IRRIGATION- WATER DEMANDS UNDER CURRENT AND FUTURE CLIMATE CONDITIONS IN EGYPT

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ABSTRACT

This study aims to investigate the effect of climate change on potential irrigation-demands for agriculture under Egyptian conditions. The investigation examined the current and future potential evapotranspiration (ET_o) trends under IPCC's SRES scenarios. Historical data for 31 stations were collected and applied to FAO-Peneman equation in order to calculate the current ET_o trends. The implications of IPCC's SRES scenarios (A1, A2, B1 and B2) to air temperature changes were used to determine the future ET_o. Future projections were estimated for years 2025s, 2050s and 2100s, using HadCM3 climate model. Temporal and spatial ET_o distribution were represented map. Results indicated that, under current conditions, about 70% of the Egyptian cultivated area have an average ET_o values more than 4 mm/day. The general trend of the climate change impacts was an increase in ET_o values from North to south. , this increase will be uneven between regions and seasons. The future climatic changes will increase the potential irrigation-demands by range of 6-16%, due to the increase in ET_o only by 2100s.

INTRODUCTION

Several studies have shown that the Earth's atmosphere is changed at the last century. In 1992 the United Nations Framework Convention on Climate Change (UNFCCC) defined these changes as "Climate change" which means "a change of climate which is attributed directly or

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indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods". IPCC described the modifications of the atmosphere as an increased in the global average surface temperature over the 20th century by about 0.6°C. According to the studies results included in IPCC third assessment report (TAR) published in 2001, the most likely rate of future global change over the period 1990-2100 due to anthropogenic emissions is estimated to be an increase in global average surface temperature by 1.5-4.5 ºC. Another type of global future changes are specified as an increase in atmospheric CO_2 levels, sea level rise, change in atmospheric N_2, O_3 and UV-B, change in precipitation patterns and amount, and an increase in the frequency of the extreme events (IPCC, 2001b). Climate change is likely to have significant impacts on the hydrological cycle, and it will be intensified with more evaporation and more precipitation, but the extra precipitation will be unequally distributed around the globe (IPCC, 2001a). Bazzaz and Sombroek (1996) reported that the projected future temperature rises are likely to reduce the productivity of the major crops, and increase its water requirements thereby directly decreasing crop water use efficiency. On the other hand, it will cause a general increase of potential evapotranspiration (ET_o), this will lead to increase of irrigation demands.

Potential evapotranspiration (ET_o) is a calculated quantity of the maximum quantity of water capable of being lost as water vapor, under a given climate, by a continuous extensive stretch of vegetation covering the ground when there is no shortage of water (Gangopadhyay et al., 1966). ET_o can be characterized as a process of mass transport wherein the rate of evaporation is treated as a diffusive process driven by the vapor pressure gradient (McKenney and Rosnberg, 1991). One of the most debated issues in irrigation science is estimating ET_o using weather data (Doorenbos and Pruitt, 1977). Smith et al. (1996) recommended the use of FAO-Penman to calculate crop-water requirements, especially under limited climatic data conditions. Since ET_o is computed from radiation, temperature, humidity and wind speed, any change in these variables due to climate change are likely to change its value. ET_o is one of the important key factors used in determining crop water requirements as it is as essential criteria for on-farm irrigation management. It should be known to design irrigation supply systems that can meet those requirements. Additionally, ETo is one of the important hydrological cycle factors, which should be estimated in large scale irrigation management and hydrological investigations. It is expected that ETo trends around the globe will be changing due to climate change, and the magnitude of this change is estimated for the global scales in many studies. Even though, it is still needed to estimate this magnitude for the regional scale as well as local scale, in order to have more accurate trends. Chattopadhyay & Hulme (1997) reported that the future warming seems likely to lead, in general, to increased potential evapotranspiration over India. Although this increase will be uneven between regions and seasons. Such changes could have marked implications for economic and environmental welfare in the country. Peterson & Keller (1990) concluded that the percentages of irrigated areas will be risen in USA, as a result of global warming. Improved use of technologies could help meet increasing evapotranspiration needs, but large new surface supplies will generally be required to maintain or increase present levels of irrigation.

In 2002 Egyptian Environmental Affairs Agency (EEAA) reported that "Egypt is highly vulnerable to climate change impacts, mainly due to the large and tightly packed population, and if climate change makes Egypt's climate drier or warmer; pressures on agriculture would intensify". Water sector is one of the sectors that face a lot of pressures under the current and the future conditions. Sanchez, et al. (2005) stated that the water gap in Egypt will increase to reach 21.0 billion m^3 by the year 2025. Competition among the limited water resources could escalate even without climate change, and the country could face an explosive situation (El-Raey, 1999). Agriculture water-demand is one of the serious pressures to water sector. This is mainly due to several factors; (i) 85% from total available water is consumed in agriculture, (ii) 95% of the cultivated area is under fixed irrigation system, and (iii) most of the on-farm irrigation systems are low efficient irrigation systems coupled with poor irrigation management (Abou Zeid, 2002).

The climate change impacts on crop water requirements, under Egyptian conditions, have been studied in scattered and limited studies (Eid, 1993, El Marsafaway and Eid, 1999, Medany, 2001, Hassanien et al., 1999) and most of these studies were focusing on specific regions in Egypt and specific crops.

This study aims to investigate the effect of climate change on water demands for agriculture under Egyptian conditions. The investigation examined the current and future ET_o trends under climate change scenarios.

MATERIALS AND METHODS

A monthly historical data for 31 stations all over Egypt were collected to calculate the current ET_o trends. The period of the historical data varied between the stations and averaged between 10 to 40 years. Maximum and minimum air temperatures, maximum and minimum relative humidity, sunshine hours and wind speed for each station were applied to FAO-Peneman equation.

Four climate change experiments were conducted by MAGICC/SCENGEN tool to extract the projection changes in air temperature (Δ air-temp) under the four IPCC's SRES scenarios that are described in Table (1). HadCM3 climate model was the base model under the four experiments. Each experiment extracted monthly Δ air-temp, for one of the four scenarios, for the coming years 2025s, 2050s and 2100s. The resulted data from MAGICC/SCENGEN were in 5°× 5° coordination grid. The future Δ air-temp data were downscaled by simple statistical approach, according to the Egyptian coordinates, and added to the historical air temperature data, to produce the future temperature data.

The future temperature data and the other climate parameters for each station were applied to FAO-Peneman equation, to determine the future ET_o trends. From the current and future ET_o monthly calculated data, annual and seasonal values were calculated to facilitate the analysis. Seasonal values were calculated as values of winter season of months December, January and February [DJF], spring season of months March, April and May [MAM], summer season of months June, July and August [JJA], and autumn season of months September, October and November [SON]. Temporal and spatial ET_o distribution were represented through Geographical Information Systems (GIS) by "ArcView©" GIS application.

Average monthly ET_o values were totalized for each Governorate to present the annual and seasonal total $ET_{o,}$ as a thematic map. Afterwards, it was associated with the spatial layer distribution of cultivated area in Governorates of Egypt (MALR, 2004). By multiplying the two layers, the total ET_o in million cubic meters is obtained.

Table (1): Description of IPCC Special Report on Emissions Scenarios (SRES)

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
A2	Heterogeneous world, self-reliance and local identities preserved, high population growth, regionally-specific economic growth, fragmented economic and technological development
B1	Convergent world with low population growth, transition to service and info economy, resource productivity improvements, clean technology towards global solutions
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

RESULTS AND DISCUSSION

A- Analysis of current trends of ET_o

Figure (1) shows the current average annual and seasonal trends of the ET_o in Egypt. The maximum ET_o value was 14 mm/day in Aswan station. Whereas, the minimum value was 1.2 mm/day in Damietta and Port Said. the overall ET_o range was 12.8 mm/day. Spatial distribution of average-annual ET_o showed that about 70% of the Egyptian area have an average ET_o values more than 4 mm/day. This result is in agreement with Eid et al. (2001). Regarding the seasonal trends, summer revealed highest trend of ET_o. Spring season trend is higher than autumn, and Table (2) shows the maximum, minimum and the average ET_o values under the four seasons. From these results, it is clear that most cultivated lands in Egypt are in high ET_o areas, especially in summer and spring. For current land reclamation projects, more attention should be given to Northern areas and winter plantation.

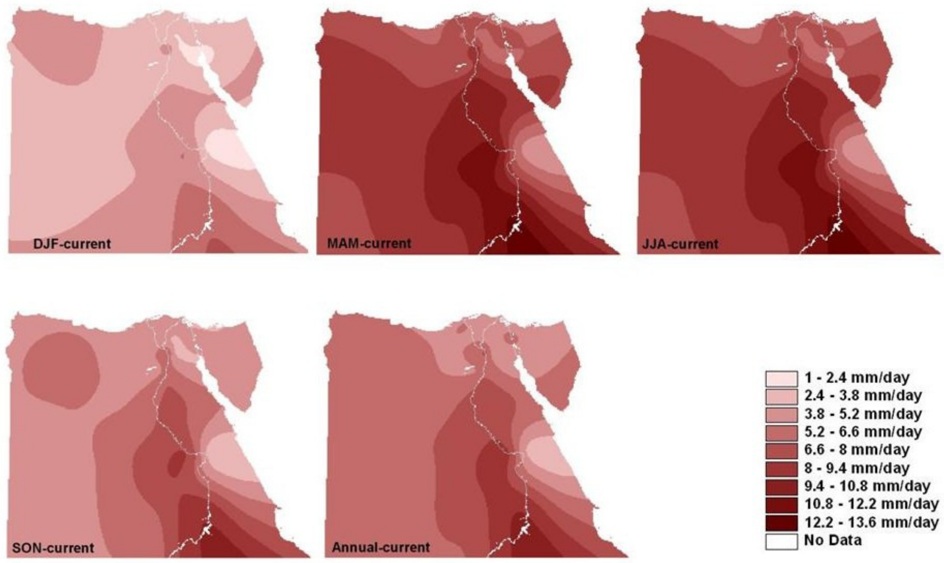

Figure (1): Current trends of ET_o in winter [DJF], Spring [MAM], Summer [JJA], Autumn [SON] and Annual average distribution.

Table (2): Seasonal trends of ET_o

	DJF	MAM	JJA	SON
Max ET_o	5.9	10.1	14.0	8.8
Min ET_o	1.2	3.8	5.1	3.2
Avg ET_o	3.2	6.1	7.5	4.9

B- Analysis of future trends of ET_o

1- Future temperature trends

A general change in air temperature is expected to cause changes in ET_o. Figure (2) shows the projected Δ air-temp form the four climate change scenarios (A1, A2, B1 and B2) in 2025s, 2050s and 2100s over Egypt. The results of scenarios experiments indicated that the air temperature all over Egypt could be increased by range of 1.0-1.3 °C, 1.9- 2.6 °C and 2.2- 4.9 °C by 2025s, 2050s and 2100s, respectively. The values of Δ air-temp were always higher under A1 scenario for 2050s and 2100s. In addition, B1 gave the lowest values of Δ air-temp by 2100s. According to these results, A1 was considered as the "worst case" of Δ air-temp, and B1 was considered as the "best case". The highest values of Δ air-temp under the climate change experiments were obtained in summer and autumn season (Figure 3).

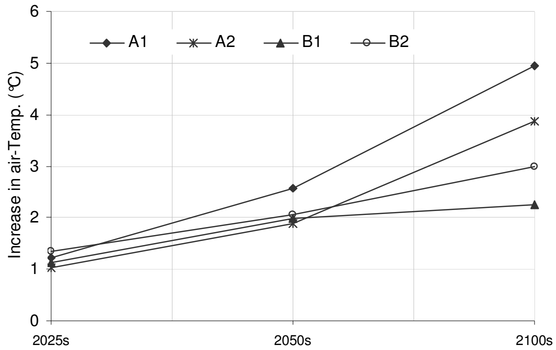

Figure (2): Average mean annual temperature increase over Egypt under SRES scenarios of A1, A2, B1 and B2, for the years 2025s, 2050s and 2100s.

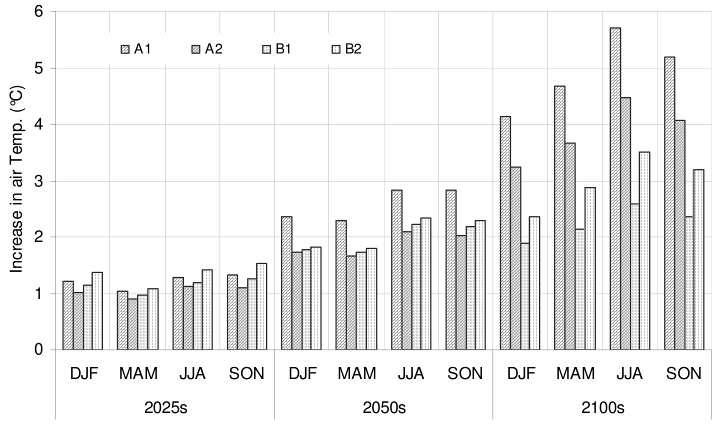

Figure (3): Average mean- seasonal temperature increase over Egypt under SRES scenarios of A1, A2, B1 and B2, for the years 2025s, 2050s and 2100s.

2- Future ET_o trends

From the climate change experiments, the resulted changes in temperature lead to an increase in ET_o values. The magnitude and the percentage of the increase are presented in Table (3). These magnitudes of ET_o change are varied according to the season, the location and the current ET_o of the location. The spatial and temporal distribution of the future ET_o values under the worst case and the best case of the climate change for 2100s is illustrated in Fig (4). From the comparison between Figure (1) and Figure (4), the increase in ET_o values from North to south is the general trend of projected ET_o changes. Whereas, the increase in ET_o values in Northern parts of upper Egypt (Fayoum- Bani Suef- Minya) and Marsa Matruh Governorate is important sign of the projected future changes under all scenarios. Besides, unlike temperature change, the magnitude of change in ET_o values in winter season under all climate change experiments were the highest in comparison with the other three seasons values.

Table (3): ET_o (mm/day) change rate (%) due to climate change for the 31 stations.

	Worst case [A1]			Best case [B1]		
Year	2025s	2050s	2100s	2025s	2050s	2100s
Δ ET_o (mm/day)	0.06-1.04	0.03-1.27	0.20-3.20	0.05-1.02	0.08-1.15	0.09-1.23
Δ ET_o (%)	1.1-21.2	2.3-25.3	6.1-50.8	0.4-21.0	1.5-23.2	2.9-23.7

The total annual irrigation demand due to evapotransipiration (potential irrigation-demands) is resulted from multiplying the total annual ET_o for the Egyptian Governorates by the cultivated area in each Governorate. According to the historical data of the current cultivated area, the current total potential irrigation-demands is 59.4 billion m^3/year. As shown in Table (5), these demands are projected to increase until 2100s to be 63.2 to 69.9 Billion m^3/year (6.4-16.0% increase in potential irrigation-demands under B1 and A1. respectively). The current and the projected irrigation demands for 2025s, 2050s and 2100s are presented in Table (6). The magnitude of change in potential irrigation-demands values in winter season was higher than the other values in the three seasons, in almost all scenarios. "Potential irrigation-demands" is a part of "actual irrigation demands" at the national level. At the farm level "irrigation requirements" is the term that indicate the actual irrigation demands". Joshi et al. (1995) reported that "irrigation requirements" may be defined as the quantity of water that must be supplied by irrigation to satisfy evapotranspiration, leaching, consumptive use by the crops and miscellaneous water requirements that are not provided by water stored in the soil and precipitation that enters the soil. The definition also includes the use of water for salinity control, frost protection and plant cooling and yields. In this context, it should be cleared that the presented indications under this study are not taking into account the extra water amounts required to overcome the increase in cultivated areas, as well as, the heat stress effect on the crops and the degradation of water and soil quality that projected to increase under global warming.

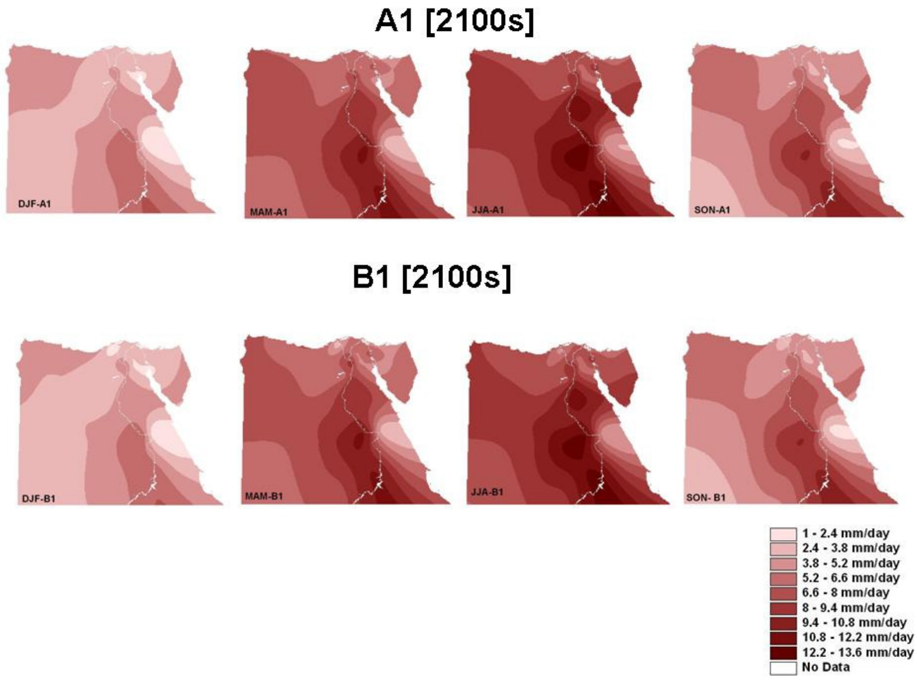

Figure (4): ET_o Future seasonal trends under A1and B1 climate change scenarios by 2100s.

Table (5): Seasonal potential irrigation-demands and change rate (%) due to climate change (2100s) associated with cultivated area (total cultivated area for 27 governorates :7.39 Million Fed).

	Current (Million m^3/day)				**Best case [B1] (Million m^3/day)**				**Worst case [A1] (Million m^3/day)**			
	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON
Seasonal average (Million m^3/day)	2907	5767	6966	4456	3107	6067	7256	4650	3434	6561	7848	5137
Annual Total (BCM)	59.4				63.2				68.9			
Total change					**6.4%**				**16.0%**			

Table (6): Total potential irrigation-demands due to ET_o (billion m^3/year) for Egypt under future conditions (2025s, 2050s and 2100s) for the SRES Scenarios (current demands= 59.4 billion m^3/year).

Scenarios	**Years**		
	2025s	**2050s**	**2100s**
A1	62.5	64.4	68.9
A2	62.2	63.4	66.2
B1	61.7	62.9	63.2
B2	62.7	63.7	65.0

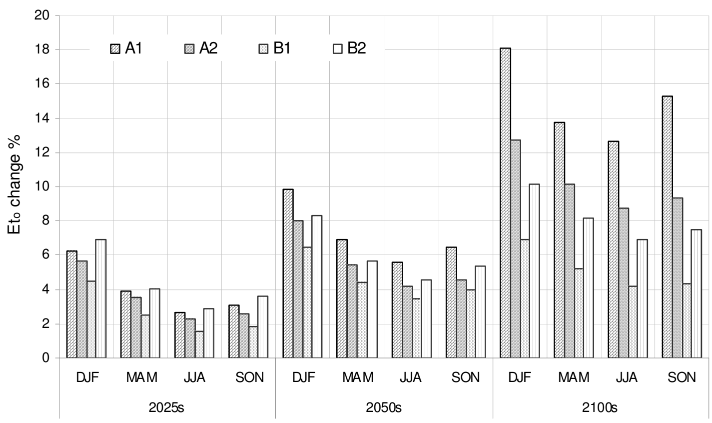

Figure (6): Seasonal potential irrigation-demands change (%) due to future conditions (2025s, 2050s and 2100s) for the SRES Scenarios.

CONCLUSION

The present study is a single-factor analysis of the impact of the climate change phenomenon on potential irrigation-demands. According to the overall changes in ET_o trends, the future warming seems to lead, in general, to increased ET_o over Egypt, This increase will be uneven between regions and seasons. Potential irrigation-demands, are projected to increase by 6.4-16.0% at 2100s.

Further studies are required to investigate vulnerability of the different Egyptian agricultural-areas to the projected incoming changes in potential irrigation- demands. In addition, to define the possible adaptation options that could be applied in agricultural sector to cope with the current and future irrigation pressures.

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الاحتياجات المائية الإروائية تحت الظروف المناخية الحالية و المستقبلية بمصر

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تهدف هذه الدراسة الى تقييم تأثير ظاهرة "تغير المناخ" على الاحتياجات المائية الاروائية الزراعية تحت الظروف المصرية. و تم ذلك بدراسة توزيعات قيم البخر-النتح المرجعى تحت الظروف المناخية الحالية و المستقبلية. و قد تم الحصول على الظروف المناخية المستقبلية من السيناريوهات الخاصة بالإنبعاثات الحرارية، هذه السيناريوهات تمثل سيناريوهات تغير المناخ الرسمية من قبل الهيئة الحكومية الدولية لتغير المناخ (IPCC).

تم حساب قيم البخر-النتح المرجعى الحالى و المستقبلى باستخدام معادلة "الفاو-بنمان"، من خلال تجميع بيانات مناخية من ٣١ محطة أرصاد بالجمهورية لحساب المعدلات الحالية. ثم استخدمت سيناريوهات تغير المناخ مع دمجها بالنموذج المناخى "HadCM3" للحصول على مقدار التغير المتوقع لدرجات الحرارة بأعوام ٢٠٢٥-٢٠٥٠-٢١٠٠. و بناء على التغير بدرجات الحرارة تم حساب قيم البخر-نتح المرجعى المستقبلى. و تلى ذلك توزيع القيم المحسوبة الحالية و المستقبلية للبخر-نتح المرجعى على خريطة الإحداثيات المصرية، باستخدام نظم المعلومات الجغرافية.

و من خلال الدراسة وجد أن التغير المناخى المتوقع سوف يزيد من الاحتياجات الأروائية المرجعية بمقدار ٦-١٦% كنتيجة لزيادة قيم البخر-نتح المرجعى فقط.

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