Original Research Article

Climate Predictions for Ludhiana District of Indian Punjab under RCP 4.5 and RCP 8.5

Abstract

Climate change poses significant threats to the global food security and water resources. In a present study, a Global Climate Model, HAD GEM2-ES under RCPs 4.5 and 8.5 was used for climate prediction of Ludhiana~~study~~. The study spanned 46 years of baseline (1970-2015) as well as two future periods' mid-century (MC) (2020-2050) and end century EC (2060-2090). The results showed that the temperature would increase by 1.56 °C and rainfall would decrease by 98 mm in MC (2020-2050); and 3.11°C and 90 mm in EC (2060-2090), respectively under RCP 4.5. In RCP 8.5 the increase in temperature and rainfall was 2.75°C and153 mm, respectively in MC and the corresponding values in EC was 5.46°C and 251 mm, respectively

Keywords: GCM, Climate Model, Representative concentration Pathways

Introduction

Climate change is considered ~~to be~~ the biggest threat of the 21th century and sustainable development in the entire world (IPCC, 2014; Lema and Majule, 2009). Climate change has been confirmed to be impacting almost all parts of the world but the Asian continent is considered to be the most vulnerable region to shocks of climate change and climate variability due to the numerous stresses and low adaptive capacity (IPCC, 2014). Despite various adaptation measures to the current climate change impacts, such interventions have been considered insufficient for future changes in climate (IPCC, 2014). According to IPCC (2014), future precipitation is predicted to be more variable. Precipitation is also predicted to increase by between 5% and 20% for November, December, January and February. Nevertheless, a decrease of 5–10% is predicted to occur for the remaining months (IPCC, 2014).

Ludhiana district falls in central part of Punjab. The district is bounded between North latitude 30° 33′ and 31° 01′ and East longitude 75° 25′ and 76° 27′ (Fig 1). The Satluj forms the border of the district in the North with Jalandhar and Hoshiarpur districts. Ropar and Fatehgarh Sahib districts mark the eastern and south eastern boundaries. The western border is adjoining Moga and Ferozepur districts. The geographical area of the district is 3790 sq.kms. The district has four sub-divisions viz-Ludhiana, Khanna, Samrala and Jagraon and eleven development blocks viz.- Ludhiana, Mangat, Doraha, Khanna, Dehlon, Pakhowal, Samrala, Machiwara, Jagraon, Sidhwan Bet and Sudhar.

The climate of Ludhiana district can be classified as tropical steppe, hot and semi-arid which is mainly dry with very hot summer and cold winter except during monsoon season when moist air of oceanic origin penetrates into the district. There are four seasons in a year. The hot weather season starts from mid-March to last week of the June followed by the south west monsoon which lasts up_to September. The transition period from September to November forms the post-monsoon season. The winter season starts late in November and remains up to first week of March. The normal annual rainfall of the district is 680 mm which is unevenly distributed over the area in 34 days. The south west monsoon sets in from last week of June and withdraws in the end of September. It normally ~~,~~contributes ~~d~~ about 78% of the annual rainfall with~~.~~ July and August as ~~are~~ the wettest months. The r~~R~~est, i.e. 22% of the total annual rainfall amount is normally received during the non-monsoon period in the wake of western disturbances and thunder storms (CGWB 2012).

The district area is occupied by Indo-Gangetic alluvium and there are no surface features worth to mention except that area is plain and major drains are Satluj and its tributaries and Budha Nala. The subsurface geological formations of the area comprise of sand, silt, clay and kankar in various proportions. In general, the groundwater of the district is fresh except in and around Ludhiana city where the groundwater is polluted due to industrial effluents. The lithological data indicates presence of about 5 prominent sand horizons down to 400 m depth separated by thick clay horizons. The aquifers are giving discharge from 3-52 lps with 4.3×10^{-4} - 6.98×10^{-4} storativity and transmissivity ranges between 628-1120 m^2/day. The sand content in the aquifer in the district varies from 50 to 80%. Clay beds though thick at places occur mostly as lens and pinches out laterally. The granular material becomes coarser with depth. The aquifer at deeper levels acts as semi-confined to confined.

Comment [a1]: I don't see the relevance of this highlighted paragraph

Materials and Methods

Comment [a2]: I note that the author(s) do not describe the methods used in the study. Data quality control is not mentioned as well. The justification for considering the study area is too weak

Long-term observed daily rainfall, maximum temperature(T_{max}), minimum temperature (T_{min}), solar radiation data from meteorological station located at Punjab Agricultural University, Ludhiana from (1970-2015) were collected and used as a baseline. Site-specific future rainfall and temperature data was generated from five GCMs, namely, (i) Hadley Center Global Environment Model 2 - Earth System (HADGEM2-ES); (ii)~~,~~ the GFDLESM-2M; (iii)~~,~~ CISRO MK 3-0; (iv)~~,~~ BCC-CSM 1-1 and (v) the GISS-E2R (Table 1) under the RCP 4.5 (representative concentration pathways) and RCP 8.5, using MarkSim DSSAT weather generator (Jones and Thornton 2013). Marksim GCM requires geographical coordinates (latitude and longitude of the specific station) and station name to downscale and generate daily future data of a given site.

The dData for the time slices representing periods 1970–2015 (baseline), mid-century (MC) climate change projection (2020–2050) and end century (EC) projection (2060–2090) were used. Here HAD GEM2-ES was one of the best performing models after statistically analyzing for RMSE and NRMSE (Table 2) whereby it had the least error followed by BCC-CSM 1-1 and was used for climate predictions for the study area.

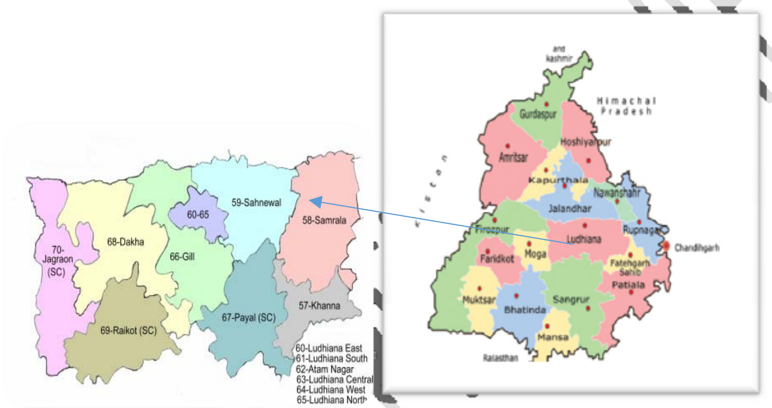


Fig.1 Location map of study area

Table 1 Climate models, resolution and scenarios involved for the present study (Chaturvedi *et al* (2012)

Model	Modelling centre(or group)	Resolution (Lat)- deg	Resolution (Long)- deg	Scenario Involved
BCC-CSM1-1	Beijing Climate Center, China Meteorological Administration	2.812	2.812	4.5 and 8.5
CSIRO-Mk3-0	Commonwealth Scientific and Industrial Research Organization in collaboration with Queensland Climate Change Centre of Excellence, Australia	1.895	1.875	4.5 and 8.5
GFDL-ESM -2M	NOAA Geophysical Fluid Dynamics Laboratory	2.000	2.500	4.5 and 8.5
GISS-E2-R	NASA Goddard Institute for Space Studies, USA	2.022	2.517	4.5 and 8.5
HadGEM 2-ES	Met Office Hadley Centre, UK	1.250	1.875	4.5 and 8.5

Table 2 RMSE and NRMSE values of different models selected for the study area

Model	RMSE	NRMSE
BCC-CSM1-1	4.67	0.284
CSIRO-Mk3-0	4.87	0.296
GFDL-ESM -2M	5.13	0.313
GISS-E2-R	4.92	0.299
HAD GEM2-ES	4.51	0.274

Results and Discussions

Comment [a3]: The discussion of the results is too poor

Climate predictions

This section presents the average annual and monthly trends of T_{max}, T_{min} and Rainfall for baseline (1970-2015), corrected mid-century and end century under RCP4.5 and RCP 8.5.

Maximum temperature

Maximum temperature under RCP 4.5

The annual and monthly trends in maximum temperature during different years of baseline, mid-century (MC) and end century (EC) is presented in Table 4.9 and Table 4.11 and their graphical representation is shown in Fig 2. Average annual T_{max} of 29.70 ± 0.5°C for the baseline would increase to 31.08± 0.4°C in MC and 33.08± 0.3°C in EC. This implies that in MC and EC, increase in T_{max} would be 1.3°C and 3.38°C respectively in future. In MC, the change in T_{max} would be positive in all months except in January. Highest positive change would be of 4.06°C in the month of March and negative change of 0.03°C in the month of January. In EC, the change in T_{max} would be positive in all the months and the maximum positive would be 6.40°C in the month of March.

Table 3.Average annual climate of Ludhiana during baseline, MC and EC under RCP 4.5

Temperature (°C)	Baseline (1970-2015)	MC (2020-2050)	EC (2060-2090)
T_{max}	29.73	31.08	33.08
T_{min}	16.64	18.40	19.51
Mean	23.18	24.74	26.29
Rain	759.79	662.24	670.10

Maximum temperature under RCP 8.5

The annual and monthly trends in maximum temperature during different years of baseline, mid-century (MC) and end century (EC) is presented in Table 4 and Table 5 and their graphical representation is shown in Fig 3. Average annual T_{max} of 29.70 ± 0.5°C for the baseline would increase to 33.14± 0.45°C in MC and 35.87± 0.7°C in EC. This implies that in MC and EC, increase in T_{max} would be 3.44°C and 6.17°C respectively in future. In MC, the change in T_{max} would be positive in all months. Highest positive change would be of 5.13°C in the month of May. In EC, the change in T_{max} would be positive in all the months and the maximum positive would be 8.58°C in the month of May.

Table 4. Average annual climate of Ludhiana during baseline, MC and EC under RCP 8.5

Temperature (°C)	Baseline (1970-2015)	MC (2020-2050)	EC (2060-2090)
T_{max}	29.73	33.14	35.87
T_{min}	16.64	18.73	21.41
Mean	23.18	25.93	28.64
Rain	759.79	912.48	1010.95

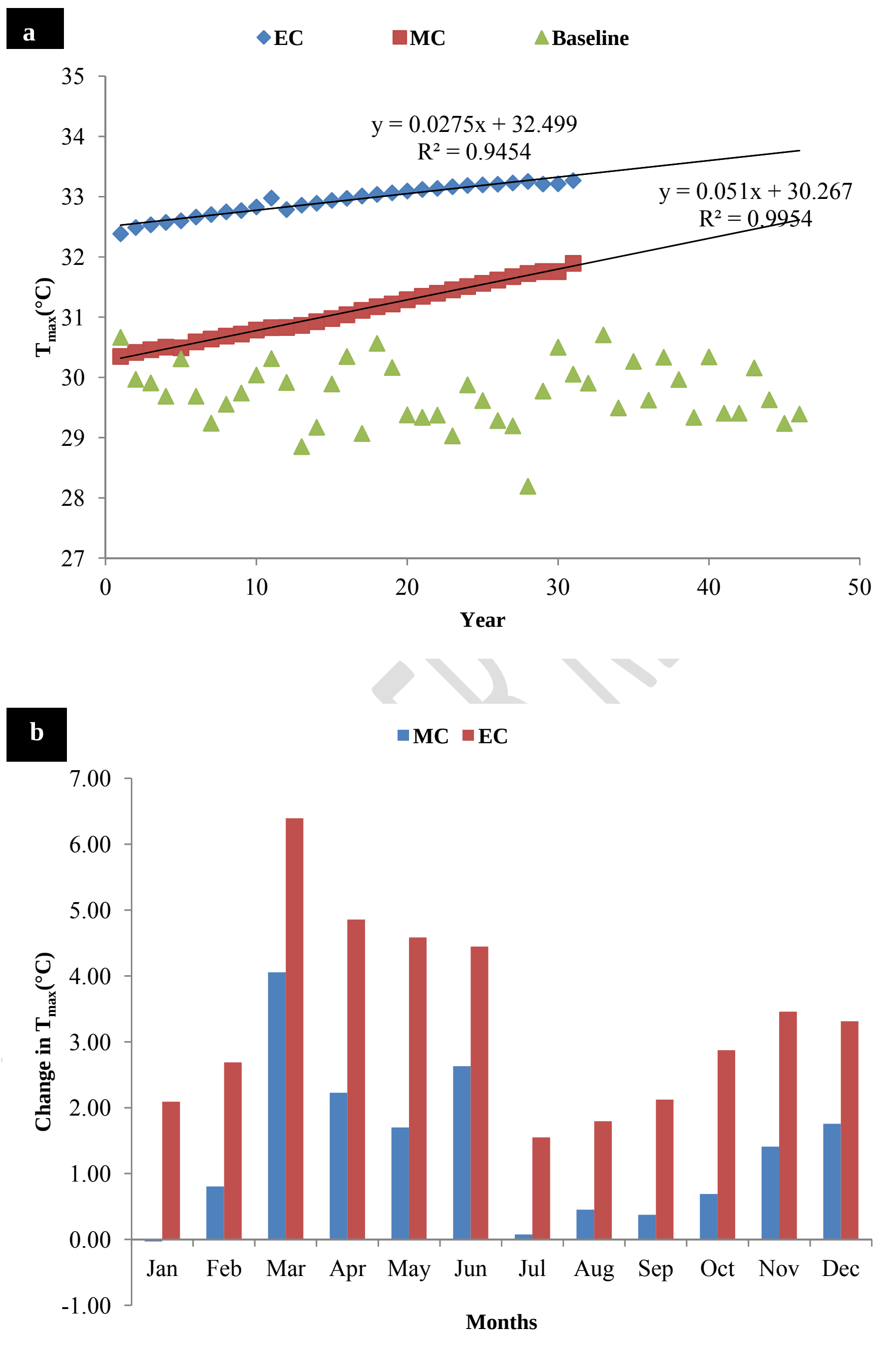


Fig. 2 **Annual (a) and monthly (b) maximum temperature trends in baseline, MC and EC under RCP 4.5**

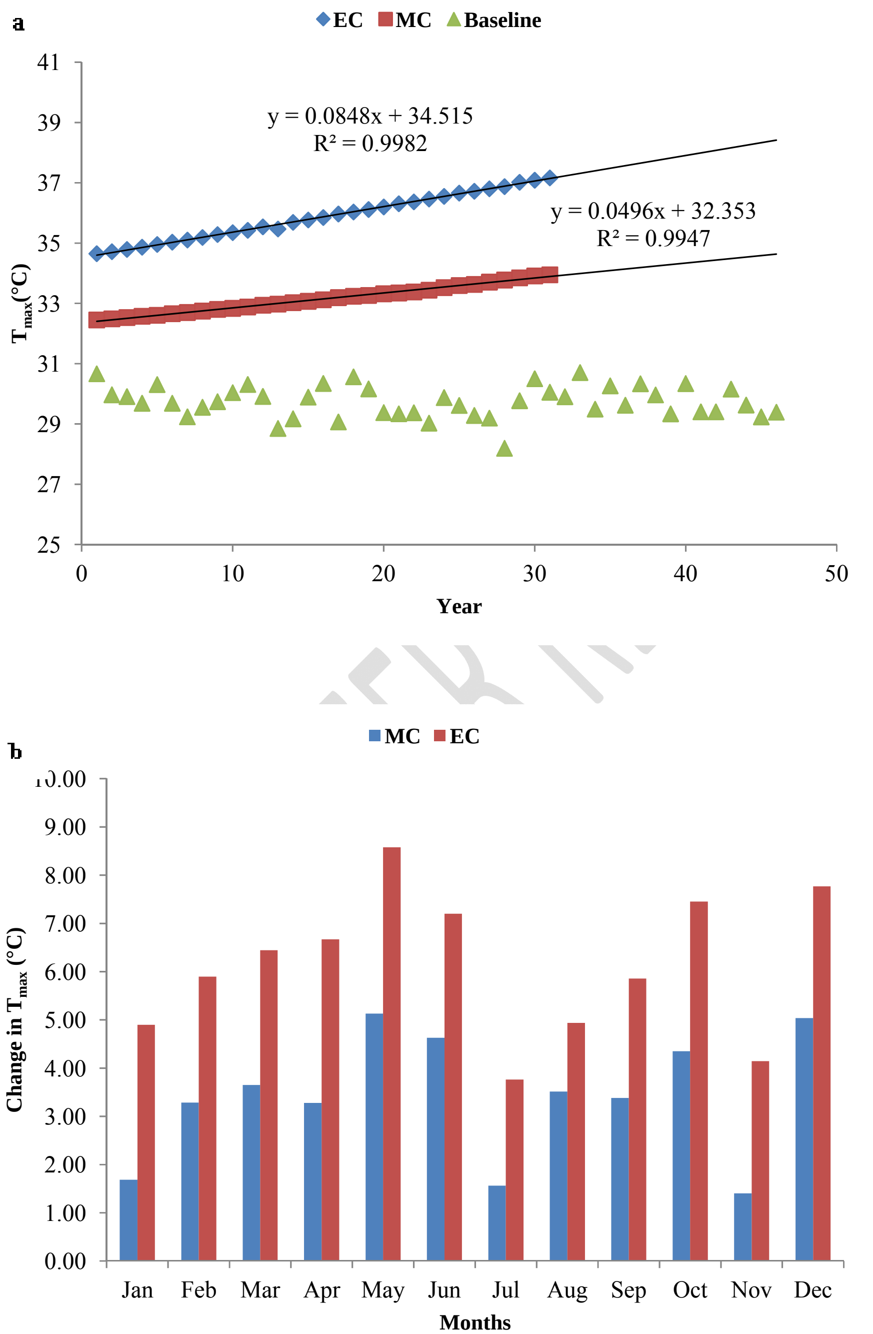


Fig. 3 **Annual (a) and monthly (b) maximum temperature trends in baseline, MC and EC under RCP 8.5**

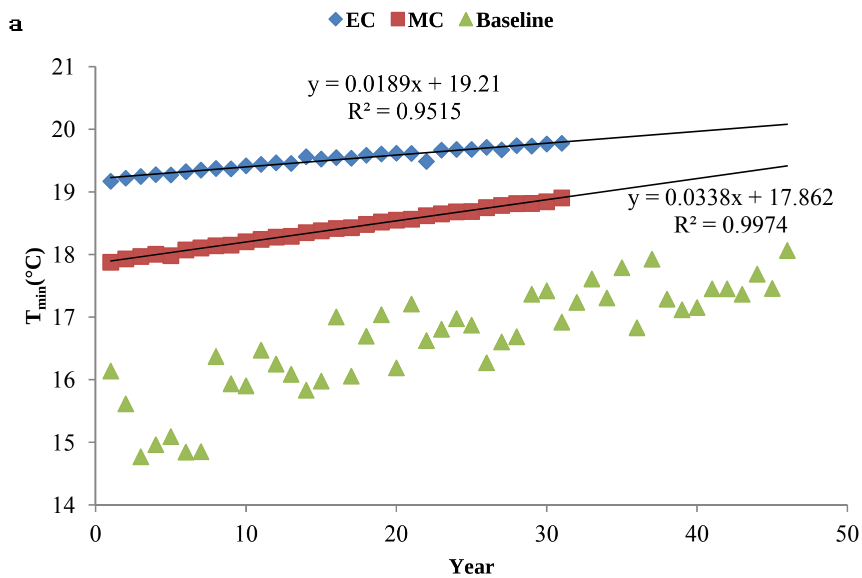
Minimum Temperature

Minimum temperature under RCP 4.5

Average annual T_{min} of 16.64 ±0.8°C of baseline would increase to 18.40 ± 0.3°C in MC and19.51 ± 0.2°C in EC (Table 5). These results predict that increase in T_{min} would be 1.9°C and 3.0°C in MC and EC respectively in future. On monthly basis, in MC there would be positive change in T_{min} in all the months with highest of 3.0°C in the month of October. In EC, the change would be positive in all the months with highest of 4.1°C in the month of October (Fig 4) and (Table 6).

Minimum Temperature under RCP 8.5

Average annual T_{min} of 16.64 ±0.8°C of baseline would increase to 18.73 ± 0.5°C in MC and21.41 ± 0.6°C in EC. These results predict that increase in T_{min} would be 2.09°C and 4.77°C in MC and EC respectively in future (Table 6). On monthly basis, in MC there would be positive change in T_{min} in all the months except months of January and November with highest of 5.26°C in the month of May. In EC, the change would be positive in all the months with highest of 7.97°C in the month of October (Fig 5) and (Table 6).The above data indicates that under RCP 4.5 scenario mean annual temperature would increase by 1.56°C in MC and 3.11°C in EC compared to that of the baseline period while in RCP 8.5 mean annual temperature would increase by 2.75°C in MC and 5.46°C in EC compared to that of the baseline period.



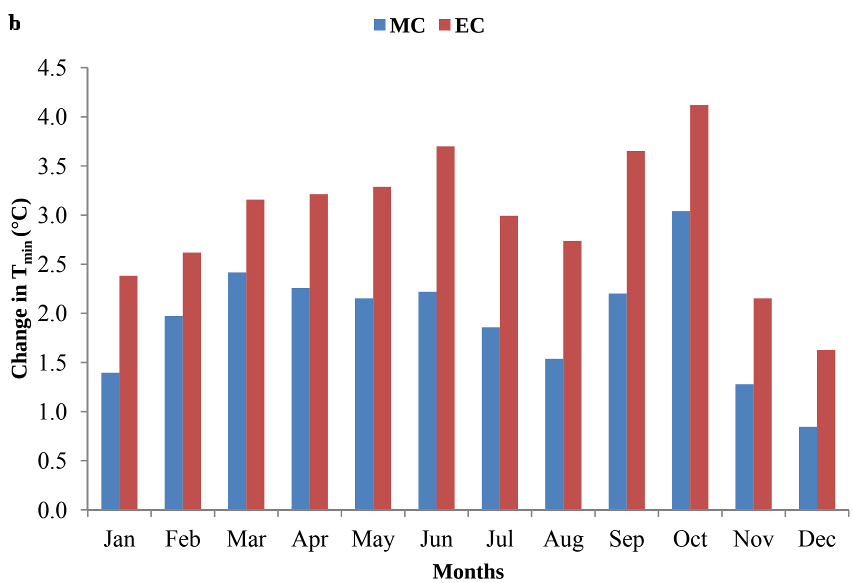
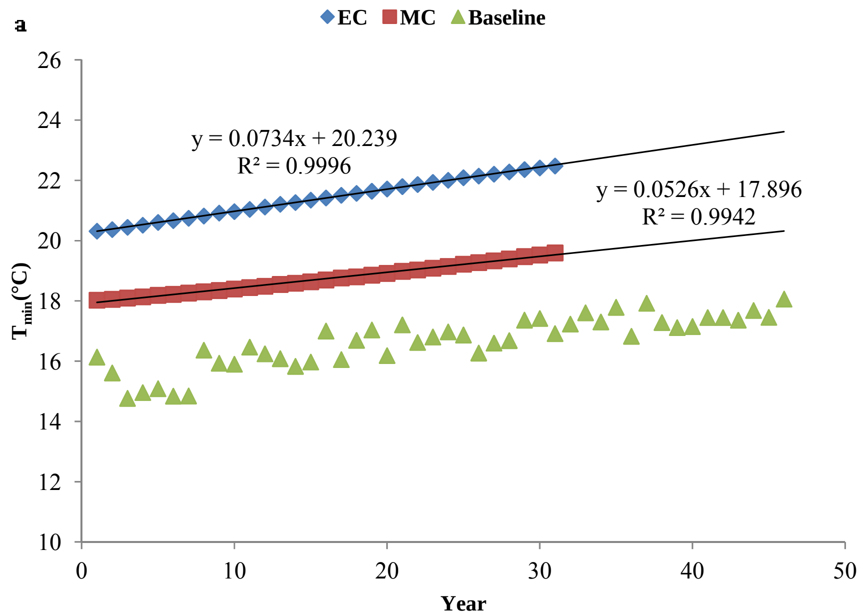


Fig. 4 **Annual (a) and monthly (b) minimum temperature trends in baseline, MC and EC under RCP 4.5**



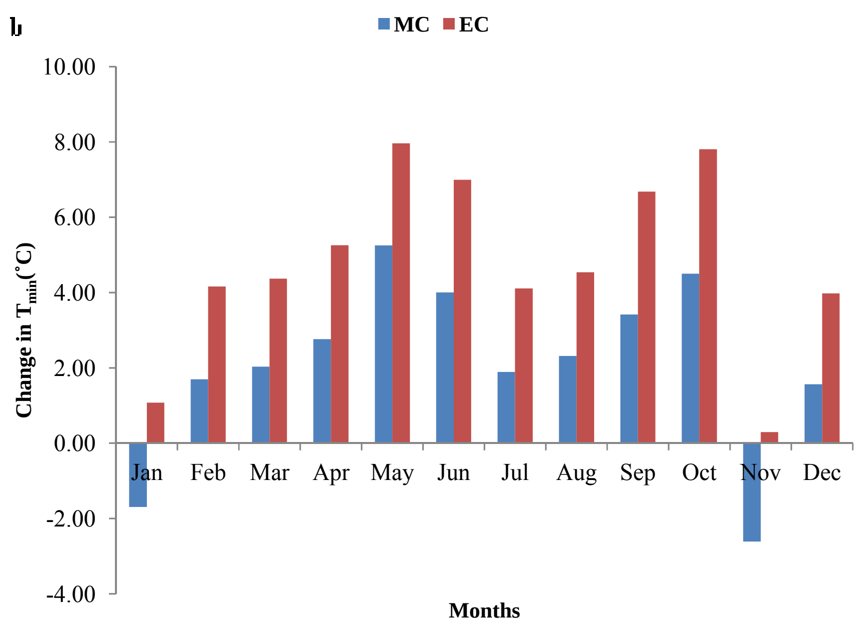


Fig. 5 **Annual (a) and monthly (b) minimum temperature trends in baseline, MC and EC under RCP 8.5**

Rainfall

Rainfall under RCP 4.5

The rainfall showed a decreasing trend with less prominent inters decadal variability. On annual basis, in baseline the average ± standard deviation of rainfall is 759.79 ± 227.1 mm which is likely to decrease to 662.24 ± 49.7mm in MC and 670.10 ±39.3 mm in EC (Table 5) and (Fig 6). These results indicate that in MC the rainfall would decrease by 98 mm (12.8%) and in EC by 90 mm (11.8%) respectively. Monthly trends (averaged over years in each time slice) showed that there will be decrease in the monthly rainfall in almost all the months of MC and EC when compared to that of the baseline, except in months of March (MC only), July, September and October (Fig 6) and (Table 5). The highest negative change in rainfall would be in the month of August, which was computed as 91 mm in MC and 55mm in EC.

Rainfall under RCP 8.5

The rainfall showed an increasing trend with less prominent inters decadal variability. On annual basis, in baseline the average ± standard deviation of rainfall is 759.79 ± 227.1 mm which is likely to increase to 912.48 ± 146.45 mm in MC and 1010.95 ± 65.06 mm in EC (Table 6) and (Fig7). These results indicate that in MC the rainfall would increase by 153 mm (20%) and in EC by 251 mm (33%) respectively. Monthly trends (averaged over years in each time slice) showed that change in rainfall would be positive in the months of May, June, July, August and October and negative in rest of the months of MC and EC compared to that of the baseline (Fig 7) and (Table 6). The highest positive change in rainfall would be in the month of July, which was computed as 247 mm in MC and 211mm in EC.

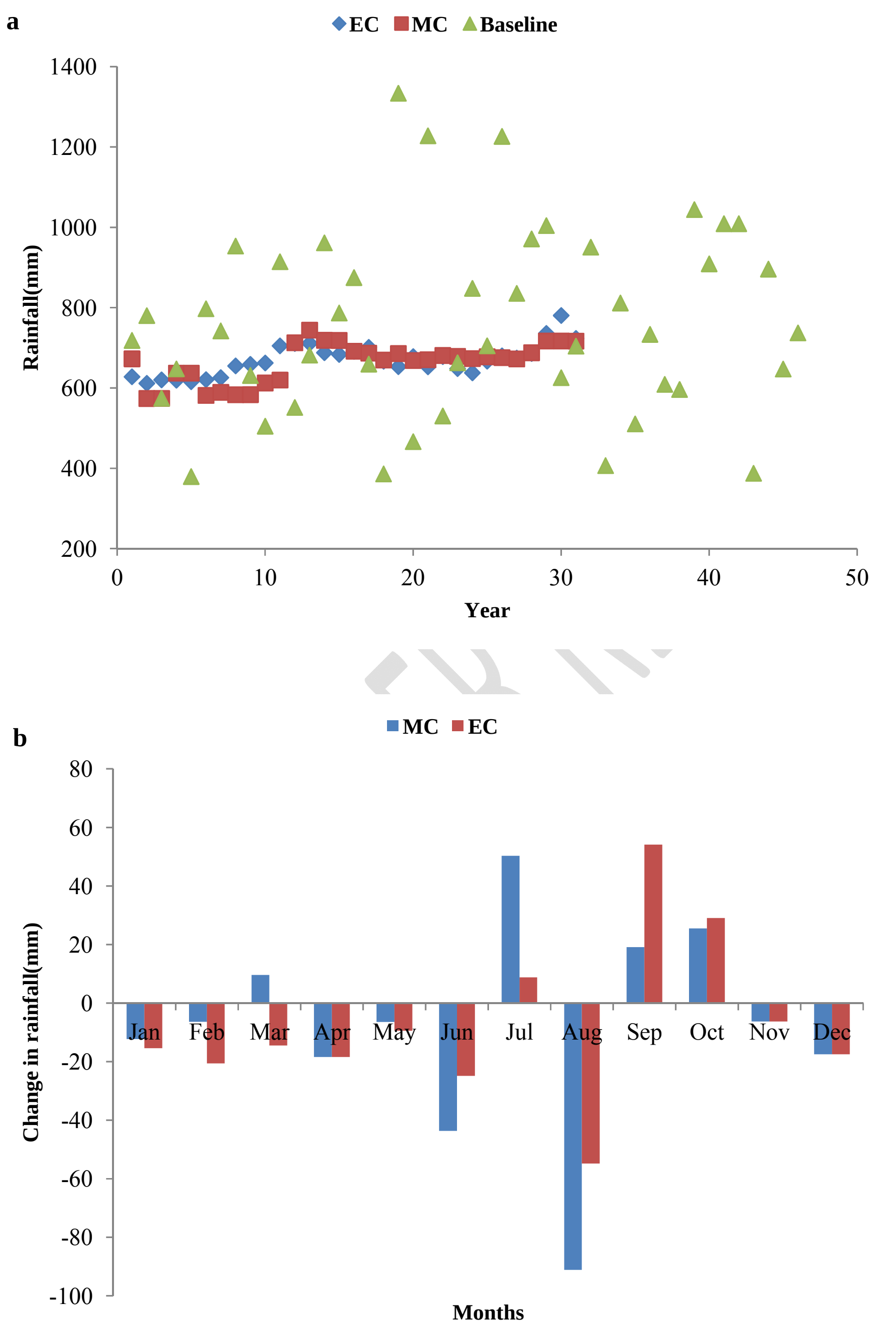
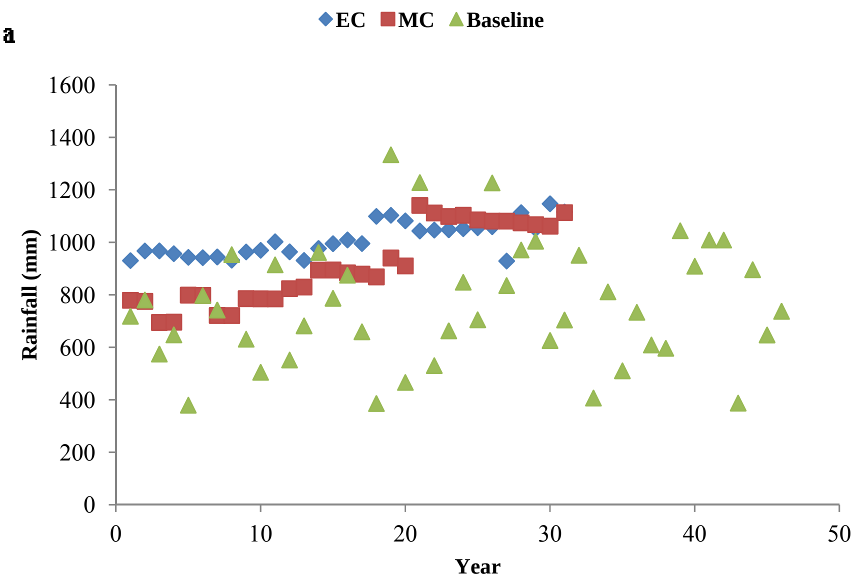


Fig. 6 Annual (a) and monthly (b) rainfall trends in baseline, MC and EC under RCP 4.5

a



b

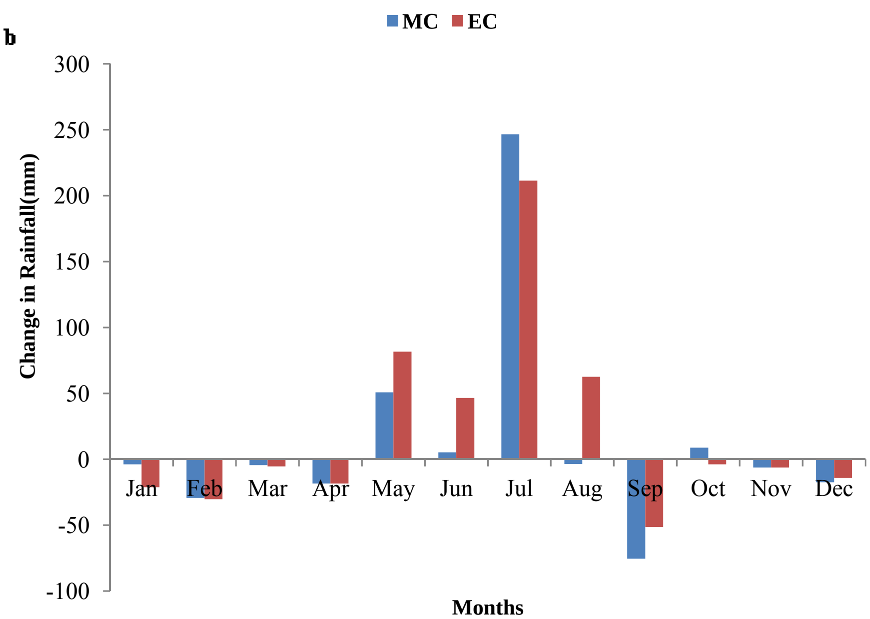


Fig.7 **Annual (a) and monthly (b) rainfall trends in baseline, MC and EC under RCP 8.5**

Table 5. Average maximum, minimum temperature and rainfall in three different time slices for Ludhiana under RCP 4.5

Month	T_{max} (°C)			T_{min} (°C)			Rainfall (mm)		
	1970-2015	2020-2050	2060-2090	1970-2015	2020-2050	2060-2090	1970-2015	2020-2050	2060-2090
Jan	18.05	18.02	20.14	5.60	6.99	7.98	25.98	13.70	10.57
Feb	21.17	21.97	23.86	7.86	9.83	10.48	33.98	27.57	13.43
Mar	26.63	30.69	33.03	11.94	14.36	15.10	22.59	32.16	8.10
Apr	34.44	36.67	39.3	17.30	19.55	20.51	18.42	0	0
May	38.72	40.42	43.30	22.68	24.84	25.97	23.92	17.49	14.45
June	37.99	40.62	42.43	25.77	27.99	29.47	86.00	42.36	61.16
July	34.24	34.31	35.79	26.21	28.07	29.21	214.52	264.85	223.34
Aug	33.31	33.76	35.11	25.57	27.11	28.31	190.51	99.38	135.71
Sep	33.36	33.73	35.48	22.92	25.12	26.57	107.86	127	162.04
Oct	31.74	32.43	34.61	16.62	19.66	20.74	12.18	37.70	41.27
Nov	26.57	27.98	30.03	10.62	11.9	12.77	6.27	0	0
Dec	20.59	22.35	23.90	6.57	7.41	8.2	17.51	0	0

Table 6 Average maximum, minimum temperature and rainfall in three different time slices for Ludhiana under RCP 8.5

Month	T_{max} (°C)			T_{min} (°C)			Rainfall (mm)		
	1970-2015	2020-2050	2060-2090	1970-2015	2020-2050	2060-2090	1970-2015	2020-2050	2060-2090
Jan	18.05	19.74	22.95	5.60	3.90	6.68	25.98	22.11	4.79
Feb	21.17	24.45	27.06	7.86	9.56	12.02	33.98	4.69	3.67
Mar	26.63	30.28	33.08	11.94	13.97	16.31	22.59	18.19	17.20
Apr	34.44	37.72	41.11	17.30	20.06	22.56	18.42	0	0
May	38.72	43.85	47.29	22.68	27.94	30.65	23.92	74.71	105.52
June	37.99	42.61	45.18	25.77	29.78	32.76	86.00	91.32	132.63
July	34.24	35.80	38.00	26.21	28.11	30.33	214.52	461.16	425.94
Aug	33.31	36.82	38.25	25.57	27.88	30.11	190.51	186.91	253.04
Sep	33.36	36.74	39.22	22.92	26.34	29.60	107.86	32.41	56.42
Oct	31.74	36.09	39.19	16.62	21.12	24.43	12.18	20.93	8.32
Nov	26.57	27.97	30.71	10.62	8.01	10.91	6.27	0	0
Dec	20.59	25.63	28.36	6.57	8.14	10.55	17.51	0	3.37

Conclusions

The global climate is changing and agriculture will have to adapt to ensure sustainability and survival. Due to the complexity of both agricultural systems and climate change, climate models are often used to understand the impact of climate change on agriculture and to assist in the development of adaptation strategies. Weather models integrate the understanding of a particular climate pattern, gathered from many years of observation and field experimentations and therefore provide an effective means for investigating crop responses to climate change and alternative management scenarios. In the Ludhiana district of central Punjab dominant cropping system is rice wheat. The climate is semi-arid. Averaged over last 46 years the rainfall, T_{max} and T_{min} are 759.7 mm, 29.7°C, and 16.6°C, respectively. The specific conclusions in context to climate predictions under RCP 4.5, predicts that the mean annual temperature would increase by 1.56°C in MC and 3.11°C in EC and rainfall would decrease by 97.5 mm (12.8%) during MC and 89mm (11.8%) during EC and under RCP 8.5, the mean annual temperature would increase by 2.75°C in MC and 5.46°C in EC and rainfall would increase by 153 mm (20%) during MC and 251mm (33%) during EC. It may be noted that the model was not able to capture the inter annual variability in the future weather data under both the scenarios.

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