Impact of Climate Change Scenario on Yield and Irrigation Water Requirements of Rice-Wheat Cropping System in Central Punjab

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Impacts of climate change on crop yield and irrigation water requirement of Rice-Wheat cropping sequence was assessed the in Ludhiana district of central Punjab. Climate change scenario was A1B of PRECIS (Providing regional climate for impact studies) model. Crop yields and irrigation water requirement were estimated by cropping system (CropSyst) model. The results showed that mean temperature and rainfall may increase by 3.5°C and 162 mm in mid century (MC); and 6.9°C and 302 mm in end century (EC) during kharif season. During rabi the corresponding values would be 2.3°C and 72 mm in MC and 4.6°C and 78 m in EC, compared to that of the present time slice (PTS).The simulations of 10 (1998-2008), 29 (2021-2050) and 27 (2071-2098) crop rotations representing PTS, MC and EC respectively indicated reduction in yield by 21% in rice and 13 % in wheat by end of the 21st century. Crop yields in MC and EC were reduced due to shortening of crop duration associated with increased temperature. As a consequence of increased precipitation and shortening of crop duration in MC and EC, irrigation requirement would decrease by 46.7% and 45.2% in rice; and 22.2% and 34.6% in wheat, respectively.

Keywords: Climate change scenario, crop yields, irrigation water requirement

There is growing evidence that global climate is changing. According to the Intergovernmental Panel on Climate Change (IPCC 2001)[1], global mean temperatures have risen 0.3 - 0.6° in the 19th century and global sea levels have risen between 10 and 25 cm. The warming trend for the last 30-year period is roughly three times that for the past 100 years as a whole (Stouffer *et al* 1994 [2], WMO 2002[3]) and it is expected that global temperatures will continue to rise between 1.4 and 5.8°C by 2100 due to the emissions of greenhouse gases (McCarthy *et al* 2001 [4]). As the warming process continues, it will bring about numerous environmental problems, among which the most severe will impart uncertainties to the supply and management of water resources (Loaiciga *et al* 2000 [5], Holman 2006[6], IPCC 2007c[7], Wolock *et al* 1993[8], Green *et al* 1997[9], Winter 2000[10]). Temperature increase affects the hydrologic cycle directly by increasing soil water evaporation and transpiration. Consequently, these changes influence rainfall amounts, timings and intensity and indirectly impact the flux and storage of water in surface and subsurface reservoirs i.e. lakes, soil moisture, groundwater (Toews and Allen 2009 [11]). In addition, there may be other associated impacts, such as sea water intrusion, water quality deterioration, potable water shortage etc. (Mearns *et al* 2001[12]).

Water is a key driver of agricultural production in Punjab. In the past three decades, annual cereal production increased three folds from 7305 million tonnes in 1970 to 27890 million tonnes in 2011. This increase is closely related to the expansion of irrigated area, which almost doubled (from 39200 sq km to 63400 sq km) during last 35 years. Increased irrigation area, growing population and competition from other sectors have put agricultural water use under great pressure. The irrigation requirement under changed climate has not been studied so far. Keeping this in view, the present study was undertaken to assess the impact of climate change on crop yields and irrigation water requirement of rice-wheat cropping sequence.

Methods and Materials:

The study was carried out for climate data of Ludhiana (75° 52' E longitude and 30° 56'N latitude) in the Punjab state (73° 53' to 76° 55' E longitude and 29° 33' to 32° 31'N latitude) of India. The climate of the area is semiarid. Past 40 years (1971-2010) daily weather data on rainfall (RF), maximum temperature (Tmax) and minimum temperature (Tmin) recorded at meteorological observatory was used in this study. Climate data on Tmax, Tmin and RF under A1B scenario for Ludhiana at daily interval for baseline (1961-1990), MC and EC was derived from regional climate model PRECIS. This model is based on the atmospheric component of the HadCM3 climate model (Gordon et al. 2000[13]) and is extensively described by Jones et al. (2004)[14]. Regional climate model (PRECIS) output was obtained in binary format from the Indian Institute of Tropical Meteorology

(IITM) – Pune. At IITM, Pune, three QUMP (Quantifying Uncertainty in Model Predictions) i.e. Q0, Q1 and Q14 runs were carried out for the period 1961–2098 and are utilized to generate an ensemble of future climate change scenarios for the Indian region (Kumar et al. 2011[15]). The A1B scenario is characterized by a future world of rapid economic growth, global population that peaks in the mid-century (MC) and declines thereafter, and rapid introduction of new and more efficient technologies. This scenario also represents balanced mix of technologies and sustainable socioeconomic and technological development. Biases of Tmax, Tmin and RF were evaluated from seasonal trends and statistical parameters like mean (μ), standard deviation (σ) and variance (σ^2). The biases were minimized by applying correction functions developed from observed and modeled data of years from 1971 to 1985 and validated on the data of years from 1986 to 1990. Four types of correction functions i.e. difference, modified difference, statistical bias correction and modified statistical bias correction at daily, monthly and annual time scale (Piani et al. 2010[16]; Senikovs and Brethers 2009[17]; Leander and Buishand 2007[18]; Haerter et al. 2010[19]) were tried.

2.1 Crop Simulation Model:

Simulations for yield, crop duration and waterbalance were run using CropSyst model by Stockle et al. (1994)[20] (http://www/bsyse.wsu.edu/ CSsuiteCropSyst/ index .html). The Model requires four main sets of data files.

2.1.1 Location Data: Daily weather files to be used in the model were prepared from the observed data for PTS and from the corrected modeled data for MC and EC. The bias from the modeled data of MC and EC for A1B scenario was removed by applying the modified daily difference correction function in RF and modified monthly correction functions in Tmax and Tmin (Leander and Buishand 2007 [18]). Solar radiation was calculated by the equation given by Hargreaves and Samani (1982)[21]. Data for relative humidity and wind speed were generated by ClimGen model (Stockle and Nelson 1999[22]), which can generate these parameters precisely for Punjab conditions (Bal *et al* 2008[23]).

2.1.2 Soil Data: The Soil file included data on cation exchange capacity (CEC), pH, parameters for the curve number approach (runoff calculation), surface soil texture (for erosion calculation) and five parameters specified by soil layer viz. layer thickness, field capacity, permanent wilting point and bulk density. The soil files for the four dominant soil series present in Ludhiana were made using the data reported by Sharma (2004)[24].

2.1.3 Crop data: Crop data include genetic specific information to calculate plant development rate. Simulations were made for normal planting dates i.e. June 20 for rice (variety PR 111) and November 5 for wheat (variety PBW 343). Validation and performance of the model have already by Jalota *et al* (2012)[25] in detail. In the model, crop parameters were derived from calibration, experimental observations, literature and some were kept as default.

2.1.4 Management file: The Management file includes automatic and scheduled management events. Management events can be scheduled using actual date, relative date (relative to year of planting), or using synchronization with phenological events (e.g., number of days after flowering). In the present study, the management file consisting of time and amount of irrigation applied was developed for different years of rice-wheat rotation. In the model, irrigation was scheduled when ratio of depth of irrigation water (IW) to difference in cumulative potential crop evapo-transpiration (ETc) and RF reached the pre set values (Prihar *et al* 1974[26]). Irrigation scheduling ratio was increased for coarse textured soil to simulate increased frequency of irrigation and decreased to simulate effect of decreased irrigation requirement in fine textured soil. The ratios used for rice and wheat crops were 3.0 and 1.0 in loamy sand, 2.5 and 0.9 in sandy loam and 2.0 and 0.8 in loam and silt loam soils, respectively. In rice, from transplanting day to first 15 days irrigation was applied frequently for proper establishment of the transplanted rice and thereafter the irrigation was scheduled as per ratio (Anonymous 2010 [27]). In wheat, this ratio was started from the day 21st after sowing in loamy sand and the day 30th in sandy loam, loam and silt loam soils. For each rotation, irrigation schedule based on cumulative potential evapotranspiration (Etc) and RF were primed separately and added in the respective management file of the model.

2.2 Future land use changes

As per A1B climate change scenario population will increase upto mid century, it was assumed for this study that the same would hold true for built-up land. The decadal statistics (1970-2011) on population and area under different land uses was obtained from Statistical Abstracts, Punjab. The population projection were made based on graphical method and consequently reduction in agriculture area was calculated

3 Results and Conclusions:

3.1 Typical biases and correction of climate data:

The modeled values of Tmax were higher than that of observed in the months from February to May and less from July to December (Fig. 1). Modeled values of Tmin also followed the trend similar trends but the values higher up to October and less in November and December months (Fig 1a). In case of RF, the modeled RF was less during the months from January to June and trend reversed thereafter up to December (Fig.1b).

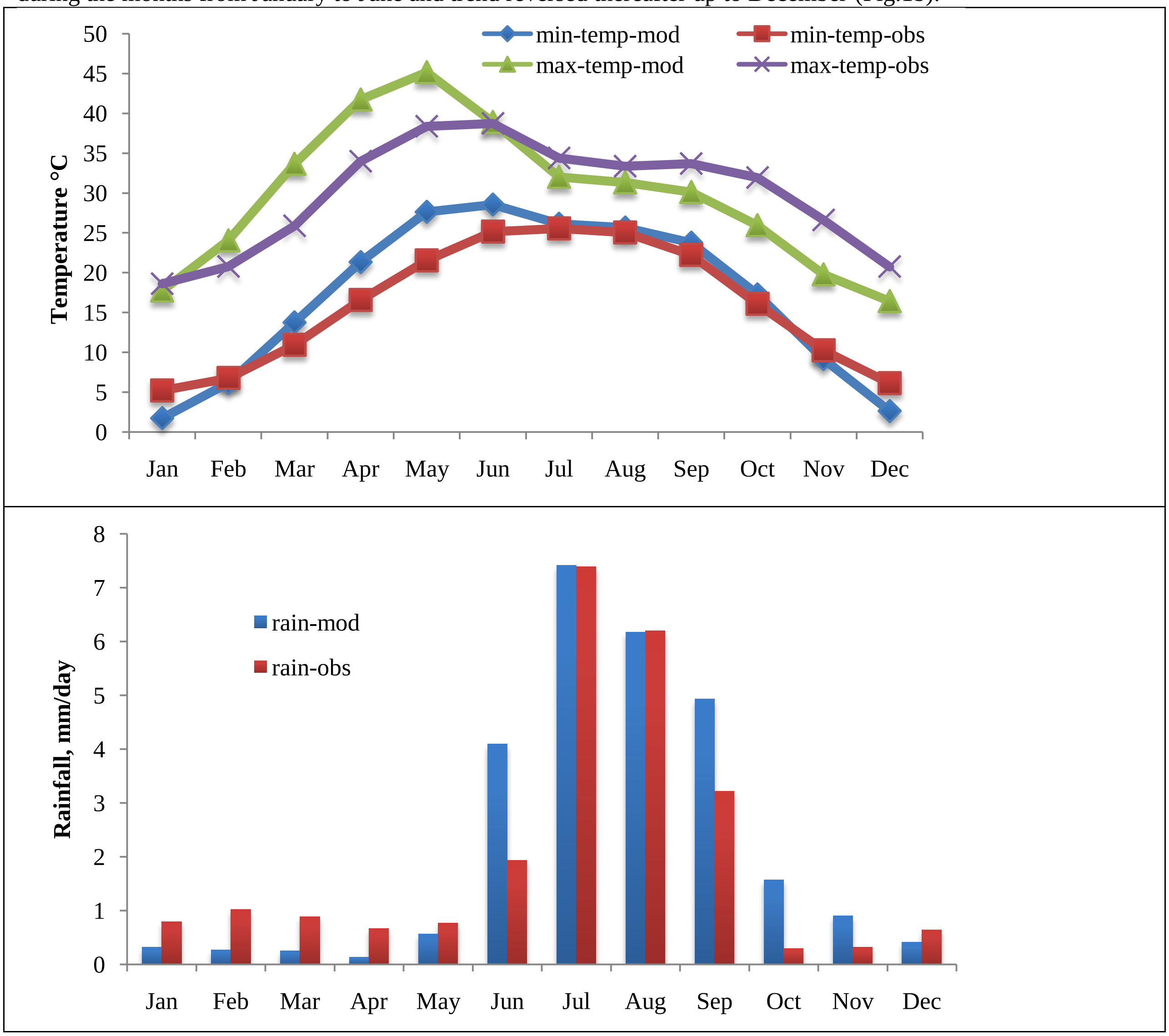

Fig 1. Biases in (a) maximum and minimum Temperature (b) rainfall for Ludhiana District

These biases with respect to the present climate of are high for direct usage of their output to drive hydrological models; Sennikovs and Bethers, 2009[17]; Sharma et al., 2007[28]) and therefore the best correction functions were evaluated comparing four different approaches were obtained for Tmax, Tmin and RF are presented in Tables 1.

Table 1. The best fitted correction factor/ transfer functions for correcting the PRECIS modeled Precipitation (RF) and temperature (T) data

Month	Leander and Buishand, 2007 method

	Rain	Tmin	Tmax
January	$RF_{cor}= (RF_{mod}-.45)*1.09$	$T_{Cor} = 8.23+0.74*(_{Tmod}-5.03)$	$T_{Cor} = 19.75+0.63*(_{Tmod}-18.54)$
February	$RF_{cor}= (RF_{mod}-0.54)*1.09$	$T_{Cor} = 6.76+0.73*(_{Tmod}-6.55)$	$T_{Cor} = 17.85+0.72*(_{Tmod}-20.74)$
March	$RF_{cor}= (RF_{mod}-0.47)*1.09$	$T_{Cor} = 7.90+0.74*(_{Tmod}-10.84)$	$T_{Cor} = 18.75+0.85*(_{Tmod}-26.18)$
April	$RF_{cor}= (RF_{mod}-0.55)*1.09$	$T_{Cor} = 12.35+0.74*(_{Tmod}-16.69)$	$T_{Cor} = 27.06+1.10*(_{Tmod}-34.21)$
May	$RF_{cor}= (RF_{mod}+0.05)*1.09$	$T_{Cor} = 15.88+0.88*(_{Tmod}-21.7)$	$T_{Cor} = 32.62+0.92*(_{Tmod}-38.80)$
June	$RF_{cor}= (RF_{mod}+2.14)*1.09$	$T_{Cor} = 21.89+1.01*(_{Tmod}-25.1)$	$T_{Cor} = 38.68+0.66*(_{Tmod}-38.60)$
July	$RF_{cor}= (RF_{mod}+1.22)*1.09$	$T_{Cor} = 24.60+1.87*(_{Tmod}-25.3)$	$T_{Cor} = 36.77+1.25*(_{Tmod}-34.30)$
August	$RF_{cor}= (RF_{mod}+0.67)*1.09$	$T_{Cor} = 24.04+2.15*(_{Tmod}-24.8)$	$T_{Cor} = 35.58+1.28*(_{Tmod}-33.4)$
September	$RF_{cor}= (RF_{mod}+3.06)*1.09$	$T_{Cor} = 19.69+1.53*(_{Tmod}-21.7)$	$T_{Cor} = 37.21+1.05*(_{Tmod}-33.7)$
October	$RF_{cor}= (RF_{mod}+1.80)*1.09$	$T_{Cor} = 13.86+0.84*(_{Tmod}-15.6)$	$T_{Cor} = 37.86+0.65*(_{Tmod}-32.00)$
November	$RF_{cor}= (RF_{mod}+0.57)*1.09$	$T_{Cor} = 10.34+0.83*(_{Tmod}-9.7)$	$T_{Cor} = 32.89+0.75*(_{Tmod}-26.3)$
December	$RF_{cor}= (RF_{mod}-0.10)*1.09$	$T_{Cor} = 9.02+0.86*(_{Tmod}-5.8)$	$T_{Cor} = 24.94+0.94*(_{Tmod}-20.6)$
Annual	$RF_{cor}= (RF_{mod}+0.39)*1.09$	$T_{cor}= 14.59+ 0.81*(_{Tmod}-15.77)$	$T_{cor}= 30.04 + 0.77*(_{Tmod}- 29.8)$

The observed, modeled and modeled corrected temperatures and RF indicate that the modeled Tmax and Tmin peaked one month earlier (in May) than that of the observed (in June). The corrected data of Tmax and Tmin were found closer to the observed with respect to time trends and magnitude. Time trends of rainfall showed that the modeled cumulative rainfall (CRF) was less than the observed up to June month, matched from June to August and became less from September to December. Annual total modeled RF was 76 mm less than that of the observed (800 mm). With correction, it is not only that time trends became similar to that of the observed but also the difference in model (corrected) and observed CRF was reduced to 24 mm only.

3.2 Climate change:

The results indicate that in MC and EC, increase in Tmax would be 3.6°C and 6.7°C during *kharif* season; and 2.4° C and 4.8° in *rabi* season, respectively. Correspondingly, the increase in Tmin would be 3.5° C and 7.1° C in *kharif* season; and 2.2° C and 4.3° C in MC and EC in *rabi* season, respectively. The RF would increase by 180 mm (32.3%) during *kharif* and 155 mm (93.4 %) during *rabi* season in MC. The corresponding values in EC would be 323 mm (58%) and 165 mm (99.4%), respectively. These results commensurate with the findings by Kumar *et al* 2011[15] indicating significant warming and increased RF over India towards the end of the 21st century using PRECIS under A1B scenario and with Chaturvedi *et al* 2012 [29], who used multi model outputs for climate projections indicating northern India, particularly States of Rajasthan, Madhya Pradesh, Uttar Pradesh, Uttaranchal, Himachal, Delhi, Punjab and Haryana are projected to experience higher levels of warming than the rest of the country

3.3 Crop yield:

Simulated crop yields of rice-wheat cropping sequence in the PTS, MC and EC for four soil series are presented in Table 2. Averaged across soil series, yield of rice in MC and EC would be reduced by 701 kg/ ha (10.6%) and 1355 kg/ ha (20.5%), respectively from 6606 kg/ha in the PTS (Table 2). Yield of wheat in MC would be almost identical to that in PTS (5642 kg/ ha) but in the EC it would be reduced by 708 kg/ ha (12.5%). Reduction in yields of rice and wheat crops in climate change scenarios was found to be directly related to increased T_{max} and T_{min}. The increase in temperature would shorten the crop duration. In MC and EC (averaged over soil series), crop duration would be shortened by 17 days (16.3%) and 24 days (23.1%) in rice; and 8 days (5%) and 22 days (13.4%) in wheat, respectively. Rice yield in MC and EC would decrease almost in all the years compared to that of the PTS. Yield of wheat would decrease in 7 out of 30 years in MC and 13 out of 28 years in EC. Though wheat yield would decrease in less number of years but the magnitude of decrease would be more than rice, especially in EC.

Table 2 Yield (kg/ha) of rice and wheat as influenced by different time slices of the century

Rice			***Wheat***		
Present time slice	Mid century	End century	Present time slice	Mid century	End century
6606	5905	5251	5642	5654	4934

3.4 Irrigation:

The irrigation requirement for different years in rice-wheat system during PTC, MC and EC is presented in Fig.2. The irrigation requirement PTS, MC and EC was computed as 906.6 ± 151.8, 489.2 ± 116.1 and 503.1 ± 123.4 mm in rice; and correspondingly in wheat was 407.9 ± 49, 320.2 ± 53.4 and 269.5 ± 39.3 mm.

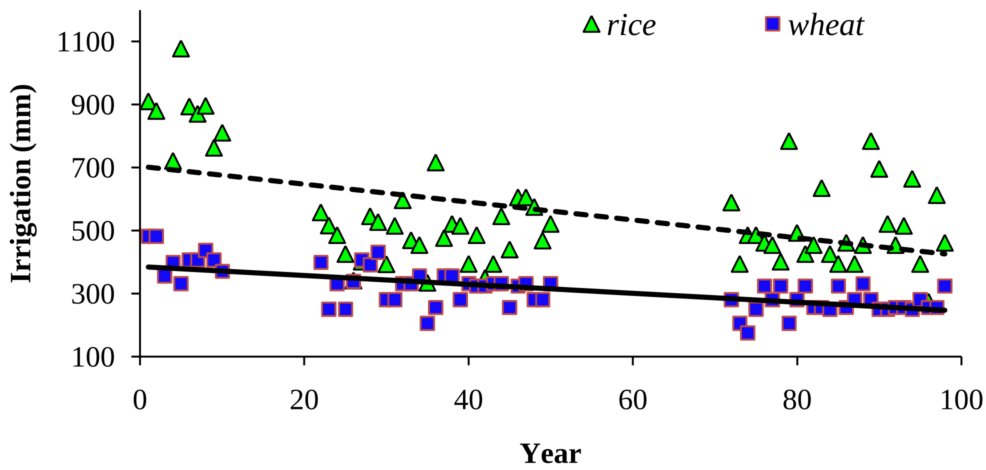

Fig. 2 Irrigation requirement (mm) in rice and wheat crops during present time slice (PTS), mid century (MC) and end century (EC)

4 Conclusions:

The study presents the impacts of future climate scenario A1B on the climatic conditions; crop yield and irrigation water requirements on rice and wheat crop at Ludhiana. The simulations conclude that Tmax, Tmin and RF in future would increase in both the cropping seasons (*kharif* and *rabi*) as compared to that of the present time slice. Earlier researches (Kumar *et al* 2011[15]; Chaturvedi et al., 2012[29]; Gosain et al., 2006 [30]) also made such projections. In future, though rainfall and temperature would increase but increased temperature would shorten crop duration (Jalota et al., 2009 [31]; Kaur et al., 2012[32]), which would affect directly crop water requirements. The annual irrigation requirement would decrease by 46.7 per cent in MC and 45.2 per cent in EC in rice; and 22.2 per cent and 34.6 per cent in wheat, respectively.

The results of this research should be interpreted as trends and not as an accurate quantitative prediction of hydrological changes as there are numerous sources of uncertainties associated with the climate change prediction (Tubiello and Ewert, 2002[33]). Uncertainty range from future greenhouse-gas emissions, the RCM used, the bias correction performed on the RCM. The crop models have been calibrated with current weather, It is possible that the relationship of CO_2 and temperature with crop growth may change in the climate change scenario (Aggarwal and Mall, 2002 [34]; Mall et al., 2004 [35]) and affect the water balance.

5 Acknowledgements:

The authors acknowledge the Indian Council of Agricultural research (ICAR) for financing the study under All India Co-ordinated Research Project on Groundwater Utilization and Emeritus Scientist Scheme. The thanks are also due to the Hadley Centre for Climate Prediction and Research, UK Meteorological office for making available regional model-PRECIS. Support of the PRECIS simulation dataset is provided by Indian Institute of Tropical Meteorology, Pune.

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