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GIS Tool for Distribution Reference Evapotranspiration under Climate Change in Egypt

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Authors' contributions

This study was carried out in collaboration between all authors. All authors managed the literature searches, read and approved the final manuscript.

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ABSTRACT

Current climatic data were collected to estimate ETo from 1998 to 2007 in the major Egyptian agro-climatic regions, i.e. Delta region, Middle Egypt and Upper Egypt, to generate future mean air temperature under climate change conditions using Magicc\Scengen model. FAO-56 Penman-Monteith equation was used to estimate ETo by using the collected and generated climatic data. The climate change data were generated under four scenarios (A1, A2, B1 and B2, according to IPCC results revealed that ETo significantly increased in 2050s and 2100s compared to the current ETo values. Results indicated that the values of ETo in 2100s were higher than those for 2050s for all studied regions. The average percentages increase in the four tested scenarios of the 2100s for Delta, Middle Egypt and Upper Egypt were 14, 17 and 18%, respectively. The most affected region by climate change was Upper Egypt because it already has the highest ETo under the current conditions; this increase in ETo could affect agricultural expansion negatively, especially if the water resources become a limiting factor. Moreover, the spatial analysis using kriging interpolation showed that the ETo in Egypt will be increased by uneven values under future climate change, the highest increasing values will appear under the A1 scenario, while the lowest increasing will be observed under B1 and B2 scenarios.

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ABBREVIATIONS

GIS: Geographical information systems; ETo: Reference crop evapotranspiration; IPCC: Intergovernmental panel on climate change; GHG: Greenhouse gases; MENA: Middle East and North Africa; FAO: Food and agriculture organization; PM: Penman-monteith.

1. INTRODUCTION

The Egyptian agricultural land area islimited by the availability of proper climate and adequate water resources. It is important to develop a scientific method to determine agro-climatic zones in Egypt to be used as the basis for agriculture development [1].

The world is facing a big challenge of climatic change, mainly due to increasing concentrations of greenhouse gases (GHGs) in the atmosphere. Many researches indicated that the climate changes occurred disproportionately on developing countries such as Middle East and North Africa (MENA) countries [2].

The combination of two separate processes, where water is lost from the soil surface and from leaf surface by evaporation and from crops by transpiration is referred to as evapotranspiration (ETo). Climatic parameters such as rainfall, wind speed, radiation, air temperature and air humidity affect the crop water requirements. Global warming, due to the enhanced greenhouse effect, is generating changes in climatic variables such as temperature, humidity, solar radiation and precipitation [3].

More attention has been given to the application of interpolation techniques to climatic analysis in recent years [4]. Several interpolation approaches are available in geographical information systems (GISs) to meet the general requirements of interpolation. For climate interpolation, spline and co-kriging methods are preferable, as they take into account the climatic dependence on topography by using a trivariate function of latitude and longitude as two independent variables and elevation as a covariate. Although spline and co-kriging methods yield results with similar accuracy when data density is adequate [5].

Geoprocessing may be necessary before programs are undertaken in conservation-oriented land management. A fundamental requisite for the evaluation of climate effects on water resources is to bridge the space-time gap between the climate scenarios and the usual scale of the inputs for the water balance estimation models. The analysis performed in this study focused on an important water cycle component (i.e. evapotranspiration) at multiple scales, where catchment is the typical scale of water resources planning. A topographically weighted radial basis function was used to generate evapotranspiration data in conditions of lack of a large climate dataset in water protection studies [6,7].

The expected climate changes according to the applied scenarios in the Duero Basin will cause an increase in ETo between 11% (118 mm) and 5% (55 mm) in the next 50 years as compared to the current situation. This annual ETo increase does not vary much, taking into account the annual or monthly trends, although the distribution during the months of these increments are totally different [8].

The reference crop evapotranspiration will increase with the predicted higher atmospheric demand (i.e. greater vapor pressure deficits and higher temperatures). However, the meteorological predictions from global climate modelsredicts that ETo rates during the growing season at the riparian sites will remain the same due to stomatal regulation. This is reflected in the theoretical evaporation modelsby the observed relationship between surface resistance and vapor pressure deficit and is coherent with the fact that native vegetation is well adapted to regulate water loss in semi-arid environments with atmospheric extremes [9].

In some studies that investigate the relationships between changes in climate variables and hydrologic balances and their impact on water resources, ETois calculated using mean air temperature- or radiation-based empirical equations. For example, temperature-based equations have been predicting increases in ETo in locations where temperatures have been increasing, by default. However, temperature-based equations provide poor estimates of ETo because they do not account for net radiation or sunshine percentage, vapor pressure deficit, or wind speed, which can play important roles when calculating ETo, especially under humid/sub-humid regions where the variations in ETo are more often due to variations in these factors than to variations in temperature [10].

The number of days of maximum temperature equal to or exceeding 45ºC has increased in Upper Egypt from 50 days in the first decade (1970-1979) to 52 days in the second decade (1980-1989), reaching 69 days in the third decade (from 1990 to 1999). In addition, the extremely hot days in the Western Desert amounted to 37 days in the third decade, compared to 22 days in each of the prior decades. The rest of Egypt did not experience increasings in the number of days with a peak temperature of 45ºC or more [11].

Temporal variations in reference evapotranspiration (ETo) and aridity index (AI) were comprehensively investigated for 23 meteorological stations during 1955–2008 in northwest China. In the past 50 years, annual temperature, humidity and precipitation had significant increasing trends with time, and wind speed and radiation had decreasing trends. ETo had a significant decreasing trend with an averagely value of about 3 mm per year [12].

Agricultural land use in Egypt is determined by climate and water availability. The country's total area is relatively large (about 1.1 x l06 km2), spanning 9 degrees of latitude (from 22.0ºN to 31.5ºN) and presenting a north-south gradient of average temperatures. This latitudinal gradient and the influences of the Mediterranean Sea, the Nile and the desert bring about climate differences among regions [7].

This study aims to trace the ETo values over time throughout almost allagroclimatic regions of Egypt under future climate change scenarios then to determine the trend of future water demand according to the ETo trends.

2. MATERIALS AND METHODS

2.1 Geography and Climate of Egypt

Egypt is located in North Africa,bordering on the Mediterranean Sea to the North, Libya to the west, the Gaza Strip to the East, and Sudan to the south. With an area of 1,001,450 square kilometers and a coastline of 2,450 kilometers. Egypt's climate is hot, dry, deserted and is getting warmer [11].

2.2 Agro-climatic Regions

Egypt has been divided into several agro-climatic regions according to the average ETo values. The most important agro-climatic regions (Fig. 1) are: The Delta region, represented in this study by five automated weather stations(Behaira(North Delta), Monufeia (Middle Delta), Ismailia (West Delta), Nubaria (East Delta) and Qalyubia (South Delta));the Middle Egypt regionrepresented by three automated weather stations (Giza, Fayoum and Menya) and the Upper Egypt regionrepresented by three automated weather stations (Sohag, Qena and Aswan). The Daily historical data of minimum and maximum air temperature, relative humidity, wind speed and solar radiationwerecollected from automated weather stations ofthe Central Laboratory for Agriculture Climate (CLAC). The data from 1998 to 2007 for different locations were collected by meteorological stationsof the different regions. The coordinates of the concerned automated weather stations are presented in Table 1.

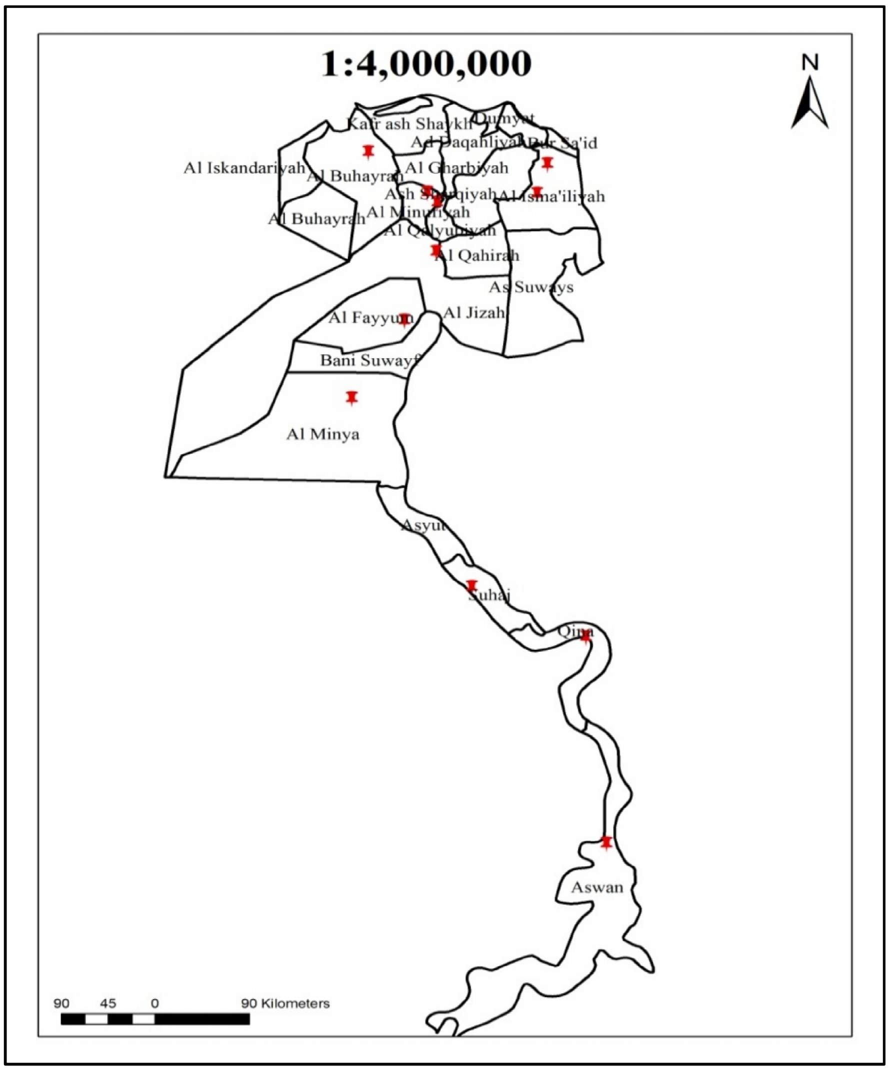

Fig. 1. Location of the automatic weather stations in Egypt used in this study

Table 1. The coordinates of automated weather stations used in this study

No.	Station	Latitude (ºN)	Longitude (ºE)	Altitude (m)
1	Aswan	24.0	32.9	108
2	Qena	26.1	32.7	72
3	Sohag	26.6	31.6	68
4	Menia	28.5	30.4	40
5	Fayoum	29.3	30.9	30
6	Giza	30.0	31.2	22
7	Behaira	31.0	30.5	6
8	Monofeia	30.6	31.1	17
9	Qulyobeia	30.5	31.2	14
10	Nubareia	30.9	32.3	13
11	Ismailia	30.6	32.2	10

2.3 Evapotranspiration Calculation

Evapotranspiration was calculated, for both, current and future conditions for different agro-climatic regions using Food and Agricultural Organization (FAO) Penman- Monteith (PM) procedure, FAO 56 method, presented by [13]. In this method, ETo is expressed as follows:

$$ET_o = \frac{0.408\Delta\ (R_n - G)\ +\ \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34\ u_2)}$$

where ETo is the daily reference evapotranspiration (mm day^{-1}), Rn is the net radiation at the crop surface (MJ m^{-2} day^{-1}), G is the soil heat flux density (MJ m^{-2} day^{-1}), T is the mean daily air temperature at 2 m height (ºC), U_2 is the wind speed at 2 m height (m s^{-1}), e_s is the saturation vapor pressure (kPa), e_a is the actual vapor pressure (kPa), Δ is the slope of vapor pressure curve (kPa $ºC^{-1}$) and γ is the psychometric constant (kPa $ºC^{-1}$).

2.4 Climate Change Scenarios

The climate change data were obtained using the MAGICC/SCENGEN tool [14] to extract the projection changes in air temperature (∆ air temp) under the four IPCC's SRES scenarios (A1, A2, B1 andB 2) that are described in Table 2. HadCM3 climate model was the base model under the four scenarios. Each simulation extracted monthly ∆ air-temp, for one of the two scenarios, for the coming years 2050s and 2100s. The resulted data from MAGICC/SCENGEN were displayed in2.5ºX 2.5º coordination grid. The future (2050s and 2100s) ∆ air temp data were downscaled according to the Egyptian coordinates

2.5 Interpolation Technique (GIS)

The interpolation is one of the most simple GIS technique concerned about drawing boundaries. Ordinary kriging interpolation is a standard technique for spatial interpolation. It provides each cell with a local, optimal prediction and an estimation of the error that depends on the variogram and the spatial configuration of the data. Kriging with external drift incorporates secondary information into the kriging system when the main and second variables are correlated. In our case, altitude was evaluated as a secondary variable. It is similar to universal kriging, but it uses an ancillary variable, which varies smoothly in space, to represent the trend instead of the spatial coordinates. The value of the secondary variable at all points where the primary variable is going to be estimated should be known and the relation between the two variables must be linear. The secondary information is used to find the local means of the primary variable and performs simple kriging on the corresponding residuals [15].

The distribution of the reference evapotranspiration in this study was demonstrated by using kriginginterpolation tool in the ARCGIS, version 10.

Table 2. Description of IPCC Special Report on Emissions Scenarios

Scenario	Storylines
A1	Rapid economic growth, low population growth, rapid adoption of new technologies, convergence of regions, capacity building, increased social interaction, reduced region differences in per capita income. Temperature increased 1.4 - 6.4ºC
A2	Heterogeneous world, self-reliance and local identities preserved, high population growth, regionally-specific economic growth, fragmented economic and technological development. Temperature increased 2.0 – 5.4ºC
B1	Convergent world with low population growth, transition to service and information economy, resource productivity improvements, clean technology towards global solutions. Temperature increased 1.1 - 2.9ºC
B2	Divergent world with emphasis on local solutions to economic, social and environmental sustainability, moderate population growth, intermediate levels of economic growth, less rapid technological change. Temperature increased 1.4 – 3.8ºC

2.6 Statistical Analysis

Statistical analysis was carried out using SAS software. The paired t– test was used to establish whether there exist significant differences in the Current ETo in 1998 to 2007and estimated ETo under climate change in 2050s, 2100s at significant level 0.05 [16]

3. RESULTS AND DISCUSSION

3.1 Current and Future air Temperature

Table 3 shows the average monthly trend of the mean air temperature under current(1998-2007) and future (2050s and 2100s)conditions for the concerned five weather stations Behaira (North Delta), Monufeia (Middle Delta), Ismailia (West Delta), Nubaria (East Delta) and Qalyubia (South Delta)) represented the Nile Delta regions. The highest mean temperature values were recorded at July, while the lowest at January for current and predicted data. The results indicated that the range of mean temperature was 13.2 to 27.1ºC. Regarding the predicted average air temperature in the Delta, the highest average temperature was found under A1 scenario in most months, while the lowest was found under B1 scenario. The difference between average mean air temperature under current and 2050s ranged between 0.8ºC at winter months to 3.4ºC at summer months, while under current and 2010s ranged between 1.7ºC at winter months to 5.7ºC at summer months. The average differences of annual mean air temperature at 2100s ranged between 2.4 under B1 scenario to 4.2 under A1 scenario. For2050s the lowest average air temperature was found under B2 scenario.

Table 3. Average monthly air temperature under current and future conditions at Delta region

Delta	Mean temperature ºC								
	1998-2007	**2050 A1**	**2100 A1**	**2050 B1**	**2100 B1**	**2050 A2**	**2100 A2**	**2050 B2**	**2100 B2**
Jan.	13.2	14.8	15.9	14.4	14.9	14.2	15.8	14.0	15.2
Feb.	13.5	15.4	17.2	15.1	15.4	15.0	16.7	14.6	16.2
Mar.	15.8	17.1	18.2	16.8	17.1	16.6	17.7	16.2	17.3
April	18.9	20.2	21.4	19.8	20.1	19.7	20.6	19.3	20.2
May	23.5	25.5	27.1	25.0	25.7	25.2	26.7	24.5	26.3
June	25.4	28.0	30.2	27.4	28.2	27.2	30.0	26.9	28.9
July	27.0	30.4	32.8	29.2	30.4	29.1	32.2	28.3	30.4
Aug.	27.1	30.2	32.6	29.5	30.0	29.3	32.3	28.3	30.4
Sept.	25.2	28.4	30.8	27.6	28.5	27.1	30.4	26.3	28.7
Oct.	22.4	25.1	27.4	24.6	25.4	24.3	26.7	23.4	25.9
Nov.	18.5	21.0	23.4	20.4	21.2	20.3	22.9	19.4	22.0
Dec.	15.1	17.5	19.3	16.9	17.4	16.6	18.7	15.9	18.1
Average	**20.5**	**22.8**	**24.7**	**22.2**	**22.9**	**22.1**	**24.2**	**21.4**	**23.3**

The same previous trends of the values of average mean air temperature were found in the Middle and Upper Egypt but with higher values Tables 4 and 5. The highest average mean air temperature was found in the Upper Egypt region under current situation as well as under future conditions (2050s and 2100s). From the above, it could be concluded that Upper Egypt had the highest average monthly mean temperature, under current and future conditions (A1, A2, B1 and B2 scenarios), as expected, followed by Middle Egypt, while the Delta region had the lowest monthly mean temperature. Furthermore, the highest average monthly air temperature values were under A1 scenario in comparison with the other scenarios during the most months of the year. These results agreed with several previous studies [4,6,7,8,9,10,11] In addition, recent climatologically studies found that the global surface air temperature increased from 1850 to 2005 by 0.76ºC and the linear warming trend over the last 50 years is determined by 0.13ºC per decade [4,8,10]

For the next two decades, a warming of about 0.2ºC per decade is projected for a range of IPCC SRES emission scenarios. Even if the concentrations of all greenhouse gases and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1ºC per decade would be expected [4,8,10].

3.2 Current and Future ETo

The average ETo values for the Delta region (Five weather stations) under current and future (2050s and 2100s) conditions are presented in Table 6. The highest ETo of the Delta region in the current situation was recorded during the summer months (June, July and August), while the lowest ETo was recorded in the winter months (December, January and February). With respect to the ETo in 2050s, all scenarios expected significant increase of ETo values in 2050s compared to current climatic conditions; the highest percentage increase in the ETo values was under A1 scenario (10%) followed by A2 and B1; while the lowest was under B2 scenario (4%).

Table 4. Average monthly air temperature under current and future conditions at Middle Egypt region

Middle Egypt	Mean temperature ºC								
	1998-2007	**2050 A1**	**2100 A1**	**2050 B1**	**2100 B1**	**2050 A2**	**2100 A2**	**2050 B2**	**2100 B2**
Jan.	12.3	14.1	15.5	13.9	14.8	13.4	15.1	13.2	14.5
Feb.	13.5	15.2	17.5	15.1	16.1	15.1	17.1	15.0	16.2
Mar.	17.0	18.5	20.1	18.4	19.3	18.2	19.5	18.0	18.8
April	20.6	22.3	23.6	21.8	22.9	21.2	22.2	21.1	22.5
May	25.6	28.2	30.6	28.0	29.4	27.6	30.3	26.7	29.7
June	27.0	29.5	32.3	29.2	30.4	29.0	31.5	28.5	30.8
July	27.3	30.9	34.8	30.8	32.6	30.0	33.6	29.5	31.9
Aug.	27.2	30.1	33.6	30.4	32.2	29.7	33.3	28.8	32.0
Sept.	26.0	29.4	32.7	29.4	31.0	28.6	31.6	28.2	30.5
Oct.	23.5	26.4	29.2	26.5	28.3	26.0	29.5	25.3	28.0
Nov.	18.6	20.8	23.2	20.6	22.0	20.5	22.8	20.0	22.2
Dec.	13.8	16.0	18.1	15.7	16.6	15.5	17.9	15.4	15.7
Average	**21.0**	**23.5**	**25.9**	**23.3**	**24.6**	**22.9**	**25.4**	**22.5**	**24.4**

Table 5. Average monthly air temperature under current and future conditions at Upper Egypt region

Upper Egypt	Mean temperature ºC								
	1998-2007	**2050 A1**	**2100 A1**	**2050 B1**	**2100 B1**	**2050 A2**	**2100 A2**	**2050 B2**	**2100 B2**
Jan.	16.3	18.4	20.1	18.0	19.1	17.7	19.6	17.5	18.7
Feb.	16.9	19.3	21.7	18.7	19.9	18.7	20.8	18.4	20.3
Mar.	21.3	23.4	24.8	23.0	24.0	22.7	24.4	21.9	23.9
April	26.0	27.9	29.3	27.6	28.2	27.0	28.9	26.9	27.6
May	29.8	32.7	36.0	32.6	34.4	32.2	36.1	31.5	34.3
June	30.5	33.8	36.0	33.3	34.4	32.3	34.8	32.1	33.8
July	31.6	35.8	39.1	35.0	36.8	33.8	37.9	33.3	36.6
Aug.	31.2	34.3	37.1	33.8	36.0	33.1	36.6	32.1	34.9
Sept.	29.7	34.0	36.6	32.9	34.5	32.8	35.7	32.0	34.6
Oct.	26.6	30.3	34.0	29.6	31.5	29.4	32.8	28.5	31.9
Nov.	21.5	23.8	26.0	23.1	24.7	23.1	25.4	22.9	24.7
Dec.	16.5	18.7	20.6	18.0	19.4	18.0	20.0	17.7	19.1
Average	**24.8**	**27.7**	**30.1**	**27.1**	**28.6**	**26.7**	**29.4**	**26.2**	**28.4**

ETo under 2100s had the highest percentage increase of the ETo values compared to current and 2050s conditions. The increasing percentage of the ETo values under 2050s and 2100s were higher than current conditions by 10 to 18% depending on the climate change scenario. The lowest increasing percentage of ETo values was projected under B1 scenario (10%); while the highest was expected under A1 scenario (18%). All ETo values under climate change scenarios increased significantly compared to current conditions.

Regarding to the average current and future ETo values for the Middle Egypt region Table 7, the current ETo values had the same trend as the Delta region with higher values. The highest average ETo value was recorded in July (8.1 mm/day); while the lowest value was recorded in January (2.3 mm/day). The percentage increase of ETo ranged from 5.9 to 21.1 % compared to current conditions. The ETo values in the Middle Egypt region under climate change scenarios were increased significantly compared to current values.

Table 6. Average reference evapotranspiration under current and future conditions at Delta region

Delta	ETo (mm/day)							
	1998-2007	**2050 A1**	**2100 A1**	**2050 B1**	**2100 B1**	**2050 A2**	**2100 A2**	**2050 B2**	**2100 B2**
Jan.	2.1	2.3	2.3	2.2	2.3	2.2	2.3	2.2	2.3
Feb.	2.5	2.7	2.9	2.7	2.7	2.6	2.8	2.6	2.8
Mar.	3.5	3.7	3.8	3.6	3.7	3.6	3.8	3.6	3.7
April	4.7	4.9	5.2	4.9	4.9	4.8	5.0	4.8	4.9
May	5.1	5.5	5.8	5.4	5.5	5.4	5.7	5.3	5.7
June	6.6	7.3	7.9	7.1	7.4	7.1	7.8	7.0	7.5
July	6.9	7.8	8.5	7.5	7.9	7.5	8.3	7.3	7.8
Aug.	6.3	7.1	7.7	6.9	7.1	6.9	7.6	6.6	7.2
Sept.	5.5	6.2	6.7	6.0	6.2	5.9	6.6	5.7	6.2
Oct.	4.3	4.8	5.2	4.7	4.8	4.6	5.1	4.5	4.9
Nov.	3.0	3.3	3.6	3.3	3.4	3.3	3.6	3.2	3.5
Dec.	2.0	2.2	2.4	2.2	2.2	2.2	2.3	2.1	2.3
P value		*	*	*	*	*	*	*	*
Average	4.4	4.8	5.2	4.7	4.8	4.7	5.1	4.6	4.9
Increasing %		**10%**	**18%**	**7%**	**10%**	**7%**	**16%**	**4%**	**12%**

** Significant at P<0.05*

Table 7. Average reference evapotranspiration under current and future conditions at middle Egypt region

Middle Egypt	ETo (mm/day)								
	1998-2007	**2050 A1**	**2100 A1**	**2050 B1**	**2100 B1**	**2050 A2**	**2100 A2**	**2050 B2**	**2100 B2**
Jan.	2.3	2.4	2.6	2.4	2.5	2.4	2.5	2.4	2.5
Feb.	2.8	3.0	3.3	3.0	3.1	3.0	3.2	3.0	3.1
Mar.	3.9	4.1	4.4	4.1	4.3	4.1	4.3	4.1	4.2
April	5.6	5.9	6.2	5.8	6.1	5.7	5.9	5.7	6.0
May	7.2	8.0	8.7	7.9	8.3	7.8	8.6	7.5	8.4
June	8.0	8.8	9.7	8.7	9.1	8.6	9.4	8.5	9.2
July	8.1	9.2	10.5	9.2	9.8	9.0	10.1	8.8	9.6
Aug.	7.3	8.2	9.2	8.3	8.8	8.1	9.1	7.8	8.7
Sept.	6.1	7.0	7.8	7.0	7.4	6.8	7.5	6.7	7.2
Oct.	4.7	5.3	5.8	5.3	5.7	5.2	5.9	5.1	5.6
Nov.	4.0	4.3	4.7	4.3	4.5	4.3	4.6	4.2	4.5
Dec.	2.6	2.9	3.1	2.9	2.9	2.8	3.1	2.8	2.8
P value		*	*	*	*	*	*	*	*
Average	**5.2**	**5.8**	**6.3**	**5.7**	**6.0**	**5.6**	**6.2**	**5.5**	**6.0**
Increasing %		**10.4%**	**21.1%**	**9.9%**	**15.5%**	**8.0%**	**18.5%**	**5.9%**	**14.7%**

** Significant at P < 0.05*

Table 8 illustrates the average ETo for the Upper Egypt region. It is clear that the Upper Egypt region had significantly higher average ETo values under current and future conditions (2050s and 2100s) than the Delta and the Middle Egypt regions. The percentage increase of average ETo values ranged between 5.8 to 22.5%. The average ETo percentage increase values under 2100s was higher than those found under 2050s and under current conditions. The percentage increase of average ETo value under 2050s ranged between 5.5 to 12.3 %; while under 2100s ranged between 15.1 to 22.5%.These results agreed with [17] who carried out a case study of Egypt to investigate the impact of climatic changes on ETo based on air temperature changes according to different scenarios. The study indicated that projected future climatic changes will increase the potential irrigation demand of Egypt by 6-16% due to the increase in ETo by the 2100s.

Table 8. Average reference evapotranspiration under current and future conditions at Upper Egypt region

Upper Egypt	**ETo (mm/day)**								
	1998-2007	**2050 A1**	**2100 A1**	**2050 B1**	**2100 B1**	**2050 A2**	**2100 A2**	**2050 B2**	**2100 B2**
Jan.	3.2	3.5	3.7	3.4	3.6	3.4	3.6	3.4	3.5
Feb.	4.5	4.9	5.3	4.8	5.0	4.8	5.1	4.7	5.1
Mar.	5.7	6.2	6.5	6.1	6.3	6.0	6.4	5.8	6.3
April	6.5	7.0	7.3	6.9	7.0	6.7	7.2	6.7	6.9
May	8.6	9.5	10.7	9.5	10.1	9.4	10.7	9.1	10.1
June	9.8	11.1	11.9	10.9	11.3	10.5	11.4	10.4	11.1
July	10.7	12.4	13.8	12.1	12.9	11.6	13.4	11.4	12.8
Aug.	9.5	10.7	11.7	10.5	11.3	10.2	11.5	9.8	10.9
Sept.	7.9	9.2	10.1	8.9	9.4	8.8	9.8	8.6	9.4
Oct.	6.2	7.1	8.1	7.0	7.4	6.9	7.8	6.7	7.6
Nov.	5.1	5.6	6.0	5.4	5.8	5.4	5.9	5.4	5.7
Dec.	3.1	3.3	3.6	3.3	3.4	3.3	3.5	3.2	3.4
P value		*	*	*	*	*	*	*	*
Average	**6.7**	**7.5**	**8.2**	**7.4**	**7.8**	**7.2**	**8.0**	**7.1**	**7.7**
Increasing %		**12.3%**	**22.5%**	**10.0%**	**16.1%**	**8.0%**	**19.5%**	**5.8%**	**15.1%**

** Significant at $P < 0.05$*

Moreover, [18] projected that the first order impacts of climate change on the Mediterranean hydrological systems as wetter winters and dryer summers, hotter summers and heat waves, and more variability and extreme weather events will take their toll. These impacts may induce an increase in evaporation (E) from natural and artificial water bodies and soils which reduce the available water supply [19]. Additionally; it will increase evapotranspiration (ETo) from crops and natural vegetation. Adapting to climate change will have close resonance with adapting to water scarcity and is likely to require implementation of water demand management strategies which may require capacity building and awareness raising across institutions and society. Adaptation measures on the supply-side include ways to improve rain-harvesting techniques, increasing extraction of ground water, water recycling, desalination, and improving water transportation. In addition, regular reviewing and updating of drought responses and research into improved long-term forecasting is essential to enhance Egypt's ability to cope with prolonged drought. Water supplies will not be available for farms and cities during summer months when demand is high. One third of the world's population will experience severe water scarcity within the next 25 years. Share in 2025 Per capita availability of water resources will decline to below 850 m^3 which exists now [20, 21]

3.3 Interpolation for Current and Future ETo

Figs. 2 and 3 show the interpolation of average annual ETo values for 11 weather stations in the different agro climatic regions. Each weather station was represented by point by using their corresponding coordinates (5 points for Delta, 3 points for Middle Egypt and 3 points for Upper Egypt). The interpolation created regions based on the same ETo range; the same colour mean the value of ETo in the range of this region. The interpolation divided Egypt to five recognized regions ranged between 3.0 to 10.0 mm/day; North Delta had the lowest ETo value and then it was recognized by the lighter colour than the other regions; in contrary Upper Egypt region had the highest ETo values (8.1-10 mm). The interpolation illustrated that the ETo values under 2050s and 2100s were higher than those under the current situation. The interpolation indicated that: Delta has two recognized climatic regions (North Delta and South Delta) as well as Upper Egypt has two climatic regions (Aswan and South of Qena)which have a recognized ETo range than other weather stations located in the Upper Egypt. These results agreed with [5,8,9,10,11,17,19,20].

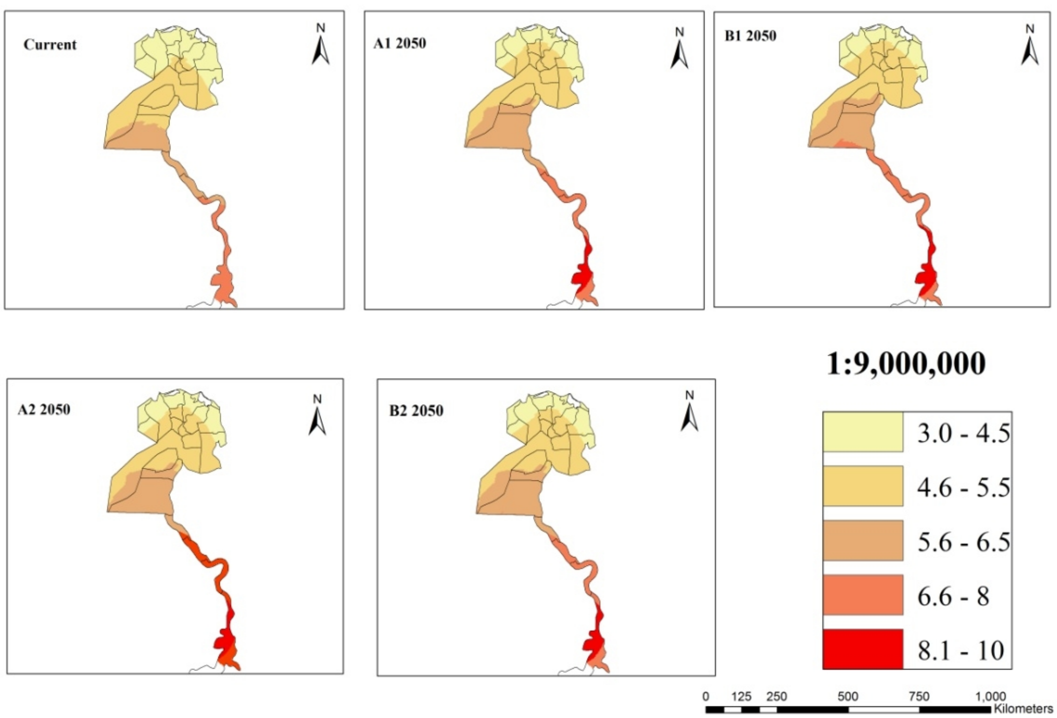

Fig. 2. Interpolation maps of average annual ETo values under current and 2050s conditions

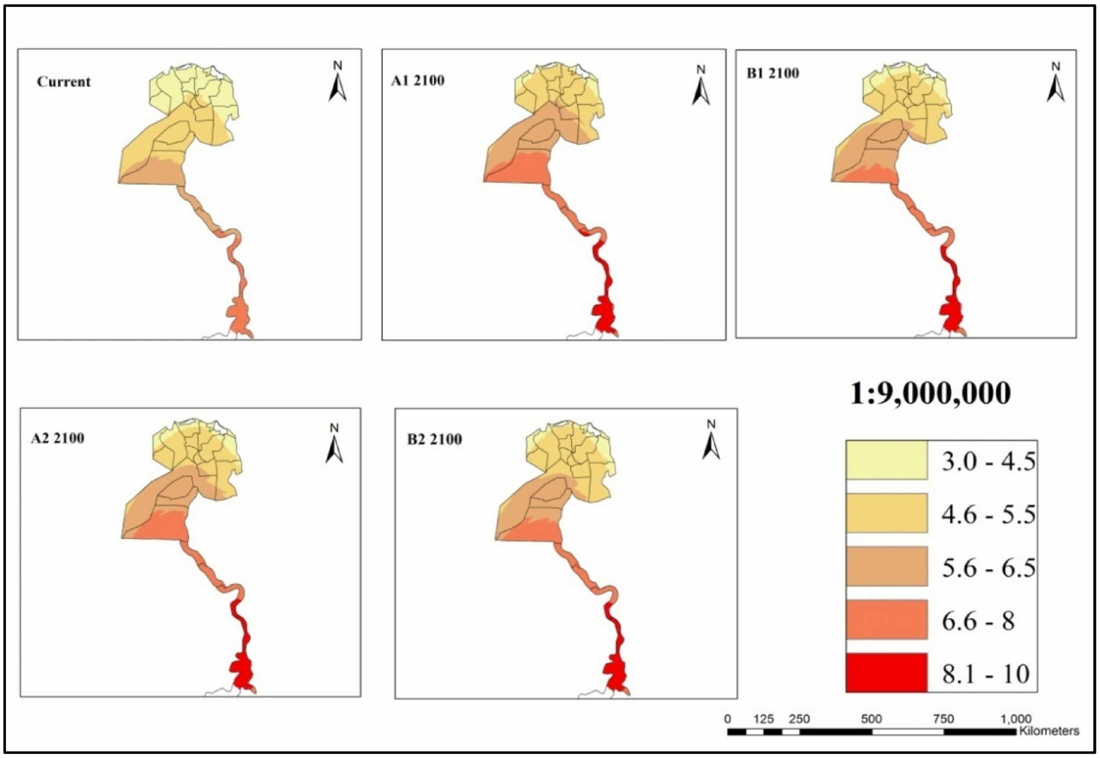

Fig. 3. Interpolation maps of average annual ETo values under current and 2100s conditions

4. CONCLUSION

The expected climate changes in Egypt according to the applied scenarios will cause an increase in ETo depending on the climate region. The increase in the Delta region was between 2.4% to 16.2 %, in the, Middle Egypt region between 5.9% to 21.1% and in the Upper Egypt region between 5.8% to 22.5% up to the year 2100_as compared to current situation. In this study a GIS tool was used to analyse the distribution of ETo on different Egyptian agricultural regions under current and future conditions.

Further studies could be done to improve current methodologies used for monitoring ETo by the linkage between climate factors and GIS with the goal of building new strategies for land reclamation based on water needs under different climatic regions.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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