Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

p-ISSN: 0972-6268
e-ISSN: 2395-3454

Vol. 16 | No. 3 | pp. 953-958 | 2017

Original Research Paper | Open Access

Modelling Climate Change Impact on Crop Evapotranspiration

J. B. Kambale*, D. K. Singh and A. Sarangi****

*Department of Agricultural Engineering, AC, B'gudi, University of Agricultural Sciences, Raichur, India
**Water Technology Centre, IARI, New Delhi, India

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 08-09-2016
Accepted: 19-10-2016

Key Words:
Climate change
Trend analysis
ARIMA
Evapotranspiration
Crop water requirement

ABSTRACT

Global warming and climate change and its impact on crop water requirement are a major concern of this century. It has been established that the regional and global temperature is rising due to increased concentration of green house gases in the atmosphere. Rising temperature is expected to affect the crop water requirement. This study was undertaken to evaluate the trend and predict the changes in climate parameters, and assess the impact of climate change on crop water requirement using local weather data. Auto Regressive Integrated Moving Average (ARIMA) model was used for forecasting the future climate trend. Assessment of impact of climate change on crop water requirement was done for different climate change scenarios. Scenarios considered for assessment were based on ARIMA, Indian Network for Climate Change Assessment (INCCA) and Inter-Governmental Panel for Climate Change (IPCC) predictions. Crop water requirement of various crops would decrease by 7.5 to 14.2 mm by 2030s if it is determined using all important climatic parameters. Increase in water requirement varied from 13 to 77.5 mm for rice and 7.2 to 43.5 mm for pearl millet depending on the scenarios. Results indicate that crop water requirement did not increase if it was estimated using all important climatic parameters even though the average temperature increased during this period. However, if only rise in temperature is considered, crop water requirement would increase under all scenarios considered in this study.

INTRODUCTION

Irrigated agriculture is the largest user of water. Intensification and extensification of agriculture for increasing food production to meet the demand of a rapidly growing population in developing countries are expected to increase the irrigation water requirement in future. Increasing crop water requirement and decreasing water availability for irrigation will affect the food production in India. Climate change and its expected impact on irrigation water requirement, will further add to this problem.

Rice, wheat, maize, pearl millet, pigeon pea and mustard are important crops grown in many agro climatic zones in India. Goyal (2004) reported an increase of 14.8% in evapotranspiration (ET) with increase in temperature by 20%. He also reported that ET was less sensitive to solar radiation and wind speed compared to temperature. Increase in vapour pressure resulted in marginal decrease in ET. He further reported that 10% increase in temperature and vapour pressure coupled with 10% decrease in net solar radiation resulted in marginal decrease of total ET. He evaluated the effect of 10% increase in temperature with 10% decrease in net solar radiation, actual vapour pressure and wind velocity and reported marginal decrease in ET. Mahmood (1997) reported that 1°C increase and 1°C decrease in air temperature would result 5% increase and 4% decrease in total seasonal evapotranspiration respectively. Shahid (2011) evaluated the impact of climate change on crop water requirement in Bangladesh and reported that the irrigation requirement will increase by 0.8 mm day^{-1} by the end of this century in the north-west. Fischer et al. (2007) reported that the daily water requirement would increase due to warming, changed precipitation patterns and extended crop calendars in temperate and subtropical zones.

Doria & Madramootoo (2009) assessed the impact of climate change on the crop water requirement in southern Quebec. They considered three sets of extreme climate scenarios (i.e. dry, normal and wet conditions) to simulate its impact on irrigation water requirements and found that irrigation water requirement of vegetable crops increased by 40-100% and that of potatoes by 80% during a dry year as compared to a normal year. The increase in temperature predicted by climate change could potentially increase agricultural water demands by up to 17% in the West Bank (Mizyed 2009).

De Silva et al. (2007) reported that potential evapotranspiration increased by 3.5% to 5.0% and as a result average paddy water requirement increased by 23.0% and 13.0% in Sri Lanka. Yano et al. (2007) studied the effects of climate change on crop growth and irrigation water demand for a wheat-maize cropping sequence in a Mediterranean environment of Turkey and reported that actual evapotranspiration (ETa) from wheat cropland would decrease by 28% and 8% during 2070 and 2079 respectively, if CO_2 concentration is doubled relative to the baseline period. Both ETa and irrigation water for maize cropland was projected to decrease by 24 and 15% and 28 and 22% respectively.

Rodriguez et al. (2007) studied the impacts of climate change on the irrigation requirements in the Guadalquivir river basin in Spain and reported an increase of 15% and 20% in seasonal irrigation need by 2050 depending on location and cropping pattern, coupled with changes in seasonal timing of demand. In a study carried out in California Central Valley, Ficklin et al. (2010) reported that an increase in temperature caused a temporal shift in plant growth pattern, redistributed evapotranspiration and irrigation water use earlier in the growing season.

Shahid (2011) evaluated the impact of temperature rise and irrigation demand of *Boro* rice in Bangladesh. He reported increase in evapotranspiration and decrease in number of irrigation days. This necessitates the detailed analysis of these contrary facts on irrigation water demand. Durand (2005) studied the impact of climate change on crop water use in South Africa. He concluded that the future crop water use in these areas would be affected by climate change as well as by the effect of climate change on runoff in the catchment areas of the river. Chattopadhay & Hulme (1997) did an assessment of evaporation and potential evapotranspiration in India under conditions of recent and future climate change. They analysed the evaporation time series data for different stations and country as a whole. They reported that both, pan evaporation and evapotranspiration decreased during 1961 to 1992 in various regions of India. They attributed this to increase in relative humidity as dominant controlling factor for evaporation which counterbalanced the effect of rise in temperature. Similar observations were also made by Peterson et al. (1995). However, they attributed decrease in ET to increased cloud cover which had implications on solar radiation.

Ziad & Siren (2010) studied the impacts of climate change on agricultural water demand and reported that irrigation demand would increase by $2.9 \times 10^6 m^3 yr^{-1}$ if temperature rise of 3°C is accompanied by 20% decrease in precipitation levels. Doll (2002) conducted a global analysis of the impact of climate change and climate variability on irrigation water requirements and reported that the irrigation requirement in two-thirds of the global area having irrigation facilities would increase.

Reviews presented above, suggest a varying effect of climate change on the crop water requirement. The projections in expected change in the crop water requirement have normally been made using IPCC predictions on temperature rise. Few studies have been conducted to evaluate the climate change impact on crop water requirement using local weather data. In many of these studies, effects of climate change on crop water requirement have been evaluated using only few climatic parameters. Crop water requirement depends on local climatic conditions and is controlled by temperature, relative humidity, wind speed and sunshine hours in addition to length of growing period and physiological processes such as photosynthesis.

There are very few studies which evaluated the impact of climate change on the crop water requirement in terms of variation in these parameters. The present study was undertaken to evaluate the climate change trend and predict the changes in climatic parameters, and assess their impact on crop water requirement.

MATERIALS AND METHODS

Analysis was carried out using weather data obtained from two meteorological observatories namely IARI and Palam located in National Capital Territory (NCT), Delhi. NCT is part of National Capital Region (NCR) of India. It lies between latitude 28°362'363" N and longitude 77°132'483" E. It is situated in Trans-Gangetic plains region and has a semi-arid climate. The normal annual rainfall is 730 mm. January is the coldest month with the mean daily maximum temperature of 21.3°C and the mean daily minimum of 7.3°C. May and June are the hottest months. In May and June, maximum temperature goes up to 47°C. The values of weather parameters such as maximum and minimum air temperature, relative humidity, sunshine hours, wind speed and total rainfall were collected from India Meteorological Department (IMD), Pune and Indian Agricultural Research Institute (IARI), New Delhi.

The study included predictions of climate using Auto Regressive Integrated Moving Average (ARIMA) model and estimation of evapotranspiration and crop water requirement under various climate change scenarios.

Auto regressive integrated moving average (ARIMA): ARIMA is a mathematical model for time series analysis of data and forecasting (Box & Jenkins 1970). ARIMA model consists of the autoregressive, integrated and moving average parts. It has three major parts: the autoregressive (or AR) part; the integrated (or I) part; and the moving average (or MA) part. The model is represented as ARIMA (p, r, q) where, p explains the AR part, r explains the integrated part and q explains the MA part.

AR: This part describes the relationship of each observation as a function of the previous p observations. If p = 1, then each observation is a function of only one previous observation. That is,

$$Y_t = c + \varphi_1 Y_{t-1} + e_t$$

Where, Y_t represents the observed value at time t, Y_{t-1} represents the previous observed value at time t-1, e_t represents some random error and c and φ_1 are both constants. Other observed values of the series can be included in the right-hand side of the equation if p > 1:

$$Y_t = c + \varphi_1 Y_{t-1} + \varphi_2 Y_{t-2} + \cdots + \varphi_p Y_{t-p} + e_t$$

I: This part of the model identifies if the observed values are modelled directly, or differences between consecutive observations were modelled. If d = 0, the observations are modelled directly. If d = 1, the differences between consecutive observations are modelled. If d = 2, the differences of the differences are modelled. In reality, d is rarely more than 2.

MA: This part of the model identifies the relationship between observation and previous q errors. If q = 1, each observation is a function of only one previous error. That is,

$$Y_t = c + \theta_1 e_{t-1} + e_t$$

Here, e_t is the random error at time t and e_{t-1} is the previous random error at time t-1. Other errors can be included in the right-hand side of the equation if q > 1.

CROPWAT 8.0: CROPWAT 8.0 is a decision support system developed by the Land and Water Development Division of FAO. CROPWAT can estimate reference evapotranspiration, crop water requirements and irrigation requirements. It can also be used to evaluate the effect of variations in climatic parameters on crop water requirement and assess the impact of climate change. The major input requirements of CROPWAT model include crop parameters, meteorological data and soil type. The required meteorological data are maximum and minimum temperature, wind speed, sunshine hours, relative humidity and rainfall. CROPWAT uses Penman-Monteith explicit equation to determine the reference evapotranspiration (ET_0). One of the major advantages of CROPWAT is that most of the parameters are directly measured or can readily be calculated from weather data.

CROPWAT was used to estimate the ET_0. Crop water requirement of rice, pearl millet, pigeon pea (*arhar*), maize, wheat and mustard, were estimated for each year starting from 1981-2009 using ET_0, crop coefficients and number of growing days. The crop coefficients and stages of crop development are presented in Table 1 and Table 2 respectively.

CROPWAT was also used to predict future crop water requirement under predicted climate change scenarios.

Table 1: Crop coefficients at different growth stages.

Crops	Initial	Mid-season	Late season
Wheat	0.28	1.15	0.42
Mustard	0.4	1.3	0.41
Maize	0.35	1.27	0.67
Pigeon pea	0.4	1.15	0.35
Rice	1.1	1.3	0.82
Pearl millet	0.27	1.09	0.55

Table 2: Stages of development for different crops.

Crops	Planting date	Stages of development				
		Initial	Development	Mid-season	Late	Total
Wheat	15-Nov	15	25	50	30	120
Mustard	15-Nov	30	20	45	25	120
Maize	01-Jul	20	35	40	30	125
Pigeon pea	01-Jul	25	30	50	20	125
Rice	01-Jul	20	30	40	30	120
Pearl millet	01-Jul	15	35	30	25	105

Table 3: Climate change scenarios considered for prediction of crop water requirement.

Scenarios	Descriptions
Reference	Average of 1990s weather parameters
	Predictions for 2030s using local weather data
1	Increase in average temperature by 0.26°C, and relative humidity by 4% and decrease in wind speed 5.15 (km day-[1]) and sunshine hours by 0.26
	INCCA scenarios for 2030s
2	Increase in average temperature 1.7°C
3	Increase in average temperature 2.0°C
	IPCC scenarios for 2100s
4	Increase in average temperature 1.1°C
5	Increase in average temperature 1.4°C
6	Increase in average temperature 2.9°C
7	Increase in average temperature 3.8°C
8	Increase in average temperature 5.4°C
9	Increase in average temperature 6.4°C

Climate change predictions done by ARIMA (using local long-term weather data), Indian Network for Climate Change Assessment (INCCA) and Inter-Governmental Panel for Climate Change (IPCC) were used to predict future crop water requirement. Climate change scenarios considered are presented in Table 3. Reference scenarios consisted of average values of parameters for the duration of 1981-2009. This was termed as weather parameters of 1990s. Water requirement for different scenarios were compared to evaluate the impact of climate on it.

RESULTS AND DISCUSSION

Climate forecast using ARIMA: ARIMA model was used for forecasting of variations in climatic parameters using

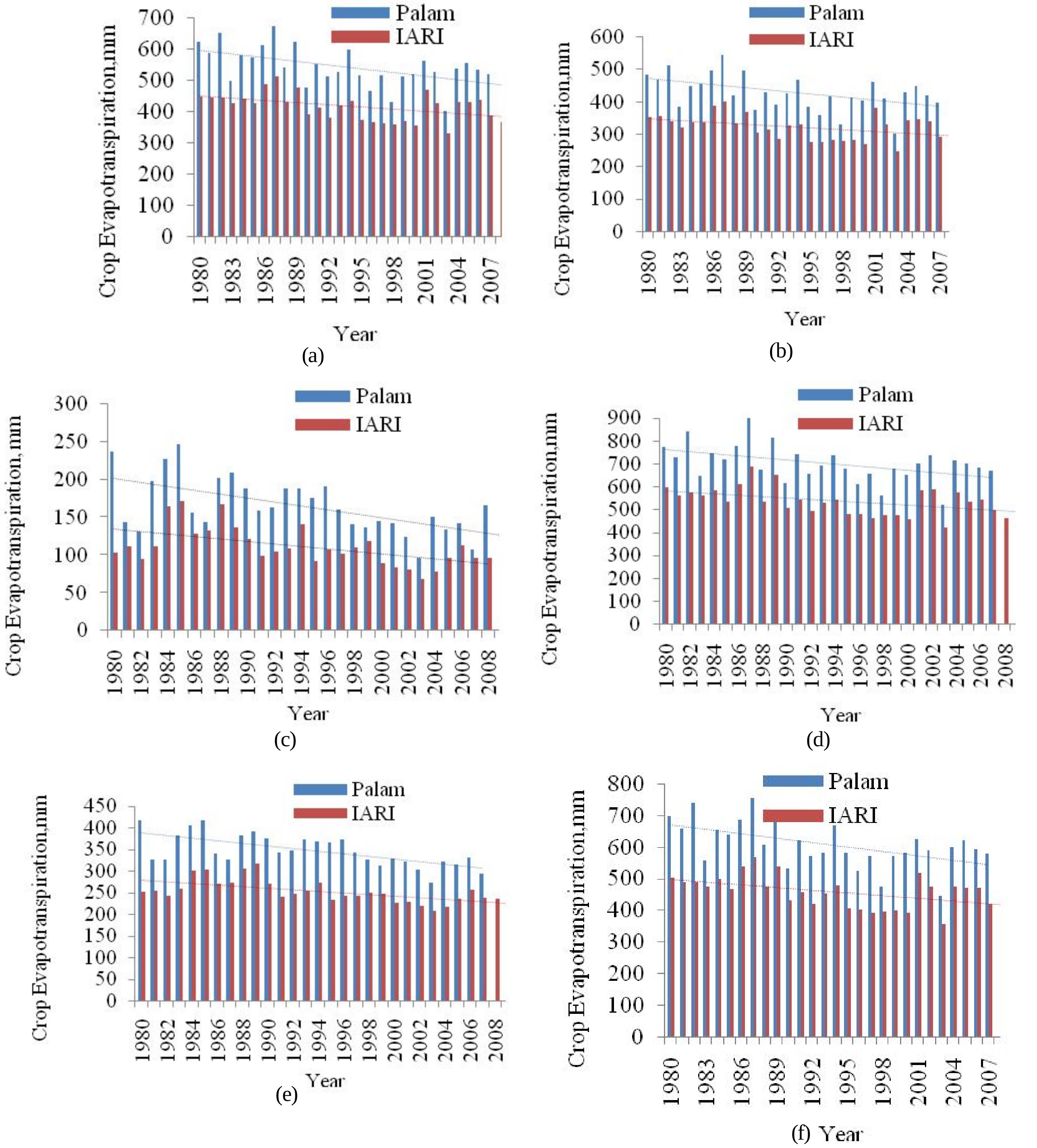

Fig. 1: Crop water requirements of (a) pigeon pea, (b) pearl millet, (c) mustard, (d) rice, (e) wheat and (f) maize.

the data of about 35 years. The data of both stations mentioned earlier were used in the analysis. The time series data were used to predict the variations during the same period and correlate it with the observed data. Based on this, ARIMA was used to make a forecast of climatic parameters up to the year 2040. The performance of ARIMA model predictions is shown through the coefficient of determination (R^2) between observed and predicted values during the

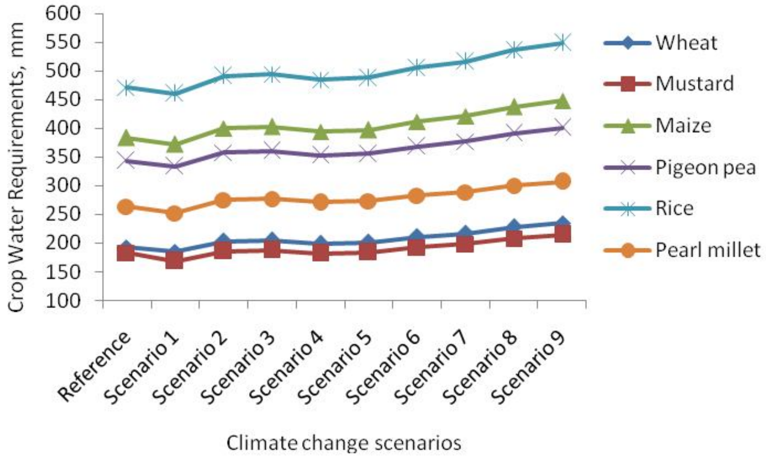

Fig. 2: Predicted crop water requirements under different climate change scenarios.

Table 4: Performance indicator of ARIMA model predictions and climate forecast for 2030s.

Meteorological Parameters	Coefficient of determination(R^2)	Forecasted variation in climatic parameters for 2030s
Total rainfall (Palam), mm	0.79	-9.00
Total rainfall (IARI), mm	0.86	+0.50
Sunshine hours (IARI), hour	0.89	-0.26
Relative humidity (Palam), %	0.77	+4.00
Average wind speed (IARI), km day^{-1}	0.78	-5.15
Average maximum temperature (IARI), °C	0.74	+0.60
Average maximum temperature (Palam), °C	0.83	+0.34
Average minimum temperature (IARI), °C	0.80	+0.83
Average maximum temperature (Palam), °C	0.84	+0.61
Average temperature (IARI), °C	0.84	+0.26
Average temperature (Palam), °C	0.75	+0.29

same period (Table 4). Coefficient of determination (R^2) values from IARI and Palam station varied from 0.74 to 0.89 and 0.75 to 0.84 respectively. Highest (0.89) coefficient of determination (R^2) was found for sunshine hours and lowest (0.74) for average maximum temperature. Higher coefficient of determination between observed and predicted values indicated that ARIMA model predictions were realistic and could be used for forecast. Average annual change in climatic parameters in 2030s with respect to 1990s values for IARI and Palam are presented in Table 4.

Crop water requirement under different climatic change scenarios: Estimated crop water requirements (ET_c) of major crops grown in this region for about 30 years using the data of Palam and IARI are presented in Fig. 1 (a to f). These were estimated using all important climatic parameters which control crop water requirement. Results indicated that ET_c of all major crops exhibited decreasing trend at both stations in past 30 years. It can be supported by the study conducted by Goyal (2004) and observed the mixed results for changes in ET_c. Predicted crop water requirements under different climate change scenarios are presented in Fig. 2. Crop water requirements of pigeon pea, pearl millet, mustard, rice, wheat and maize were 343.2 mm, 343.2 mm, 183 mm, 471.3 mm, 192.4 mm, and 383.5 mm, respectively, used in reference scenario. Scenario 1 is based on ARIMA predictions whereas scenarios 2, 3 and scenarios 4, 5, 6, 7, 8 and 9 are based on INCCA and IPCC predictions respectively. In case of scenario 1, water requirement of all crops would decrease by 7.5 to 14.2 mm in 2030s. However, water requirement of crops such as wheat, mustard, maize, pigeon pea, rice and pearl millet would increase by 7.1 mm to 42.4 mm, 0.1 mm to 31.6 mm, 10.7 mm to 64.2 mm, 9.6 mm to 57.8 mm, 13.0 mm to 77.5 mm and 7.2 mm to 43.5 mm respectively, under various climatic change scenarios (Fig. 2). Similar results were also obtained by Shahid (2011) and Fisher et al. (2007) in their conducted studies. Maximum and minimum increase in crop water requirement of crops was observed under scenario 9 and scenario 4, respectively.

Scenario 9 and Scenario 4 correspond to 6.4°C and 1.1°C rise in temperature, respectively. It is important to note that the predicted crop water requirement under scenario 1 follows trend of crop water requirement estimated from long term local weather data. This further confirms that crop water requirement in this region would not increase as for near future belief commonly.

CONCLUSIONS

ARIMA prediction for 2030s indicated increase in average temperature (0.26°C) and relative humidity (4%), and decrease in wind speed (5 km day^{-1}) and daily sunshine hours (0.26 h). Result also indicated that crop water requirement under INCCA and IPCC scenarios increased, whereas it decreased under the scenario generated using local climatic parameters (ARIMA predictions). Crop water requirement of various crops would decrease by 7.5 to 14.2 mm by 2030s if it is determined using all important climatic parameters. Increase in water requirement varied from 13 to 77.5 mm for rice and 7.2 to 43.5 mm for pearl millet depending on the scenarios. Similar trend was observed in case of other crops. Under the scenarios based on INCCA and IPCC predictions, which consider only rise in temperature, crop water requirement of wheat, mustard, maize, pigeon pea, rice and pearl millet, respectively. Based on the results of the study, it can be concluded that assessment of impact of climate change on crop water requirement should be done considering all the important parameters which determine it and not only temperature.

REFERENCES

Box, G.E.P. and Jenkings, G.M. 1970. Time Series Analysis: Forecasting and Control. San Francisco: Holden-Day.

Chattopadhay, N. and Hulme, M. 1997. Evaporation and potential evapotranspiration in India under conditions of recent and future climate change. Agric. for Meteorol., 87: 55-72.

De Silva, C.S., Weatherhead, E.K. and Knox, J.W. 2007. Predicting the impacts of climate change-a case study on paddy irrigation water requirements in Sri Lanka. Agricultural Water Management, 93: 19-29.

Doll, P. 2002. Impact of climate change and variability on irrigation requirements: a global perspective. Climatic Change, 54: 269-293.

Doria, R.O. and Madramootoo, C.A. 2009. Estimation of irrigation requirements for some crops in Southern Quebec using CROPWAT. Irrigation and Drainage, 61(4).

Durand, W. 2005. Assessing the impact of climate change on crop water use in South Africa. Report submitted to World Bank. Centre for Environmental Economics and Policy in Africa (CEEPA) of the University of Pretoria.

Ficklin, D.L, Elike, L. and Zhang, M. 2010. Sensitivity of groundwater recharge under irrigated agriculture to changes in climate, CO_2 concentrations and canopy structure. Agricultural Water Management, 97: 1039-1050.

Fischer, G., Tubiello, F.N. and Velthuizen, H. 2007. Climate change impacts on irrigation water requirements: effects of mitigation, 1990-2080. Technological Forecasting and Social Change, 74: 1083-1107.

Goyal, R.K. 2004. Sensitivity of evapotranspiration to global warming: A case study of arid zone of Rajasthan (India). Agricultural Water Management, 69(1): 1-11.

Mahmood, R. 1997. Impacts of air temperature variations on the *Boro* rice phenology in Bangladesh: implications for irrigation requirements. Agricultural Forest Meteorology. 84(3-4): 233-247.

Mizyed, N. 2009. Impact of climate change on water resources availability and agricultural water demand in the west bank. Water Resources Management, 23(10): 2015-2029.

Peterson, T. C., Golubev, V. S. and Groisman P. Y. 1995. Evaporation losing its strength. Nature, 377(6551): 687–688.

Rodriguez Diaz, J.A., Weatherhead, E.K. and Knox, J.W. 2007. Climate change impacts on irrigation water requirements in the Guadalquivir river basin in Spain. Regional Environment Change, 7: 149-159.

Shahid, S. 2011. Impact of climate change on irrigation water demand of dry season *Boro* rice in northwest Bangladesh. Climatic Change, 105: 433-453.

Yano, T., Aydin, M. and Haraguchi, T. 2007. Impact of climate change on irrigation demand and crop growth in a Mediterranean environment of Turkey. Sensors, 7: 2297-2315.

Ziad, A.M. and Siren, A.J. 2010. Climate change and agricultural water demand: Impacts and adaptations. African Journal of Environmental Science and Technology, 4(4): 183-191.