

Chapter 2

Potential Evapotranspiration Under Present and Future Climate

Mostafa Morsy, Tarek El-Sayed and Samiha A.H. Ouda

Abstract The objective of this chapter was to calculate potential evapotranspiration (PET) values for five governorates in Egypt (North Sinai, Marsa Matrouh, El-Gharbia, El-Sharkia and Sohag) using Penman-Monteith equation with climate normals values (1985–2014). These calculated values of PET was used in next chapters to calculate water requirements for the prevailing and suggested crops structures. Furthermore, the effect of climate change on PET was assessed using comparison between RCPs scenarios developed from four global models and the boundary of the more close scenario to the measured data was input into a regional climate model (WRF-RCM) to develop more accurate weather data to be used in PET calculation under climate change. The methodology described in this chapter resulted in achieving higher level of certainty in the prediction of weather elements with 92 % degree of accuracy. Thus, we used these data to calculate PET values under climate change in 2030. The results indicated that the values of weather elements and PET were slightly higher in North Sinai and Marsa Matrouh. The difference in PET was increase in El-Gharbia and El-Sharkia governorates and in 2030 it was be noticeably high in Sohag governorate. These increases will have its negative implication on water consumption by the cultivated crops in these governorates. Therefore, it is important for policy makers in Egypt to be alert on these anticipated risks associated with climate change in 2030.

Keywords Potential evapotranspiration • RCPs developed from AR5 models • WRF-RCM model

M. Morsy (✉) • T. El-Sayed

Astronomy and Meteorology Department, Faculty of Science (Boys),
Al-Azhar University, Cairo, Egypt
e-mail: mustafa_meteorology@yahoo.com

T. El-Sayed

e-mail: ta_sayad@yahoo.com

S.A.H. Ouda

Water Requirements and Field Irrigation Research Department, Agricultural Research Center,
Soils, Water and Environment Research Institute, Giza, Egypt
e-mail: samihaouda@yahoo.com

© The Author(s) 2016

S.A.H. Ouda and A. Zohry, *Management of Climate Induced Drought and Water Scarcity in Egypt*, SpringerBriefs in Environmental Science,
DOI 10.1007/978-3-319-33660-2_2

Introduction

Water is important for all forms of life and will become a scarce natural resource in the future owing to climate variability and change. The relationships between climate, crop, water and soil are complex with many biological processes involved (Rao et al. 2011). The Efficient water management of crops requires accurate irrigation scheduling which, in turn, requires accurate measurement of crop water requirement. Potential evapotranspiration (PET) plays an important role for the determination of water requirements for crops and irrigation scheduling (Kumar et al. 2012). Various equations varying in the degree of complexity are available for estimating PET (Penman-Monteith; Allen et al. 1989; Blaney-Criddle 1950; Hargreaves and Samani 1982, 1985). The Penman-Monteith equation is widely recommended, although it is characterized by its complication because of its detailed theoretical base and its accommodation of small time periods.

Climate change is expected to increase PET due to higher temperature, solar radiation and wind speed (Abteu and Melesse 2013), which will affect the hydrological system and water resources (Shahid 2011). Previous research in Egypt on the effect of climate change on PET values revealed that temperature rise by 1 °C may increase PET rate by about 4–5 % (Eid 2001). Furthermore, Khalil (2013) used SERS scenarios to calculate PET values in the future and indicated that it will increase under climate change compared to current climate. Ouda et al. (2016) indicated that PET values will increase depending on the location of the region, where it will be lower in North Egypt, compare to the middle and south of Egypt. This assessment was done using AR4 scenarios.

The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC 2013) is the recent that contained a large number of comprehensive climate models and Earth System Models, whose results form the core of the climate system projections. These models produce new Representative Concentration Pathways (RCP2.6, RCP4.5, RCP6.0 and RCP8.5), which based on Coupled Model Inter-comparison Project Phase 5 (CMIP5) to replace the SRES scenarios in IPCC Fourth Assessment Report (AR4) released in 2007 (Wayne 2013). Even though general circulation models (GCMs) have proven their relative ability to simulate many aspects (e.g. atmospheric circulation, global surface temperature, monsoon circulation, and climate oscillation) of climate variability at large or global scale (Solomon et al. 2007), they still cannot reproduce local-scale climate variability. Furthermore, using global and region models in projection of climate change effects on PET could achieve higher level of certainty.

The objective of this chapter was to calculate PET values in five governorates in Egypt using Penman-Monteith equation with climate normals values (1985–2014). Furthermore, to reduce uncertainty in the projection of the effect of climate change on PET, a comparison between RCPs scenarios developed from four global models was done and the boundary of closer scenario to the measured data was input into a regional model (WRF-RCM) to develop more accurate weather data to be used in PET projection under climate change.

Selected Governorates

Five governorates were selected to represent rain fed and irrigated agriculture in Egypt. Regarding to rain fed areas in North Egypt, North Sinai governorate was selected to represent North East Egypt and Marsa Matrouh to represent North West Egypt. Two governorates were selected to represent old clay soil in Nile Delta and Upper Egypt, i.e. El-Gharbia and Sohag governorates. Furthermore, one governorate was selected in North Nile Delta to represent salt-affected soil, i.e. El-Sharkia. (Table 2.1).

Figure 2.1 showed a map for the selected governorates in North Egypt, Nile Delta and in Upper Egypt.

Calculation of PET Values Under Present Climate

The BISm model (Snyder et al. 2004) was used to calculate monthly PET. The model calculates PET using Penman-Monteith equation (Monteith 1965) as presented in the United Nations FAO Irrigation and Drainage Paper (FAO 56) by Allen et al. (1989). Climate normals (1985–2014) were used to calculate ET values for each governorate. Monthly values of PET in the selected governorates are presented in Table 2.2.

Assessment of the Effect of Climate Change on PET Values

To lower the uncertainty of climate change projections in the future for PET calculation, Morsy (2015) developed a methodology to determine the most suitable global climate model (GCMs) and scenarios for four governorates (Kafr El-Sheik, El-Gharbia, El-Minia and Sohag). Two of these governorates, i.e. El-Gharbia, and Sohag are included in our analysis. In his methodology, he compared measured meteorological data with the projected data from four global climate models

Table 2.1 Latitude, longitude and elevation above sea level for the selected Governorates

Governorate	Latitude (°)	Longitude (°)	Elevation above sea level (m)
<i>North Egypt</i>			
North Sinai	32.07	33.45	17.10
Marsa Matrouh	31.30	27.20	7.00
<i>Nile Delta</i>			
El-Gharbia	30.36	31.01	17.90
El-Sharkia	30.35	31.30	13.00
<i>Upper Egypt</i>			
Sohag	26.36	31.38	68.70

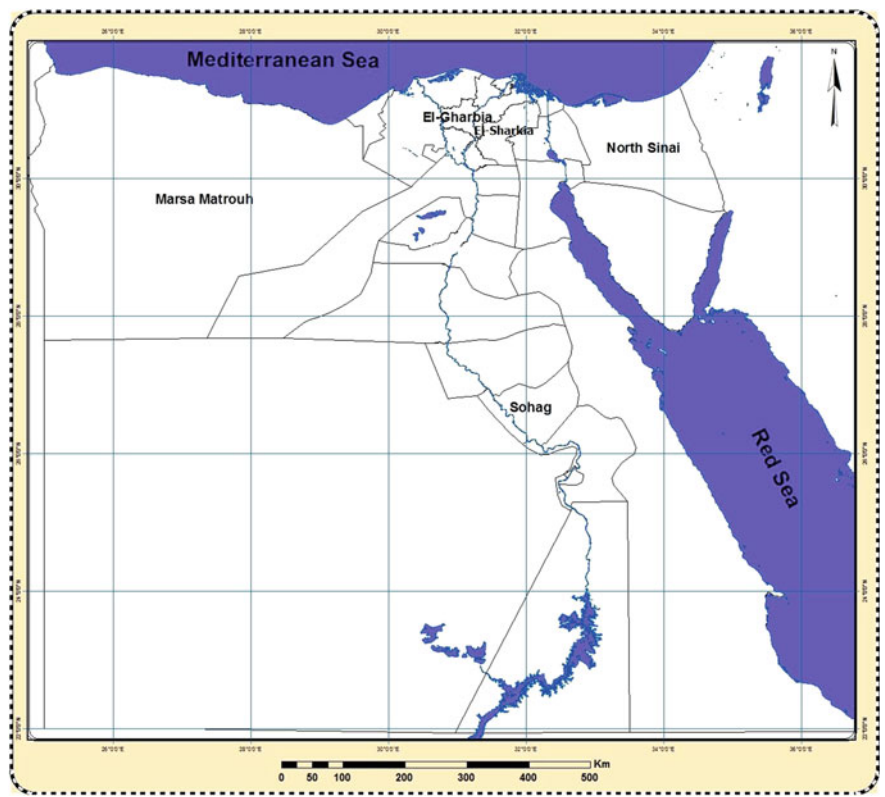


Fig. 2.1 Map of the selected governorates in Egypt

Table 2.2 Monthly PET values (mm/day) for the selected governorates

	Marsa Matrouh	North Sinai	El-Gharbia	El-Sharkia	Sohag
January	2.5	2.4	2.7	2.8	3.0
February	3.0	2.9	3.4	3.8	4.0
March	3.7	3.6	4.4	4.5	5.1
April	4.7	4.6	5.4	5.9	6.5
May	5.6	5.4	6.5	6.6	7.5
June	6.5	6.2	7.2	7.3	8.5
July	6.9	6.4	7.5	7.6	8.2
August	6.5	6.1	6.9	7.3	7.8
September	5.4	5.2	6.2	6.3	7.4
October	3.9	3.9	4.5	4.9	5.5
November	2.9	2.9	3.2	3.2	4.0
December	2.5	2.4	2.8	2.8	3.0
Average	4.5	4.3	5.1	5.3	5.9

represented by its four RCPs scenarios during the period from 2006 to 2012. His results indicated that RCP6.0 scenario from CCSM4 model was more accurate to project the meteorological and climate variables because it achieved the closest values of goodness of fit test. Thus, we will use his results for El-Gharbia, and Sohag and we followed his procedure for the rest of the five studied governorates. His procedure is explained in details in the following section.

CMIP5 Global Climate Models

The selected four models have differing levels of sensitivity to Green House Gases (GHG) forcing, which focused on daily RCPs climate change scenarios. The selected models are listed in Table 2.3.

Each model produces four RCPs scenarios to represent a larger set of mitigation scenarios and have different targets in terms of radiative forcing in 2100. Each RCP defines a specific emissions trajectory. The emission pathway of RCP2.6 is representative of scenarios in the literature that lead to very low greenhouse gas concentration levels. It is a “peak-and-decline” scenario, where its radiative forcing level first reaches a value of around 3.1 W/m^2 by mid-century, and returns to 2.6 W/m^2 by 2100. In order to reach such radiative forcing levels, greenhouse gas emissions and indirectly emissions of air pollutants are reduced substantially over time (Van Vuuren et al. 2006, 2007). Regarding to RCP4.5, it is a stabilization scenario, in which total radiative forcing is stabilized shortly after 2100, without overshooting the long run radiative forcing target level (Smith and Wigley 2006; Clarke et al. 2007; Wise et al. 2009). Furthermore, RCP6.0 is a stabilization scenario, in which total radiative forcing is stabilized shortly after 2100, without overshoot, by the application of a range of technologies and strategies for reducing

Table 2.3 List of selected CMIP5 GCM models and their horizontal resolutions

Model	Institution	Horizontal resolution
BCC-CSM1-1	Beijing Climate Center, China Meteorological Administration, China	$2.80^\circ \times 2.80^\circ$
CCSM4	National Centre for Atmospheric Research (NCAR), Community Climate System Model, USA	$1.25^\circ \times 0.94^\circ$
GFDL-ESM2G	National Oceanic and Atmospheric Administration (NOAA), Geophysical Fluid Dynamics Laboratory (GFDL), USA	$2.02^\circ \times 2.00^\circ$
MIROC5	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology, Japan	$1.40^\circ \times 1.40^\circ$

greenhouse gas emissions (Fujino et al. 2006; Hijioka et al. 2008). With respect to RCP8.5, it is characterized by increasing greenhouse gas emissions over time, where it is representative of scenarios in the literature that lead to high greenhouse gas concentration levels (Riahi et al. 2007).

Statistical Analysis

Goodness of fit test between the measured and projected meteorological data (solar radiation, maximum, minimum temperatures and wind speed) by the RCPs for selected governorates was done using the following tests.

Willmott Index of Agreement (d-stat)

It is the standardized measure of the degree of model prediction error which varies between 0 and 1. A value of 1 indicates a perfect match, and value of 0 indicates no agreement at all (Willmott 1981).

$$d - stat = 1 - \frac{\sum_{i=1}^n (O_i - S_i)^2}{\sum_{i=1}^n \left[(|S_i - \bar{O}| + |O_i - \bar{O}|)^2 \right]} \quad (2.1)$$

where O_i , $\bar{O}$ and S_i represent the observed, observed average and simulated values.

Coefficient of Determination (R^2)

R^2 tells us how much better we can do in predicting observation by using the model and computing the simulation by just using the mean observation as a predictor (Jamieson et al. 1998).

$$R^2 = 1 - \frac{\sum_{i=1}^n (O_i - S_i)^2}{\sum_{i=1}^n (O_i - \bar{O})^2} \quad (2.2)$$

R^2 ranges from 0 to 1, with higher values indicating less error variance, and typically values greater than 0.5 are considered acceptable (Santhi et al. 2001; Van Liew et al. 2003; Moriasi et al. 2007).

Root Mean Square Error Per Observation (RMSE/Obs)

It gives the general standard deviation of the model prediction error per observation (Jamieson et al. 1998).

$$RMSE/obs = \sqrt{\left(\frac{\sum_{i=1}^n (S_i - O_i)^2}{n}\right)}$$
 (2.3)

where n represents the number of observed and simulated values used in comparison.

The Averages of the Goodness of Fit Test

Regarding to North Sinai governorate, the averages of goodness of fit test for each RCP scenario from the selected four GCMs models are shown in Table 2.4. The results revealed that RCP6.0 scenario from CCSM4 model was suitable and more accurate to project the meteorological and climate variables because it achieved the highest d-stat, R² and the lowest RMSE/obs.

With respect to Marsa Matrouh, the averages of the goodness of fit tests for each RCP scenario of the four GCMs models are shown in Table 2.5. Similar results were found, where RCP6.0 scenario from CCSM4 model has the highest d-stat and R² values and lowest RMSE/obs value.

Regarding to El-Gharbia governorate (Table 2.6), the goodness of fit test revealed that RCP6.0 climate change scenario developed by CCSM4 model produced the highest d-stat and R² values and the lowest RMSE/obs values.

Table 2.4 Goodness of fit test between measured and projected meteorological data by the four models in North Sinai governorate

	BCC-CSM1-1 model			CCSM4 model		
	d-stat	R ²	RMSE/obs	d-stat	R ²	RMSE/obs
RCP2.6	0.897	0.758	0.159	0.918	0.759	0.134
RCP4.5	0.906	0.778	0.150	0.920	0.766	0.133
RCP6.0	0.904	0.777	0.153	0.923	0.779	0.131
RCP8.5	0.909	0.787	0.150	0.922	0.768	0.131
	GFDL model			MIROC5 model		
	d-stat	R ²	RMSE/obs	d-stat	R ²	RMSE obs
RCP2.6	0.867	0.671	0.185	0.905	0.710	0.142
RCP4.5	0.864	0.658	0.187	0.902	0.697	0.144
RCP6.0	0.850	0.633	0.199	0.909	0.720	0.139
RCP8.5	0.865	0.671	0.188	0.897	0.686	0.147

Table 2.5 Goodness of fit between measured and projected weather data by the four models in Marsa Matrouh governorate

	BCC-CSM1-1 model			CCSM4 model		
	d-stat	R ²	RMSE/obs	d-stat	R ²	RMSE/obs
RCP2.6	0.920	0.757	0.148	0.926	0.770	0.137
RCP4.5	0.922	0.767	0.144	0.922	0.762	0.138
RCP6.0	0.925	0.775	0.141	0.927	0.776	0.136
RCP8.5	0.851	0.770	0.203	0.923	0.764	0.138
	GFDL model			MIROC5 model		
	d-stat	R ²	RMSE/obs	d-stat	R ²	RMSE/obs
RCP2.6	0.900	0.707	0.166	0.921	0.757	0.145
RCP4.5	0.898	0.699	0.169	0.919	0.751	0.147
RCP6.0	0.899	0.710	0.172	0.922	0.762	0.144
RCP8.5	0.900	0.709	0.169	0.924	0.764	0.143

Table 2.6 Averages goodness of fit test between measured and projected weather data by the four models in El-Gharbia governorate

	BCC-CSM1-1 model			CCSM4 model		
	d-stat	R ²	RMSE/obs	d-stat	R ²	RMSE/obs
RCP2.6	0.845	0.667	0.232	0.886	0.700	0.211
RCP4.5	0.845	0.683	0.227	0.882	0.685	0.211
RCP6.0	0.849	0.688	0.227	0.888	0.702	0.206
RCP8.5	0.852	0.692	0.225	0.883	0.691	0.211
	GFDL model			MIROC5 model		
	d-stat	R ²	RMSE/obs	d-stat	R ²	RMSE/obs
RCP2.6	0.844	0.653	0.238	0.840	0.657	0.227
RCP4.5	0.845	0.657	0.238	0.845	0.668	0.225
RCP6.0	0.846	0.655	0.241	0.845	0.670	0.225
RCP8.5	0.849	0.668	0.236	0.846	0.673	0.223

In El-Sharkia governorate, the same trend was obtained for goodness of fit test, where RCP6.0 developed by CCSM4 model produced the highest d-stat and R² values and the lowest RMSE/obs values (Table 2.7).

Furthermore, the same trend was found for Sohag governorate, where RCP6.0 developed by CCSM4 model produced the highest d-stat and R² values and the lowest RMSE/obs values (Table 2.8).

The results existed in Tables 2.4, 2.5, 2.6, 2.7 and 2.8) clearly showed that the RCP6.0 scenario from CCSM4 model will be suitable for the studied governorates. Thus, we use the RCP6.0 from CCSM4 model as initial and lateral boundary conditions to the regional climate model WRF-RCM for regional climate studies over Egypt.

Table 2.7 Goodness of fit test between measured and projected weather data by the four models in El-Sharkia governorate

	BCC-CSM1-1 model			CCSM4 model		
	d-stat	R ²	RMSE/obs	d-stat	R ²	RMSE/obs
RCP2.6	0.881	0.709	0.200	0.915	0.755	0.183
RCP4.5	0.885	0.726	0.193	0.912	0.740	0.182
RCP6.0	0.887	0.729	0.193	0.918	0.757	0.177
RCP8.5	0.891	0.737	0.191	0.913	0.746	0.183
	GFDL model			MIROC5 model		
	d-stat	R ²	RMSE/obs	d-stat	R ²	RMSE obs
RCP2.6	0.876	0.702	0.208	0.893	0.718	0.184
RCP4.5	0.877	0.704	0.209	0.897	0.727	0.181
RCP6.0	0.877	0.705	0.212	0.898	0.729	0.181
RCP8.5	0.880	0.716	0.206	0.899	0.734	0.179

Table 2.8 Goodness of fit test between measured and projected weather data by the four models in Sohag governorate

	BCC-CSM1-1 model			CCSM4 model		
	d-stat	R ²	RMSE/obs	d-stat	R ²	RMSE/obs
RCP2.6	0.854	0.594	0.224	0.872	0.645	0.205
RCP4.5	0.857	0.606	0.217	0.869	0.640	0.203
RCP6.0	0.860	0.609	0.216	0.876	0.655	0.198
RCP8.5	0.860	0.610	0.219	0.874	0.654	0.200
	GFDL model			MIROC5 model		
	d-stat	R ²	RMSE/obs	d-stat	R ²	RMSE/obs
RCP2.6	0.852	0.597	0.220	0.859	0.625	0.222
RCP4.5	0.855	0.610	0.216	0.866	0.639	0.216
RCP6.0	0.857	0.613	0.221	0.860	0.626	0.222
RCP8.5	0.863	0.633	0.211	0.866	0.642	0.217

WRF-RCM Model

WRF-RCM model is a regional climate model used to study specific areas in more details. The recent version of WRF (3.7.1) was released in August 14, 2015. WRF-RCM is a result of a multiagency collaboration, consisting mostly of the National Center for Atmospheric Research (NCAR), the National Center for Environmental Prediction (NCEP), the Forecast Systems Laboratory (FSL), the Air Force Weather Agency (AFWA), the Naval Research Laboratory (NRL), Oklahoma University, and the Federal Aviation Administration (FAA). The model is updated each year, sometimes few times a year, and a new version made public (Caldwell et al. 2009; Qian et al. 2010; Bukovsky and Karoly 2009; Bell et al. 2004).

Table 2.9 Average of goodness of fit values between measured and projected values for climate parameters from WRF-RCM and CCSM4-RCP6.0

Locations	WRF-RCM model			CCSM4 model		
	d-stat	R ²	RMSE/obs	d-stat	R ²	RMSE/obs
North Sinai	0.962	0.877	0.090	0.910	0.727	0.138
Marsa Matrouh	0.960	0.905	0.099	0.922	0.784	0.137
El-Gharbia	0.969	0.899	0.104	0.926	0.770	0.165
El-Sharkia	0.969	0.898	0.104	0.924	0.768	0.168
Sohag	0.969	0.898	0.106	0.922	0.744	0.165

Weather data for the same period of time, i.e. 2006–2012 was predicted by WRF-RCM model and compared to the measured metrological data. The same statistical analysis was also used to test the goodness of fit between the measured and projected data. The results in Table 2.9 indicated that the predictions of WRF-RCM model were more close to the measured weather data. The values of d-stat were between 0.956 and 0.969 for WRF-RCM model, whereas it was between 0.910 and 0.926 for CCSM4 model. Similarly, R² values for WRF-RCM model was higher than its counterpart for CCSM4 (0.866–0.969 vs. 0.727–0.784). Furthermore, the lowest RMSE/obs was obtained by WRF-RCM model when it was compared to the measured metrological data.

The above results implied that WRF-RCM model has high potentiality to be more accurate in projecting climate variables at all studied governorates. Furthermore, the results also suggested that the model can be used in simulating and projecting climate variables under varied situations with high accuracy and efficiency. Thus, the above results provide a general evaluation of the WRF-RCM model for prediction of climate variables over different locations in Egypt with different latitudes and longitudes. For that reason, the WRF-RCM model was used to predict weather data in 2030 to assess the effect of climate change on PET values more accurately with higher certainty.

Projected Weather Data and PET Values in 2030

The weather elements in 2030 were projected for the five studied governorates by WRF-RCM model. These data were solar radiation (SR, MJ/m²/day), maximum temperature (T-Max, °C), minimum temperature (T-Min, °C) and wind speed (WS, m/s). BISm model was used to calculate PET (mm/day) values in the studied governorates in 2030. The above values are presented in Tables 2.10, 2.11, 2.12, 2.13 and 2.14.

The results in Tables 2.10 and 2.11 illustrated the projected weather element in North Sinai and Marsa Matrouh in 2030. As a result of being located on the Mediterranean Sea, weather elements and PET values was the lowest in all Egypt.

Table 2.10 Monthly mean values for climate elements projected by WRF-RCM model and PET in 2030 in North Sinai governorate

	SR (MJ/m ² /day)	T-Max (°C)	T-Min (°C)	WS (m/s)	PET (mm/day)
January	12.2	18.2	15.4	5.2	2.4
February	17.1	18.2	15.2	4.4	2.9
March	21.9	19.7	15.0	4.5	3.7
April	25.3	22.8	17.4	3.5	4.7
May	28.5	26.0	18.6	3.8	5.5
June	30.2	28.6	22.0	3.0	6.3
July	29.5	31.6	25.0	3.0	6.5
August	27.2	31.8	26.2	3.2	6.2
September	24.0	30.8	25.7	3.6	5.4
October	19.0	26.7	23.0	4.1	4.0
November	14.4	23.4	20.8	3.6	3.0
December	11.9	19.9	17.3	3.9	2.2

Table 2.11 Monthly mean values for climate elements projected by WRF-RCM model and PET in 2030 in Marsa Matrouh governorate

	SR (MJ/m ² /day)	T-Max (°C)	T-Min (°C)	WS (m/s)	PET (mm/day)
January	12.9	17.4	11.9	4.5	2.7
February	17.4	17.7	12.2	4.5	3.1
March	22.6	17.7	12.4	4.1	3.6
April	26.2	21.0	14.8	3.7	4.6
May	28.8	23.0	16.8	4.0	5.3
June	29.7	27.1	20.4	4.1	6.2
July	29.7	30.5	23.6	4.4	6.9
August	27.2	30.3	23.9	4.2	6.4
September	23.8	27.5	22.3	4.3	5.3
October	19.1	24.8	19.2	3.7	4.1
November	12.8	22.0	16.9	3.9	3.0
December	11.8	18.4	13.4	4.1	2.6

Tables 2.12 and 2.13 showed projected weather elements in 2030, as well as PET values in two Nile Delta governorates. El-Gharbia located in the middle of the Nile Delta and El-Sharkia is located in the north east of Nile Delta. Higher values of weather elements and PET are found in these governorates.

The projected values of weather elements for Sohag governorate, as well as PET values are presented in Table 2.14. These values are the highest, compared to the values of the rest of the studied governorate.

Table 2.12 Monthly mean values for climate elements projected by WRF-RCM model and PET in 2030 in El-Gharbia governorate

	SR (MJ/m ² /day)	T-Max (°C)	T-Min (°C)	WS (m/s)	PET (mm/day)
January	12.7	20.3	8.5	2.5	2.8
February	17.5	21.7	8.8	2.6	3.5
March	22.7	23.8	10.6	2.9	4.6
April	25.9	29.0	13.7	2.8	6.0
May	29.2	33.1	16.2	3.1	6.9
June	29.9	37.0	21.1	3	8.2
July	29.4	39.2	23.4	2.8	8.4
August	26.9	39.6	23.5	2.9	8.2
September	23.7	34.9	21.8	2.8	6.7
October	19.9	30.8	17.8	2.5	4.9
November	15.0	25.2	13.8	2.5	3.5
December	12.5	19.9	9.6	2.4	2.8

Table 2.13 Monthly mean values for climate elements projected by WRF-RCM model and PET in 2030 in El-Sharkia governorate

	SR (MJ/m ² /day)	T-Max (°C)	T-Min (°C)	WS (m/s)	PET (mm/day)
January	12.7	20.3	8.5	2.5	2.8
February	17.5	21.7	8.8	2.5	3.5
March	22.7	23.8	10.6	2.8	4.6
April	25.9	29.0	13.7	2.7	6.0
May	29.2	33.1	16.2	3.0	6.9
June	29.9	37.0	21.1	2.9	8.2
July	29.4	39.2	23.4	2.6	8.4
August	26.9	39.6	23.5	2.8	8.2
September	23.7	34.9	21.8	2.7	6.7
October	19.9	30.8	17.8	2.5	4.9
November	15.0	25.2	13.8	2.4	3.5
December	12.5	19.9	9.6	2.4	2.8

Comparison Between Climate Normals and Its Values in 2030

Regarding to North Sinai, solar radiation (SR), maximum temperature (T-Max) and minimum temperature (T-Min) in 2030 will be slightly higher than its normal value in all the months. High variation in wind speed is expected to occur in 2030. It will be the highest in the winter months and lower than its normal values in June and July (Fig. 2.2). It is expected that these different trends will have its implication on PET values in 2030.

Table 2.14 Monthly mean values for climate elements projected by WRF-RCM model and PET in 2030 in Sohag governorate

	SR (MJ/m ² /day)	T-Max (°C)	T-Min (°C)	WS (m/s)	PET (mm/day)
January	17.0	22.6	8.8	2.9	3.6
February	21.1	24.0	10.6	3.1	4.4
March	25.0	28.2	12.7	3.8	5.6
April	27.3	34.4	18.2	3.5	7.2
May	29.8	37.8	21.8	3.6	7.9
June	30.8	41.3	24.9	4.6	9.1
July	30.0	41.4	25.9	3.5	9.2
August	28.3	41.9	26.4	4.4	9.3
September	26.7	38.9	23.2	4.4	8.3
October	21.7	34.0	20.2	3.1	6.3
November	16.9	28.8	15.5	3.3	4.8
December	15.5	23.3	10.2	3.0	3.6

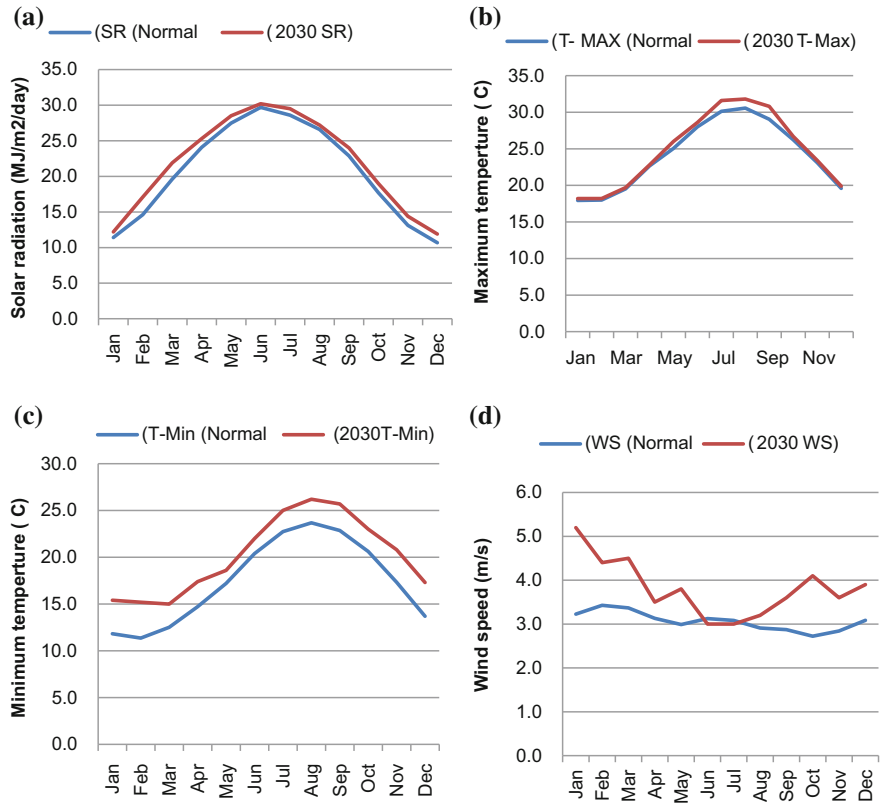


Fig. 2.2 Comparison between climate normals and its value in 2030 for **a** solar radiation, **b** maximum temperature, **c** minimum temperature and **d** wind speed in North Sinai governorate

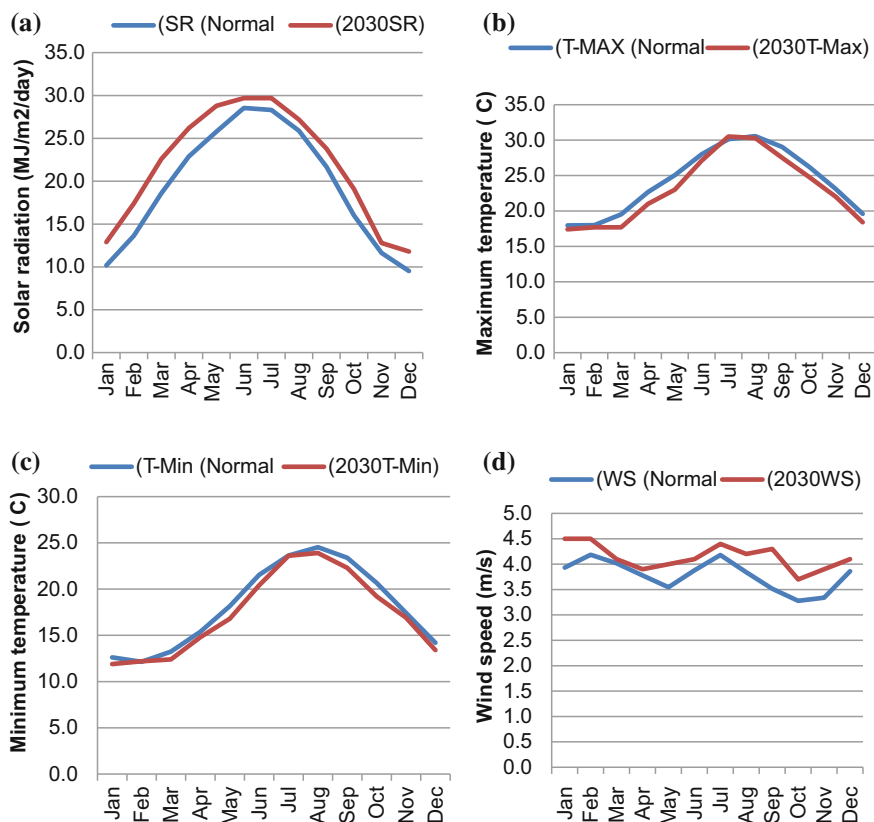


Fig. 2.3 Comparison between climate normals and its value in 2030 for **a** solar radiation, **b** maximum temperature, **c** minimum temperature and **d** wind speed in Marsa Matrouh governorate

Regarding to solar radiation, maximum temperature and minimum temperature in Marsa Matrouh in 2030, its trend was similar to the trend found in North Sinai, i.e. higher than normal values. Lower variation in wind speed will be exist in 2030, compared to its value in North Sinai, however it was higher than its normal values (Fig. 2.3).

Figure 2.4 indicated that in 2030, solar radiation will be higher in all months, whereas maximum temperature in El-Gharbia will be higher only in the summer months. Minimum temperature will be higher from January to August, and then it will be similar to normal minimum temperature. Highly variable trend will exist for wind speed in 2030, compared to its normal values.

Higher increase in the projected weather elements can be observed in 2030 in El-Sharkia governorate, where solar radiation, maximum temperature and minimum temperature will increase. Regarding to wind speed, a variable change will occur in 2030, compared to its normal values (Fig. 2.5).

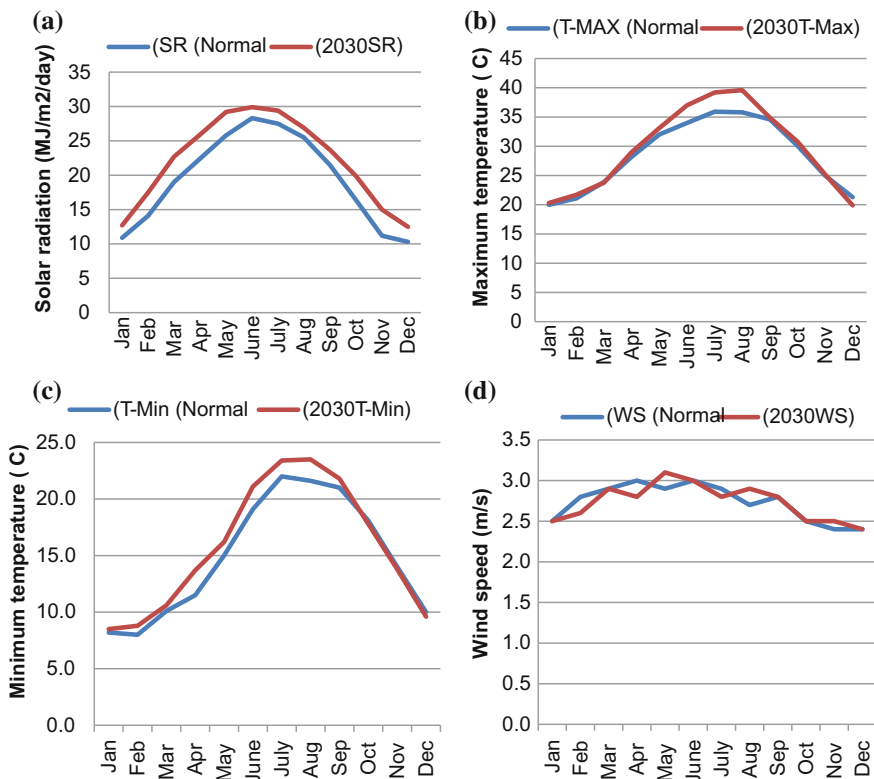


Fig. 2.4 Comparison between climate normals and its value in 2030 for **a** solar radiation, **b** maximum temperature, **c** minimum temperature and **d** wind speed in El-Gharbia governorate

Figure 2.6a–d showed that solar radiation, maximum temperature, minimum temperature and wind speed values will be higher in 2030 than its normal values in Sohag governorate. This could be attributed to its location in south of Egypt, where it will experience higher changes in weather elements in 2030.

Comparison Between Normal and Future PET Values

Figure 2.7a, b indicated that PET will slightly increase in 2030 in North Sinai and Marsa Matrouh governorates. This could marginally increase crops evapotranspiration values in these governorates. Because rain fed agriculture is prevailed there, the main weather element affects crops production is the availability of rain. Thus, the impact of climate change on rain fall in these two governments will be thoroughly analyzed in next chapter.

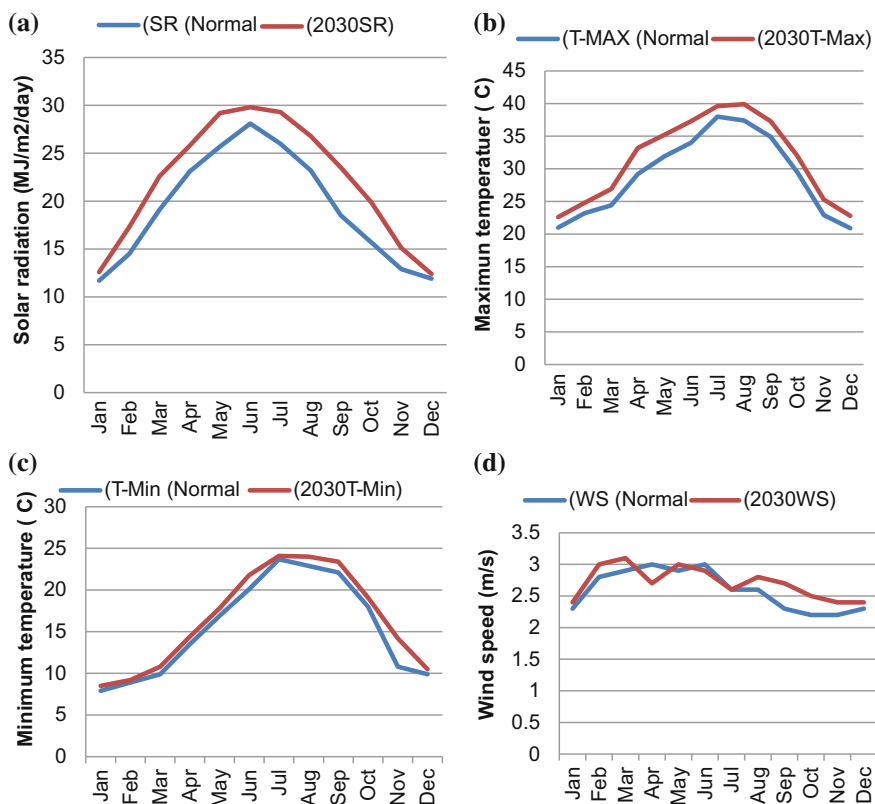


Fig. 2.5 Comparison between climate normals and its value in 2030 for **a** solar radiation, **b** maximum temperature, **c** minimum temperature and **d** wind speed in El-Sharkia governorate

Slight increase in PET values in winter months of 2030 can be noticed in El-Gharbia and El-Sharkia governorates, compared to normal PET values (Fig. 2.8a, b). Whereas, there will be higher increase in PET values in summer months of 2030 in both governorates.

Higher noticeable increase in PET values in Sohag governorate in 2030, compared to normal PET values will exist. These increases will occur in both winter and summer months, where it will be even higher in summer months (Fig. 2.9).

Table 2.15 showed that the percentage of difference between annual PET values calculated from climate normals and annual PET values in 2030. Our analysis showed that the annual PET value in Marsa Matrouh will not change in 2030. Furthermore, the lowest percentage of difference between normal PET and 2030 PET values was found for North Sinai and the highest percentage of difference was found in Sohag governorate, i.e. 2 and 13 % increase, respectively. Previous research by Ouda et al. (2016) revealed that percentage of increase in PET values in 2030 calculated by A1B climate change scenario developed by ECHAM5 model

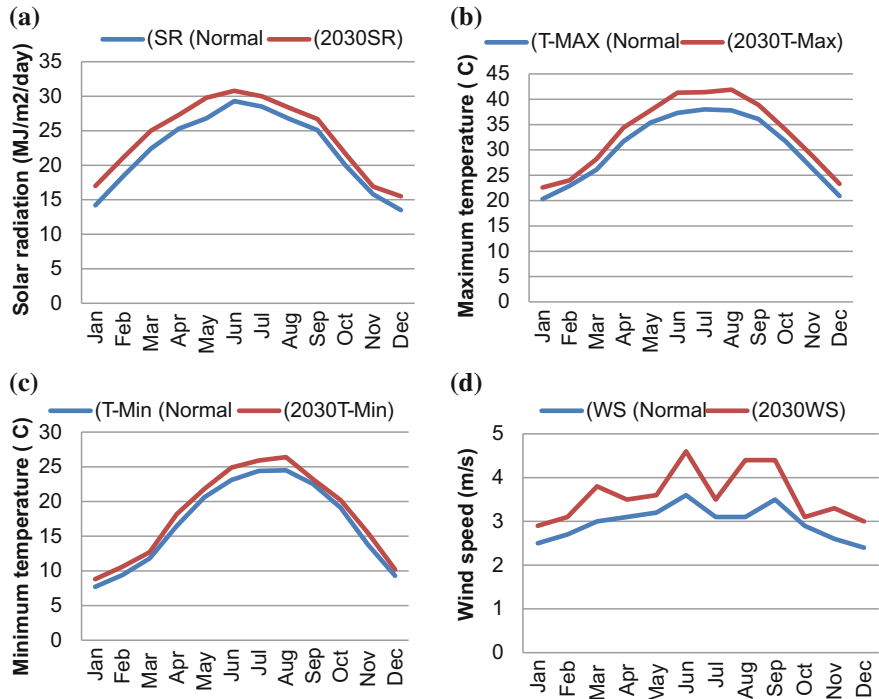


Fig. 2.6 Comparison between climate normals and its value in 2030 for **a** solar radiation, **b** maximum temperature, **c** minimum temperature and **d** wind speed in Sohag governorate

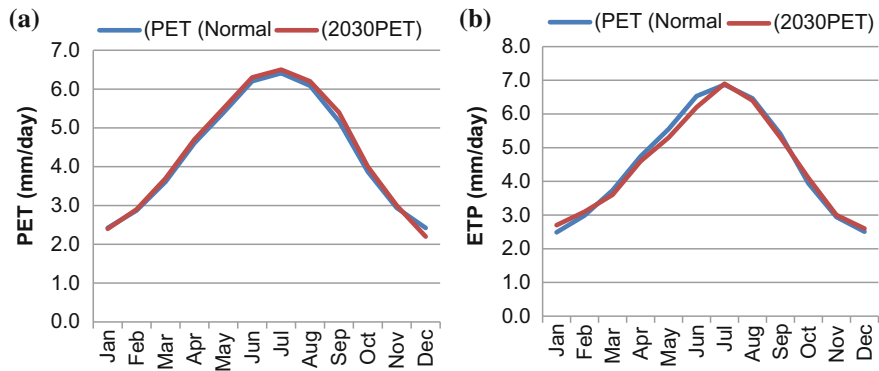


Fig. 2.7 Comparison between normal and future PET values in 2030 in North Sinai **(a)** and Marsa Matrouh **(b)**

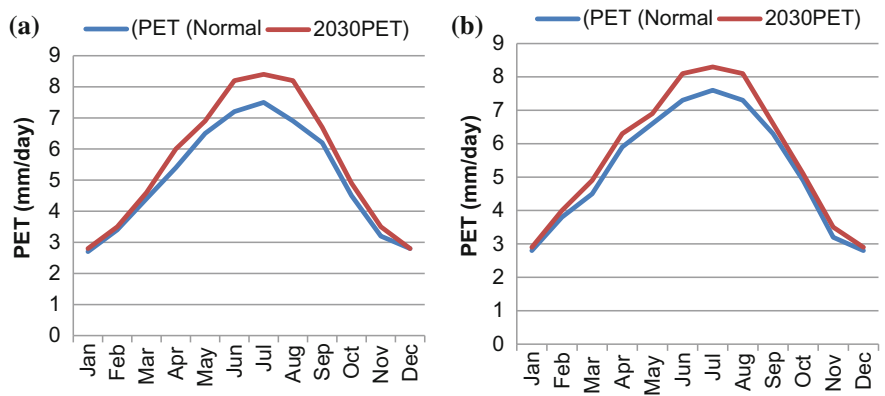


Fig. 2.8 Comparison between normal and future PET values in 2030 for in El-Gharbia (a) and El-Sharkia (b)

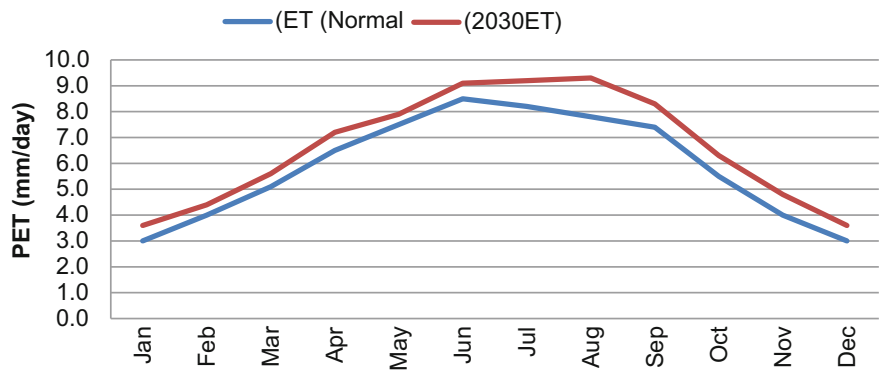


Fig. 2.9 Comparison between normal and future PET values in 2030 in Sohag governorate

Table 2.15 Comparison between annual PET value (mm/day) from climate normals, in 2030, percentage of difference between them (PD %) and percentage of difference using A1B in 2030 (PD1)

Location	PET (normals)	PET (2030)	PD (%)	PD1 (%)*
North Sinai	4.3	4.4	+2	–
Marsa Matrouh	4.5	4.5	0	–
El-Gharbia	5.3	5.6	+7	+10
El-Sharkia	5.1	5.5	+10	+10
Sohag	5.9	6.6	+13	+14

*Source Ouda et al. (2016)

was higher in El-Gharbia and Sohag and similar in El-Sharkia. Hopefully, this result will be an indication of higher accuracy by our methodology in the projection of the effect of climate change on PET values.

Conclusion

Accurate calculation for PET values is very important procedure to be done to improve water management on field level under irrigated agriculture. Due to the uncertainty associated with climate projection in the future, improvements should be developed to reduce these uncertainties. The implemented methodology in this chapter could be a base for projection of climate change effects on different economic sectors.

Our results revealed that the projection of PET values in 2030 using our methodology were lower than the value projected by Ouda et al. (2016) using A1B climate change scenario of ECHAM5 model for El-Gharbia and Sohag. Furthermore, the projected value of PET for El-Sharkia using our methodology was the same as the value projected by ECHAM5 model. Hopefully, this result will be an indication of higher accuracy by our methodology in projection of the effect of climate change on PET values.

References

- Abtew W, Melesse A (2013) Climate change and evapotranspiration. In: Evaporation and evapotranspiration: measurements and estimations. Springer Science Business Media, Dordrecht. doi:[10.1007/978-94-007-4737-113](https://doi.org/10.1007/978-94-007-4737-113)
- Allen RG, Jensen ME, Wright JL, Burman RD (1989) Operational estimate of reference evapotranspiration. *Agron J* 81:650–662
- Bell JL, Sloan LC, Snyder MA (2004) Regional changes in extreme climatic events: a future climate scenario. *J Clim* 17(1):81–87
- Blaney HF, Criddle WD (1950) Determining water requirements in irrigated areas from climatological and irrigation data. USDA/SCS, SCS-TP 96
- Bukovsky MS, Karoly DJ (2009) Precipitation simulations using wrf as a nested regional climate model. *J Appl Meteorol Climatol* 48(10):2152–2159
- Caldwell PM, Chin H-NS, Bader DC, Bala G (2009) Evaluation of a WRF dynamical downscaling simulation over California. *Clim Change* 95:499–521. doi:[10.1007/s10584-009-9583-5](https://doi.org/10.1007/s10584-009-9583-5)
- Clarke LE, Edmonds JA, Jacoby HD, Pitcher H, Reilly JM, Richels R (2007) Sub-report 2.1a of synthesis and assessment product 2.1. Climate Change Science Program and the Subcommittee on Global Change Research, Washington DC
- Eid HM (2001) Climate change studies on Egyptian agriculture. Soils, Water and Environment Research Institute (SWERI), Agricultural Research Center, Ministry of Agriculture, Giza, Egypt
- Fujino J, Nair R, Kainuma M, Masui T, Matsuoka Y (2006) Multi-gas mitigation analysis on stabilization scenarios using AIM global model. *Multi-gas Mitigation and Climate Policy. The Energy J Spec* 27:343–353

- Hargreaves GH, Samani ZA (1982) Estimating Potential Evapotranspiration. *J Irrig Drainage Div* 108(3):225–230
- Hargreaves GH, Samani ZA (1985) Reference crop evapotranspiration from temperature. *Trans of ASAE* 1(2):96–99
- Hijioka Y, Matsuoka Y, Nishimoto H, Masui M, Kainuma M (2008) Global GHG emissions scenarios under GHG concentration stabilization targets. *J Glob Environ Eng* 13:97–108
- IPCC (2013) Summary for policymakers. In: Stocker TF, Qin D, Plattner GK, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V and Midgley PM (eds) *Climate change. The physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change*, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA
- Jamieson PD, Porter JR, Goudriaan J, Ritchie JT, Keulen H, Stol W (1998) A comparison of the models AFRCWHEAT2, CERES-Wheat, Sirius, SUCROS2 and SWHEAT with measurements from wheat grown under drought. *Field Crops Res* 55:23–44
- Khalil AA (2013) Effect of climate change on evapotranspiration in Egypt. *Researcher* 5(1):7–12
- Kumar R, Jat MK, Shankar V (2012) Methods to estimate irrigated reference crop evapotranspiration—a review. *Water Sci Technol* 66(3):525–535. doi:[10.2166/wst.2012.191](https://doi.org/10.2166/wst.2012.191)
- Monteith JL (1965) Evaporation and environment. In: GE Fogg (ed), *Symposium of the society for experimental biology: The state and movement of water in living organisms*, vol 19. Academic Press, Inc., NY, pp. 205–234
- Moriasi DN, Arnold JG, Van Liew MW, Bingner RL, Harmel RD, Veith TL (2007) Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Am Soc Agric Biol Eng* 50(3):885–900
- Morsy M (2015) Use of regional climate and crop simulation models to predict wheat and maize productivity and their adaptation under climate change. PhD thesis. Faculty of Science Al-Azhar University
- Ouda S, Abd El-Latif K, Khalil F (2016) Water requirements for major crops. In: *Major crops and water scarcity in Egypt*. Springer Publishing House. pp 25–31. ISBN: 978-3-319-21770-3
- Qian Y, Ghan SJ, Leung LR (2010) Downscaling hydroclimatic changes over the Western US based on CAM subgrid scheme and WRF regional climate simulations. *Int J Climatol* 30:675–693
- Rao KPC, Ndegwa WG, Kizito K, Oyoo A (2011) Climate variability and change: farmer perceptions and understanding of intra-seasonal variability in rainfall and associated risk in semi-arid Kenya. *Exp Agric* 47:267–291
- Riahi K, Grübler A, Nakicenovic N (2007) Scenarios of long-term socioeconomic and environmental development under climate stabilization. *Greenhouse Gases-Integrated Assessment. Special Issue of Technological Forecasting and Social Change*, 74(7): 887–935. doi:[10.1016/j.techfore.2006.05.026](https://doi.org/10.1016/j.techfore.2006.05.026)
- Santhi C, Arnold JG, Williams JR, Dugas WA, Srinivasan R, Hauck LM (2001) Validation of the SWAT model on a large river basin with point and nonpoint sources. *J Am Water Resour Assoc* 37(5):1169–1188
- Shahid S (2011) Impact of climate change on irrigation water demand of dry season boro rice in Northwest Bangladesh. *Clim Change* 105:433–453. doi:[10.1007/s10584-010-9895-5](https://doi.org/10.1007/s10584-010-9895-5)
- Smith SJ, Wigley TML (2006) Multi-gas Forcing stabilisation with the MiniCAM. *The Energy J Spec Issue* 3:373–392
- Snyder RL, Orang M, Bali K, Eching S (2004) Basic irrigation scheduling (BIS). http://www.waterplan.water.ca.gov/landwateruse/wateruse/Ag/CUP/Californi/Climate_Data_010804.xls
- Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt K, Tignor M, Miller H (eds) (2007) *Climate change 2007: the physical science basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp
- Van Liew MW, Arnold JG, Garbrecht JD (2003) Hydrologic simulation on agricultural watersheds: choosing between two models. *Trans Am Soc Agric Eng* 46(6):1539–1551

- Van Vuuren DP, Eickhout B, Lucas PL, den Elzen MGJ (2006) Long-term multi-gas scenarios to stabilise radiative forcing—exploring costs and benefits within an integrated assessment framework. Multi-gas mitigation and climate policy. *The Energy J Spec Issue* 27:201–233
- Van Vuuren DP, den Elzen MGJ, Lucas PL, Eickhout B, Strengers BJ, Van Ruijven B, Wonink S, Van Houdt R (2007) Stabilizing greenhouse gas concentrations at low levels: an assessment of reduction strategies and costs. *Clim Change* 81:119–159
- Wayne GP (2013) The beginner’s guide to representative Concentration pathways. Skeptical science, Version 1.0, http://www.skepticalscience.com/docs/RCP_Guide.pdf
- Willmott CJ (1981) On the validation of models. *Phys Geogr* 2:184–194
- Wise MA, Calvin KV, Thomson AM, Clarke LE, Bond-Lamberty B, Sands RD, Smith SJ, Janetos AC, Edmonds JA (2009) Implications of limiting CO₂ concentrations for land use and energy. *Science* 324:1183–1186

Management of Climate Induced Drought and Water
Scarcity in Egypt

Unconventional Solutions

Ouda, S.A.H.; Zohry, A.E.-H.

2016, IX, 100 p. 30 illus., 25 illus. in color., Softcover

ISBN: 978-3-319-33659-6