



Water requirements for wheat and maize under climate change in North Nile Delta

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Abstract

Determination of water requirements for wheat and maize under climate change is important for policy makers in Egypt. The objectives of this paper were to calculate (i) ETo and (ii) water requirements for wheat and maize crops grown in five governorates (Alexandria, Demiatte, Kafr El-Sheik, El-Dakahlia and El-Behira) located in North Nile Delta of Egypt under current climate and climate change. ECHAM5 climate model was used to develop A1B climate change scenario in 2020, 2030 and 2040. Monthly values of evapotranspiration (ETo) under the different scenarios in these governorates were calculated using Hargreaves-Samani equation (H-S). Then, these values were regressed on ETo values previously calculated by Penman-Monteith equation (P-M) and linear regression (prediction equations were developed for each governorate). The predicted ETo values were compared to the values of ETo calculated by P-M equation and the deviations between them were very low (RMSE/obs=0.04-0.06 mm and $R^2=0.96-0.99$). Water requirements for wheat and maize were calculated using BISM model under current climate and in 2020, 2030 and 2040. The results showed that average annual ETo would increase by low percentage in 2020 and 2030. However, in 2040 the increase would reach 8%. Water requirements are expected to increase by 2-3% for wheat and by 10-15% for maize, which would result in reduction of the cultivated area. Thus, it is very important to revise and fix the production system of wheat and maize, in terms of the used cultivars, fertilizer and irrigation application to overcome the risk of climate change.

Additional key words: *Triticum* spp; *Zea mays*; Penman-Monteith equation; Hargreaves-Samani equation; BISM model; ECHAM5 climate model; A1B climate change scenario.

Abbreviations used: BISM (basic irrigation scheduling model); CCAFS (Climate Change, Agriculture and Food Security); ETo (evapotranspiration); H-S (Hargreaves & Samani); Kc (crop coefficient); PI (percentage of increase); P-M (Penman Monteith); RMSE (root mean square error); WHC (water holding capacity).

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Introduction

Climate plays an important role in the crop production. Crops growth periods, crops water requirements and irrigation scheduling for crops are dependent on weather conditions in a site. The amount of applied water for a crop is associated with the calculation of reference evapotranspiration (ETo). The ETo is a combination of two processes: water evaporation from soil surface and transpiration from the growing plants (Gardner *et al.*, 1985). Direct solar radiation and, to a lesser extent, the ambient temperature of the air provides energy for evaporation. Whereas, solar radiation,

air temperature, air humidity and wind speed should be considered when assessing transpiration (Allen *et al.*, 1998). Various equations are available for estimating ETo. These equations range from the most complex energy balance equation requiring detailed climatological data, such as Penman Monteith (Allen *et al.*, 1989) to simpler equations requiring limited data (Blaney & Criddle, 1950; Hargreaves & Samani, 1982, 1985). The Penman-Monteith equation (P-M) is widely recommended because of its detailed theoretical base and its accommodation to small time periods. However, the detailed climatological data required by the P-M are not often available especially in developing

countries. In the meantime, a reduced-weather-data-equation to calculate ETo could be more appropriate in some developing countries. However, using this type of equation could reduce accuracy of calculation. Therefore, calibrating more simple equation needs limited data requirements with P-M equation could be a solution to that problem (Shahidian *et al.*, 2012).

Agriculture is strongly influenced by the availability of water. Agriculture water demand in Egypt represents serious pressure on water sector, since 85% of total available water is consumed in the agricultural area and most of the on-farm irrigation systems are low efficient coupled with poor irrigation management (Abou Zeid, 2002). Climate change will modify rainfall, evaporation, runoff, and soil moisture storage (IPCC, 2007). A temperature rise of 1°C may increase ETo by about 4-5%, while a rise of 3°C may increase ETo by about 15% (Eid, 2001). Thus, irrigation water management becomes increasingly important in the presence of low water supplies and expected future climate change. In order to avoid underestimation or overestimation of crop water consumption, knowledge of the exact water loss through actual ETo is necessary for sustainable development and environmentally sound water management (Shideed *et al.*, 1995), which could reduce both waste of water and negative impacts on economic, social and environmental levels (Katerji & Rana, 2008). Furthermore, the evidence of future warming is the reason for paying more attention to the efficiency of water application to crops (Abou Zeid, 2002).

Previous studies on the effect of climate change on the Nile flow clearly indicated that the Nile is very sensitive to temperature and precipitation changes (Soliman *et al.*, 2008) mainly because of its low runoff/rainfall ratio, which equals to 4% (IPCC, 2007). Furthermore, Sayed (2004) indicated that the magnitude of temperature change varies and the direction of this change is clear. For rainfall, however, not only the magnitude varies substantially across the models, but also the signal of the change varies. Thus, water gap in Egypt could increase in the future, under the expected climate change (Sanchez *et al.*, 2005). The uncertain climate change impacts on the Nile flow could add another challenge for water management in Egypt. It is expected that the projected high temperature would increase the local water demands, especially for agricultural sector. Attaher *et al.* (2006) concluded that future climate change will increase potential irrigation demands in all Egypt by a range of 6-16%, due to the increase in ETo. Another study by Ouda *et al.* (2011) revealed that an increase by 33% in water required for irrigation is expected to occur in Egypt in 2025, as a result of temperature increase by 2°C and population increase. Thus, it is important to

quantify how climate change will affect the water requirements for strategic crops in Egypt, such as wheat (*Triticum* spp) and maize (*Zea mays*). These two crops are cultivated mostly under surface irrigation with low application efficiency, *i.e.* 60% (Abou Zeid, 2002).

The objectives of this research were to calculate, under current climate and under climate change (i) ETo and (ii) water requirements for wheat and maize grown in five governorates in North Nile Delta of Egypt.

Material and methods

Description of the study area

The study area is composed of five governorates in the North Nile Delta. These governorates are: Alexandria (lat. 31.70°, long. 29.00°, 7.00 masl), Demiatte (lat. 31.25°, long. 31.49°, 5.00 masl), Kafr El-Sheik (lat. 31.07°, long. 30.57°, 20.00 masl), El-Dakahlia (lat. 31.03°, long. 31.23°, 7.00 masl) and El-Behira (lat. 31.02°, long. 30.28°, 6.70 masl). Each of these governorates has a weather station. All these governorates are close to the Mediterranean Sea, thus they have relatively similar weather conditions. Fig. 1 shows the map of the studied governorates.

Evapotranspiration (ETo) under current climate

Monthly ETo values were calculated using the Penman Montieith equation (P-M) for each governorate, as

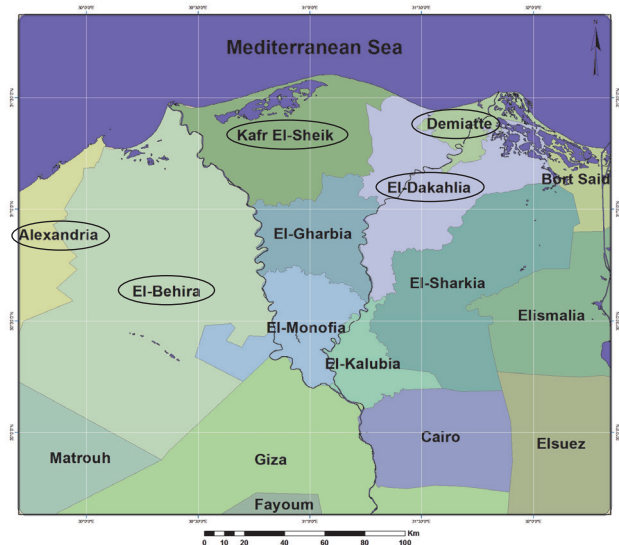


Figure 1. Map of the studied governorates in the North Nile Delta in Egypt.

an average over 10 years, from 2002 to 2011. The used weather data were maximum and minimum temperature, relative humidity, wind speed and potential sun shine hours. The stability of these weather parameters through time were tested through comparison of ETo values with previously calculated values from 1960 to 1991, where R^2 was 0.91. Furthermore, when these values were compared with ETo values calculated from 1997 to 2006, R^2 was 0.83. Eid (2001) stated that the weather parameters in northern Nile Delta are fairly stable.

Climate change model ECHAM5

Research program on Climate Change, Agriculture and Food Security (CCAFS) is part of CGIAR (Consortium of International Agricultural Research Centers) research programs that implement a uniquely innovative and transformative research program that addresses agriculture in the context of climate variability, climate change and uncertainty about future climate conditions. In the CCAFS web site (<http://www.ccafs.cgiar.org/marksimgcm#.Ujh1gj-GfMY>), which describes seven global climate change models, three climate change scenarios (A1B, A2 and B1) can be downloaded. The details of these models are presented in Jones *et al.* (2009). The climate model ECHAM5 (Roeckner *et al.*, 2003) is one of them and was used in this analysis.

The ECHAM5 is an atmospheric oceanic general circulation model (EC stands for being developed from the ECMWF operational forecast model cycle 36 in 1989, and HAM for the parameterization package being developed at Hamburg). The part describing the dynamics of ECHAM is based on the ECMWF documentation, which has been modified to describe the newly implemented features and the changes necessary for climate experiments. Since the release of the previous version, ECHAM4, the whole source code has been extensively redesigned in the major infrastructure and transferred to FORTRAN 95. ECHAM5 is now fully portable and runs on all major high performance platforms. The resolution of the model is 1.9×1.9 degrees.

Climate change scenario

ECHAM5 model was used to develop A1B climate change scenario for each weather station in each governorate. IPCC (2007) describes the A1 storyline and scenario family as a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduc-

tion of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. One of A1 family is A1B climate change scenario, where it is characterized by technological balance across all sources (balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end-use technologies).

The downloaded scenario was for the years 2020, 2030 and 2040 and composed of maximum and minimum temperature, rain and solar radiation. These weather parameters were not enough to calculate ETo with P-M equation. However, they are enough to calculate ETo using Hargreaves-Samani equation (H-S) (Hargreaves & Samani, 1985; modified later by Hargreaves, 1994). Thus, the H-S equation was used to calculate ETo for the studied governorates under current climate using maximum and minimum temperature and then it was compared to the previously calculated values by P-M equation. The comparison showed that there were deviations (positive or negative) between monthly ETo values. Therefore, to increase the accuracy of estimation, a linear regression equation established with P-M values was plotted as the dependent variable and values from H-S equation were plotted as the independent variable. The intercept a and calibration slope b of the best fit regression line, were then used as regional calibration coefficients for each governorate, following Shahidian *et al.* (2012):

$$ETo[P-M] = a + b (ETo[H-S]) \quad [1]$$

An equation for each governorate was developed, where different a and b values were estimated. The quality of the fit between the two values was presented in terms of the coefficient of determination (R^2), which is the ratio of the explained variance to the total variance and through calculation of root mean square error per observation (RMSE/obs), which gives the standard deviation of the model prediction error per observation (Jamieson *et al.*, 1998). The obtained equation for each governorate was used to predict monthly values of ETo similar to the values calculated with P-M equation and was compared with the obtained values of ETo[P-M], to check its accuracy. Then, the developed prediction equations were used to calculate monthly ETo values under A1B climate change scenario in 2020, 2030 and 2040 for every month and annual average value was calculated and compared to average ETo values under current climate.

BISm model

The Basic Irrigation Scheduling model (Snyder *et al.*, 2004) which helps planning irrigation management of crops, calculates ETo, crop Kc, water depletion from root zone and schedules irrigation. Moreover, ETo values can be directly input in the model. The BISm application calculates ETo using the P-M equation (Monteith, 1965) as presented in Allen *et al.* (1998). If only temperature data are input, H-S equation is used to calculate ETo (Hargreaves & Samani, 1985). For ETo calculations, the station latitude and elevation must be input. After calculating daily means per month, a cubic spline curve fitting subroutine was used to estimate daily ETo rates for the entire year. The model requires the input of: sowing and harvest dates to calculate crop Kc; irrigation frequency to determine initial Kc; and total water holding capacity (WHC) and available water to calculate water depletion from root zone. The model then determines the time when irrigation needs to be applied and the required amounts (Snyder *et al.*, 2004).

Calculation of water requirements

The obtained monthly values for ETo under current climate and the calculated values under climate change using the prediction equations were used in BISm model to calculate water requirements for wheat and maize grown under surface irrigation in each of the five governorates. Sowing date for wheat was assumed to be 15th of November, which is the recommended sowing date and 18th of April was set as a harvest date. The season length for wheat as winter crop is 155 days. The recommended sowing date for maize is 15th of May and harvest date is 1st of September, with a season length of 110 days. The same sowing date was assumed under climate change and harvest date was assumed to be one week earlier for wheat and maize crops. Previous research on the effect of climate change on season length of wheat and maize indicated that it could be reduced by 7-12 days (Khalil *et al.*, 2009; Ouda *et al.*, 2009). Representative values for WHC and available water for the soil of each governorate were used in the model (Table 1). These values were obtained from our Department (unpublished results). Irrigation schedule for each crop was developed in each governorate and water requirements under surface irrigation were calculated. Irrigation efficiency was assumed to be 60% under both current and climate change conditions, which is the efficiency of surface irrigation in Egypt (Abou Zeid, 2002).

Table 1. Soil water holding capacity (WHC) and available water prevailed in each governorate

| Governorate | WHC (m/m) | Available water (m/m) |
|----------------|-----------|-----------------------|
| Alexandria | 0.373 | 0.206 |
| Demiatte | 0.376 | 0.222 |
| Kafir El-Sheik | 0.405 | 0.170 |
| El-Dakahlia | 0.395 | 0.196 |
| El-Behira | 0.408 | 0.230 |

Results

Comparison between ETo[P-M] and ETo[H-S] values

The obtained values of ETo[P-M] and the calculated values by ETo[H-S] in North Nile Delta governorates were compared in Fig. 2. The results showed that in all governorates the H-S equation under-estimated ETo during all months, especially in the summer months. There were deviations between monthly ETo values calculated from each equation in each governorate.

Prediction of ETo[P-M] values under current climate

Table 2 presents the developed regression equations, coefficients of determination (R^2 : between 0.95 and 0.98) and root mean square error per observation (RMSE/obs: between 0.04 and 0.06 mm), which shows a good accuracy of the prediction of these equations. These equations were used to predict values of ETo[P-M]. Figure 3 indicates that the predicted values were close to obtained values of ETo[P-M] in most of the months, which implies a high degree of accuracy because R^2 for each equation was close to one and RMSE/obs was close to zero (Table 2).

Calculation of ETo under a climate change scenario

Table 3 shows that under climate change conditions, the annual ETo value is expected to increase by low percentage in 2020 and 2030. However, in 2040 it is expected to increase by 8% in all the studied governorates (Table 3).

Water requirements under climate change

With respect to wheat, Table 4 shows that water requirements were the lowest at Alexandria and the highest at El-Dakahlia. Water requirements will in-

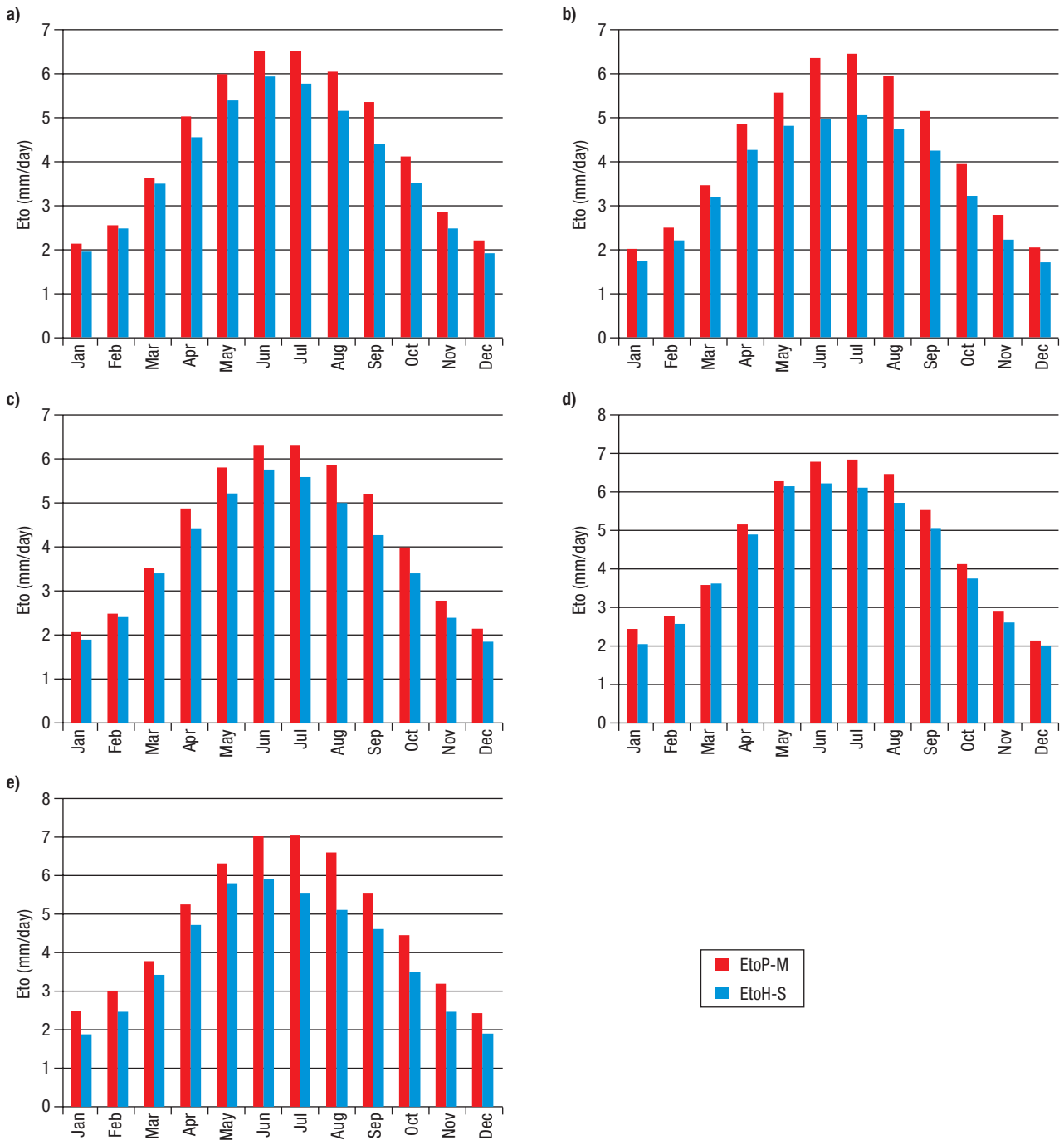


Figure 2. Comparison between ETo[P-M] and ETo[H-S] in (a) Alexandria, (b) Demiatte, (c) Kafr El-Sheik, (d) El-Dakahlia and (e) El-Behira governorates.

Table 2. Prediction equations for ETo, coefficients of determination (R^2) and root mean square error per observation (RMSE/obs) between Penman-Monteith and Hargreaves-Samani equations in each governorate studied

| Governorate | Prediction equation | R^2 | RMSE/obs (mm/day) |
|---------------|--|-------|-------------------|
| Alexandria | $ETo[P-M] = -0.4252 + 1.2134 * ETo[H-S]$ | 0.95 | 0.06 |
| Demiatte | $ETo[P-M] = -0.2297 + 1.2714 * ETo[H-S]$ | 0.98 | 0.05 |
| Kafr El-Sheik | $ETo[P-M] = -0.1280 + 1.1690 * ETo[H-S]$ | 0.98 | 0.05 |
| El-Dakahlia | $ETo[P-M] = 0.0338 + 1.0745 * ETo[H-S]$ | 0.98 | 0.04 |
| El-Behira | $ETo[P-M] = 0.3432 + 1.1157 * ETo[H-S]$ | 0.96 | 0.04 |

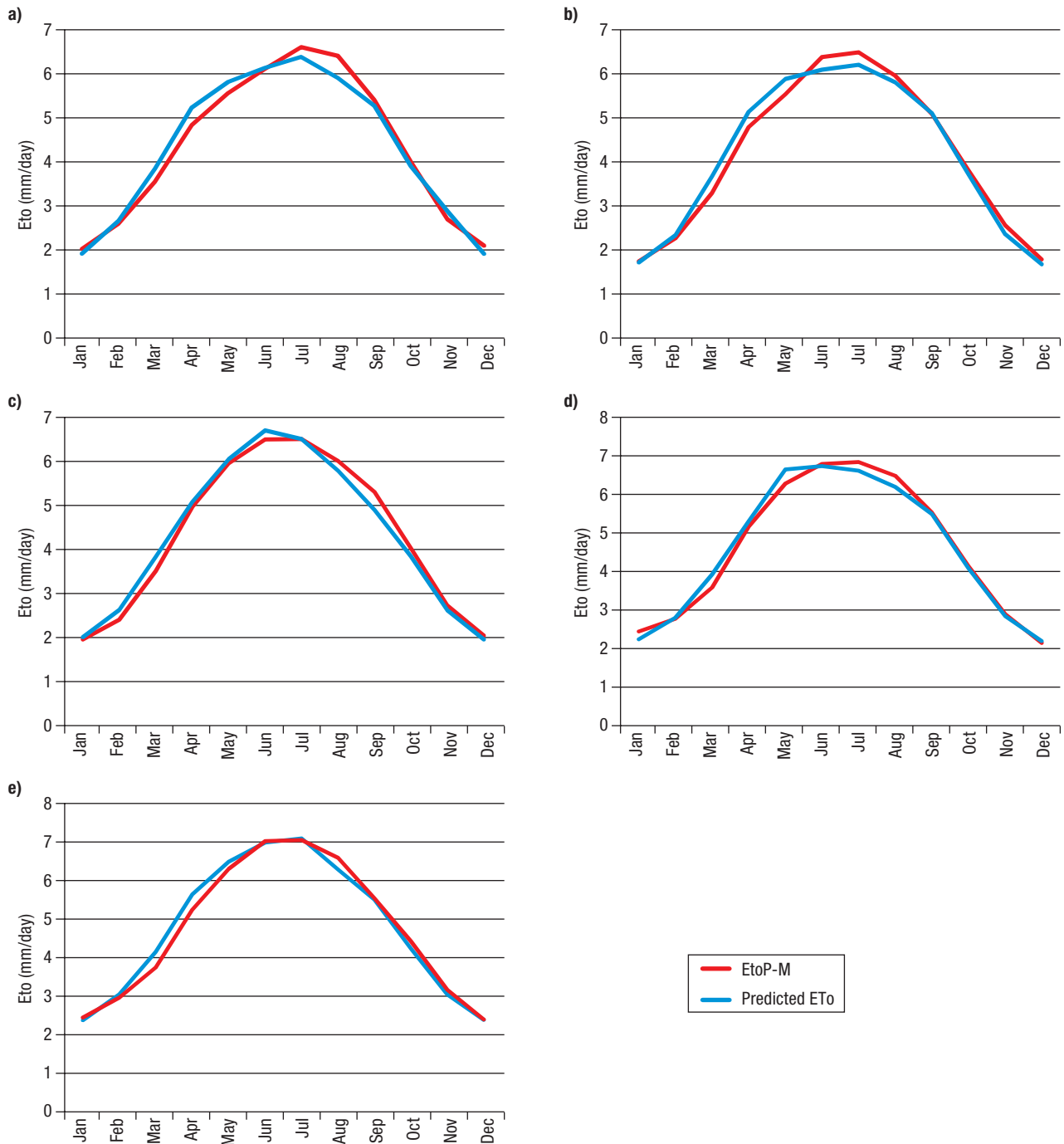


Figure 3. Comparison between ETo[P-M] and predicted values of ETo in (a) Alexandria, (b) Demiatte, (c) Kafr El-Sheik, (d) El-Dakahlia and (e) El-Behira governorates.

crease in 2020 by low percentage, 1-2%. In 2030, the percentage of increase between water requirements under current climate and under climate change conditions will be 1-3%, whereas in 2040, the percentage of increase will be 2-3%. This increase will result in reduction in wheat cultivated area and that will increase wheat production-consumption gap in Egypt.

With respect to maize, Table 4 shows that in 2020, water requirements are expected to increase by a low

percentage in all governorates (3-4%), except for El-Behira governorate, where PI=9%. In 2030, the highest PI is expected to occur in El-Dakahlia and El-Behira (11% and 14%, respectively). This can be attributed to the fact that ETo values in both governorates in the summer months were over 7.00 mm day⁻¹ (Figs. 3d and 3e). Water requirements for maize in 2040 are expected to increase between 10% and 15%.

Table 3. Mean annual values of ETo (mm/day) and percentage of increase (PI%) under current climate, and under 2020, 2030 and 2040 climate change scenarios

| Governorate | Current climate | 2020 | | 2030 | | 2040 | |
|---------------|-----------------|------|-----|------|-----|------|-----|
| | ETo | ETo | PI% | ETo | PI% | ETo | PI% |
| Alexandria | 4.3 | 4.5 | 4 | 4.5 | 5 | 4.7 | 8 |
| Demiatte | 4.3 | 4.4 | 2 | 4.4 | 4 | 4.6 | 8 |
| Kafr El-Sheik | 4.3 | 4.5 | 5 | 4.5 | 6 | 4.6 | 8 |
| El-Dakahlia | 4.6 | 4.7 | 2 | 4.7 | 3 | 5.0 | 8 |
| El-Behira | 4.8 | 4.9 | 3 | 5.1 | 5 | 5.2 | 8 |

Table 4. Water requirements (mm) for wheat and maize under current climate, and under A1B climate change scenario in 2020, 2030 and 2040

| Governorate | Current (mm) | 2020 | | 2030 | | 2040 | |
|----------------|--------------|------|-----|------|-----|------|-----|
| | | mm | PI% | mm | PI% | mm | PI% |
| Wheat | | | | | | | |
| Alexandria | 462 | 467 | 1 | 476 | 3 | 478 | 3 |
| Demiatte | 495 | 499 | 1 | 503 | 2 | 505 | 2 |
| Kafr El-Sheikh | 510 | 519 | 2 | 520 | 2 | 521 | 2 |
| El-Dakahlia | 519 | 522 | 1 | 526 | 1 | 528 | 2 |
| El-Behira | 501 | 510 | 2 | 514 | 2 | 513 | 2 |
| Maize | | | | | | | |
| Alexandria | 772 | 797 | 3 | 795 | 3 | 859 | 11 |
| Demiatte | 735 | 756 | 3 | 799 | 9 | 812 | 10 |
| Kafr El-Sheikh | 780 | 813 | 4 | 817 | 5 | 865 | 11 |
| El-Dakahlia | 703 | 732 | 4 | 780 | 11 | 797 | 13 |
| El-Behira | 728 | 793 | 9 | 829 | 14 | 838 | 15 |

PI%: percentage of increase.

Discussion

Quantification of the impact of climate change on water requirements of two strategic crops in Egypt, *i.e.* wheat and maize, is very important for policy makers when developing future plans. This requires an accurate equation to calculate ETo values. With only monthly maximum and minimum temperature measurements and solar radiation available, monthly ETo can be calculated by H-S equation and, then regressed on ETo value previously calculated from P-M equation to develop calibration coefficients for each site. The calibration coefficients (*a* and *b*) should be developed for each site to increase the accuracy of prediction of EToP-M values. Furthermore, the results showed in Fig. 3 prove that the calibration coefficients were capable to account for the effect of relative humidity, wind speed and potential sun shine hours, which were not included in the H-S equation. Shahidian *et al.* (2012) concluded that both temperature and radiation can be used successfully to calculate ETo values with relative ac-

curacy. Regional calibration is important in decreasing the bias of the ETo estimates.

Our results showed that this method was accurate and the predicted ETo values were close to the previously calculated values by P-M equation. Thus, these developed equations can be used for accurate prediction of ETo values under climate change scenarios using the same methodology.

The rise in temperature, as a syndrome of climate change, is going to increase water requirements for both wheat and maize, as a result of increase in evaporation from soil and transpiration from plants surface (Abdrabbo *et al.*, 2013). Khalil (2013) calculated ETo values under climate change similar to what is presented in Table 3. Furthermore, he also stated that ETo value calculated for Demiatte was the lowest in all studied governorates. Snyder *et al.* (2011) concluded that the impact of global warming on ETo will likely be less in locations with higher wind speeds. So, the studied governorates are located close to the Mediterranean Sea and are characterized by wind speeds between 4.3 and 4.9 m/s. Moreover, Ouda *et al.*

(2010) and Ibrahim *et al.* (2012) calculated water requirements for wheat grown in El-Behira governorate under climate change in 2030. They both concluded that it would increase by an average of 3-4% under A2 and B2 climate change scenarios developed by Hadley model. In Demiatte governorate, the water requirement used for wheat is expected to increase under climate change condition by 3% (Noreldin *et al.*, 2013). Regarding to maize, similar results were obtained by Ouda *et al.* (2012) and Abdrabbo *et al.* (2013) under El-Behira governorate. The expected increase in water requirements for both wheat and maize will probably cause reduction in the cultivated area of these crops in each governorate due to unavailability of water for irrigation. Taking into consideration population increase, food insecurity problem could increase.

Furthermore, the above methodology could solve a large problem that researchers and extension workers face on irrigation scheduling in Egypt and in other developing countries. The availability of a number of meteorological stations, to measure weather parameters is limited and reliability of the measured data could be an obstacle. There are also concerns about the accuracy of the observed meteorological parameters (Droogers & Allen, 2002), since pyranometers (solar radiation) and hygrometers (relative humidity), are often subject to stability errors, where it is common to see a drift as high as 10% in pyranometers (Samani, 2000). Sepaskhah & Razzaghi (2009) have observed that hygrometers lose about 1% in accuracy per installed month. Thus, they recommend the use of ETo equations that require fewer variables. Hargreaves & Allen (2003) concluded that the differences in ETo values, calculated by the different methods, are minor when compared with the uncertainties in estimating actual crop ETo from measured weather data. Additionally, these equations can be more easily used in adaptive or smart irrigation controllers that adjust the application depth according to the daily ETo demand (Shahidian *et al.*, 2009).

The methodology presented in this paper could be applied in developing countries, where few weather stations exist or few weather parameters are measured. The values of ETo for any site on Earth can be obtained from FAO AQUASTAT website (<http://www.fao.org/nr/water/aquastat/main/index.stm>), which provides climate normals (1960-1991) in this site, as well as ETo values. These values can be compared to ETo values recently calculated with H-S equation and if the deviation is high, a linear regression equation should be established with ETo[P-M] values plotted as the dependent variable and values from H-S equation plotted as an independent

variable. The intercept a and calibration slope b of the best fit of regression line, are then used as regional calibration coefficients for each region.

In semiarid regions, where Egypt is located, more pressure will be put on water resources distribution between economic sectors under climate change, especially agriculture. Reduction in the amount of allocated water for irrigation, increase in water requirements for crops and yield reduction under climate change conditions will worsen food security situation in Egypt. The studied area is located in North Egypt and it has the lowest temperature, as a result of its location near the Mediterranean Sea, which implies that the risk of climate change on water requirements for crops will increase in the rest of the country. Furthermore, in the five studied governorates, surface irrigation was used. However, changing irrigation system from surface irrigation to sprinkler for wheat and drip for maize could increase application efficiency from 60% under surface to 80% under sprinkler or 95% under drip irrigation. Another option was successfully used in Egypt and proved to save irrigation water, increase yield and does not involve any extra cost for farmers, *i.e.* cultivation on raised bed. These options, if implemented, will save on the applied irrigation water, which can be used to irrigate new lands under climate change conditions.

In conclusion, water requirements for wheat (winter crop) under climate change in 2020, 2030 and 2040 are expected to increase by a low percentage, 2-3%. For maize (summer crop), the percentage of increase is expected to be high (15% at El-Behira governorate). Thus, it is very important to revise and fix the production system for wheat and maize, in terms of the used cultivars, fertilizer and irrigation application.

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