, El-Gharbia, Ismailia, El-Monofia, El-Sharkia, El-Kalubia, Giza, Fayoum, Beni Swief, El-Minia, Assuite, Souhag, Quena, Aswan, El-Wadi El-Gedid. The data were measurements of weather parameters from one weather station in each governorates, where a set of 10-year weather data from 1997-2006 was available, except for North Sinai, Alexadria, Quena, Aswan and El-Wadi El-Gedid, where the set was composed of 8-year data from 1999-2006.

3. CROPWAT MODEL

CROPWAT (FAO, 1992 [11]) is a computer program for irrigation planning and management. The model calculates reference evapotranspiration (ET_o) based on the FAO Penman-Monteith method (Allen et al., 1998 [5]). Crop water requirements is calculated by the model, in addition to the effect of water stress on the crop yield by relating the relative yield decrease to the relative evapotranspiration deficit through an empirically derived yield response factor (FAO 1979 [12]). The input data required by the model include monthly temperature (maximum and minimum), relative humidity, sunshine hours, and wind speed. The model was used to calculate monthly values of ETo using weather data of the 20 governorates and for the studied time period.

4. Statistical analysis

4.1. Descriptive statistical analysis for the weather parameters was preformed 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 (Snedicor and Cochran, 1980 [12]).

4.2. Simple correlation coefficients (Snedicor and Cochran, 1980 [13]) between ETo values and its components, i.e. weather parameters were calculated to determine the strength of the relationship between them.

4.3. Multiple linear regression (Draper and Smith, 1987 [14]) was used to fit a line through the set of observations (number of years), and test how a ETo is affected by the value of its components, i.e. weather parameters. As a result, a prediction equation, coefficient of determination (R^2) and standard error of estimates (SE%) were obtained. Coefficient of determination is the amount of variability due to all independent variables, and standard error of estimates is a measurement of precision i.e. closeness of predicted and observed yield to each other. Both simple correlation and multiple linear regression analyses were used to determine the correctness of using these weather parameters in calculating ETo.

4.4. Analysis of variance (Snedicor and Cochran, 1980 [12]) was done using one factor randomize complete block design, with 10 replications (number of years). Then the means was separated and ranked using least significant difference test ($LSD_{0.05}$).

RESULTS AND DISCUSSION

1. Total area and cultivated area for the studied governorates

The results in Table (1) revealed that El-Wadi El-Gadid, Giza, North Sinai, and Assuite governorates were together in group (1), where the percentage of cultivated area to the total area was less than 10%. The lowest percent of cultivated area to the total area existed in El-Wadi El-Gadid governorate (0.2%), whereas the highest percentage was found for Assuite governorate estimated by 6% (Table 1). Furthermore, the second group contained only one governorate, i.e. El-Beheira, where the percentage is 39% (Table 1). In these above mention five governorates, there is high probability to increase cropped area by reclaiming new lands, without increasing the allocated amount of irrigation water to them. Using new techniques of irrigation systems and improved agricultural management practices could contribute in conserving a large amount of the currently applied irrigation water to be used in irrigating these new lands. In El-Wadi El-Gadid governorate, using modern irrigation systems, such as sprinkler and drip irrigation, will allow to increase application efficiency and save irrigation water. Furthermore, improved agricultural management, such as fertigation and chemigation could increase crops water use efficiency by the crops (Sayed et al., 1999 [15] and Ouda et al., 2010 [16]). Similarly, in North Sinai governorate, water harvesting techniques and using both modern irrigation systems and improved agricultural management could have the same effect on saving a significant amount could be used to cultivate more land.

Regarding to Giza, Assuite and El-Beheira governorates and under surface irrigation, using lined canals could reduce water loss through infiltration and using piped canals could reduce water evaporation, in addition to infiltration, which will increase water conveyance efficiency and save irrigation water. Moreover, using improved agricultural management, such as wide furrows cultivation could save irrigation water (Abouenein, et al., 2009 [17] and Abouenein et al., 2010 [18]). These results are important information to be presented to the policy makers to direct their effects into these governorates.

Regarding to the rest of the six groups, the potential to increase cultivated area for governorates in it is low because the percentage of cultivated area to the total area is higher than 50%.

Table (1): Total area and cultivated area for the 20 studied governorates

Group	Governorate	Total area (km^3)	Cultivated area (km^3)	% of cultivated area to total area
Group (1)	El-Wadi El-Gadid	376505	640	0.2
	Giza	85153	914	1
	North Sinai	27574	610	2
	Assuite	25926	1483	6
Group (2)	El-Beheira	9118	3534	39
Group (3)	Alexandria	2679	1481	55
	El-Monofia	2544	1453	57
Group (4)	Kafr El-Sheik	3437	2490	72
	Quena	1796	1355	75
	El-Kalubia	1001	756	75
	Demiatt	589	460	78
	Aswan	679	531	78
	El-Dakahlia	3471	2746	79
Group (5)	El-Gharbia	1942	1558	80
	El-Sharkia	4180	3405	81
	Ismailia	1442	1203	83
	Souhge	1547	1328	86
Group (6)	Beni Swief	1322	1202	91
	El-Minia	2262	2076	92
	Fyoum	1827	1708	93

2. Weather data

The values of annual mean temperature, relative humidity, wind speed and potential sunshine hours were averaged over the studied time period in each governorate and the range of each parameter are included in Table (2). The results indicated that the range of mean temperature between the northern and the southern governorates was 6.2°C, where the lowest temperature was observed in Demiatte (19.5°C) and the highest mean temperature was observed in both Aswan and El-Wadi El-Gedid (25.7°C). The range for relative humidity was 41%, where it was higher in North Egypt and lower in the south. Wind speed followed the same trend with two exceptions, i.e. El-Behira and Gharbia, where the range was 278.5 km/day. The range for potential sunshine hours was 1.6 hr. These results clearly reflect the climatic differences between the northern and southern governorates in Egypt (Table 2). Furthermore, these climatic differences implied that under climate change condition, which is expected to occur in the future, the agriculture production from the southern governorates will be affected more as result of heat stress.

Table (2): Average values of weather parameters over the studied period for the 20 agricultural governorates

Governorate	Latitude	Longitude	Elevation (m)	MTemp (°C)	RH (%)	WS (km/day)	PSSH (hr)
Lower Egypt							
North Sinia	31.07	33.45	17.10	20.6	79	252.4	9.3
Alexandria	31.70	29.00	7.00	21.0	77	255.6	9.4
Demiatte	31.25	31.49	5.00	19.5	65	221.0	9.2
Kafr El-Sheik	31.07	30.57	20.00	19.9	65	117.2	9.3
El-Dakahlia	31.03	31.23	7.00	21.7	66	126.2	9.1
El-Beheira	31.02	30.28	6.70	21.2	57	350.6	9.4
El-Gharbia	30.47	32.14	14.80	21.9	63	72.1	9.3
Ismailia	30.36	32.14	10.00	22.0	57	138.3	9.3
El-Monofia	30.36	31.01	17.90	21.2	62	186.5	9.3
El-Sharkia	30.35	31.30	13.00	23.6	61	144.7	9.3
El-Kalubia	30.28	31.11	14.00	21.9	58	187.2	9.3
Middle Egypt							
Giza	30.02	31.13	22.50	22.8	53	195.1	9.5
Fayoum	29.18	30.51	30.00	23.2	58	231.2	9.8
Beni Swief	29.04	31.06	30.40	22.9	55	122.4	9.9
El-Minia	28.05	30.44	30.00	21.3	55	145.4	10.3
Upper Egypt							
Assuite	27.11	31.06	71.00	22.5	50	207.4	10.5
Souhg	26.36	31.38	68.70	22.4	53	159.1	10.5
Quena	26.10	32.43	72.60	24.2	39	126.2	10.7
Aswan	24.02	32.53	108.30	25.7	38	145.4	10.7
El-Wadi El-Gadid	25.26	30.34	72.70	25.7	42	103.7	10.5
Mean	--	--	--	22.3	58	174.4	9.7
Range	--	--	--	6.2	41	278.5	1.6

MTemp= mean temperature; RH= relative humidity; WS= wind speed; PSSH= potential sunshine hours.

2. Annual ETo values

Annual ETo values for the 20 agricultural governorates are presented in Table (3). Regarding to the governorates located in North of Egypt and Delta region (Gov # 1-11), the lowest value of ETo was found for El-Gharbia (ETo=3.76 mm/day) and the highest value of ETo was found in El-Behira (ETo= 5.60 mm/day). This variation is attributed to the speed of the wind in both governorates (Table 2). With respect to Middle Egypt governorates (Gov # 12-15), the highest value of ETo was found at Fayoum governorate (Table 3) as a result of wind speed compared with the other 3 governorates (Table 2). Results in Table (3) also showed that the highest value of ETo was found in Aswan (ET= 5.92 mm/day) in Upper Egypt governorates (Gov # 16-20) as a result of the higher temperature and lower relative humidity prevailed in this governorate compared with the other four governorates (Table 3).

Table (3): Annual ETo values (mm/day) for the 20 agricultural governorates in Egypt

Gov #	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Average
LE											
1	--	--	4.00	3.88	3.99	3.94	3.98	3.90	4.00	3.94	3.95
2	--	--	4.29	4.26	4.30	4.21	4.30	4.15	4.13	4.14	4.22
3	3.93	4.60	4.58	4.14	3.94	4.27	4.47	3.95	4.17	4.14	4.22
4	3.74	3.94	3.72	3.61	3.80	3.79	3.81	3.90	3.95	3.94	3.77
5	3.99	4.10	4.17	4.16	4.07	4.11	4.13	3.94	4.00	3.96	4.06
6	5.22	5.63	5.88	5.84	6.16	6.04	5.33	5.36	5.26	5.37	5.61
7	3.54	3.76	3.75	3.73	3.83	3.88	3.86	3.82	3.69	3.75	3.76
8	4.45	4.68	4.24	4.58	4.45	4.21	4.58	4.44	4.49	4.42	4.45
9	4.39	4.55	4.48	4.51	4.66	4.79	4.85	4.52	4.65	4.78	4.62
10	4.38	4.64	4.77	4.84	4.73	4.44	4.45	4.43	4.56	4.52	4.58
11	4.45	4.80	4.87	4.85	4.94	4.93	4.79	4.79	4.64	4.70	4.78
ME											
12	4.89	5.29	5.55	5.66	5.42	5.14	5.19	5.17	5.13	5.04	5.25
13	5.43	5.68	5.60	5.56	5.75	5.80	5.63	5.69	5.59	5.58	5.63
14	4.19	4.49	4.71	4.73	4.90	4.81	4.65	4.74	4.67	4.71	4.66
15	4.46	4.82	4.77	4.76	4.77	4.69	4.78	4.76	4.81	4.85	4.75
UE											
16	5.73	5.77	5.80	5.78	5.95	5.85	5.83	5.85	5.87	6.17	5.86
17	5.15	5.05	5.00	5.37	5.12	5.29	5.35	5.29	5.18	5.17	5.20
18	--	--	5.21	5.11	5.18	4.97	5.56	5.22	5.12	5.16	5.31
19	--	--	5.91	5.78	5.90	6.01	5.84	5.96	6.00	5.90	5.92
20	--	--	5.14	5.20	5.18	5.20	5.18	5.15	5.16	5.22	5.18

Gov= governorate; LE= Lower Egypt; 1= North Sinia; 2= Alexandria; 3= Demiatte; 4= Kafr El-Sheik; 5= El-Dakahlia; 6= El-Beheira; 7= El-Gharbia; 8= Ismailia; 9= El-Monofia; 10= El-Sharkia; 11= El-Kalubia; ME= Middle Egypt; 12= Giza; 13= Fayoum; 14= Beni Swief; 15= El-Minia; UE= Upper Egypt; 16= Assuite; 17= Souhag; 18= Quena; 19= Aswan; 20=El-Wadi El-Gedid.

4. Statistical analysis

4.1. Simple correlation analysis

Results in Table (4) illustrate the strength of the relationship between the studied weather parameters and ETo values. The highest correlation coefficient was found between relative humidity and ETo, where the relationship was negative and highly significant. This result emphasis on the importance effect of relative humidity on ETo. Furthermore, a highly significant and positive relationship was found between ETo and its attributes, i.e. mean temperature, potential sunshine hours and solar radiation.

Table (4): Correlation matrix coefficient between the weather parameters and ETo values

	MTemp	RH	WS	PSSH	ETo
MTemp	1.000				
RH	-0.791**	1.000			
WS	-0.373	0.344	1.000		
PSSH	0.669*	0.781**	-0.208	1.000	
ETo	0.630*	-0.755**	0.272*	0.722*	1.000

MTemp= mean temperature; RH= relative humidity; WS= wind speed; PSSH= potential sunshine hours; SR= solar radiation; * and ** = Significant at 0.01 and 0.05.

4.2. Multiple linear regression analysis

Multiple linear regression analysis showed that there were a positive and significant relationship between mean temperature and potential sunshine hours with ETo. Whereas, there was a negative and significant relationship between relative humidity and ETo. These four weather parameters contributed with 93% of the total variability in ETo (the value of R^2). The value of the standard error of estimate was low (SE%= 0.038), which reflect the accuracy of the estimation (Table 5).

Table (5): Regression coefficients and probability of the parameters

	Regression Coefficients	P-value	R^2	SE%
Intercept	1.292	0.521	0.931	0.038
MTemp	0.091	0.056		
RH	-0.038	0.000		
WS	0.006	0.000		
PSSH	0.267	0.059		

MTemp= mean temperature; RH= relative humidity; WS= wind speed; PSSH= potential sunshine hours.

Simple correlation and multiple linear regression analyses indicated that weather parameters were highly and significantly correlated with ETo. This result implied that using Penman-Monteith method in the determination of agro-climatic zones was appropriate. Thus, these results encourage us to proceed with the classification.

4.3. Analysis of variance

Analysis of variance of one factor randomize complete block design for the values of ETo for the 20 governorates and number of years as replicates showed that both years and ETo values were significant (Table 6). The significance of the years implied that there were differences between them. The years in the analysis are an indirect indication of weather parameters and consequently it affects the values of ETo.

Table (6): Analysis of variance for ETo values of the 20 governorates and number of years.

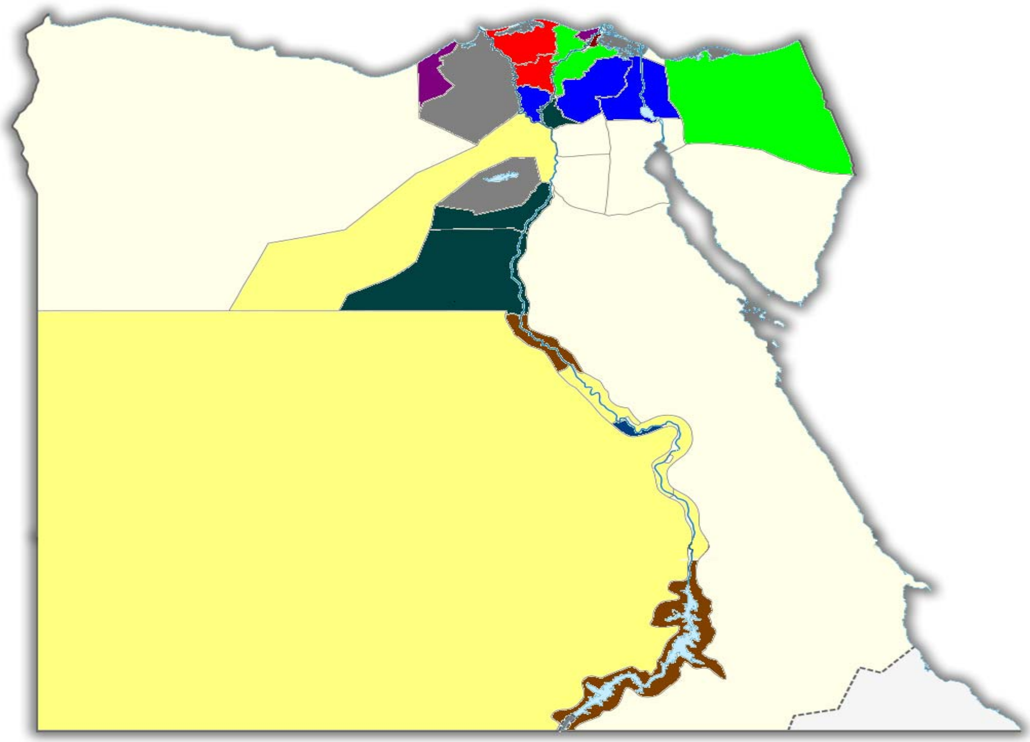
Source	Degree of freedom	Sum of squares	Mean squares	F value	Probability*
Years	9	0.768	0.085	3.809	0.0002
ETo	19	84.881	4.467	199.498	0.0000
Error	171	0.022	0.022		
Total	199	89.478			

*Least Significant Difference was at 0.05 equal to 0.131.

4.4. Separation of ETo means and determination of Agro-climatic zones

The statistical analysis of ETo values of the 20 governorates recognized eight classes, in another words, eight agro-climatic zones (Figure 1). This classification clearly implied that water requirement is similar within each zone and different between zones. In all these zones, the Nile River is main source for irrigation, except for North Sinai governorate, where precipitation is the main source for irrigation and El-Wadi El-Gedid, where the main source for irrigation is ground water. A brief description of each zone is followed.

Figure (1): Classification of Egypt into eight agro-climatic zones.



Zone (1): Kafr El-Sheikh and El-Gharbia (red color); Zone (2): El-Dakhlia and North Sinai (light green); Zone (3): Alexandria and Demiatte (purple color); Zone (4): Ismalia, El-Sharkia and El-Monofia (dark blue color); Zone (5): El-Kalubia, Beni Sweif and El-Minia (dark green color); Zone (6): Giza, Quena, Sohage and El-Wadi El-Gedid (yellow color); Zone (7): El-Behira and El-Fayoum (grey color); Zone (8): Assuite and Aswan (brown color)

Zone (1): Kafr El-Sheikh and El-Gharbia

Kafer El-Sheikh is located on the Northern Coast of the Mediterranean Sea. It is located between El-Behira and El-Dakahlia. El-Gharbia is located in the south of Kafer El-Sheikh. The total area of this zone is 5379 km^2. The percentage of cultivated area to the total area is 75% in this zone. The value of ETo for this zone is 3.76-3.77 mm/day, which equivalent to 1372-1376 mm/year. Using the previous value, the total annual irrigation amount needed to support the cultivated crops in an area of 4691 km^2 (cropped area) is 113754 m^3/km^2 (Table 7). The main cultivated crops in this zone are wheat, clover, sugar beat, rice, cotton, maize, fruits and vegetables.

Zone (2): El-Dakhlia and North Sinai

The total area of this zone is 31045 km^2. El-Dakhlia governorate is located on the North Delta with small shoreline area on the Mediterranean Sea. North Sinai governorate is located on Northern East Coast of the Mediterranean Sea. The percentage of cultivated area to the total area is 11%, which implied that land reclamation could occur in this zone to increase the above mentioned percentage. The value of ETo for this zone is 3.95-4.06 mm/day, which equivalent to 1442-1482 mm/year. The cropped area is 6078 km^2, which require a total annual irrigation amount of 156789 m^3/km^2 to irrigate the cultivated crops in that area (Table 7). In El-Dakhlia governorate, the main cultivated crops are wheat, clover, sugar beat, cotton, maize, fruits and vegetables. Whereas, in North Sinai governorate, barley and wheat are the main field crops and olives and peaches are the main fruits crops.

Zone (3): Alexandria and Demiatte

Alexandria and Demiatte governorates are located on the Northern Coast of the Mediterranean Sea. They are separated by El-Behira, Kafer El-Sheikh and El-Dakahlia governorates. The total area of this zone is 3268 km^2. There is a potential to increase the cultivated area in this zone by reclamation of new land because the percentage of cultivated area to the total area is 37%. The ETo value in this zone is 4.22 mm/day or 1540 mm/year. The total annual amount of irrigation water needed to support the growth of the cultivated crops in a cropped area of 2356 km^2 is 64034 m^3/km^2 (Table 7). The main cultivated crops are wheat, clover, sugar beat, rice, cotton, maize, fruits and vegetables.

Zone (4): Ismalia, El-Sharkia and El-Monofia

The total area of this zone is 8166 km^2; with a percentage of cultivated area to the total area is 74%. Ismalia is located to the east of the Nile Delta. Whereas, El-Sharkia is located between Ismalia and El-Dakhlia inside the Nile Delta. The ETo value in this zone is 4.45-4.62 mm/day or 1621-1686 mm/year. Using the previous value, the total annual irrigation amount needed to support crops grown in a cropped area of 11366 km^2 is 332007 m^3/km^2 (Table 7). Because the soil of Ismalia is sandy, the common crops are vegetables, sesame, peanut and mangos. In El-Sharkia and El-Monofia, the main cultivated crops are wheat, clover, faba bean, cotton, maize, sunflower, fruits and vegetables.

Zone (5): El-Kalubia, Beni Sweif and El-Minia

This zone is composed of three governorates: El-Kalubia, which is located at the southern part of the Nile Delta, Beni Sweif and El-Minia, which are located in Middle Egypt. The total area of this zone is 4585 km^2; with an 88% of cultivated area to the total area. The value of ETo is 4.66-4.78 mm/day or 1701-1745 mm/year. Based on the previous value and the value of cropped area, an annual amount of irrigation water equal to 228750 m^3/km^2 should be assigned to this zone (Table 7). Because El-Kalubia is located near to the Greater City of Cairo, the main cultivated crops are vegetables and fruits with some field crops. The main cultivated crops in Beni Sweif and El-Minia are wheat, clover, faba bean, sunflower, cotton, maize, fruits and vegetables, in addition to sugarcane cultivated in El-Minia.

Zone (6): Giza, Quena, Sohage and El-Wadi El-Gedid

The total area of this zone is 465001 km^2. It is composed of four governorates: Giza, which is located in Middle Egypt, Quena, and Sohage which are located in Upper Egypt, in addition to El-Wadi El-Gedid which is located in the south west of Egypt. The percentage of cultivated area to the total area is only 1%, which gave a large change for land horizontal expansion, especially in Giza and El-Wadi El-Gedid. The value of ETo is 5.18-5.31 mm/day or 1891-1938 mm/year. The total annual amount of irrigation water needed to support the growth of the crops in a cropped area of 7177 km^2 is 240434 m^3/km^2 (Table 7). The main cultivated crops in Giza, Quena and Souhage are wheat, clover, faba bean, cotton, maize, sunflower, peanut, fruits and vegetables. In El-Wadi El-Gedid, palm dates, olives and wheat are the main crops.

Zone (7): El-Behira and Fayoum

This zone is composed of two governorates, i.e. El-Behira located between Alexandria and Kafer El-Sheikh in North Delta and Fayoum located in Middle Egypt, with a total area of 10945 km^2. The percentage of cultivated area to the total area is 49%. The value of ETo is 5.61-5.63 mm/day or 2048-2055 mm/year. The total cropped area is 10721 km^2, which needs an amount of annual irrigation water equal to 388108 m^3/km^2 (Table 7). The main cultivated crops are wheat, clover, sugar beat, rice, cotton, maize, fruits and vegetables.

Zone (8): Assuite and Aswan

Both Assuite and Aswan are located in Upper Egypt. The total area of this zone is 26605 km^2; with only 8% of cultivated area. Therefore, to increase this percentage more land need to be reclaimed. The value of ETo is 5.86-5.92 mm/day or 2139-2161 mm/year. Based on the previous value and the value of cropped area, an annual amount of irrigation water equal to 139957 m^3/km^2 should be assigned to this zone (Table 7). The main cultivated crops are wheat, clover, faba bean, sunflower cotton, maize, sugarcane, fruits and vegetables in both governorates. Furthermore, medical plants are common in Assuite and palm dates are common in Aswan.

Table (7): Description of agro-climatic zones in Egypt

Zone	Total area (km^2)	Cultivated area (km^2)	% of cultivated area to total area	Cropped area (km^2)	Annual needed irrigation water (m^3/km^2)*
1	5379	4048	75	4691	113754
2	31045	3356	11	6078	156789
3	3268	1201	37	2356	64034
4	8166	6061	74	11366	332007
5	4585	4033	88	7524	228750
6	465001	4237	1	7117	240434
7	10945	5339	49	10721	388108
8	26605	2225	8	3689	139957

Zone (1): Kafr El-Sheikh and El-Gharbia; Zone (2): El-Dakhlia and North Sinai; Zone (3): Alexandria and Demiatte; Zone (4): Ismalia, El-Sharkia and El-Monofia; Zone (5): El-Kalubia, Beni Sweif and El-Minia; Zone (6): Giza, Quena, Sohage and El-Wadi El-Gedid; Zone (7): El-Behira and El-Fayoum; Zone (8): Assuite and Aswan;

* Annual needed irrigation water (m^3/km^2) calculated on ETo basis and not included irrigation system efficiency and type of cultivated crops..

CONCLUSION

Egypt with its lands extending over one million square kilometers is gifted with varied climatic features, geomorphic characteristics and land use patterns, which have its socio-economic implications. Thus, the developed agro-climatic zones could be incorporated with soil map and land use map to formulate meaningful agro-ecological zones for Egypt. Such zoning will increase the ability of the Egyptian policy makers to prepare the appropriate developmental policies as a result of the availability of proper information on each zone.

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