# Future Precipitation Changes over the Wainganga Sub-Basin using NEX-GDDP High-Resolution Statistically Downscaled Data

**Aradhana Thakur[1*], Prabhash Kumar Mishra[2], Anupam Kumar Nema[1], Hitesh Prasad Thakur[2] and Aparajita Singh[1]**

[1]*Department of Farm Engineering, IAS, BHU, Varanasi, U.P, India*

[2]*National Institute of Hydrology, Roorkee, Uttrakhand*

* *Corresponding author* email: arru.aradhana@gmail.com

**Abstract:** In the present study, the near, mid and long-term future precipitation projection is done for the Wainganga sub-basin using high resolution statistically downscaled dataset of NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP). This dataset presents climate projection from 1950 to 2100 by linking observations and GCM results and remarkably improves CMIP5 hind casts and projections from courser to finer resolution with an unaffected long-term trend. To forecast the variation in future precipitation, four multi-ensemble statistical downscaled models viz. BCC-CSM1-1, BNU ESM, CNRM-CM5, and MPI-ESM-LR were considered. The analysis was done on a grid basis with three future series viz. near (2010-2039), mid (2040-2069) and long-term (2070-2099) for two scenarios RCP 4.5 and RCP 8.5 at annual and seasonal scale. As per the results from all models under both scenarios, the annual as well as monsoon precipitation will increase at the end of the century. For the Wainganga sub-basin, the precipitation from MPI-ESM-LR model shows very close relation with India Meteorological Department (IMD) precipitation and according to this model annual precipitation will rise in both scenarios till mid-term after that variation will be constant or quite low. For the monsoon season, precipitation will increase with higher magnitude in near-term as compare to mid-term under both scenarios after that precipitation will decrease as per RCP 8.5 scenario. However, as per RCP 4.5 there will be a considerable increase in precipitation in long-term.

**Keywords**: Forecasting; NEX-GDDP datasets; RCP Scenarios; Bias correction; Precipitation.

***Abbreviations***

**A1, A2 and A3:** Change in precipitation with respect to IMD data in near-term, mid-term and long-term respectively in BCC-CSM1-1model**.**

**B1, B2 and B3:** Change in precipitation with respect to IMD data in near-term, mid-term and long-term respectively in BNU ESM model.

**C1, C2 and C3:** Change in precipitation with respect to IMD data in near-term, mid-term and long-term respectively in CNRM-CM5 model.

**D1, D2 and D3:** Change in precipitation with respect to IMD data in near-term, mid-term and long-term respectively in MPI-ESM-LR model**.**

**Yr:** Year

## 1. Introduction

Climate change is a worldwide challenge that is challenging today. It affects the economy, water resources, and natural ecosystems, as highlighted in the Intergovernmental Panel on Climate Change reports (Field, 2014; Chen *et al.*, 2017). In India, monsoon precipitation is a major source of water for agriculture where about 60% of the total sown area comes under rainfed agriculture. During the last century, a 1–2°C increase in global mean temperature was remarked, which has far-reaching consequences such as accelerated glacier melting and increases in the frequency of extreme weather events (Cruz *et al*., 2007) while over the Wainganga sub-basin mean temperature was increased by 0.37°C in last 63 years i.e. 1951-2013 (Thakur *et al*., 2019). Nowadays, GCMs are very popular in the scientific communities to evaluate the past climates and to forecast the climate in upcoming times under different emission scenarios (Taylor *et al*., 2012; Bokhari *et al*., 2018). Bokhari *et al*. (2018) examined the change in future temperature and precipitation over the Kabul River Basin using high resolution statistically downscaled data and Raw GCMs data as well as compared both datasets with observed data and suggested that the NEX-GDDP dataset is a more reliable and precise dataset for climate projection. They found temperature will be increasing in the future in both scenarios while mean precipitation under RCP 8.5 was decreasing and the variations are uneven over the basin. Jain *et al*. (2019) assessed the advantage of the NEX-GDDP dataset over CMIP5 and CORDEX dataset for the Indian summer monsoon and the outputs from all datasets reflected that the NEX-GDDP dataset captures the changes more precise rather than CMIP5 and CORDEX dataset. As per now, no study has been done on the future climate projection of the Wainganga sub-basin using a bias-corrected and higher resolution GCMs dataset. This study aims to analyze the climate change impacts on precipitation over the Wainganga sub-basin under two emission scenarios (RCP4.5 and RCP8.5) using statistically downscaled data of NEX-GDDP. For this persistence, we hired the NEX-GDDP dataset (Thrasher *et al*., 2012; Raghavan *et al*., 2018) and these four GCMs consist of "CanESM2" of Canadian Centre for Climate Modeling and Analysis, "CNRM-CM5" of Centre National de Recherches Meteorologiques, France, "BNU-ESM" of Beijing Normal University Earth System Model and "MPI-ESM-LR" of Max Planck Institute for Meteorological Earth System Model, Germany. In this context, initially, we analyzed the historical precipitation for Wainganga sub-basin using IMD and NEX-GDDP dataset and assessed the possible variation in seasonal and annual precipitation in the future over the study area under RCP 4.5 and RCP 8.5 emission scenario.

## 2. Materials and Methodology

### Study area

The Wainganga sub-basin is lies between 19°60′ to 22°07′ N latitude and 78°00′ to 81°00′ E longitude which covers some part of Madhya Pradesh, Chhattisgarh and Maharashtra. The elevation of the sub-basin ranges from 146 to 1048 m above mean sea level (Fig. 1). The study area covers an area of 51,758.65 km$^2$ with the river Wainganga traverse for a length of 567 kms before meeting the Wardha River. The average precipitation of the study area spatially varies; in eastern part of sub-basin precipitation fluctuates from 1400 mm to 1600 mm while for western part of the basin, it varies from 900 mm to 1200 mm. The climate of the sub-basin is considered as summer from March to May with monsoon season from June to September having some rains in post monsoon season too.

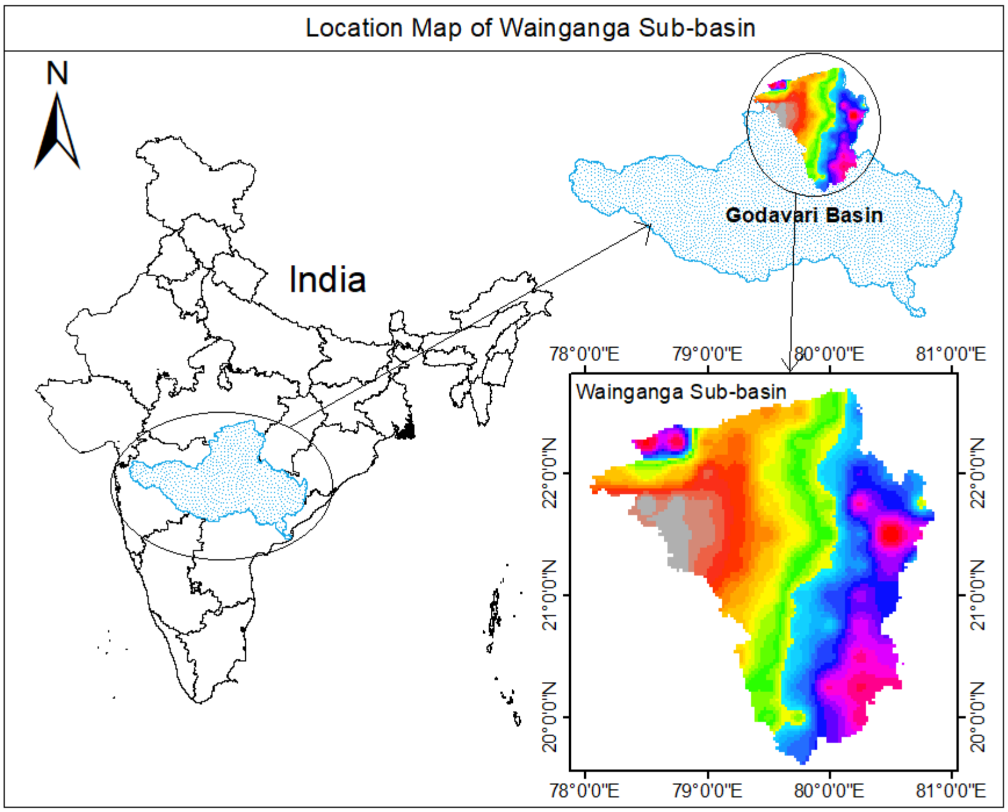


**Fig.1:** Location map of the study area

**Data source**

In the present study, we have utilized the fine resolution (0.25° × 0.25°) IMD gridded daily precipitation for the period 1976–2005 as a historical period and NEX-GDDP datasets for the period 2006 to 2099 with two emission scenarios, RCP 4.5 and RCP 8.5 as well as for historical period (1976-2005). The NEX-GDDP dataset is a fine resolution, bias corrected statistically downscaled dataset which is available on a global scale and prepared from the CMIP5 model outputs. To produce finer resolution NEX-GDDP datasets from CMIP5 model outputs, the Bias-Corrected Spatial Disaggregation (BCSD) method of statistical downscaling was used. Flowchart showing the methodology adopted in the study is shown in Fig. 2.

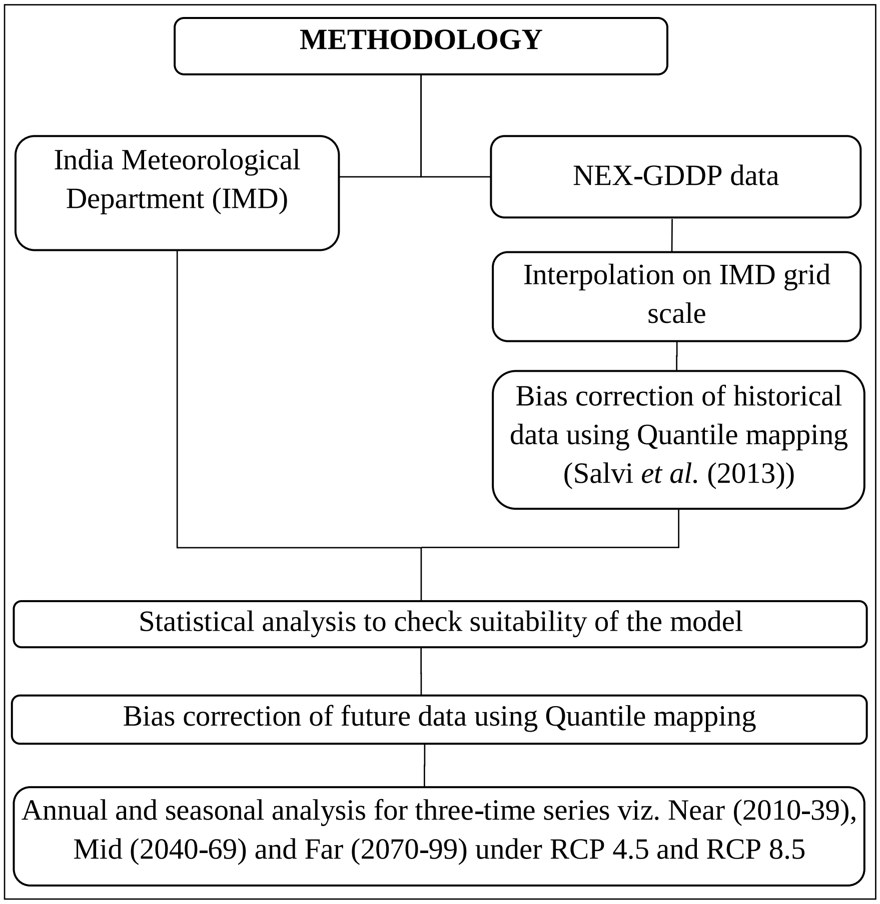


**Fig. 2:** Flowchart showing methodology for climate change projection using NEX-GDDP dataset

## 3. Results and Discussion

Initially the precipitation data of NEX-GDDP models were bias corrected and validated against IMD daily precipitation data for historical period or base period (1976–2005) on grid basis. The suitability of the GCM model for the region were decided at monthly scale on the basis of mean (spatial) $R^2$ (Table-1) after bias correction which is presented in Fig. 3. The climate change projections over Wainganga under both global warming scenarios were reviewed for the near-term (2010–2039), mid-term (2040–2069), and long-term (2070–2099) time series.

**Table 1** – Suitability of Models for the region

| Model | BCC-CSM1-1 | BNU ESM | CNRM-CM5 | MPI-ESM-LR |
|---|---|---|---|---|
| Mean $R^2$ before bias correction | 0.51 | 0.53 | 0.49 | 0.58 |
| Mean $R^2$ after bias correction | 0.53 | 0.51 | 0.5 | 0.61 |

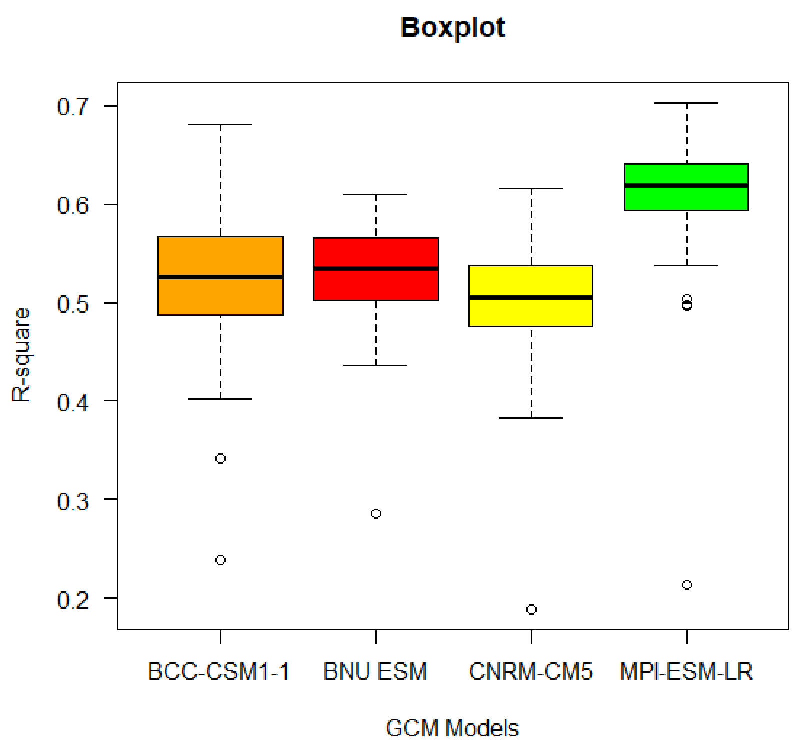


**Fig. 3:** Boxplot of $R^2$ values for All the Grids Covering Wainganga Sub-basin for All Models

**Annual precipitation**

Here shift in annual precipitation in all-time series under the RCP 4.5 and RCP 8.5 scenario with respect to IMD historical precipitation was examined for all the models. For the study output of quantile mapping and bias corrected data were used while in case of BNU-ESM model direct NEX-GDDP data was used because after quantile mapping the correlation between BNU-ESM model data and IMD data was decreased.

**BCC-CSM1-1**

The results come from the study reveals that in the near term, the precipitation is decreasing up to 60 cm/yr in both scenarios as compared to historical precipitation while the major part of the sub-basin displays the least variation i.e. 20 cm/yr increase in annual precipitation. In the mid-term annual precipitation (Fig. 4-A2, Fig. 5-A2) both reflecting similar pattern of changes over the basin and in downstream part precipitation will drop in the future while the major part of the basin showing the variation in precipitation up to 20 cm/yr. when examined the long-term precipitation (Fig. 4-A3, Fig. 5-A3) for both scenarios, it has been found that the precipitation will increase under RCP 4.5 which alters up to 80 cm/yr while under RCP 8.5 precipitation will be likewise the base period.

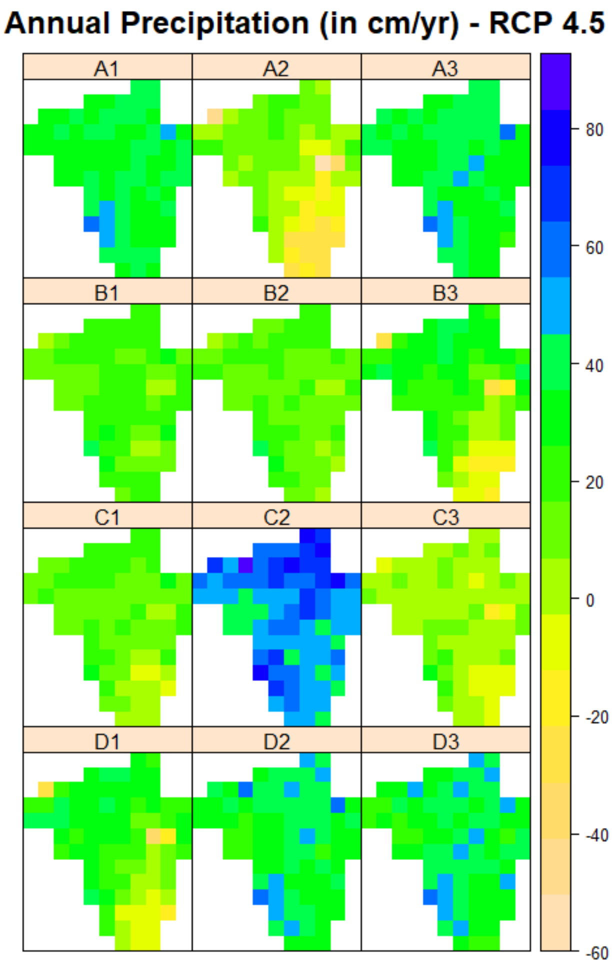


**Fig. 4**

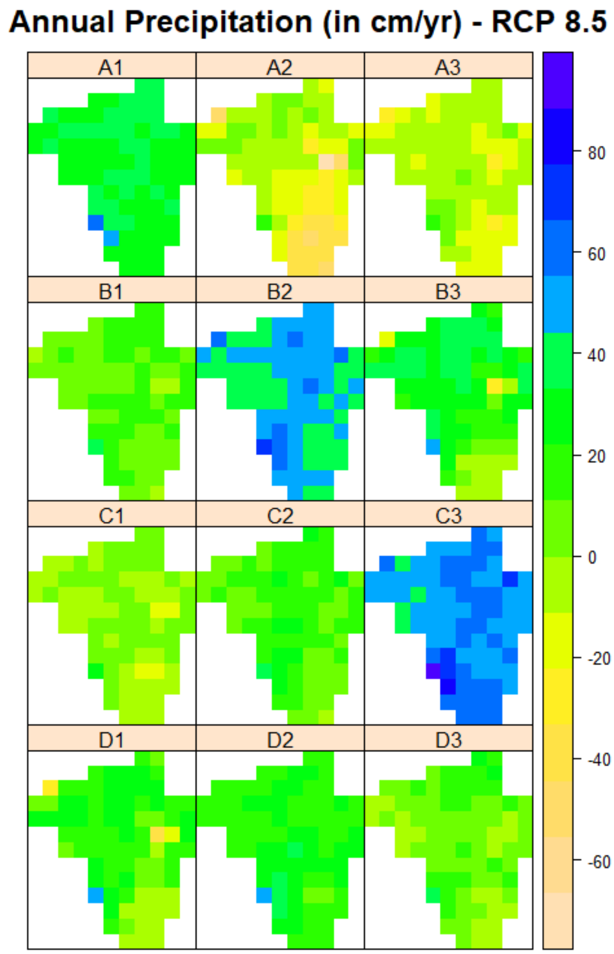


**Fig. 5**

***BNU ESM***

The model presents in the near-term, the variation in precipitation will be the same in both scenarios, someplace it will decrease someplace increase but variation is up to 20 cm/yr only (Fig. 4-B1, Fig. 5-B1). In the middle of the century, precipitation will be the same as near-term under RCP 4. 5 (Fig. 4-B2) while according to RCP 8.5 it will deviate drastically i.e. 80 cm/yr (Fig. 5-B2). Fig. 4-B3 and Fig. 5-B3 reflect the change in precipitation at the end of the century which showing under both scenarios at the upper part of the basin it changes up to 40 cm/yr while in the lower part of the basin precipitation will decrease.

***CNRM-CM5***

The CNRM-CM5 model shows the progressively rise in precipitation from the historical period in the middle of the century (Fig. 4-C2) while in the long-term (Fig. 4-C3) precipitation will decrease as compared to mid-term (Fig. 4-C3) under RCP 4.5. In the near-term and long-term (Fig. 4-C1, C3) precipitation will be varying up to 20 cm/yr. In the near term spatially varied while in long-term precipitation having an upward trend.

In RCP 8.5 scenario precipitation will drop in the near term (Fig. 5-C1) after that it will rise constantly, in a mid-term increase in precipitation will be up to 40 cm/yr (Fig. 5-C2) while at the end of the century it will be 80 cm/yr (Fig. 5-C3).

***MPI-ESM-LR***

This model is more reliable for this study area out of all four models. Precipitation forecasted from this model shows that precipitation will rise in the future. In the near term, the whole western part showing precipitation will increase up to 40 cm/yr while at the downstream side it may decrease or constant in both scenarios (Fig. 4-D1, Fig. 5-D1). During mid-term precipitation will increase in major part of the basin up to 60 cm/yr under RCP 4.5 while under RCP 8.5 variations are less (Fig. 4-D2, Fig. 5-D2). Similarly, at the end of the century precipitation will increase up to 60 cm/yr under RCP 4.5 while according to RCP 8.5 precipitation will either decrease or constant (Fig. 4-D3, Fig. 5-D3).

**Monsoon precipitation**

***BCC-CSM1-1***

In monsoon, variation in precipitation during near-term (Fig. 6-A2) will be more as compared to mid and long-term series (Fig. 6-A2, A3) under RCP 4.5. In the near term, precipitation will rise by up to 60 cm/yr which spatially varied under RCP 4.5 while under RCP 8.5 most of the area has up to 20 cm/yr variation in precipitation. In mid-term under both scenarios, precipitation either increasing or constant (Fig. 6-A2, Fig. 7-A2). According to RCP 4.5 at the end of the century precipitation will either constant or decreasing up to 20 cm/yr in some parts only while RCP 8.5 showing the precipitation will increase at the end of the century up to 80 cm/yr (Fig. 6-A3, Fig. 7-A3).

***BNU ESM***

According to this model, more changes in precipitation will happen in mid of the century whereas in near-term and long-term comparatively less under RCP 4.5 (Fig. 6-B2, B1, B3). RCP 8.5 show the precipitation will increase in future but in near-term and mid-term not much while in long-term it varies up to 40 cm/yr (Fig. 7-C1, C2, C3)

***CNRM-CM5***

The precipitation will decrease as per RCP 4.5 while according to RCP 8.5 results it will constant till near-term (Fig. 6-C1, Fig. 7-C1). In mid-term precipitation will increase in both scenarios but in RCP 8.5 magnitude will be higher than RCP 4.5 (Fig. 6-C2, Fig. 7-C2). It will increase up to 80 cm/yr in RCP 8.5 while under RCP 4.5, precipitation will rise as well as drop and spatially varied up to 20 cm/yr. According to RCP 4.5 precipitation will increase at the end of the century by 100 cm/yr while under RCP 8.5, precipitation will either constant or drop with respect to the base period (Fig. 6-C3, Fig. 7-C3).

***MPI-ESM-LR***

The model shows the precipitation will be rising with time and at end of the century, it will rise by 60 cm/yr as per RCP 4.5 while under RCP 8.5 variations will quite low (Fig. 6-D3, Fig. 7-D3). In near-term precipitation will increase up to 40 cm/yr in the western part of the basin while in some part it will either constant or decrease up to 20 cm/yr under RCP 4.5 and under RCP 8.5 variation will be up to 30 cm/yr (Fig. 6-D2, Fig. 7-D2). According to RCP 8.5, at the end of the century precipitation will be having the same pattern as mid-term.

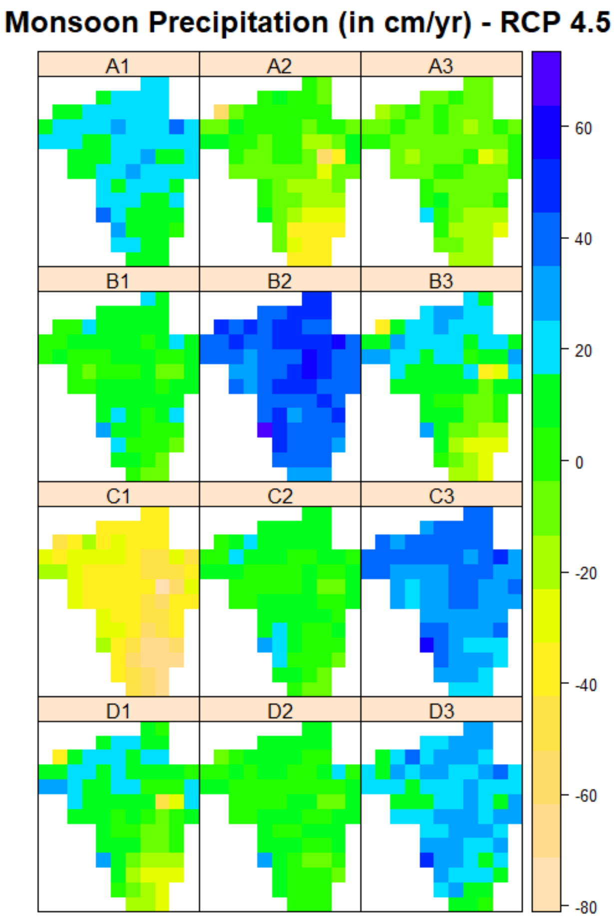


Fig. 6

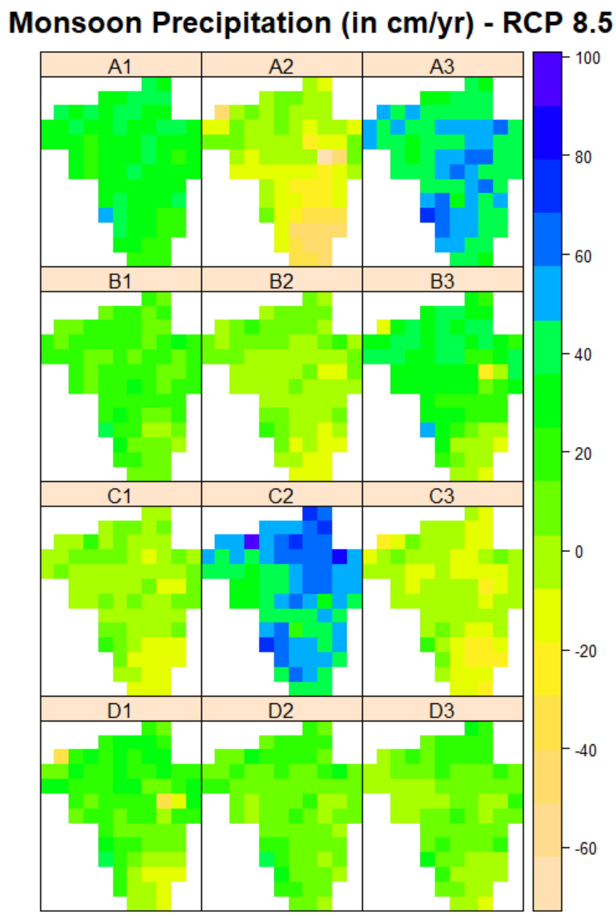


Fig.7

The assessment of climate change scenario shows that the annual, as well as monsoon precipitation, will increase in the future under RCP 4.5. Raghavan *et al*. (2018) also obtained the same results for Southeast Asia. RCP 8.5 demonstrated the precipitation will either decrease or remains constant which was also detected by Bokhari *et al*. (2018) for the Kabul River basin of the Hindu Kush Mountain ranges of Pakistan and Afghanistan. Chen *et al*. (2017) inferred the precipitation for China using the NEX-GDDP dataset and noticed that the precipitation will increase in the future.

## 4. Conclusions

This study evaluated the precipitation of the base period (1976-2005) w.r.t. future changes under RCPs 4.5 and 8.5 scenarios using four GCM models using data provided by NEX-GDDP for the Wainganga sub-basin, a tributary to Godavari river. In general, NEX-GDDP data represents precipitation well on a monthly scale. Based on projection, the annual mean precipitation will increase in the future under both the RCP scenarios. According to the most reliable GCM model-MPI-ESM-LR out of four models for the Wainganga sub-basin, the precipitation will increase continuously till the end of the century and varied up to 60 cm/yr under RCP 4.5 whereas under RCP 8.5 variations is quite low. Results from four models for both the scenarios, it can be concluded that the mean annual precipitation will rise with a maximum rate of 40 cm/yr till mid-term but after that, it will remain constant. In the case of monsoon precipitation, it will increase at the rate of 60 cm/yr at end of the century under the RCP 4.5 scenario while under RCP 8.5, monsoon precipitation will increase in the near term while in mid and end-term it will remain to constant. The overall conclusion of this study is that the annual, as well as monsoon precipitation, will be increasing till mid-term. Most models were designed with some boundary conditions and a particular model is not suitable for every condition, so it is better to use ensembles of models for climate forecasting.

## References

Bokhari, S. A. A., Ahmad, B., Ali, J., Ahmad, S., Mushtaq, H., & Rasul, G. (2018). Future Climate Change Projections of the Kabul River Basin Using a Multi-model Ensemble of High-Resolution Statistically Downscaled Data. *Earth Systems and Environment*, *2*(3), 477-497.

Chen, H. P., Sun, J. Q., & Li, H. X. (2017). Future changes in precipitation extremes over China using the NEX-GDDP high-resolution daily downscaled data-set. *Atmospheric and Oceanic Science Letters*, *10*(6), 403-410.

Cruz RVH, Change Climate et al (2007) Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp 469–506.

Field, C. B. (Ed.). (2014). *Climate change 2014–Impacts, adaptation and vulnerability: Regional aspects*. Cambridge University Press.

Jain, S., Salunke, P., Mishra, S. K., Sahany, S., & Choudhary, N. (2019). Advantage of NEX-GDDP over CMIP5 and CORDEX Data: Indian Summer Monsoon. *Atmospheric Research*.

Raghavan, S. V., Hur, J., & Liong, S. Y. (2018). Evaluations of NASA NEX-GDDP data over Southeast Asia: present and future climates. *Climatic change*, *148*(4), 503-518.

Salvi, K., Kannan, S., & Ghosh, S. (2011, September). Statistical downscaling and bias-correction for projections of Indian rainfall and temperature in climate change studies. In *4th International Conference on Environmental and Computer Science* (pp. 16-18).

Taylor, K. E., Stouffer, R. J., & Meehl, G. A. (2012). An overview of CMIP5 and the experiment design. *Bulletin of the American Meteorological Society*, *93*(4), 485-498.

Thakur, A., Mishra, P. K., Nema, A. K., & Sahoo, S. P. (2019). Spatio-temporal trends and shift analysis of temperature for Wainganga sub-basin, India. *International Journal of Environmental Studies*, 1-16.

Thrasher, B., Maurer, E. P., Duffy, P. B., & Mc Kellar, C. (2012). Bias correcting climate model simulated daily temperature extremes with quantile mapping.