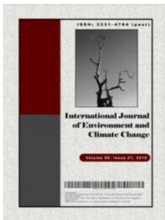

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Climate Predictions for Ludhiana District of Indian Punjab under RCP 4.5 and RCP 8.5

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Authors' contributions

This work was carried out in collaboration among all authors. Author MUDD designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors RA and SK managed the analyses of the study. Author SK managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Climate change poses significant threats to 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 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 and 153 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.

1. INTRODUCTION

Climate change is considered to be the biggest threat of the 21th century and sustainable development in the entire world [1,2]. 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

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region to shocks of climate change and climate variability due to numerous stresses and low adaptive capacity [1]. Despite various adaptation measures to current climate change impacts, such interventions have been considered insufficient for future changes in climate [1]. According to [1], 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 [1]. The hydrological response to climate change is generally predicted using downscaled future climate projections to drive a hydrological model [3,4]. One of the key challenges in factoring climate change into water resources management lies in the uncertainty in the projections [5,6]. The sources of the projection uncertainties could be from the GCMs, the downscaling approaches, or the hydrological models [7,8,9]. The performance of GCMs over the South Asia region has been investigated by quite a few researchers (e.g., [10,11,12,13,14, 15]. For example, [15] found that the majority of the CMIP5 GCMs fail to simulate the post-1950 decreasing trend of Indian summer monsoon rainfall, as they did not capture the weakening monsoon associated with the warming of southern Indian Ocean and strengthening of cyclonic formation in the tropical western Pacific Ocean. Some studies have suggested placing more weight on or using only projections from the better performing GCMs As noted by [14], however, it is challenging in selecting better performing GCMs for the region as none of GCMs can reproduce all the salient features (e.g. seasonal and annual rainfall amounts, distribution and trend, or the large scale atmospheric-oceanic drivers of rainfall in the region). Like the GCMs, the latest dynamic downscaling runs in the CORDEX regional climate model experiments also do not capture the observed monsoon precipitation trends or the correct magnitude of observed warming [16,17]. 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. 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. 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 upto 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 end of September, contributed about 78% of annual rainfall. July and August are the wettest months. Rest 22% rainfall is received during non-monsoon period in the wake of western disturbances and thunder storms [18].

2. MATERIALS AND METHODS

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, Hadley Center Global Environment Model 2 - Earth System

(HADGEM2-ES), the GFDLESM-2M, CISRO MK 3-0, BCC-CSM 1-1 and the GISS-E2R (Table 1) under the RCP 4.5 (representative concentration pathways) and RCP 8.5, using MarkSim DSSAT weather generator [19]. 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. Data 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.

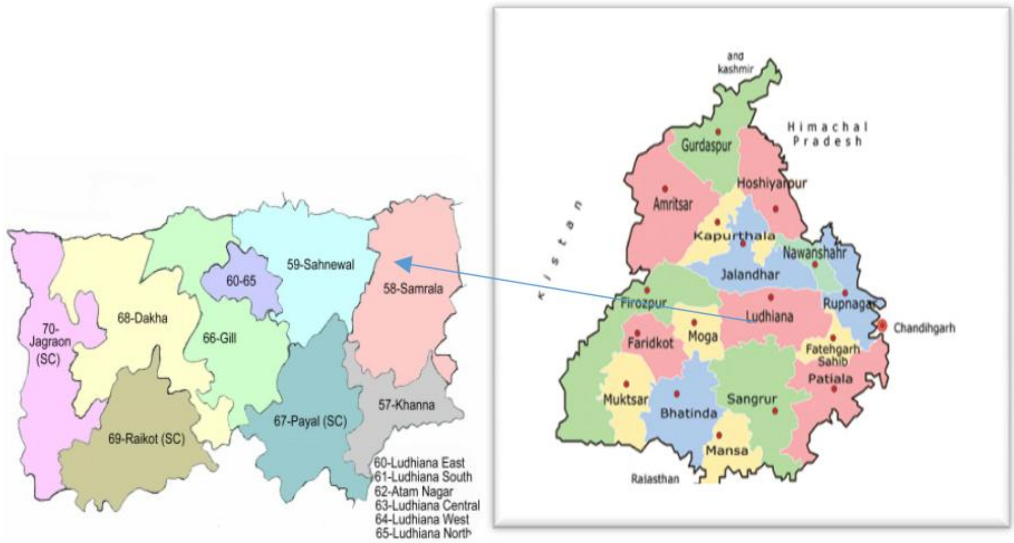


Fig. 1. Location map of study area

Table 1. Climate models, resolution and scenarios involved for the present study [13]

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
Had GEM 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

3. RESULTS AND DISCUSSION

3.1 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.

3.2 Maximum Temperature

3.2.1 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.

3.2.2 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.

3.3 Minimum Temperature

3.3.1 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).

3.3.2 Minimum Temperature under RCP 8.5

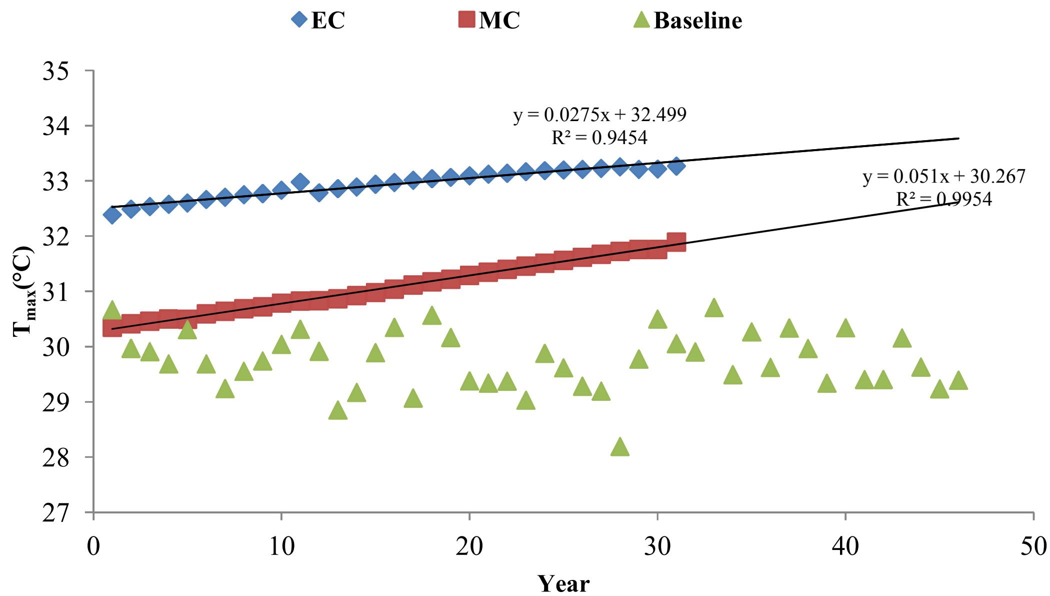
Average annual T_{min} of 16.64 ±0.8°C of baseline would increase to 18.73 ± 0.5°C in MC and21.41 ± 0.6°C in EC. These results predict that increase in T_{min} would be 2.09°C and 4.77°C in MC and EC respectively in future (Table 6). On monthly basis, in MC there would be positive change in T_{min} in 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.

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

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



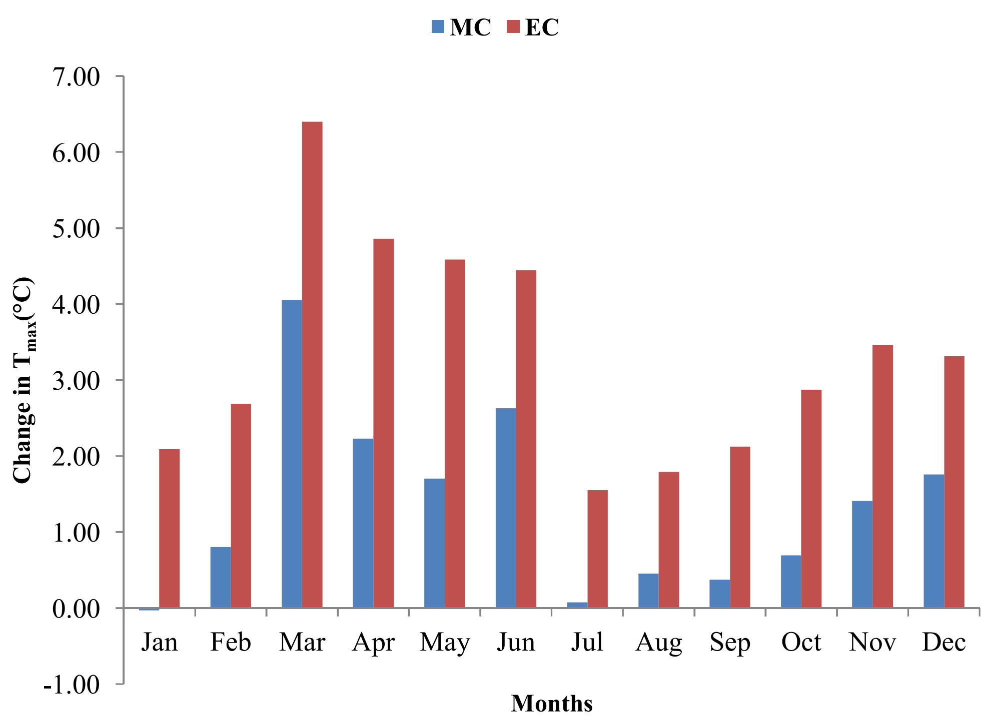


Fig. 2. Annual (a) and monthly (b) maximum temperature trends in baseline, MC and EC under RCP 4.5

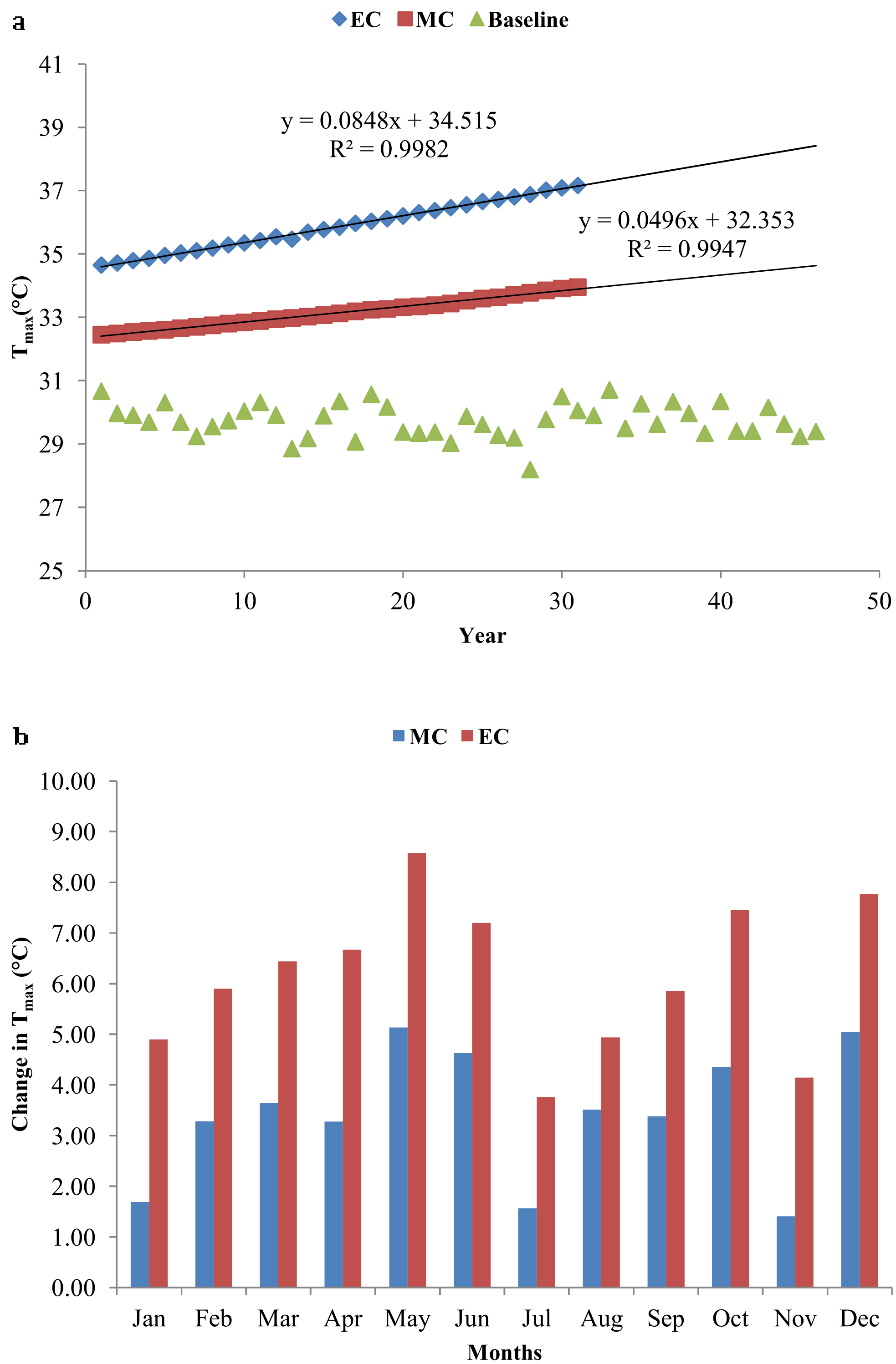


Fig. 3. Annual (a) and monthly (b) maximum temperature trends in baseline, MC and EC under RCP 8.5

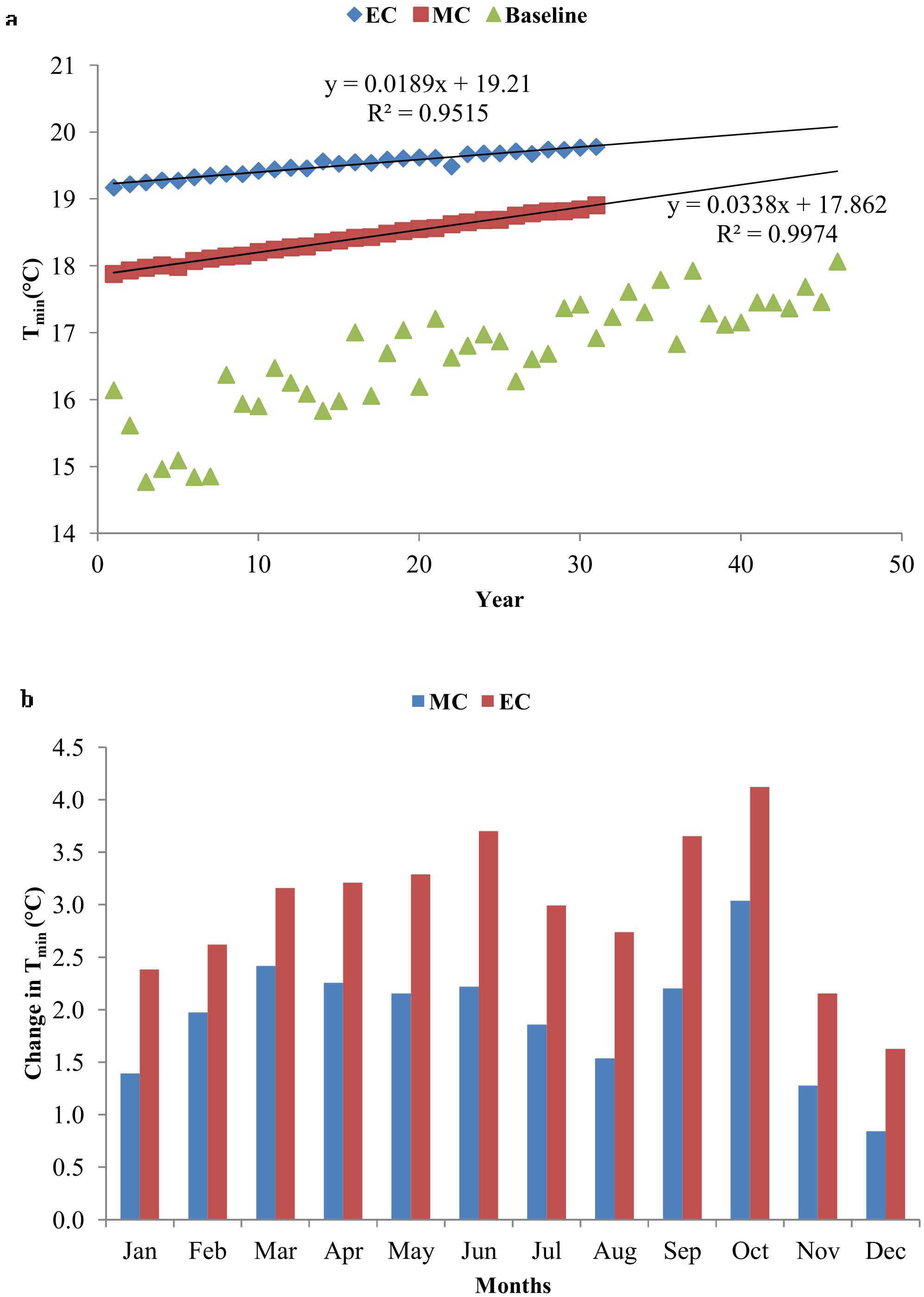
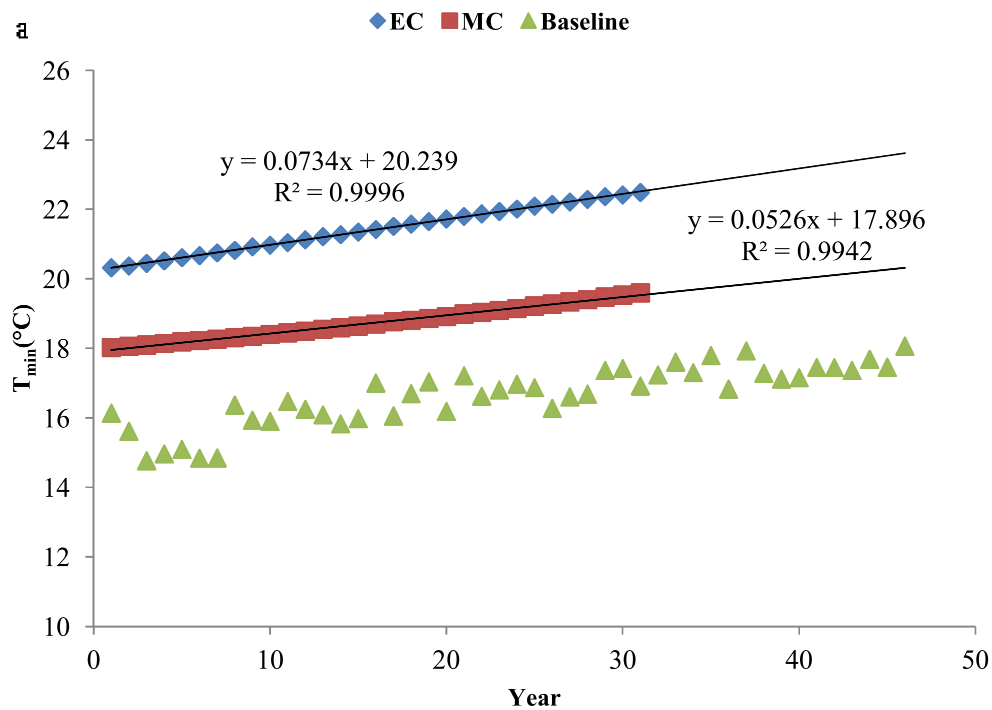


Fig. 4. Annual (a) and monthly (b) minimum temperature trends in baseline, MC and EC under RCP 4.5



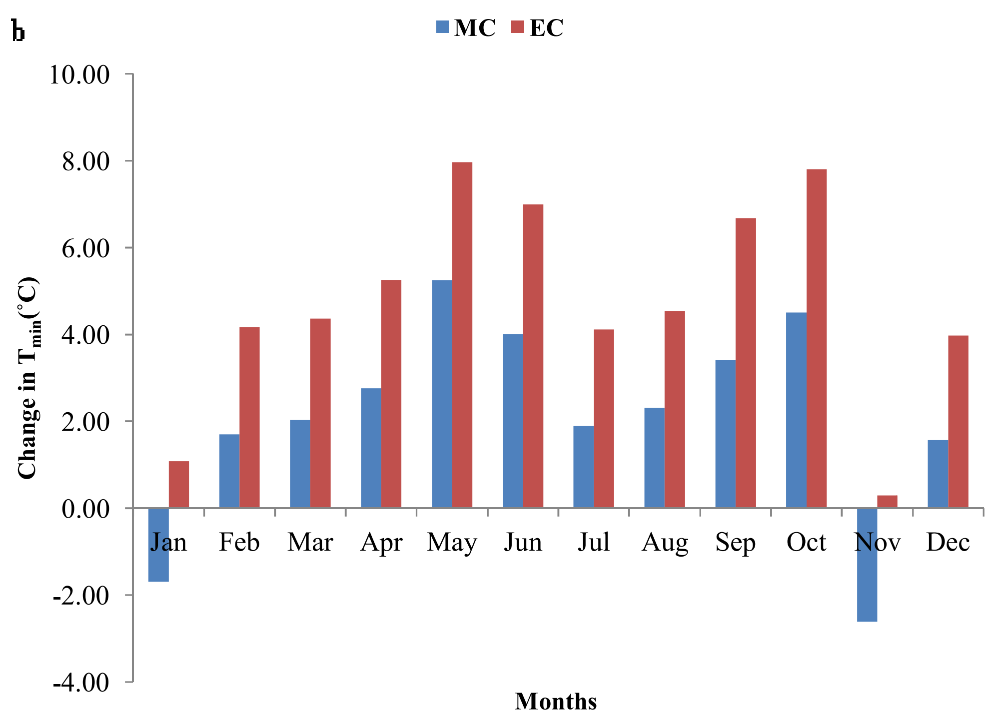
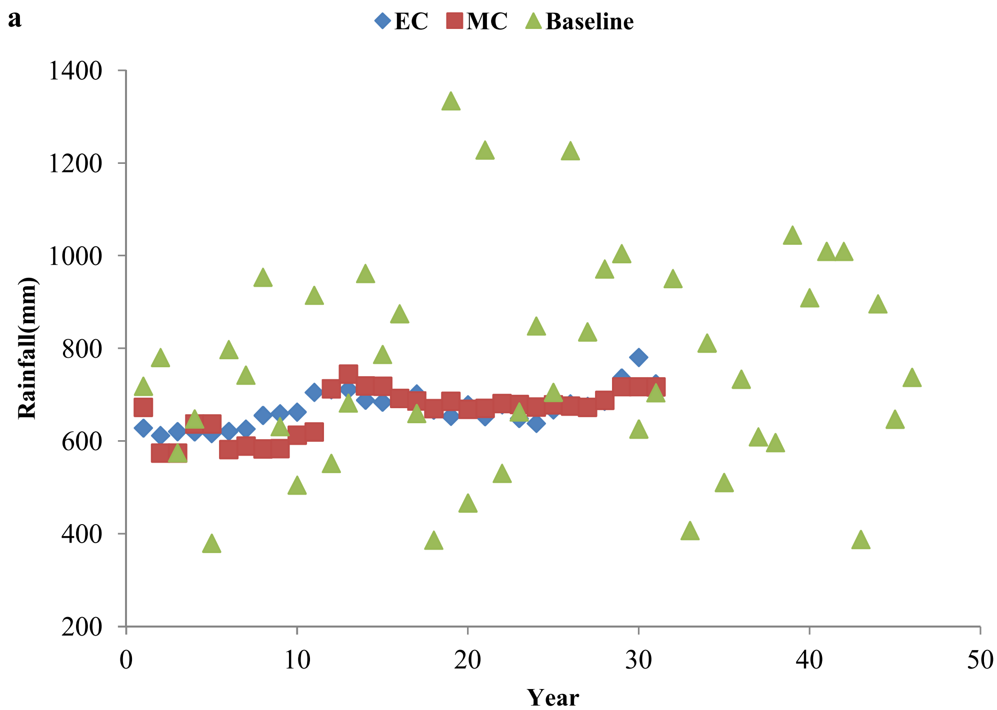


Fig. 5. Annual (a) and monthly (b) minimum temperature trends in baseline, MC and EC under RCP 8.5



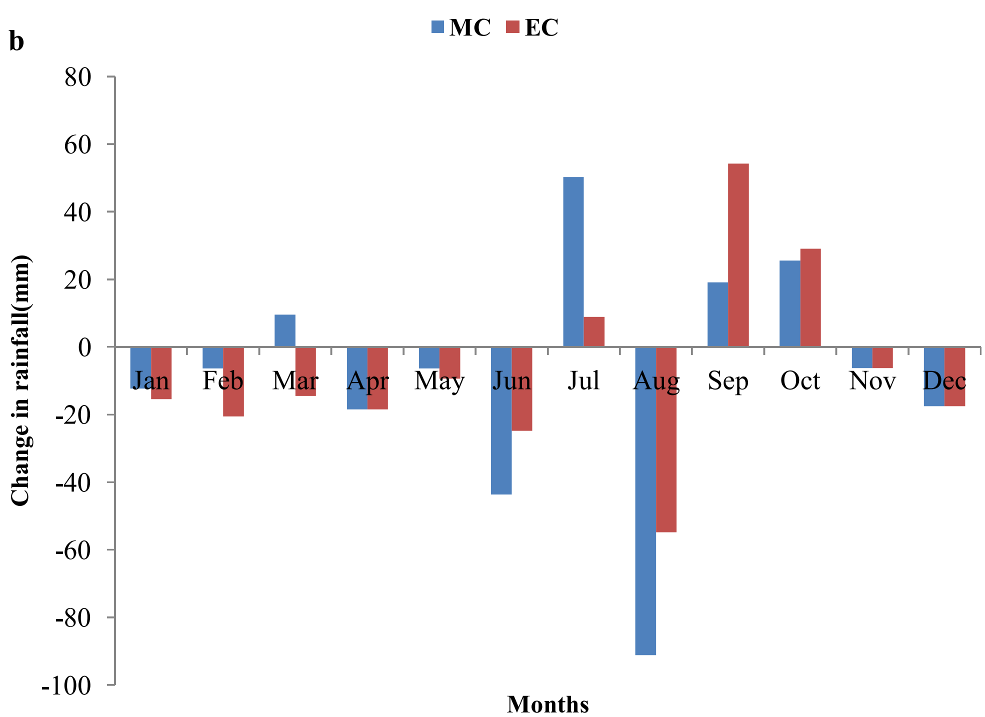


Fig. 6. Annual (a) and monthly (b) rainfall trends in baseline, MC and EC under RCP 4.5

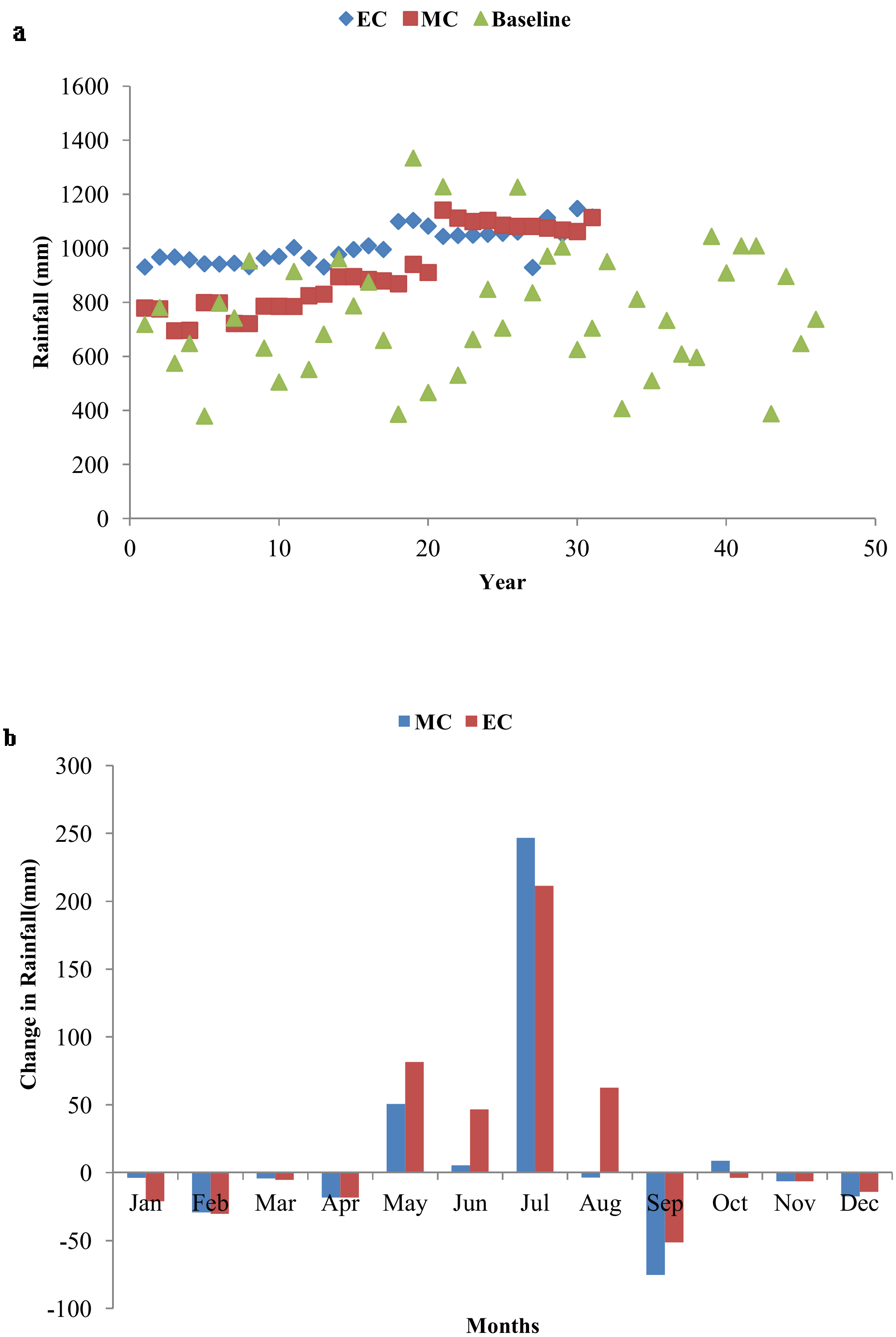


Fig. 7. Annual (a) and monthly (b) rainfall trends in baseline, MC and EC under RCP 8.5

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

3.4 Rainfall

3.4.1 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 55 mm in EC.

3.4.2 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 (Fig. 7). 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 211 mm in EC.

4. 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 89 mm (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 251 mm (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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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. IPCC. Climate Change (2014): Impacts, adaptation, and vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Inter-governmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (Eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 2014;1132.
2. Lema MA, Majule AE. Impacts of climate change, variability and adaptation strategies on agriculture in Semi-Arid Areas of Tanzania. The Case of Manyoni District in Singida Region, Tanzania. African Journal of Environmental Science and Technology. 2009;3(8):206-218.
3. Chiew FHS, Teng J, Vaze J, Post DA, Perraud JM, Kirono DGC, Viney NR. Estimating climate change impact on runoff

across south-east Australia: Method, results and implications of modelling method. Water Resour. Res. 2009a;45: W10414.
Available:http://dx.doi.org/10.1029/2008WR007338

4. Teng J, Vaze J, Chiew FHS, Wang B, Perraud JM. Estimating the relative uncertainties sourced from GCMs and hydrological models in modeling climate change impact on runoff. J. Hydromet. 2012a;13:122–139.
Available:http://dx.doi.org/10.1175/JHM-D-11-058.1
5. Jiménez Cisneros BE, Oki T, Arnell NW, Benito G, Cogley JG, Döll P, Jiang T, Mwakalila SS. Freshwater resources. In: Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., White, L.L. (Eds.), Climate Change 2014: Impacts, adaptation, and vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 2014;229–269.
6. Lopez A, Fung F, New M, Watts G, Weston A, Wilby RL. From climate model ensembles to climate change impacts and adaptation: A case study of water resource management in the southwest of England. Water Resour. Res. 2009;45:W08419.
Available:http://dx.doi.org/10.1029/2008WR
7. Chen J, Brissette FP, Leconte R. Uncertainty of downscaling method in quantifying the impact of climate change on hydrology. J. Hydrol. 2011;401:190–202.
Available:http://dx.doi.org/10.1016/j.jhydrol.2011.02.020
8. Teng J, Chiew FHS, Vaze J, Marvanek S, Kirono DGC. Estimation of climate change impact on mean annual runoff across continental Australia using Budyko and Fu equations and hydrological models. J. Hydrometeor. 2012b;13:1094–1106.
Available:http://dx.doi.org/10.1175/JHM-D-11-097.1
9. Vetter T, Reinhardt J, Flörke M, et al. Evaluation of sources of uncertainty in projected hydrological changes under climate change in 12 large-scale river basins. Clim. Change. 2016;1–15.
Available:http://dx.doi.org/10.1007/s10584-016-1794-y
10. Chaturvedi RK, Joshi J, Jayaraman M, Bala G, Ravindranath NH. Multi-model climate change projections for India under representative concentration pathways. Curr. Sci. India. 2012;103(7):791–802.
11. Freychet N, Hsu H-HC, Chou C, Wu CH. Asian summer monsoon in CMIP5 projections: A link between the change in extreme precipitation and monsoon dynamics. J. Clim. 2015;28(4):1477–1493.
Available:http://dx.doi.org/10.1175/JCLI-D-14-00449.1
12. Jourdain N, Gupta A, Taschetto A, Ummenhofer C, Moise A, Ashok K. The Indo-Australian monsoon and its relationship to ENSO and IOD in reanalysis data and the CMIP3/CMIP5 simulations. Clim. Dyn. 2013;41(11–12): 3073–3102.
Available:http://dx.doi.org/10.1007/s00382-013-1676-1
13. Ogata T, Ueda H, Inoue T, Hayasaki M, Yoshida A, Watanabe S, Kira M, Ooshiro M, Kumai A. Projected future changes in the Asian monsoon: A comparison of CMIP3 and CMIP5 model results. J. Meteorol. Soc. Jpn. Ser. II. 2014;92(3): 207–225.
Available:http://dx.doi.org/10.2151/jmsj.2014-302
14. Palazzi E, von Hardenberg J, Terzago S, Provenzale A. Precipitation in the karakoram-himalaya: A CMIP5 view. Clim. Dyn. 2015;45(1-2):21–45.
Available:http://dx.doi.org/10.1007/s00382-014-2341-z
15. Saha A, Ghosh S, Sahana AS, Rao EP. Failure of CMIP5 climate models in simulating post-1950 decreasing trend of Indian monsoon. Geophys. Res. Lett. 2014;41:7323–7330.
16. Ghimire S, Choudhary A, Dimri AP. Assessment of the performance of CORDEX-South Asia experiments for monsoonal precipitation over the Himalayan region during present climate: Part I. Climate Dynamics. 2015;1-24.
Available:http://dx.doi.org/10.1007/s00382-015-2747-2
17. Mishra V, Kumar D, Ganguly AR, Sanjay J, Mujumdar M, Krishnan R, Shah RD. Reliability of regional and global models to simulate precipitation extremes over India.

J. Geophy. Res. (Atmos). 2014;119(15): 9301–9323.
18. CGWB. Ground Water Year Book, Ministry of Water Resources. Government of India, New Delhi. 2012;4-34.
19. Jones PG, Thornton PK. Generating downscaled weather data from a suite of climate models for agricultural modelling applications. Int J Agri Syst. 2013;114:1-5.

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