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# IMPACT ASSESSMENT OF LONG TERM CLIMATE CHANGE ON REFERENCE EVAPOTRANSPIRATION AND WATER MANAGEMENT IN NORTH DELTA

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## ABSTRACT

The objective of this study was to identify the effect of climate change within last 30 years on reference crop evapotranspiration (ETo) and to predict its future trend in the Northern coastal areas of Egypt. Correct estimating of ETo is important to determine the exact quantity of irrigated water needed for specific crop. The overuse of water for irrigation has resulted in eliminating the water resources in the whole country. Estimating ETo, which is the main input for water balance simulations, using Hargreaves, Penman Monteith, FAO Penman Monteith, Penman (Modified) and Penman Open Water models was through DAILYET version 3.0 model. The determination of ETo using simulation models, for irrigation purposes will be used as a vital tool for supporting the decision-making process in the future management of water resources and on the other hand will have a positive effect on the rest of limited water resources of Egypt. It was observed the over last 30 years, air temperature has risen by 2 degree Celsius in the study area. However, this change in air temperature did not affect the ETo estimates by using different models. Among the different methods tested, Pan Evaporation Rate method behaved the best and appeared as a simple method for accurate ETo daily estimations.

**Keywords:** Evapotranspiration, water management, climate change, Egypt.

## INTRODUCTION

In general, water supply planning and management requires selecting a future time frame for conducting analyses. Scenario analyses of the sensitivity of water availability and demand to climate change will provide estimates of how much water will be available and how much water will be needed by consumers if climate changes by specified amounts. Climate, water availability, and water demand scenarios are based on a set of specified reasonable assumptions about the future.

Analogously, arid lands have a lot of problems on field of water management, for example; Egypt (our case study) has a large population (74.7 million capita in July 2003). The agricultural land base is 7.5 million feddans (1 feddan = 4200 $m^2$) and annual consumption of fresh water is 891.2 $m^3$/ capita. With only 3.5 % of land area being arable, holding average less than 0.8 ha, this makes the country one of the lowest in the world. Also, water shortage has become more frequent and farmers often face deficiencies in water deliveries, resulting in reduced yields and incomes. Furthermore, there is poor management of available water in both of irrigation system and farm levels (Abou El Hassan *et al*, 2005).

Furthermore, climate change is any systematic change in the long-term statistics of climate elements (precipitation, temperature, pressure, wind speed ...etc) over several decades or longer. Climate change can be an expression of changes in long-term average precipitation or temperature, and/or changes in the frequency of extreme climate events. Consequently, ETo (potential or reference crop evapotranspiration) is a climatic parameter and can be computed from weather data. Therefore, water requirement is related to the climatic conditions. In general, the need for an accurate and standard method to estimate ETo, to predict crop water requirements, has been stated by several authors (Allen, 1996 and Chiew *et al*., 1995). A great number of numerous methods for estimating ETo are reported (Gavila´n *et al*., 2006 and DehghaniSanij *et al*., 2004). Among the several methods to estimate ETo, the FAO Penman–Monteith method is recommended as the most precise one for its good results when compared with other equations in various regions of the world for determining ETo (Chiew *et al*., 1995; Garcia *et al*., 2004; Gavila´n *et al*., 2006; Torres *et al*, 2011).

Regarding for daily or monthly ETo calculation, the FAO Penman Monteith method requires daily or monthly data on maximum and minimum air temperature (T-max and T-min), relative humidity (RH), solar radiation (Rs) and wind speed (u). Unfortunately, for many locations in developing countries such as Egypt, meteorological variables are often incomplete and/or not available. Allen *et al*. (1998) proposed the use of the Hargreaves (HG) equation (Hargreaves and Samani, 1982) as an alternative ETo estimation equation when only air temperature data is available at weather stations. This method behaves best for weekly or longer predictions although some accurate ETo daily estimations have been reported in literature (Hargreaves and Allen, 2003). This method might not be suitable for all regions. Therefore, find out simple and accurate methodology for estimation of ETo is urgent especially in developing countries such as Egypt. This is due to limited facilities and high accuracy equipments.

Similarly, the United Nations Food and Agriculture Organization (FAO) proposed a methodology for computing crop evapotranspiration based on the use of ETo and crop coefficients **(**Kc**)** (Doorenbos and Pruitt, 1977). These coefficients depend on several factors including crop type, stage of crop growth, canopy height and density (Allen *et al*., 1998). In general, estimation of ET is an important path to study of hydrology, climate, agricultural and crop-growth, water balance, planning, design and operation of irrigation systems (Amatya *et al*., 1996 and Trajkovic, 2005). Analogously, the Egypt Water Use Project was in effect from 1977 to 1984; it aimed to improve agriculture and water-management programs (EWUP, 1984). From 1993 up to now the World Bank, International Organizations and Donors in cooperation with Egypt Government launched different Irrigation Improvement Projects (IIP) at different irrigation scales and command areas of Egypt. The main objectives of the IIP are to improve irrigation infrastructure, water-distribution systems, on-farm irrigation management, increase irrigation efficiency and agricultural productivity as well as improve drainage and groundwater management. In general, the irrigation improvement projects in Egypt aims at increasing the overall irrigation efficiency. On-farm application efficiency, Mesqa conveyance efficiency, and the main and secondary canal efficiencies were reported on the Staff Appraisal Report (World Bank, 1994) as 0.7, 0.85, and 0.85 respectively. Therefore, the overall efficiency was 0.50 to 0.55 for the present conditions. This efficiency is expected to increase after the IIP as reported in the same report (0.61) and other monitoring study (0.66) (IIP Monitoring and Evaluation Unit and the IAS, 1994).

Therefore, it is important to link between the current improvements projects with the expected climate change and future water requirements. Most of climate changes studies for Egypt concentrate on its affect on sea level rise include inundation and erosion, saltwater intrusion, increased soil salinity, changes of coastal ecosystems and losses of productivity. Studies on the effect of climate change on evapotranspiration are scanty and not well documented. It is therefore important to assess the effect of climate change within last 30 years on the calculated ETo. Thus, the objectives of this study were to: (i) assess the possibility of changing the ETo obtained using FAO-56 PM method with long time under the environmental conditions of north Egypt; (ii) assess the importance of using the predicted ETo model, as an easy method to estimate ETo when limited meteorological data are available and (iii) find out the expected water requirements for the main crops based on the increase of overall irrigation efficiency.

## MATERIALS AND METHODS

Baseline climatic data were collected from Kafr El-Sheikh governorate (Weather Station of the Sakha Experimental Research Station), Water Management Research Institute, located in Northern Nile Delta, Egypt Figure 1, for the past 30 years (1981- 2010). The experiment site is located at the $31^{0}$ 07′ N latitude, $30^{0}$ 57′ E longitude and 6 m altitude.

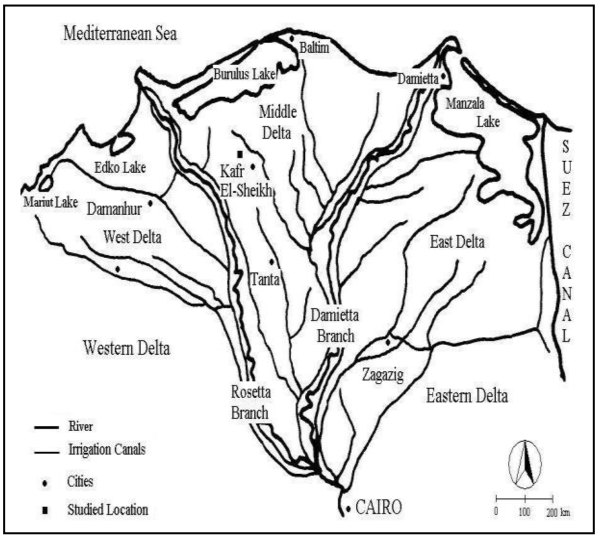

**Fig.1. Map of Egypt showing the location of the study area**

The study area suffers from shortage of fresh water. The soil at the experiment site is clayey in texture. The principle daily weather parameters affecting evapotranspiration (ETo) which used in this research are maximum air temperature, minimum air temperature, sunshine duration, relative humidity, wind speed and evaporation rate. Reference evapotranspiration (ETo), was calculated using DAILYET version 3.0 model which indicate the following equations: Hargreaves, Penman Monteith, FAO Penman Monteith, Penman (Modified) and Penman Open Water. Methods used are as detailed in (Smith, 1988; Hess and Stephens, 1993; and Allen *et al*, 1998). DAILYET is a simple 'calculator' for estimating daily reference evapotranspiration (ETo) using data collected from a conventional weather station.

**Evapotranspiration Model:** The description of each method is presented as follows:

a) **Penman Monteith equation:**

$$\mathrm{ETo} = \frac{\Delta R_n + (e_a - e_d) \times \left[ \frac{\rho . C_p}{r_a} \right]}{\lambda [\Delta + \gamma * (1 + \frac{r_s}{r_a})]} \qquad (1)$$

Where:

$R_n$ = Net radiation (W $m^{-2}$)

$\rho$ = Density of air (kg $m^{-3}$)

$C_p$ = Specific heat of air (J $kg^{-1}K^{-1}$)

$r_s$ = Net resistance to diffusion through the surface of the leaves and soil (sec $m^{-1}$)

$r_a$ = Net resistance to diffusion through the air from surfaces to height of measuring instruments (sec $m^{-1}$)

$\gamma$ = Hygrometric constant

$e_a$ = Saturated vapor pressure at air temperature (sec $m^{-1}$)

$e_d$ = Mean vapor pressure

b) **FAO Penman Monteith equation:**

$$\mathrm{ETo} = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma * (1 + 0.34 u_2)} \qquad (2)$$

Where:

$G$ = The soil heat flux density (MJ $m^{-2}$ $day^{-1}$)

$T$ = The mean daily temperature at 2 m height ($^{o}C$)

$u_2$ = The wind speed at 2 m height (m $sec^{-1}$)

$e_s - e_a$ = The saturation vapor pressure deficit (kPa)

$\Delta$ = The slope of the vapor pressure curve (kPa $^{o}C^{-1}$)

c) **Hargreaves equation:**

$$\mathrm{ETo} = 0.0023(T_m + 17.8)(\sqrt{T_{\max} - T_{\min}})R_a \qquad (3)$$

Where:

$T_m$ = Daily mean air temperature ($^oC$)

$T_{max}$ = Daily maximum air temperature ($^oC$)

$T_{min}$ = Daily minimum air temperature ($^oC$)

$R_a$ = Extraterrestrial radiation

d) **Modified Penman equation:**

$$\mathrm{ETo} = C\left[W \times Rn + (1-W) \times f(u) \times (ea - ed)\right] \quad (4)$$

Where:

$C$ = Adjustment factor to compensate for the effect of day and night weather

$W$ = Weathering factor related to temperature and altitude

$Rn$ = Net radiation in equivalent evaporation, ($Rn= 0.75\ Rs-Rn_1$) (mm $d^{-1}$)

Rs = Incoming short wave radiation, [Rs = (0.25+0.5 n/N) Ra] (mm $d^{-1}$)

Ra = Extra-terrestrial radiation (mm $d^{-1}$)

n/N = (1 – 0.094 mc), where: mc= cloud cover,

$f(u)$ = wind related function, f(u) = 0.27 [ 1 + ($u_2$/100)],

$u_2$ = Daytime wind speed at 2-meter height.

$(ea - ed)$ =Difference between the saturation vapor pressure at mean air temperate and the mean actual vapor pressure of the air (mbar)

e) **Penman Open Water equation:**

$$\mathrm{ETo} = \left[Kp \times Epan\right] \quad (5)$$

Where:

$Kp$ = Pan coefficient, which depends on type of pan, conditions of humidity, wind speed, environmental conditions around the pan.

$Epan$ = Pan evaporation observed using Class A- Pan (mm $d^{-1}$)

Crop Coefficient (Kc), defined as the ratio between actual crop evapotranspiration ($ET_a$) and reference evapotranspiration ($ET_o$) when both are in a large field under optimum growing conditions is given as (Doorenbos and Pruitt, 1977):

$$Kc = \left(\frac{\mathrm{ETa}}{\mathrm{ETo}}\right) \quad (6)$$

On the other hand, the values of 0.55, 0.60, 0.65, 0.70 and 0.75 were selected for the overall irrigation efficiency to evaluate the relation between crop water requirements under predicted climate change and the current irrigation improvements projects, in this study. The suggested values are based on previous studies such as (Elshorbagy, 2000).

## RESULTS AND DISCUSSION

### Evaluation of the selected estimation methods for ETo:

The reference estimated monthly average data (1981-2010) of crop evapotranspiration (ETo) from Kafr El Sheikh governorate was computed as shown in Figure 2. In general, the ETo values increased with the increase in climatic factors. As expected, the highest values were recorded for summer season (April to September) than the winter season (October to March).

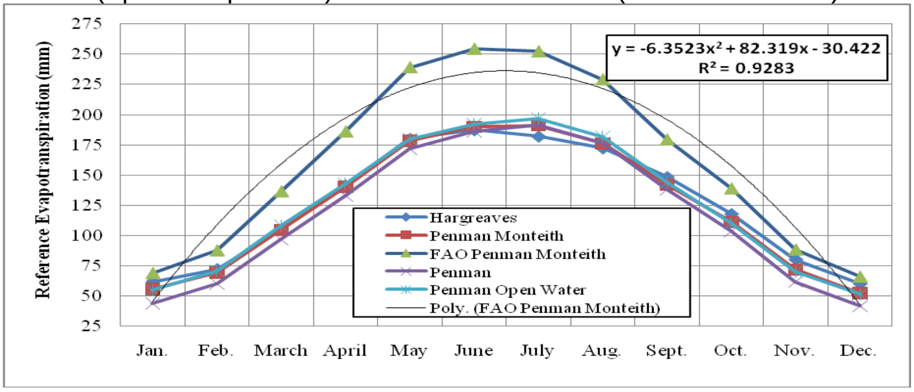

**Figure 2: Average ETo for Kafr El Sheikh (mm) using DAILYET model.**

It is noticed that FAO Penman Monteith method give the highest values of ETo compared with other selected methods all over the years. While other methods (Hargreaves, Penman Monteith and Modified Penman) gave the nearest results with Penman Open Water method. Allen *et al*. (1998) and Torres *et al*. (2011) stated that the only factors affecting ETo are climatic parameters. Consequently, ETo is a climatic parameter and can be computed from weather data. Among the several methods to estimate ETo, the FAO Penman Monteith method is recommended as the sole method for determining ETo in the Egypt. This method has been selected because it closely approximates grass ETo in the study area, is physically based and explicitly incorporates both physiological and aerodynamic parameters. As the degree of fit was high (r2 = 0.9238), this relationship can be used to estimate the future ETo for the area. Therefore, statistical analyses of the data used have identified the following simple polynomial relationship to be used for estimation of monthly ETo values by FAO Penman Monteith method as shown below:

$$\mathrm{y} = -6.3523X^{2} + 82.319X - 30.422 \qquad (7)$$

The advantage of simple models is their use in regions of minimal available weather data. Their major disadvantage is that these models may not reflect the effects of localized climatic and geographic variations such as narrow valleys, presence of high ground elevations, extreme latitudes or strong winds. Simple methods are usually best suited for weekly or monthly ETo estimates and are less suited for daily estimates Torres *et al*. (2011). In case of difficulty to get the required climatic parameters, in many areas of developing countries, Pan Evaporation Rate method can be used to identify ETo in the selected study area (Figure 3) according to the following simple liner relationship:

$$\mathrm{y} = 311.62X + 4.7576 \qquad (8)$$

As the degree of fit was high (r2 = 0.9372), this relationship can be used efficiently with low cost to estimate the future ETo for the area. Similarly, Figures 4 and 5 shows the trend of ETo values over last 30 years using different methods. It can be observed that there is no clear trend for the estimated ETo values over the years using different methods of evaluation. However, the obtained data proved that there is no effect of the climate change on the estimated ETo values over the last 30 years using different methodologies for ETo.

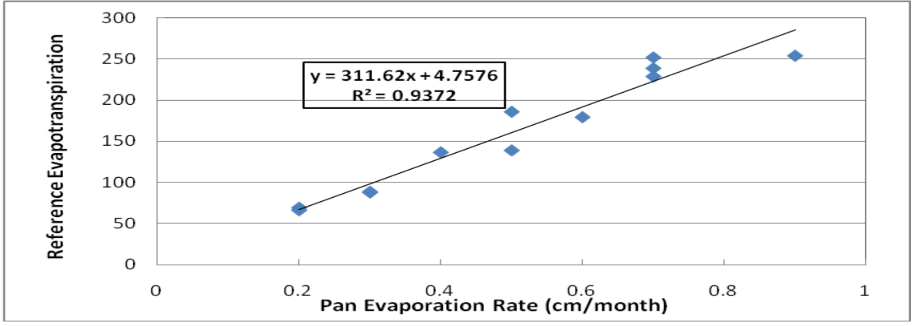

**Figure 3: Relationship between ETo and Pan Evaporation Rate method over thirty years.**

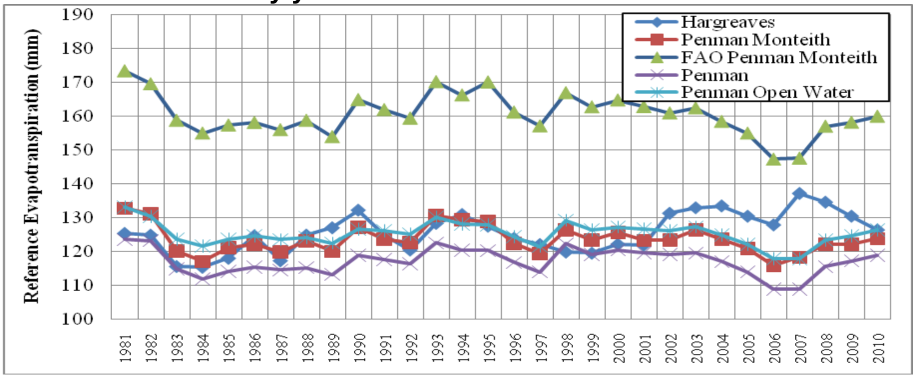

**Figure 4: ETo using different methods (DAILYET model) over last 30 years.**

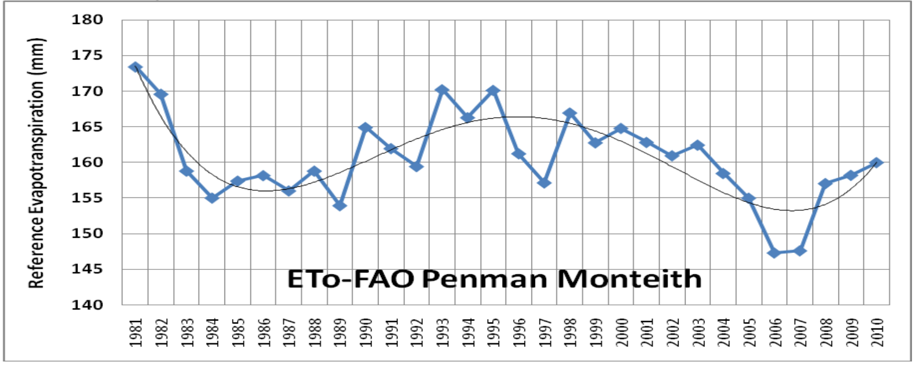

**Figure 5: ETo trend using FAO Penman Monteith method over last 30 years.**

## Effect of climate parameters on ETo:

There are many inputs to calculate the required ETo as stated earlier. However, the analysis for each variable factor in correlation with ETo (FAO Penman Monteith) are showen in Figure 6. The measured factors which change with time are maximum air temperature, minimum air temperature, relative humidity and wind speed. As the degree of fit were adequate between ETo and maximum air temperature ($r^2$ = 0.7422), as presented in equation (9) and between ETo and minimum air temperature ($r^2$ = 0.6856), as presented in equation (10).

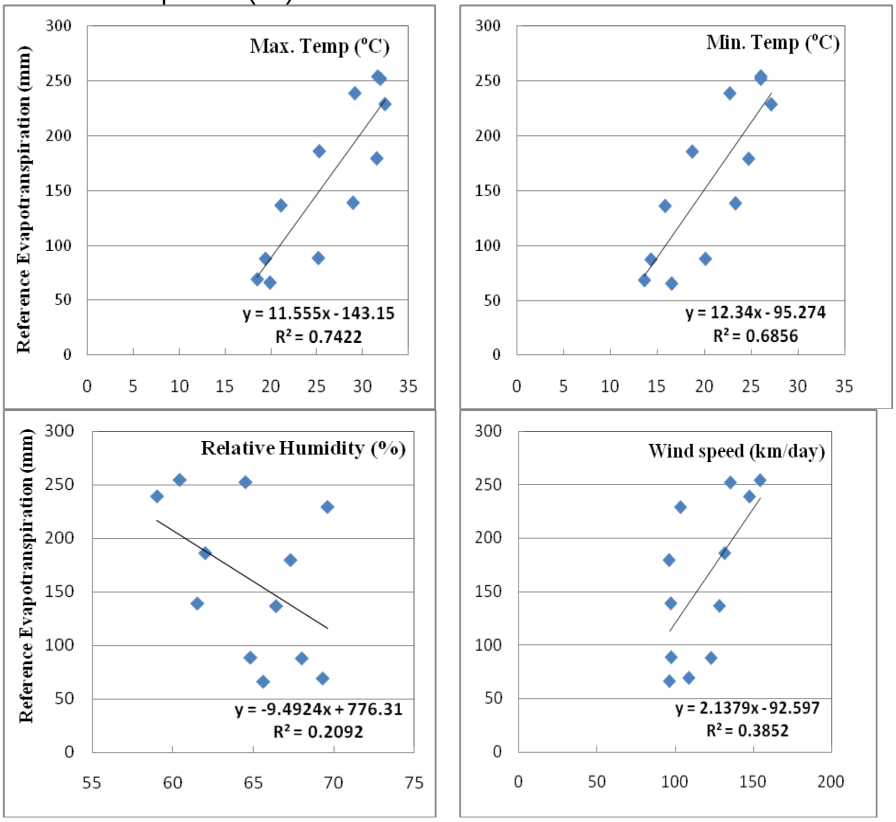

**Figure 6: ETo (FAO Penman Monteith) correlation with climate data over last 30 years.**

This means that the main factors affecting the estimation of ETo are maximum air temperature and minimum air temperature. Generally, the ETo estimates increased with increasing the air temperature. Regarding for relative humidity and wind speed, the correlation with estimated ETo is not fit as air temperature.

$$y = 11.555X - 143.15 \qquad (9)$$

$$y = 12.34X - 95.274 \qquad (10)$$

Where y is the Reference Evapotranspiration and x is the maximum and minimum air temperature as presented in equations 9 and 10, respectively.

The average air temperature values (maximum and minimum) for the studied location during the last 30 years are shown in Figure 7. Within the study period, it is noted that the maximum air temperature increased by about 2 degrees while the minimum air temperature increased by about < 1 degree. However, these changes in the air temperature did not significantly affect the observed ETo values using different models as shown in Figure 4. In order to confirm the obtained results, data of evaporation rate recorded during the same period in the same study area as shown in Figure 8 was analyzed. It is clear that the evaporation rate sharply fluctuated and did not take any positive and/or negative direction and did not show any clear trend line over the time.

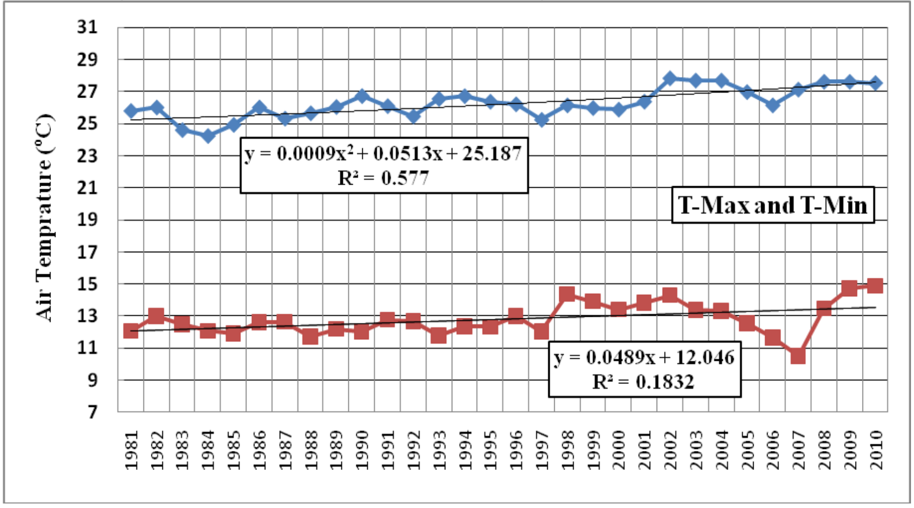

**Figure 7: Air temperature trend in the study area over last 30 years.**

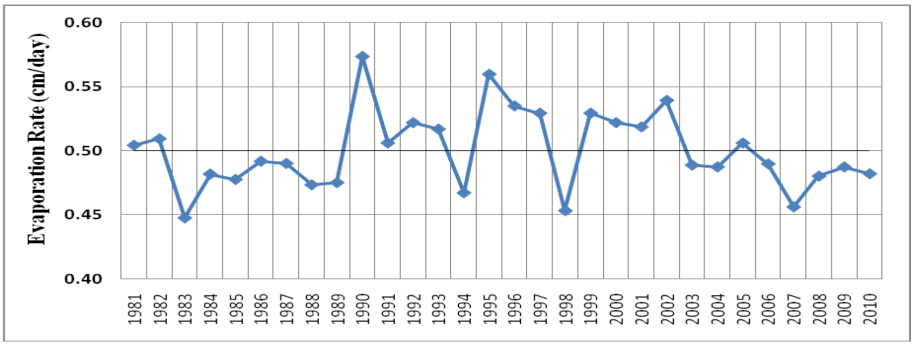

**Figure 8: Evaporation rate trend in the study area over last 30 years.**

**Crop Water Requirements and Irrigation Improvements:**

In the study area, the main summer crops are rice, maize and cotton. While, the main winter crops are wheat, alfalfa and sugar beet. Crop Coefficient (Kc) for the major summer and winter crops is defined for the study area by many local researchers (Ibrahim *et al*, 1988; Meleha, 2002 and Meleha, 2006). Therefore, the average five year water requirements ($m^3 \cdot fed^{-1}$) for the selected summer and winter crops in the study area are shown in Table 1. These requirements were calculated on the basis of meteorological data by using the FAO Penman Monteith method. This method is considered to be the most suitable method to predict the water requirements of crops grown under North Delta conditions because it yields the highest correlation coefficient ($R^2$ = 0.914) between actual evapotranspiration (ETa) and reference evapotranspiration (ETo) (Abou El Hassan *et al*., 2005). The average water requirements for the summer and winter crops were as follows: summer, rice (4366 $m^3 \cdot fed^{-1}$) > cotton (3725 $m^3 \cdot fed^{-1}$) > maize (2651 $m^3 \cdot fed^{-1}$); and winter, sugar beet (2081 $m^3 \cdot fed^{-1}$) > wheat (1787 $m^3 \cdot fed^{-1}$) > alfalfa (1760 $m^3 \cdot fed^{-1}$). In general, the crop water requirements for the selected crops fluctuated based on ETo.

**Table 1: Change of main summer and winter season crops Evapotranspiration ($m^3.fed^{-1}$) within last 30 years.**

| **Season** | Main Summer Crops | | | Main Winter Crops | | |
|---|---|---|---|---|---|---|
| **Years** | ***Rice** | ***Maize** | ***Cotton** | ****Wheat** | ****Alfalfa** | ****Sugar beet** |
| **1981-85** | 4441 | 2701 | 3781 | 1791 | 1768 | 2090 |
| **1986-90** | 4412 | 2681 | 3758 | 1718 | 1685 | 2007 |
| **1991-95** | 4403 | 2665 | 3797 | 1910 | 1885 | 2221 |
| **1996-2000** | 4423 | 2681 | 3760 | 1805 | 1781 | 2100 |
| **2001-2005** | 4308 | 2620 | 3682 | 1791 | 1766 | 2086 |
| **2006-2010** | 4206 | 2558 | 3575 | 1706 | 1678 | 1983 |
| **Ave.** | **4366** | **2651** | **3725** | **1787** | **1760** | **2081** |

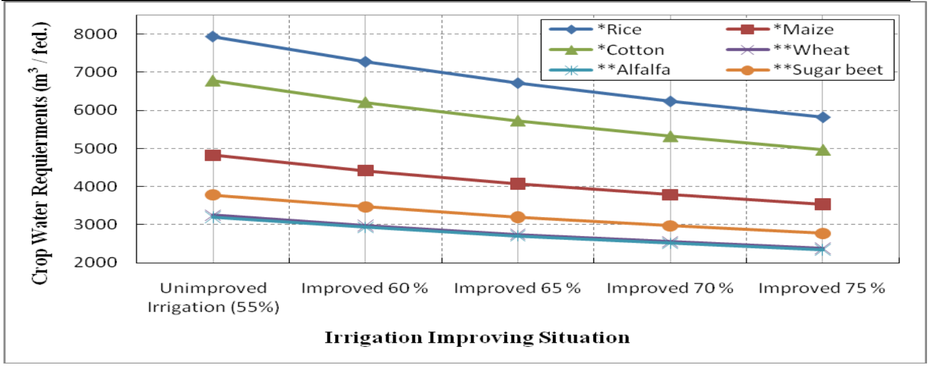

**Figure 9: The predicted crop water requirements as affected by Irrigation Improvements Projects**

On the other hand, it is predicted to increase the final irrigation efficiency (actual efficiency considering the reuse) increase from 0.65 to 0.74, even though the efficiencies due to conveyance and application (neglecting the reuse) were 0.5 and 0.65, before and after the irrigation improvement project respectively (Elshorbagy, 2000). Therefore, the main crops water requirements after improving overall irrigation efficiency are presented in Figure 9. It is clear that the increasing irrigation efficiency will led to decrease the crop water requirements for all crops.

## Conclusion

Water usage in the agricultural sector should be optimized in order to ensure efficient use of limited water resources. Accurate estimation of Evapotranspiration (ET) is one of the most important components of water balance, irrigation system design, water resources planning and management. In this study, we evaluated the effect of long-term climate change (30 years) on ETo for the management of irrigation systems in order to improve irrigation efficiency in Egypt. The following are our conclusions: (1) Among the selected models for ETo estimation, FAO Penman Monteith method gives the highest values; (2) Pan Evaporation Rate method is recommended as the most simple and precise one for its good results to identify ETo; (3) the limitation of change in air temperature (+2 °C) within last 30 years led to non significant effect on estimated ETo; (4) among the climate parameters, maximum and minimum air temperatures have the most effect on ETo; and (5) it is predicted that the increasing overall irrigation efficiency due to irrigation improvement projects will led to the significant decrease in crop water requirements.

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## تقييم تأثير التغيرات المناخيه علي النتح بخر المرجعي و ادارة المياه في شمال الدلتا

**وليد حسن أبو الحسن**

**معهد بحوث اداره المياه- المركز القومي لبحوث المياه- القناطر الخيريه- مبني المركز القومي لبحوث المياه - ص ب 13621-5 مصر**

الهدف من هذه الدراسه هو تقييم تأثير التغيرات المناخيه في الثلاثون سنه الماضيه (1981-2010) علي قيم النتح بخر المرجعي و التنبؤ المستقبلي بتاثيراتها علي شمال دلتا مصر. هدف تقييم النتح بخر المرجعي هو دراسه كميات المياه اللازمه لري المحاصيل المختلفه بدقه. حيث أن هناك حاجه ماسه لتقنين كميات مياه الري نظرا لمحدوديه البلاد من الموارد المائيه. في هذه الدراسه تم استخدام البرنامج الحسابي DAILYET لحساب النتح بخر المرجعي بمعادلات: FAO -Penman Monteith - Hargreaves Penman (Modified) - Penman Monteith و كذلك معادله Water Penman Open نظرا لان نظم البرامج الحسابيه تعد طرق فعاله و رخيصه لمساعده متخذي القرار علي اداره المياه بدقه.

اتضح من النتائج ان قيم النتح بخر المرجعي في منطقه الدراسه لم تتاثر حلال الثلاثون سنه الماضيه. و ذلك علي الرغم من ان درجه حراره الهواء زادت حوالي 2 درجه مئويه في نفس الفتره. و اتضح من الدارسه انه يمكن الاعتماد علي طريقه وعاء البخر كطريقه فعاله و رخيصه و لقياس قيم النتح بخر المرجعي اليومي في منطقه الدراسه.

**قام بتحكيم البحث**

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| **أ.د / السيد محمود فوزي الحديدي** | **كلية الزراعة – جامعة المنصورة** |
| **أ.د / محمد إبراهيم مليحة** | **المركز القومي لبحوث المياه** |