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Article

Prediction of Rice Water Requirement Using FAO-CROPWAT Model in North Iran under Future Climate Change

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Abstract: In this paper, Rice water requirement and irrigation water requirement in Amol agro meteorological Station in 2016-2045 are forecasted based on the projected meteorological data of Hadcm3 under A2 scenario. Rice water requirements are estimated by using crop coefficient approach. Reference evapotranspiration are calculated by FAO Penman-Monteith method. Moreover, the irrigation water requirements are simulated by calibrated CROPWAT model using the meteorological parameters. The results show that both crop water requirement and irrigation water requirement present downward trend in the future. In 2016-2045, the rice water requirement and irrigation water requirement decrease by more than 9.9% under A2 scenario, respectively. Furthermore, the precipitation rise may be the main reason for the decrease in crop water requirement, while significant decrease of irrigation water requirement should be attributed to combined action of rising precipitation and a slight increase in temperature.

Keywords: rice; water requirement; climate change; Penman-Monteith; CROPWAT

1. Introduction

Climate change is now one of the problems of human society and the threat to the planet is counted. Earth temperature increasing caused alterations in Climate been ground and cause changes in rainfall and temperature time and place that many of the human losses, especially in recent decades has been compiled [15]. Although all the causes of climate change or not to change the world climate is not fully known. But talk about climate change, certainly attention of many researchers and will be. Climate as average weather conditions in certain special and is described and climate change include significant changes in the average weather data during a certain period of time during this period, 10 years or more are [8]. In order to study climate change and revelation, investigated a number of climatic parameters, including temperature and rainfall, higher priority has other parameters. The role of temperature in climate change studies to determine the monthly temperature process compared with an average monthly rate of change of temperature is of more importance [1]. Different climatic parameters such as temperature and rainfall of a place on the climate factors which influenced the region and its understanding of the climate determining region. Occurrence of phenomena such as sudden increase or decrease in temperature and rainfall and other atmospheric parameters important one year or several years can be climate change reason to know the area [2]. Global Warming and changes significantly when the temperature series throughout the world as the most important aspects of climate change in the twenty-first century are assessed. Several studies, increasing the average surface temperature have been confirmed. Calculations based International Institute for (IPCC) land and ocean temperatures average between 0.3-0.6 degree Celsius between the years 1900 to 1995 and about 0.2 to 0.3 degree Celsius increase in 40 years has [7]. Daily and night temperatures in the center, south and East Europe have reviews [9]. For hundreds of years, the global climate is gradually warming as the main characteristic of the significant change; average temperature has increased 0.74°C. In Iran, global warming has caused

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significant influence in agricultural and food security. Rice is one of the most important foods in the world. North of Iran is a big region of rice production and consumers. Crop water and irrigation water requirements should be changed under the background that the relationship of precipitation and soil moisture has been influenced by the global climate change.General Circulation Model (GCM) from the IPCC was used to assess the impact of climate change.Scenario used for the past period (1961-1990) was 20C3M, and the future periods (2046-2065 and 2081-2100) used two different emission scenarios SRA1B and SRB1. Using the data from the output of GCM,the change trends of crop water and irrigation water requirements are analyzed in the future. Serious water shortages are developing in many countries particularly in Iran and water for agriculture is becoming increasingly scarce in the light of growing water demands from different sectors [11, 13]. Agriculture is the largest (81%) consumer of water in Iran and hence more efficient use of water in agriculture needs to be top most priority [10]. The uneven rainfall distribution pattern and low water holding capacity of soils, soil moisture stress occurs during summer season and it is considered as one of the major limiting factors for higher productivity in the State. Many studies conducted by various research institutions like Amol Agro meteorological station, Central Plantation Crops Research Institute, Centre for Water Resources Development and Management etc. have shown that irrigation can enhance the productivity of the crops in the State. However, the area with a gross irrigation facility still hovers around 17.0 % (2009-10) of the gross cropped area of the State – a level far below the average for India (38.7%) [12]. Hence this needs to be improved to attain an improved productivity. Analyses of the secondary data on the yield of paddy in Amol under irrigated and non-irrigated conditions confirmed that irrigation has a great effect on enhancing the yield levels by about one-sixth (about 500 kg per hectare) to that of the irrigated level. One of the main reasons for the low irrigation efficiency in the State is the lack of location-specific scientific information on irrigation scheduling for different crops. The present irrigation recommendations for the State are of general nature and does not account for all the soil types and climate in different agro-ecological zones. While studies have identified the influence of one or more parameters on irrigation water requirements, there is a lack of information with respect to Amol on these parameters when water requirements are to be aggregated at a regional scale. To achieve effective planning on water resources, accurate information is needed for crop water requirements, irrigation withdrawal as a function of crop, soil type and weather conditions. The rainfall and evapotranspiration ultimately determine water balance, crop water and irrigation requirements of different crops of the region. Studies of such climatic parameters are thus helpful in defining risk levels in arable agriculture. However, a detailed study by comprising all the data on water requirement and availability is also not available under humid tropical Amol conditions. Keeping all this in background the study was carried out with the following objective to compute the agricultural water demand (crop water requirements) of major crops in different agro-ecological zones of Amol district with the long term climatic data by using CROPWAT 8.0 model [6]. Penman-Monteith method [5] is used in the present study for determining reference crop evapotranspiration (ET0) since it is reported to provide values that are very consistent with actual crop water use data worldwide [10].The irrigation schedule recommendations for various crops should be location-specific, considering the soil types and agro-ecological conditions. The scientific crop water requirements are required for efficient irrigation scheduling, water balance, canal design capacities, regional drainage, water resources planning, reservoir operation studies, and to assess the potential for crop production [4]. There is a lack of information with respect to Amol on crop water requirements in general and the shortfall of data at a regional scale. Hence, in this paper an attempt has been made to compute the crop water requirements of major crops in different agro-ecological zones of Amol district using CROPWAT 8.0 [5] and comparing the same with the available water resources in that district to assess the current status and future demand, which is essential for planning.

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2. Materials and Methods

The study area is Amol district of humid tropical North of Iran, which is one of the largest districts in Mazandaran province, having a total geographical area of 3074 km2. It is in the central part of the Mazandaran province.

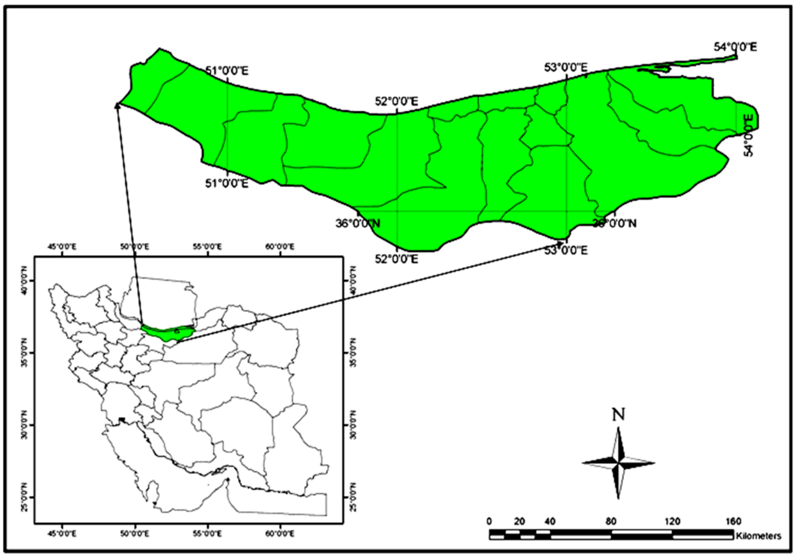

Fig1. Location Mazandaran province in Iran

The climate model Hadcm3 was used in this study, which spatial resolution is 1.85°×1.85°. The fourth IPCC assessment report provided eight kinds of climate change scenarios. The A2 scenario represents the climate of the 20th century. This experiment runs with greenhouse gases increasing as observed through the 20th century [14,15]. Under scenario A2, it is a future world of very rapid economic growth with global population that peaks in mid-century and declines thereafter. The other emission scenario is SRB1. It is a convergent world with the same global population as that of the A2 storyline but with rapid changes in economic structures towards a service and information economy. The meteorological elements from GCM model predictions must project changes in daily solar radiation, min temperature, max-temperature, mean wind speed, precipitation, relative humidity.

2.1 Crop water requirement

The reference evapotranspiration ET0 of individual agro-ecological units are calculated by FAO Penman-Monteith method, using decision support software –CROPWAT 8.0 developed by FAO, based on FAO Irrigation and Drainage Paper 56 [6]. The FAO CROPWAT program incorporates procedures for reference crop evapotranspiration and crop water requirements and allow the simulation of crop water use under various climate, crop and soil conditions [6]. Crop coefficient values (Kc) are taken from available published data. Kc values for initial, mid and late growth stages of annual and seasonal crops are used. In the case of perennial crops, same Kc value is used for the growth period.

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3. Results

3.1 Evaluation of LARS-WG model in simulated meteorological parameters in Amol station

Model validation is one of the most important steps of the process. The objective was to assess the performance of the model in simulating climate at the chosen site to determine whether or not it is suitable for using. Firstly, LARS-WG model was done based on the historical climate data obtained from 2001-2015 for verification of the model. A large number of years of simulated daily weather data were generated and were compared with observed data by using the t test. Table 1 typically represents the comparison between synthetic and observed data in Amol Station. The mean monthly correlation of the precipitation, minimum and maximum temperature and solar radiation were acceptable in 0.05 level of confidence.

Table1. Evaluation model in simulated meteorological parameters in Amol station

parameter	maximum temperature(ºC)	minimum temperature(ºC)	solar radiation(hr)	Precipitation (mm)
R^2	0.99	0.99	0.98	0.92
RMSE	0.3	0.2	0.2	11.2
MBE	-0.1	0.0	0.0	1.8
MAE	0.2	0.2	0.1	7.8

Research results showed that mean of precipitation in Amol region has decreased during 2016-2045. Precipitation has increased in the most parts of study area. Precipitation in growth period of rice (April to September) has increased 11.4 mm rather than observed period (2001-2015). Generally the mean of minimum temperature in study area has increased during 2016- 2030 that its amount having 0.5 ºC. The most of changes has been in winter and spring that the minimum temperature has increased in these times. It has increased the maximum temperature of Amol region with having 0.3 ºC. (Table 2)

3.2 Effective Rainfall

Many water studies have used the CROPWAT v8.0 model to estimate monthly effective rainfall. Although the software offers several alternative methods, the method referred to as the "USDA SCS method" has generally been used due to its simplicity; being only a function of monthly precipitation and not requiring local calibration. However, the implementation in the CROPWAT model [6] is a simplified version of the USDA SCS model based on an assumed average consumptive use (ET) of 8"/month (≈200 mm/month) and "useable" soil water storage of 3" (≈75 mm). Although this may be an appropriate simplification for irrigation system design in semi-arid environments, it is clearly inappropriate for estimating green water use in English conditions; where ET rates in the peak months of the year may only average 100 mm/month. The original USDA SCS method estimates monthly effective rainfall from gross rainfall, soil water holding capacity and ETC. It was calibrated on 50 years of rainfall records at 22 locations throughout the United States and has been shown to perform well in well-drained soils in the USA. However, is found that it under-predicted effective rainfall in India compared to other methods. No evidence could be found of the original USDA SCS method being used in water foot printing studies.

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Table2. Evaluation model in simulated meteorological parameters in Amol station

Total	Ave	Dec	Nov	Oct	Sep	Aug	Jul	Jun	May	Apr	Mar	Feb	Jan	Climatic Parameter and period	
746.5	62.2	93.8	130.7	117.9	80.0	31.4	32.1	20.3	21.8	30.0	59.2	57.3	72	Observed	Precipitation (mm)
743.2	61.9	93.1	112.1	124.2	71.7	3.37	26.1	25.8	27.9	35.8	66.1	56.6	66.6	Predicted	
164.4	13.7	5.5	10.2	15.9	20.2	22.6	22.7	21.3	17.5	12.0	7.8	4.9	4.0	Observed	Min Tem (ºC)
168.8	14.1	5.9	10.1	16.1	20.6	23.0	23.3	21.5	17.8	12.7	8.4	5.3	4.1	Predicted	
261.4	21.8	14.3	19.3	24.6	28.3	31.3	30.4	28.6	24.5	19.4	15.5	12.6	12.7	Observed	Max tem (ºC)
264.3	22.1	14.4	19.8	24.9	28.6	31.7	30.7	28.4	24.8	20.1	15.6	12.7	12.6	Predicted	
65.9	5.5	4.3	4.8	5.3	5.5	6.8	6.8	7.4	6.7	5.0	4.4	4.2	4.7	Observed	Sol Rad (hr)
65.9	5.5	4.2	5.1	5.4	5.5	6.8	6.8	7.1	6.4	5.1	4.5	4.3	4.8	Predicted	

Effective Rainfall Method For each station-month, effective rainfall (Peff) was estimated using the USDA SCS method as implemented in the CROPWAT v8.0 software [3]. For each station-month, effective rainfall (Peff) was estimated using the USDA SCS method as implemented in the CROPWAT v8.0 software,(Equation 1,2):

$$P_{eff} = p\frac{(125 - 0.2p)}{125} for\ P \leq 250\, {}^{mm}/_{m} \qquad (1)$$

$$P_{eff} = 125 + 0.1p\ for\ P > 250\, {}^{mm}/_{m} \qquad (2)$$

The CROPWAT model also offers an option to estimate actual evapotranspiration from a water balance based on average monthly rainfall and ETo data (using the irrigation schedule function with the option to select “no irrigation”) (Equation3). So it has been recommended using this method as the model includes a dynamic soil water balance.

3.3 Estimate of Crop Water (ETC)

Water used by crops is predominantly lost by transpiration (T) but there are also evaporative (E) losses from the soil and from plant surfaces. The amount of water used by plants together with water losses through evaporation is called evapotranspiration (ET). Other potential areas of water loss during irrigation include lateral run off, deep drainage and leaks in the delivery system. These are not directly accounted for in ET calculations, but can be measured and included in estimates of crop irrigation requirements. ETo is used as a reference point from which crop ET (termed ETcrop)

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can be calculated by multiplying ETo by a crop species-specific, and often cultivar-specific, value. The water requirements of a crop can be compared with the ETo by using an experimentally-derived crop coefficient (Kc) as follows:

$$ET_{crop} = K_c * ET_o \quad (3)$$

To estimate crop water requirements CROPWAT model was used. In this study, for the calculation of reference evapotranspiration, FAO - Penman-Monteith equation is used. To calculate the reference evapotranspiration using FAO Penman-Monteith equation, climate data such as minimum and maximum air temperature, relative humidity, sunshine hours and wind speed is required. Other inputs of the model is cultivation pattern, the plant coefficient, the area under cultivation (1 to 100 percent of area), irrigation scheduling, soil type, the available soil moisture, root depth and water content in the soil.

Table3. Effective Rainfall and Crop water requirement quantities for predicted (2016-2045) and observed period in Amol Station.

ETC - PEFF	PEFF	ETC	period
446.0	117.1	563.2	2005 - 2001
490.9	62.0	563.0	2010 - 2006
488.7	124.8	613.4	2015 - 2011
414.5	113.3	527.7	2020 - 2016
379.9	130.0	509.9	2025 – 2021
432.4	93.0	525.4	2030 - 2026
394.7	121.4	516.1	2035 -2031
413.1	97.5	510.5	2040 -2036
449.2	78.5	527.7	2045 -2041

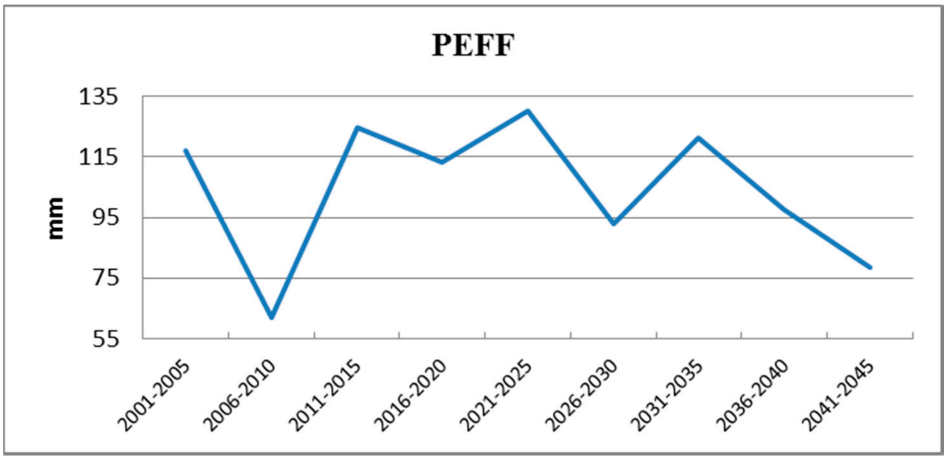

Fig2. Effective Rainfall for predicted (2016-2045) and observed period in Amol Station

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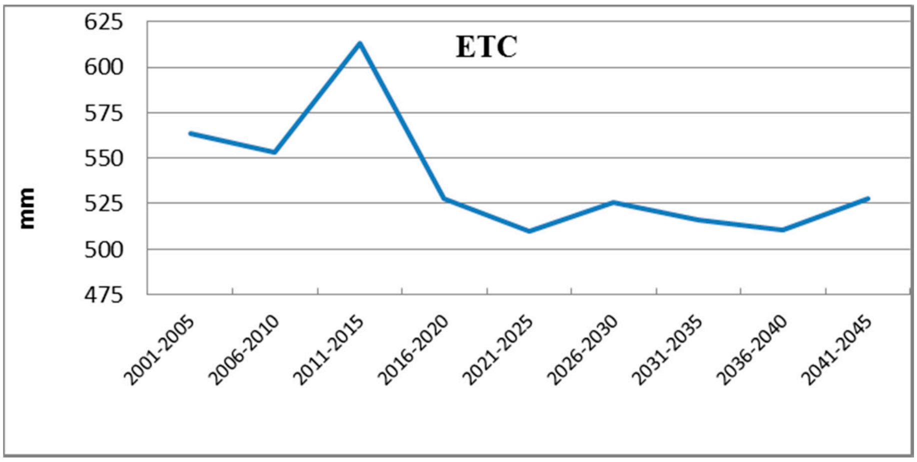

Fig3. Crop water requirement quantities for predicted (2016-2045) and observed period in Amol Station

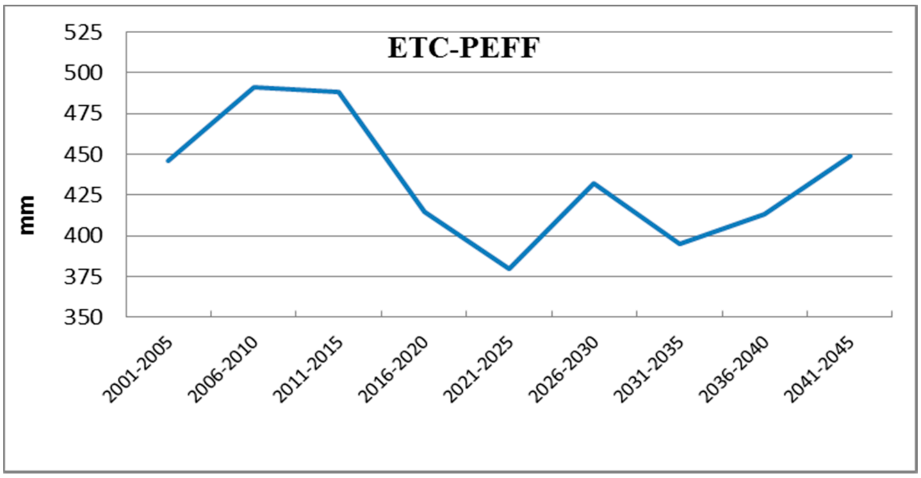

Fig4. Different of Effective Rainfall and Crop water requirement quantities for predicted (2016-2045) and observed period in Amol Station

4. Discussion

In the present study, applicability of LARS-WG has been tested in downscaling daily rainfall, and maximum and minimum temperature in the Amol region. After ascertaining the applicability of the model, it has been used to downscale future changes of precipitation, minimum temperature (Tmin), and maximum temperature (Tmax) from the GCM outputs of A2 scenario for the periods of 2016–2045. The following conclusions can be arrived at from the present study:

1. The LARS-WG model has been found to perform reasonably well in downscaling daily precipitation. The performance is excellent in downscaling Tmax and Tmin in the study region.

2. At Amol station, the downscaled precipitation from the predictions of the GCMs indicates no coherent change trends among various GCM predictions of precipitation during 2016–2045. This is indicative of the fact that there are great uncertainties in the prediction of future rainfall using GCM should be considered in the study of climate change to reduce their uncertainty.

3. Contrary to rainfall, the downscaled Tmax and Tmin from the predictions of seven GCMs show consistent increasing trend for all the stations of the study region. In general, at the Amol daily average Tmax and Tmin would increase by at least 0.2, 0.6 degree Celsius during 2016–2045 respectively, compared to the baseline temperature.
4. Rainfall predictions from the GCMs indicate 11.4 mm increase compared to the baseline during rice growth (April to August).
5. According to the results of the CROPWAT software, average of the rice water requirement, were calculated 576.5 and 519.5 mm for observed and predicted (2016-2045) period. In other words in 2016-2045, the rice water requirement and irrigation water requirement decrease by more than 9.9% under A2 scenario, respectively. Furthermore, the precipitation rise in rice growth period may be the main reason for the decrease in crop water requirement, while significant decrease of irrigation water requirement should be attributed to combined action of rising precipitation and a slight increase in temperature. (Table 3 and Fig2, 3, 4).

5. Conclusions

The results show that both crop water requirement and irrigation water requirement present downward trend in the future. In 2016-2045, the rice water requirement and irrigation water requirement decrease by more than 9.9% under A2 scenario, respectively. Furthermore, the precipitation rise may be the main reason for the decrease in crop water requirement, while significant decrease of irrigation water requirement should be attributed to combined action of rising precipitation and a slight increase in temperature.

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