VARIABILITY OF RAINFALL, TEMPERATURE AND EVAPOTRANSPIRATION VARIABLES UNDER CLIMATE CHANGE IN FIVE SELECTED DISTRICTS OF CENTRAL PUNJAB BASED ON DATA DERIVED FROM IITM-REGCM4 BASED...

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Research Article

VARIABILITY OF RAINFALL, TEMPERATURE AND EVAPOTRANSPIRATION VARIABLES UNDER CLIMATE CHANGE IN FIVE SELECTED DISTRICTS OF CENTRAL PUNJAB BASED ON DATA DERIVED FROM IITM- REGCM4 BASED SIX MODEL ENSEMBLES

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ABSTRACT

Rainfall, maximum air temperature and minimum air temperature data for the five critically ground water depleted districts of central Punjab *viz.*, Barnala, Moga, Sangrur, Patiala and Ludhiana for the baseline period from 1983-2005 and the near future, 2030 under medium emission scenario RCP 4.5 was obtained from six climate model ensembles based on IITM-RegCM4 model. The potential evapotranspiration (PET) and actual evapotranspiration (AET) data were estimated using bias corrected climate data and validated SWAT model for the study districts. Modified Mann-Kendall trend test stastic (Mmk-Z) indicated a significant decrease in rainfall at $p<0.05$ during 2030 for all the study districts except Ludhiana and Patiala. Sens's slope estimator indicated rate of decrease of rainfall by 3.4 mm/year, 3.3 mm/year, 2 mm/year, 1.9 mm/year and 1.2 mm/year for Moga, Patiala, Barnala, Sangrur and Ludhiana district, respectively and an increase in minimum air temperature by 0.02^{o}C/year for the whole study region during 2030. The estimated PET vales showed an increase by 13.6 %, 11.7 %, 11.6 %, 10.6 % and 10.1 % for Ludhiana, Sangrur, Moga, Barnala and Patiala districts respectively, whereas, the estimated AET values showed a decrease by 33.5 %, 31.7 %, 30.7 %, 28.6 % and 27.1 % for Patiala, Sangrur, Ludhiana, Barnala and Moga districts, respectively during 2030 over the base period. An increased irrigation water demand by 43%, 36%, 31%, 21% and 21% for Ludhiana, Patiala, Sangrur, Barnala and Moga districts, respectively during 2030 over the baseline period was observed indicating more dependency on ground water for meeting crop irrigation demand in the study districts.

KEYWORDS: Central Punjab**,** IITM-RegCM4, climate change, Modified Mann-Kendall trend test, Sens's slope estimator**.**

Citation

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Competing Interest: The authors have declared that no competing interest exists and that both Manish Debnath and Dipaka Ranjan Sena are jointly the 1st authors.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Changes in rainfall and other climatic parameters at regional scales influence the hydrologic cycle leading to spatio-temporal variability of irrigation water [1-2]. It has been projected that global water demand will increase by 55 % from 2000 to 2050 and there will be adverse impact of climate change on world water resources and food production with high degree of regional variability and scarcity [3]. Groundwater recharge, surface runoff, and soil water content is reported to be affected due to significant decrease in rainfall and increase in air temperature in the mid of 21st century [4-5]. In India, about 90% of the annual ground water draft is being used for irrigation purposes [6]. The State of Punjab, India is one of the major food bowls of India with about 85% of the total cropped area under the rice-wheat cropping system. Rice is a major water guzzling crop corroborated by crop evapo-transpiration, percolation and other losses during the crop cycle [7-9]. Due to dominance of rice-wheat cropping system in Punjab, a huge amount of ground water is being pumped for irrigating the crops. Central Punjab covers around 40% geographical area of the Punjab state, India and paddy–wheat is the main cropping system in the region [10]. In central Punjab region of India, there was a major shift from canal irrigation to tube well irrigation and due to easy availability of ground water resources farmers have shifted to paddy-wheat cropping system from the wheat-maize cropping system. Because of which the central Punjab districts have witnessed an excessive groundwater exploitation resulting in over-exploitation in all the blocks of central Punjab [11]. Further, out of the total 13 districts of central Punjab, five districts *viz.* Moga, Barnala, Sangrur, Patiala and Ludhiana cover 34.4% of the total rice cultivated area (3.1mha) of the State. The ground water table depth depletion in these five districts were found higher amongst the 13 central Punjab districts based on the pre-monsoon groundwater table depth analysis [12]. Climate change will further affect the water resource availability in Central Punjab districts, India. It is therefore imperative to study how the climate change parameters and the evapotranspiration will vary in the study districts so that suitable mitigation and adaptation strategies can be adopted by the state government, researchers and other beneficiaries. Moreover, for effective water management plans climate change data from multimodal ensembles are suggested. Chaturvedi *et al.* (2012) used CMIP5 based 18 GCMs for future projection of temperature and precipitation for India under RCPs 2.6, 4.5, 6.0 and 8.5 scenarios for the period 1880–2099 and suggested use of multiple climate models for better climate projections for India [13]. Mishra *et al.* (2018) evaluated the precision of CMIP5 GCMs and CORDEX RCMs data from 1975–2005 by comparing them with India Meteorological Department (IMD) data [14]. The study suggested use of appropriate bias correction methods to the dynamically downscaled regional climate models (CORDEX RCMs) before using them in vulnerability and impact assessment studies. No studies using multiple climate model-based outputs were used in the present study area by past researchers which will be of paramount importance for the study area for devising effective water management plans. Present study was therefore aimed at the trend analysis of climate variables *viz.*, rainfall (RF), maximum air temperature (T_{max}) and minimum air temperature (T_{min}) derived from model ensembles and also the trend analysis of the potential evapotranspiration (PET) and actual evapotranspiration (AET) data estimated through validated SWAT model.

MATERIALS AND METHODS

Study area description

Study area was comprised of Barnala, Moga, Sangrur, Patiala and Ludhiana districts of Central Punjab, India located between 29.9°N-31.07°N latitude to 74.9°E-76.8°E longitude covering an area of 10,501 Km^2. Three distinct climatic periods are prominent in the study area *viz.* the summer period from mid of April to June, the rainy period from beginning of July to the end of September and the winter from early December to the end of February. The region receives 80% of rainfall due to the south west monsoon (*i.e.*, from end of June to September). The average monsoon rainfall for the study area for past 30 years varied from 276.3 mm to 498.5 mm, whereas, the average annual rainfall for the study area varied from 363.4 mm to 609.8 mm for the same period. The location map of the study area is shown in Fig.1.

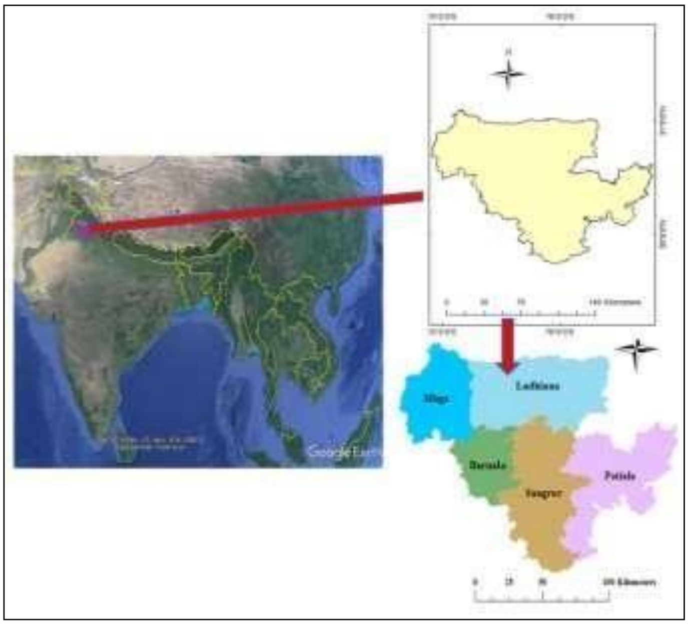


Fig.1 Location map of the study area depicting Moga, Barnala, Sangrur, Patiala and Ludhiana districts of central Punjab, India

Climate change data extraction

The World Climate Research Programme (WCRP) Coordinated Regional Climate Downscaling Experiment (CORDEX) dataset for South Asian region archived and published on the Centre for Climate Change Research Indian Institute of Tropical meteorology (CCCR-IITM) ESGF data node (http://cccr-dx.tropmet.res.in:8000/cccrindia/) was used for extraction of the rainfall, minimum and maximum air temperature data for RCP 4.5 scenario for near future, 2030 (time period from 2006-2030 was considered representing 2030). Six CORDEX South Asia RCM ensembles based on IITM Regional Climate Model version4, RegCM4 [15] were used in the study. Details of CORDEX South Asia IITM-RegCM4 six ensemble members are presented in Table 1. Historical data sets from 1983-2005 and future climate projection datasets for2030 forced with the Representative Concentration Pathway, RCP 4.5 (mid-range emissions) under the six IITM-RegCM4 ensemble members was downloaded and were bias corrected for further analysis.

Bias correction of climate data

In the present study the RCM historical and future climate data in net CDF (Network Common Data Form) format were bias corrected using observed IMD gridded data for the study region. The CMhyd tool was used for bias correction. Fig.2 shows the bias correction framework used in CMhyd tool. In the present study the precipitation data were bias-corrected using distribution mapping method [16-17] and the temperature data were bias-corrected using delta method [18-19] for the observed daily IMD gridded precipitation and temperature data. Overlapping period from 1983-2005 between the CORDEX RCM derived historical climate data and the IMD observed gridded precipitation data was used for bias correction of model simulated historical climate data.

Table 1: List of the six CORDEX South Asia RCMs used in present study					
CORDEX South Asia RCM	**RCM Description**	**Contributing CORDEX Modelling Centre**	**RCM Ensemble Member Name**	**Driving CMIP5 AOGCM**	**Contributing CMIP5 Modelling Centre**
IITM-RegCM4 (6 ensemble members)	The Abdus Salam International Centre for Theoretical Physics (ICTP) Regional Climatic Model version 4.4.5 (RegCM4; Giorgi et al., 2012)	Centre for Climate Change Research (CCCR), Indian Institute of Tropical Meteorology (IITM), India	CCCma-CanESM2	CanESM2	Canadian Centre for Climate Modelling and Analysis (CCCma), Canada
			NOAA-GFDL-GFDL-ESM2M	GFDL-ESM2M	National Oceanic and Atmospheric Administration (NOAA), Geophysical Fluid Dynamics Laboratory (GFDL), USA
			CNRM-CERFACS-CNRM-CM5	CNRM-CM5	Centre National de RecherchesMe´te ´orologiques (CNRM), France
			MPI-M-MPI-ESM-MR	MPI-ESM-MR	Max Planck Institute for Meteorology (MPI-M), Germany
			IPSL-IPSL-CM5A-LR	IPSL-CM5A-LR	Institut Pierre-Simon Laplace (IPSL), France
			CSIRO-QCCCE-CSIRO-Mk3-6-0	CSIRO-Mk3.6	Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia

Reference:[20]

Trend analysis of RF, temperature and evapotranspiration data

Validated SWAT modelfor the study areaby Debnath *et al.*,(2022) was used for estimation of potential evapotranspiration (PET) and actual evapotranspiration (AET)in the study districts using the bias corrected rain fall and temperature data for 2030 under RCP 4.5 scenario [21]. The modified Mann-Kenndall test statistic (mMK-Z) and the Sen's slope estimator [22-24]were used as statistical indicators to estimate the trend of the climatic variables and evapotranspiration using R Studio platform.Positive value of mMK-Z indicates an increasing trend, whereas their negative values indicate a decreasing trend. Similarly, the positive and negative values for Sen's slope (SS) estimator rate of change of the variables per year.

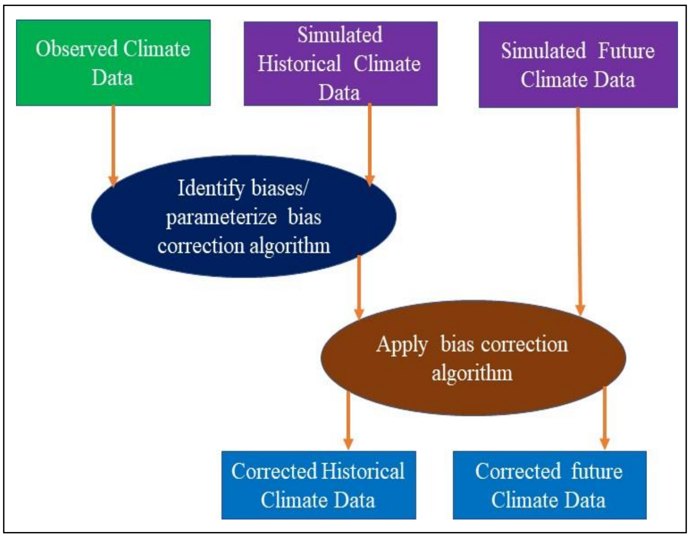


Fig.2: Bias correction framework used in CMhyd tool. Adopted from [25]

A new water demand factor due to climate change was introduced for all the five study districts in the present study (WDF_{CC}) in order to understand how much more or less irrigation demand will be there under the impact of climate change in the study districts. WDF_{CC} were calculated based on the difference between average PET and AET values from 2006-2030 to over the base period (1983-2005) as shown in Equation 1.

$$\mathbf{WDF}_{cc} = 1 + \left[\frac{\Delta \mathrm{ET_{cc}} - \Delta \mathrm{ET_b}}{\Delta \mathrm{ET_b}}\right] \ \ldots\ldots \text{(Equation 1)}$$

Where, ΔET_{cc} refers to the average of difference of PET and AET for 2006-2030 and ΔET_b refers to the average of differences between PET and AET for the base period (1983-2005).

RESULTS AND DISCUSSION

Changes in climatic variables during 2030 over the base period (1983-2005)

The climatic variables *viz.*, rainfall, minimum and maximum air temperatures derived from CCCma-CanESM2, NOAA-GFDL-GFDL-ESM2M, CNRM-CERFACS-CNRM-CM5, MPI-M-MPI-ESM-MR, IPSL-IPSL-CM5A-LR, CSIRO-QCCCE-CSIRO-Mk3-6-0 models under RCP 4.5 for 2006- were averaged out on yearly basis for further analysis. Modified Mann-Kendall test confirmed a significant decreasing trend ($p<0.05$) for rainfall for Moga, Patiala, Sangrur and Barnala districts. Both the minimum and maximum air temperature were found to be increasing during 2006-2030. The Modified Mann-Kendall test statistics (mMK-Z) and Sen's slope estimator (SS) confirmed a significant decreasing rainfall trend during the period from to 2006-2030 (Table 2). The yearly total rainfall for Moga district varied from 315.5-470.3 mm for the base period (1983-2005), whereas for the same period, it varied from 527.4-788.2 mm, 388-592.6 mm, 323.2-542.9 mm and 568.3-795.1 mm for Patiala, Sangrur, Barnala and Ludhiana district, respectively. The annual average rainfall for the base period for Moga, Patiala, Sangrur, Barnala and Ludhiana districts were 348.9 mm, 670 mm, 498.3 mm, 436.4 mm and 696.8 mm, respectively. The predicted rainfall for 2030 under RCP 4.5 varied from 180.8-356.4 mm, 358.8-628.2 mm, 250.8-497.1 mm, 198.3-453.7 mm and 375.8-583.6 mm for Moga, Patiala, Sangrur, Barnala and Ludhiana districts, respectively. The yearly average rainfall under RCP 4.5 was found to be 284.4 mm, 468.2 mm, 357.9 mm, 331.9 mm and 480.4 mm for the Moga, Patiala, Sangrur, Barnala and Ludhiana districts, respectively. Fig.3(a) and Fig.3 (b) shows the Box and Whisker plots for district wise rainfall variability for the base period (1983-2005) and for 2030, respectively. The yearly average rainfall during 2030 was predicted to decrease by 26 %, 30 %, 28 %, 24 % and 31 % for Moga, Patiala, Sangrur, Barnala and Ludhiana districts, respectively as compared to the base period. Fig.4 shows the trend and Sen's estimator for rainfall in Moga, Patiala, Sangrur, Barnala and Ludhiana district under climate change scenario.

Table 2: The Modified Mann-Kendall test statistics (mMK-Z) and Sen's slope estimator (SS) for rainfall in under RCP 4.5.

Test statistics of Rainfall for						
Statistics	**Barnala**	**Ludhiana**	**Moga**	**Patiala**	**Sangrur**	**Averaged for 5 districts**
mMK-Z value	-2.2**	-1.6	-2.5**	-0.5	-2.3**	-2.3**
Sen's slope	-2.0	-1.2	-3.4	-3.3	-1.9	-3.0

**Trend at 5% significance level ($p < 0.05$)

The maximum air temperature during 2030 was found to be increasing although the increase was not significant, whereas there was a significant increase ($p<0.05$) in minimum air temperature for the year under RCP 4.5. Table 3 shows the Modified Mann-Kendall test statistics (mMK-Z) and Sen's slope estimator (SS) for the maximum and minimum air temperatures averaged over the five study districts.

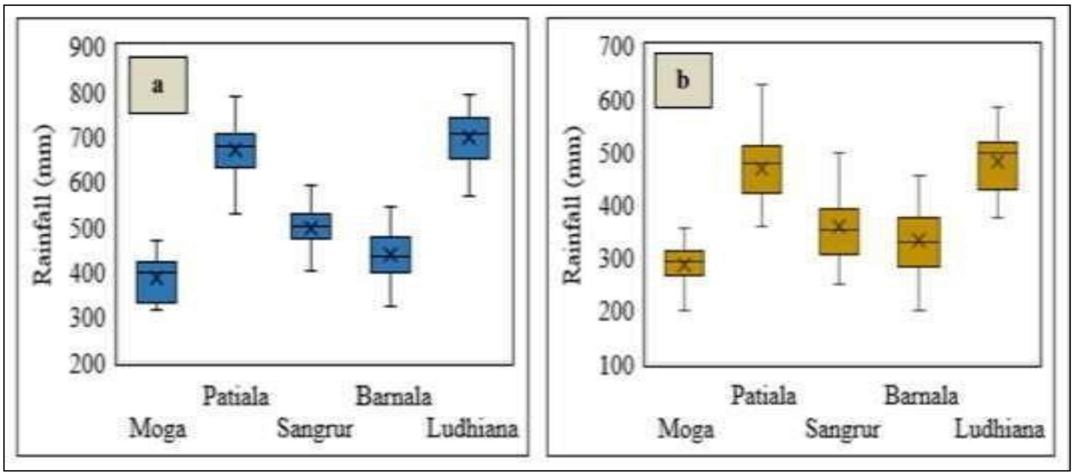


Fig. 3: Box and Whisker plots showing district wise rainfall variability for a) base period (1983-2005) and b) 2030 under RCP 4.5.

Table 3: Modified Mann-Kendall test statistics (mMK-Z) and Sen's slope estimator (SS) for the maximum and minimum air temperatures for 2030

Test statistics of Minimum and Maximum air Temperature from 2006-		
Statistics	**Minimum air Temperature**	**Maximum air Temperature**
mMK-Z value	2.03*	0
Sen's slope	0.02878	0.00057

*Trend at 5% significance level ($p < 0.05$)

The average maximum and minimum air temperature for the base period for all the study districts were observed to be 30.2°C and 16.5°C, respectively. Whereas, the average maximum and minimum air temperatures were estimated to be 32°C and 18°C, respectively for 2030. The maximum air temperature was observed to increase by 1.8°C and the minimum air temperature was found to increase by 1.5°C during 2030 over the base period. Fig.5 shows the trend and Sen's estimator for minimum and maximum air temperatures averaged over the five districts for 2006-2030 under RCP 4.5.

These findings were in line with the results reported by Dar *et al.*, (2019) in which the rainfall decreased by 98 mm and the minimum and maximum air temperatures increased by 1.9°C and 1.3 °C, respectively during 2020-2050 under RCP 4.5 for the Ludhiana district of Punjab, India [26]. Kaur *et al.*, (2021) reported a decrease in annual rainfall by 33-554 mm during 2020-2049 and 3-610 mm during 2066-2095 under RCP 4.5 over the base line period (2016-17) for Sirhind canal tract area, Punjab [27].

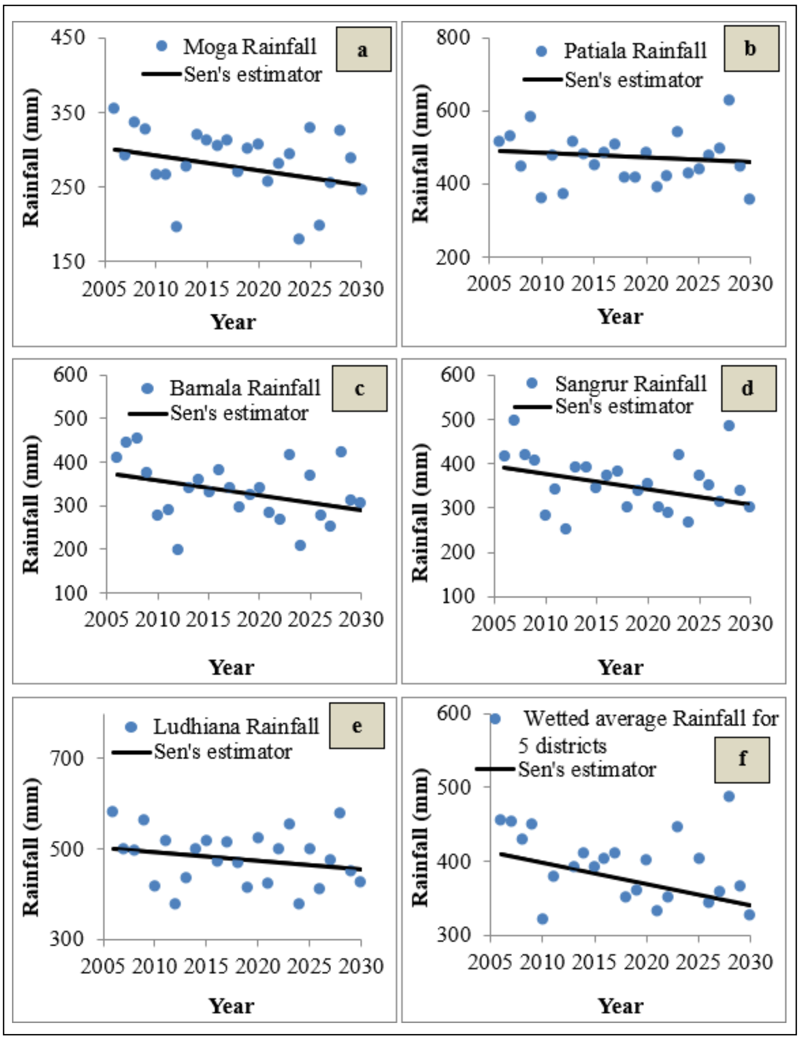


Fig. 4: Trend and Sen's estimator for a) Moga, b) Patiala, c) Barnala, d) Sangrur, e) Ludhiana and f) Five districts wetted average Rainfall for 2030 under RCP 4.5.

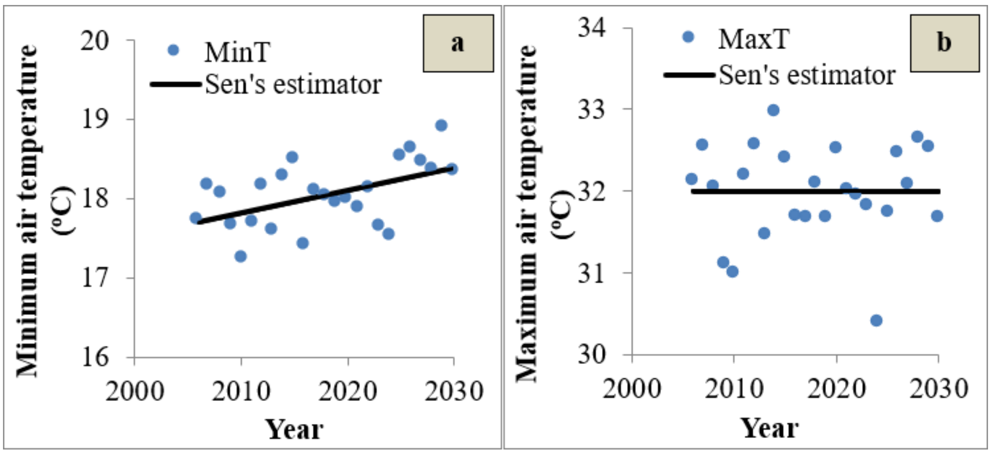
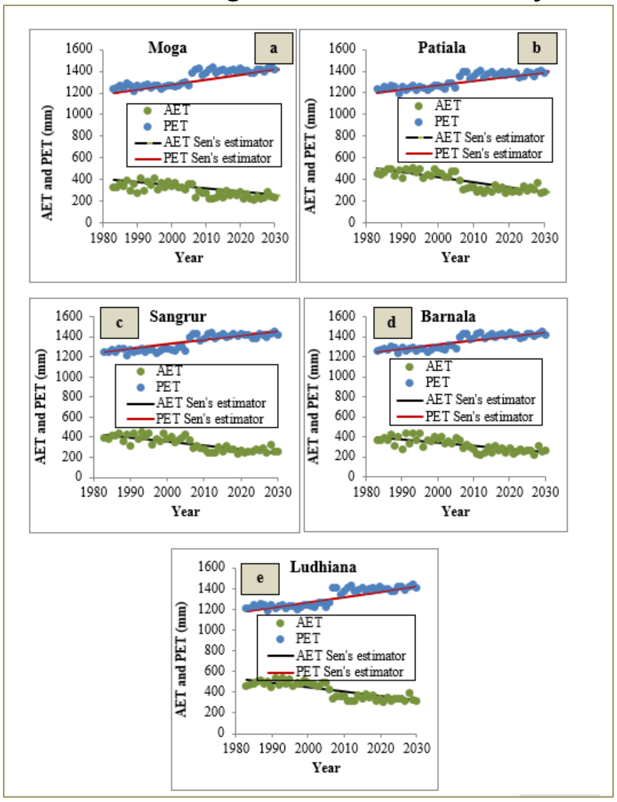


Fig.5: The trend and Sen's estimator for Minimum and Maximum air temperatures averaged over the five districts for under RCP 4.5.

Yearly variation of PET and AET during 1983-2030 in the study districts



Yearly variation of PET and AET values estimated through validated SWAT model from 1983-2030 are shown in Fig.6. Modified Mann-Kendall test ascertained a significant increasing trend for PET over time whereas, there was a significant decrease in AET values, respectively for p<0.05 over time. Table 4and Table 5 shows the Modified Mann-Kendall test statistics and Sen's slope estimator (SS) for the PET and AET values over time. This difference in PET and AET values over time shows that there will be increase in water demand in the study districts for irrigating the crops under climate change scenarios. The increased water demand factors under climate change for the study districts is presented in Table 6. Results indicated that there would be an increase of irrigation water demand of by 43%, 36%, 31%, 21% and 21% under climate change for Ludhiana, Patiala, Sangrur, Barnala and Moga districts, respectively. This increase in irrigation water demand would put extra burden on the ground water extraction from the study districts as ground water meets 89 % of the total irrigation water need in the study districts [28].

Fig. 6 Yearly variation of PET and AET values from 1983-2030 for a) Moga, b) Patiala, c) Sangrur, d) Barnala and e) Ludhiana district along with Sen's slope estimator.

Table 4: Modified Mann-Kendall test statistics (mMK-Z) and Sen's slope estimator (SS) for PET from 1983-2030

Test statistics of PET					
Statistics	**Barnala**	**Ludhiana**	**Moga**	**Patiala**	**Sangrur**
mMK-Z value	4.3*	3.6*	3.8*	4.0*	3.9*
Sen's slope	4.2	5.1	4.5	4.0	4.5

*Increasing trend at p<0.05.

Table 5: The Modified Mann-Kendall test statistics (mMK-Z) and Sen's slope estimator (SS) for AET from 1983-2030					
Test statistics of AET					
Statistics	**Barnala**	**Ludhiana**	**Moga**	**Patiala**	**Sangrur**
mMK-Z value	-3.4*	-3.5*	-3.4*	-3.8*	-3.8*
Tau	-0.52	-0.55	-0.52	-0.57	-0.55
Variance	29352	31093	29925	28633	27107
Sen's slope	-3.4	-4.5	-3.1	-4.7	-4.0

*Decreasing trend at $p<0.05$

Table 6: District wise calculated water demand factor (WDF_{CC}) under climate change for RCP 4.5 scenario			
District Name	Difference between PET and AET (mm)		Water demand factors under climate change (WDF_{CC})
	Base Period (1983-2005)	Climate change period (2006-2030)	
Moga	915.1	1154.9	1.26
Barnala	910.0	1151.0	1.26
Ludhiana	741.9	1058.1	1.43
Sangrur	870.9	1142.6	1.31
Patiala	785.9	1066.2	1.36

CONCLUSIONS

Central Punjab districts *viz.*, Barnala, Moga, Sangrur, Patiala and Ludhiana being critically depleted ground water regions in India will further witness more dependency on ground water for irrigating the major rice-wheat cropping system in the region as there would be a significant decrease in RF in near future. Rainfall would decrease by 26 %, 30 %, 28 %, 24 % and 31 % for Moga, Patiala, Sangrur, Barnala and Ludhiana districts, respectively during 2030 as compared to the base period 1983-2005. Further, an increase in irrigation water demand of by 43%, 36%, 31%, 21% and 21% under climate change for Ludhiana, Patiala, Sangrur, Barnala and Moga districts, respectively would put an extra burden on the ground water extraction from the study districts as ground water meets 89 % of the total irrigation water need in the study districts at present. Present analysis would help policy makers, researchers and end users to adopt appropriate water management strategies for sustainable crop production in the study districts.

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Conflict of Interest Statement: The author(s) declare(s) that there is no conflict of interest.

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