CMIP5 based seasonal long-term rainfall change scenario of West Bengal

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ABSTRACT

Studies to detect climate change and its impact on various sectors deserve urgent attention in light of the impact of climate change on agriculture, increased risk of hunger and water scarcity, rapid melting of glaciers, and decrease in river flows (IPCC, 2012). Considering the importance, the current paper aims at investigating the past and future rainfall change scenarios over six agro climatic zones of West Bengal using the observational rainfall data from the India Meteorological Department (IMD) and the 20 numbers of Global Climate Models (GCMs) simulations from the Coupled Model Intercomparison Project Phase 5(CMIP5). The results indicate that zone to zone rainfall change scenarios using both model and observation indicated a gradual decreasing trend from north Bengal zones to south Bengal zones which is also reproduced by 20 GCMs. The past rainfall over each agro-climatic zone has increased except in the winter season during 1901-2005. Although changing patterns of rainfall are almost similar both for GCMs simulations and station observation but there is a clear variation of magnitudes of the changes in different GCMs and years and seasons and zones. It is also noticed that models are unable to capture pre-monsoon season rainfall which is influenced by mesoscale phenomenon. The ability of seasonal cycle reproduction and the values of four conventional statistical measures (correlation,d-index,NRMSE,Pbias) indicated that 3 models namely CCSM4, HadGEM2_AO, NorESM1_M performed well whereas the worst performing models are GISS_E2_R, IPSL_CM5A_LR, MRI_CGCM3 among 20 analyzed GCMs. Trend analysis of future projection of rainfall revealed an increasing tendency for all zones irrespective to season and RCPs. Percentage change of future rainfall with respect to mean observed rainfall during 1971-2000 produced highest change (15-20%) over red and Laterite zone and lowest change (1-7%) over coastal and saline zone.

***Keywords* :** Climate change scenarios, agro-climatic zone, GCMs simulation, CMIP5 models, RCPs.

1. INTRODUCTION

Although the subject area of climate change is vast, the changing pattern of rainfall is a topic within this field that deserves urgent and systematic attention, since it affects both the availability of fresh water and food production (Dore, 2005). Climate change trends and its impact vary significantly on regional, sub-regional and local scales. So assessing or quantifying its amount on a smaller region and location is more appealing and challenging (Das *et al.,* 2016). But how much climate has changed over different smaller scales like different agro-climatic zones may attract more attention to public and government agencies. Over the state of West Bengal there is no reliable past and future climate change information (except Das and Lohar, 2005) using multi observational data sources including recent generation GCM simulations. In the state of West Bengal, there are six distinct agro climatic zones. So creating zone specific past and future climate change scenario may provide some useful informations for the multi-level stake holders, policy makers and local Government for implementing any developmental policy and mitigation and adaptation strategies towards combating climate change.

A clear picture of local scale (station level) climate change information using the combined approach of observed station data and GCMs simulations over the six agro-climatic zones of West Bengal are still missing. The present study aims to construct local scale climate scenarios from CMIP5 GCMs simulation along with IMD observational and gridded data as well as to construct a future rainfall projection using four RCPs simulation of CMIP5 GCMs.With this background information, the present study has been carried out for following objectives.

1) To quantify the historical rainfall change during 1901-2005 using multiple sources of data.
2) To evaluate IPCC's CMIP5 GCMs over the concerned agro-climatic zones towards selection of best performing models.
3) To construct ensemble based future rainfall change scenario.

2. Study area, data and methods

2.1. Study area

The present study has confined over the state of West Bengal. It is situated in the eastern part of the country between 21°20' to 27°32' N latitude and 85°50' and 89°52' E longitude.On the basis of distribution of climate,soil and

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agricultural feasibility whole state of West Bengal is divided into 6 distinct agro-climatic zones (Fig 2.1) which are: i) Hill Zone (HZ) ii) Terai Zone (TZ) iii) Old Alluvial Zone (OAZ) iv) New Alluvial Zone (NAZ) v) Red and Laterite zone (RLZ) and vi) Coastal Saline Zone (CSZ)

2.2 Data

In this study, two types of long term data have been used. They are as follows:

Observational data

Monthly rainfall station data during the period of 1901-2017 and IMD's high resolution (0.25° x 0.25°) rainfall gridded data (Pai *et al.,* 2014) for 19 district headquarters of West Bengal has been procured from the India Meteorological Department (IMD), Pune, to check how much rainfall has changed through analysis of different sources of data.

Model data

For past and future rainfall analysis, we have used 20 numbers of CMIP5 GCMs through the data portal of the Royal Netherlands Meteorological Institute (https://climexp.knmi.nl/selectfield_cmip5. cgi? id5 someone @ somewhere). List of 20 GCMs used in this study are given below in Table 2.1.

Table 2.1: Description of the CMIP5 GCMs used in this study

Sl. no.	Model	Horizontal resolution (latitude(°) x longitude(°))	Sl no.	Model	Horizontal resolution (latitude(°)x longitude(°))
1	bcc-csm1-1	2.8×2.8	11	GISS-E2-R	2×2.5
2	bcc-csm1-1-m	1.125×1.125	12	HadGEM2-AO	1.25×1.875
3	CCSM4	0.95×1.25	13	IPSL-CM5A-LR	1.875×3.75
4	CESM1-CAM5	0.95×1.25	14	IPSL-CM5A-MR	1.25×2.5
5	CSIRO-Mk3-6-0	1.875×1.875	15	MIROC5	1.4×1.4
6	FIO-ESM	2.8×2.8	16	MIROC-ESM-CHEM	2.8×2.8
7	GFDL-CM3	2×2.5	17	MIROC-ESM	2.8×2.8
8	GFDL-ESM2G	2×2.5	18	MRI-CGCM3	1.125×1.125
9	GFDL-ESM2M	2×2.5	19	NorESM1-ME	1.875×2.5
10	GISS-E2-H	2×2.5	20	NorESM1-M	1.875×2.5

2.3. Methodology

- ✓ Generated district-wise monthly rainfall time series during 1901-2005 for historical and 2006-2095 for future projection using bilinear interpolation techniques which takes weightage of four nearby grid points.
- ✓ Created historical rainfall change trends for each zone using linear regression for 1901-2005.
- ✓ Calculated the percentage change of rainfall during 2020s, 2050s, 2080s using four RCPs with respect to the base period of 1971-2000.
- ✓ Calculated the values of similarity indices like (correlation and d-index) and error statistics (NRMSE and Pbias) for evaluating the GCMs performance with the following expression defined in Table 2.2

Table 2.2

Describes the description of statistical measures where **M** = Model output, $\bar{M}$ = Mean of model output, σ_M = standard deviation of model output, **O** = observations, $\bar{O}$ = mean of observations, σ_O = standard deviation of the observations and N= number of the year.

3. RESULTS AND DISCUSSION

The results of this work are described as follows:

3.1 Historical (1901-2005) rainfall change

- Historical rainfall change during 1901-2005 using 20 numbers of GCMs along with IMD station and gridded data reveals that mean winter rainfall was more ranging from 50-190mm over hill and terai zone whereas it was slightly lesser in other zones. It also indicated that MME20 simulate more rain (54-102mm) compared to IMD station and gridded data (25-46mm).
- In case of pre-monsoon season similar pattern indicating more rain over hill and terai zone and less rain over other zones. The GCM CESM1_CAM5 simulated excessive pre-monsoon rain (above 800mm) in hill and terai zone along with HadGEM2_AO and MIROC5 simulate high pre-monsoon rainfall over almost all zones compared to other GCMs.MME20 simulate less rain compared to IMD gridded and IMD station for all zones.
- As per expectation of common people the long term mean during 1901-2005 was estimated from 20GCMs along with two IMD data sources which revealed that MME20 and IMD station showed similar rainfall (1690-1793mm) over hill and terai zone but station rainfall was exceeding MME20 over other zones but IMD gridded estimated high rainfall 2547-2562mm over HZ and TZ compared to MME20 and IMD station.

Name of similarity statistics	Equations	Reference/ studies that used this expression
Mean bias	$\mathrm{MB} = \left[\frac{1}{N}\sum_{n=1}^{N}(M_n - O_n)\right]$	Willmott (1982)
Correlation	$\mathrm{R} = \frac{\frac{1}{N}\sum_{n=1}^{N}(M_n - \overline{M})(O_n - \overline{O})}{\sigma_M \sigma_O}$	Taylor (2001)
Index of agreement (*d*-index)	$d - \mathrm{index} = 1.0 - \left(\frac{\sum_{n=1}^{N}(O_n - M_n)^2}{\sum_{n=1}^{N}(\lvert M_n - \overline{O}\rvert + \lvert O_n - \overline{O}\rvert)^2}\right)$	Willmott (1981), Legates & McCabe (1999)
Normalised total RMSE	$\mathrm{NTRMSE} = \frac{1}{\sigma_O}\left[\frac{1}{N}\sum_{n=1}^{N}(M_n - O_n)^2\right]^{1/2}$	Janssen & Heuberger (1995), Covey et al. (2002)

- In case of post monsoon season mean rainfall during 1901-2005 varies from 114-185mm irrespective to all zones where MME20 indicated more rainfall compared to station and gridded data over HZ and TZ. It also observed that all data showed a decreasing amount of post monsoon rainfall from north Bengal zones to south Bengal zones.
- Historical annual rainfall was also quantified from different models and station data. Models showed high variability of annual rainfall (1070mm in case of CSIRO_Mk3_6_0 to 5239mm for CESM1_CAM5) particularly over HZ &TZ. Annual rainfall over RLZ was minimum viz. 986mm for MME20, 1386mm for IMD grid and 1411mm for IMD station respectively. While maximum annual rainfall was received almost more than double over HZ.
- Winter rain has shown increasing trend 0-6mm over HZ, TZ while it was decreased 0-8mm over other zones for two IMD data while MME20 showed nominal increasing trend for all zones.
- Monsoon rain has increased 0-150mm in case of IMD grid while MME20 showed it was decreased 0-15mm over all zones in the last century.
- In general annual rainfall has shown an increment of 0-200mm irrespective of all zones and data sources except HZ for MME20 and OAZ for IMD station showed decreasing trend.

3.2 Evaluation of CMIP5 GCMs

Model evaluation study over agro-climatic zones indicated that no models are able to capture historical rainfall over each zone indicating models have strong positive or negative bias. Zone wise GCM evaluation was carried out using comparison of seasonal cycle along with four conventional statistical measures (correlation, d-index, NRMSE

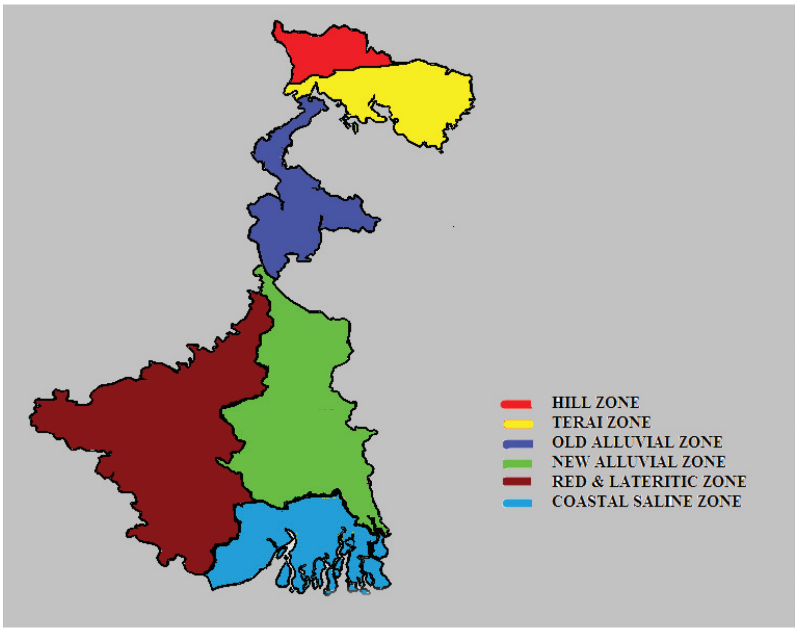

Fig. 2.1: Agro-climatic zones of West Bengal

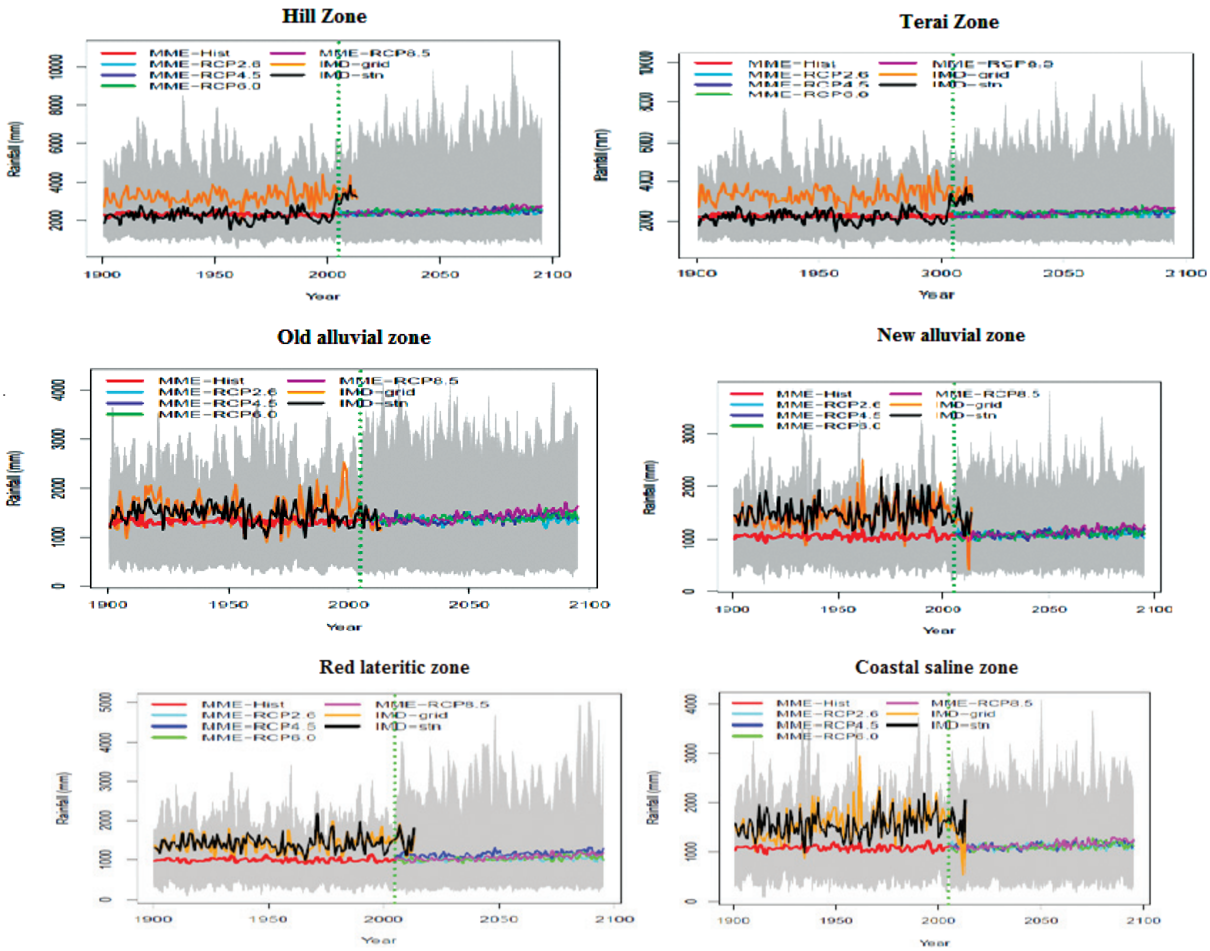

Fig. 3.1 : Variation of annual past and future rainfall change using 20 CMIP5 GCMs for four RCPs over six agro-climate zones of West Bengal

and Pbias), which indicates that performance of GCM varies from zone to zone and index to index. Some models like CCSM4, HadGEM2_AO and NorESM1_MI showed comparatively better performance over most of the zones which obtain highest rank while GISS_E2_R, IPSL_CM5A_LR and MRI_CGCM3 performed poorly almost in all zones and consider in the bottom level of the ranking system (Table 3.1). These better performing top ranked model can be used over any agro climatic zone for any impact study without any further evaluation while poor models need to be improved its simulation through different downscaling techniques like bias correction etc.

3.3 Multi-model ensemble based future rainfall change scenarios

The comparison of past rainfall pattern with its future projection with 4 RCPs indicated that model to model variation are more in the future time scale which implies models simulation with each agro-climatic zone has huge uncertainty which has been depicted through wide range of model spread both in past as well as in future (Fig. 3.1)

3.4 Percentage future rainfall change

- Future rainfall for all six agro-climatic zones were calculated for 3 different times namely 2020s,2050s,2080s with respect to climatological base period of 1971-2000 which reveals that percentage of decreasing rain 5-12 % is increasing from 2020s to 2080s in winter season over HZ. It is cleared that over HZ winter rain is going to be decreased at the end of 21st century while other seasons and annual showed an increasing trend (5-15%) of rainfall as per 4 RCPs over HZ.
- Similarly winter rain is going to be decreased according to all RCPs in three times while other seasons and annual rainfall is going to be increased 5-18% over TZ. In all cases rainfall change is low in 2020s and high in 2080s.

Table 3.1: Zone –wise ranking of CMIP5 GCMs based on their performance

Model	HZ	TZ	OAZ	NAZ	RLZ	CSZ	Overall rank
bcc-csm1-1	18	14	14	13	16	16	17
bcc-csm1-1-m	11	11	12	12	13	17	16
CCSM4	7	6	13	5	3	1	3
CESM1-CAM5	10	1	8	6	5	2	6
CSIRO-Mk3-6-0	19	20	16	4	4	6	13
FIO-ESM	9	10	6	14	15	15	11
GFDL-CM3	17	16	4	3	6	3	5
GFDL-ESM2G	1	8	17	16	10	10	4
GFDL-ESM2M	2	7	7	17	12	14	8
GISS-E2-H	3	5	2	9	17	13	9
GISS-E2-R	14	15	15	18	20	19	18
HadGEM2-AO	6	9	3	2	2	5	1
IPSL-CM5A-LR	20	17	18	19	19	18	19
IPSL-CM5A-MR	19	18	20	8	8	4	14
MIROC5	13	12	9	11	11	8	12
MIROC-ESM-CHEM	12	11	11	15	14	12	15
MIROC-ESM	8	2	1	1	1	9	10
MRI-CGCM3	18	19	19	20	18	20	20
NorESM1-ME	5	4	10	10	9	11	7
NorESM1-M	4	3	5	7	7	7	2

- Similar decreasing trend of winter rainfall over OAZ and NAZ is projected for all RCPs while other season and annual showing an increasing for all time period and RCPs. It is noticed that RCP4.5 indicates high increasing trend of future projection over RLZ compared to other RCPs in all season except winter.
- Over CSZ both winter and pre-monsoon season rainfall has increased as well as decreasing trends as per different RCPs while monsoon and annual indicated an increasing rainfall upto 12%.

4. Conclusion

- Multi sources historical records (both model and observation data) indicates more rainfall over north Bengal agro-climatic zones compared to south Bengal zones.
- Annual rainfall has shown in increasing trends almost all zones (50-200mm) whereas winter rainfall has indicated a nominal decreasing trend by 5-7mm over NAZ, RLZ and CSZ during 1901-2005.
- In general models are unable to reproduce zone specific rainfall satisfactorily.
- However some models like HadGEM2_AO, NorESM1_M and CCSM4 capture the observed rainfall over some zones quite accurately.
- Future projection using four RCPs reveals that model projection exhibits high uncertainty meaning lower radiative forcing (RCP2.6) simulated lower rainfall and extreme radiative forcing (RCP8.5) indicates higher rainfall change.
- Except winter, the rainfall over hill zone is going to be increased by 0-15% irrespective of all seasons and all future time period.
- Rainfall projection will be highest over red & Laterite zone (15-20%) and lowest 1-7% over coastal and saline zone.
- RCPs from the best performing models able to reproduce observed inter-annual variability during 2006-2017 adequately, indicating GCM projection during 2018-2100 will be more reliable over six agro climatic zones of West Bengal.

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