

# Simulating Precipitation and Temperature Trends in Pakistan using three GCMs under RCP8.5 scenario

Ishtiaq Hassan<sup>1</sup>

**Abstract** - Precipitation and temperature are the two main factors considered in studies related to climate change and impact of global warming. Such studies involve application of results of climate models. US geological survey developed a web site [1] which provides visualization and access to global and regional (downscaled) climate data. In this study, results of three GCMs i.e. bcc-csm1-1m, HadGEM2-ES and GFDL-CM3, each with RCP8.5 scenarios, have been applied to study changes in precipitation and temperature over Pakistan. The results of three models showed that temperature variation is expected to range from 1.5-2.35 °C during 2025-2049, 3.23-4.48 °C during 2050-2074, and 4.49-6.57 °C during 2071-2095. Taking the average of the three models, this change is 1.89°C, 3.82°C and 5.49°C for the simulated periods of 2025-250, 2050-2074 and 2071-2095, respectively, with reference to modelled values for the base period (1980-2004). The precipitation variation is expected to be 3.31%, 8.16% and 9.45% when worked as average for above three models during simulated periods of 2025-250, 2050-2074 and 2071-2095, respectively.

**Key Words** - Climate, precipitation, temperature, GCM, RCP8.5

## I. Introduction

Pakistan has been experiencing flood and drought conditions. Flooding occurs during a La Niña phase of the El Niño Southern Oscillation (ENSO), which is connected with above-average summer monsoon rainfall [10, 22]. High rainfall variation is observed all over the world annually as well as seasonally [4, 6, 7]. Global environmental changes are continuously affecting the intensity, duration, and spatial/temporal distribution of precipitation [8].

Several studies have been carried out to assess trends of precipitation in the Indus basin. It has been observed that major river flows occur during the monsoon season. These studies include 3, 4, 5, 6, 7, 8, 9, 10, 17, 18, 19 and 20. Trend of precipitation has been reported differently in each study due to difference of periods (annual, monthly, daily), data and stations.

<sup>1</sup>Associate Professor (PhD)

Department of Civil Engineering, Capital University of Science and Technology Islamabad Pakistan  
0092-333-8340999

The study of environmental changes is a complex task due to the fact that there are many factors responsible for the change in global environment and there exist non-linear relationships between the forces which cause change and the regional or local characteristics [13, 15]. For this purpose, GCMs (general circulation models) are used to produce accurate results [13, 14, 23]. These GCMs couple system of four environmental components like atmosphere, land, ocean and ice and define their interaction [21]. These GCMs produce results (output) on the basis of different experiments called scenarios [12].

## II. Study Area

Pakistan with an area of 796,095 km<sup>2</sup> exists between latitude 24° and 37° North and longitude 62° and 75° East. There exists Iran on the West and India in the east. Northwest is surrounded by Afghanistan and northeast by the People's Republic of China Pakistan has the temperate zone. The climate is mostly semiarid with aridity in the south. Its experiences hot summers and cold winters Climatically, north and northwestern high mountain ranges are extremely cold in winter while the summer months from April to September are very pleasant. The vast plains of the Indus valley are extremely hot in summer and have cold weather in winter. The coastal strip in the South has a temperate climate. The country is general deficient in the rainfall. In the plains, the annual average ranges from 130 mm in the northern parts of the lower Indus plains to 890 mm in the Himalayan region. Great variations in seasonal rainfalls are observed in Pakistan. Average rainfalls are observed the least in autumn, less in spring, reasonable in winter and maximum in monsoon season as shown in figure 1 below.



Figure 1: Average Precipitation per month

### III. Methodology

A web site [11] developed by US geological survey provides visualization and access to global and regional (downscaled) climate data. Free access to data, figures and other information associated with climate change research are available here. The web site is serving to provide fine scale present and future climate data obtained from dynamical and statistical downscaling efforts. This data has been used to do the trend analysis in future. There are 26 GCMs and a mean of these models. Time periods could be any month of the year or annual and only two variables i.e. temperature and precipitation could be selected for further analysis at the country level. This has eliminated the need of GCMs' coarse data downloading and then downscaling it with further by using various techniques which thereafter is subject to analysis and conclusions. From the downloaded data (with 99% confidence level), the researcher can; (a) interpret the data and trends, and (b) compare the data between models and with other time periods.

In this study, results of three GCMs each with RCP8.5 scenario have been applied to study changes in precipitation and temperature over Pakistan. The data has been extracted from [1, 2]. These models and scenario have been explained below.

- *bcc-csm1-1m*: This model is developed by Beijing Climate Center (BCC), China Meteorological Administration, China.
- *HadGEM2-ES*: Met office Hadley Center Fitzroy road, Exeter, Devon EX1 3PB, UK.
- *GFDL-CM3*: NOAA GFDL (201 Forrestal Rd, Princeton, NJ, 08540).
- *RCP8.5 scenario*: RCP stands for Representative Concentration Pathways. This scenario assumes high population with relatively slow income growth, modest rates of technological change and energy intensity improvements. These factors lead towards long term high energy demands and GHG emissions in absence of proper climate change policies [16]. RCP defines the pathway with the highest greenhouse gas emissions. In this scenario, GHG (green house gases) emissions are continuously rising due to increase in fossil-intensity (coming out of energy sector) and population increase demanding high food. As per this scenario concentration of CO<sub>2</sub> (main GHG) is expected to be double in 2050 and triple by year 2100 as compared with year 2000. Concentration of 2<sup>nd</sup> GHG i.e. methane (CH<sub>4</sub>) is also attributed due to increase in life-stock population, rice production, and enteric fermentation processes needed to meet food

requirements of increased population. Increased use of fertilizers for more crop productions is mainly giving rise to N<sub>2</sub>O (3<sup>rd</sup> GHG). Globally, the mitigation potential is thus limited to about 50% and 30% of the RCP8.5 baseline emissions for CH<sub>4</sub> and N<sub>2</sub>O, respectively [16].

### IV. Results and discussion

#### Trend of Simulated changes in Temperature:

Figure 2 shows variation in temperature simulated for 2025-2049 period, for the study area, by using models mentioned above. Figure 2(a) is a global picture of change in mean temperature (°C) expected during 2025-2049 as compared to 1980-2004 (RCP8.5) for the mean of models. A change of 1.82°C is fore-seen for the mean of all 26 models. Figures 2(b), (c) and (d) indicate changes of 1.5°C, 2.35°C and 1.82°C during the simulation period of 2025-2049 as compared to base modelled period of 1980-2004 for bcc-csm1-1, GFDL-CM3 and HadGEM2-ES models, respectively.

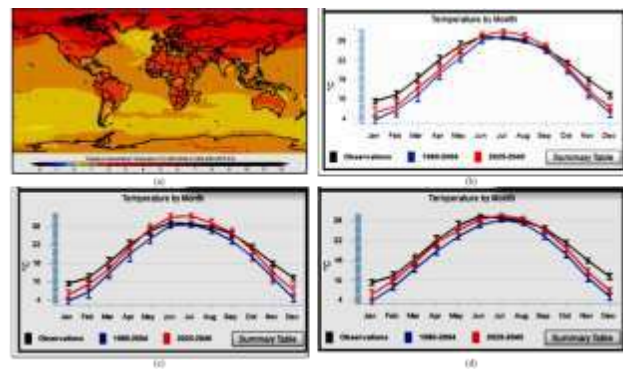


Figure 2: Mean Temperature (°C) Variations for Pakistan - 2025-2049 Vs 1980-2004 (RCP8.5) – (a) Global variation trend for models' mean, (b) *bcc-csm1-1* Model output, (c) *GFDL-CM3* Model output, (d) *HadGEM2-ES* Model output

Figure 3 shows variation in temperature simulated for 2050-2074 period, for the study area, by using models mentioned above. Figure 3(a) is a global picture of change in mean temperature (°C) expected during 2050-2074 as compared to 1980-2004 (RCP8.5) for the mean of models. A change of 3.38°C is foreseen for the mean of all 26 models. Figures 3(b), (c) and (d) indicate changes of 3.23°C, 4.48°C and 3.76°C during the simulation period of 2050-2074 as compared to base modelled period of 1980-2004 for bcc-csm1-1, GFDL-CM3 and HadGEM2-ES models, respectively.

Figure 4 shows variation in temperature simulated for 2071-2095 period, for the study area, by using models mentioned above. Figure 4(a) is a global picture of change in mean temperature (°C) expected during 2071-2095 as compared to 1980-2004 (RCP8.5) for the mean of models. A change of 4.47°C is foreseen for the mean of all 26 models. Figures 4(b), (c) and (d) indicate

changes of 4.49°C, 6.57°C and 5.40°C during the simulation period of 2071-2095 as compared to base modelled period of 1980-2004 for bcc-csm1-1, GFDL-CM3 and HadGEM2-ES models, respectively.

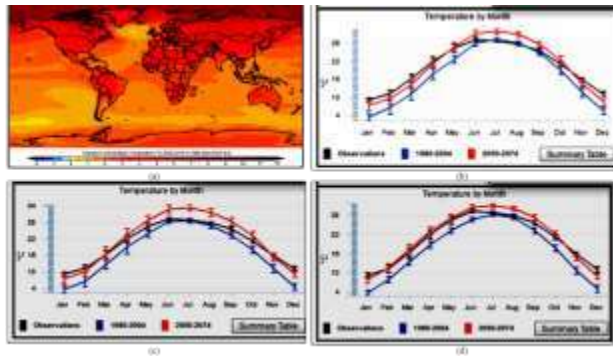


Figure 3: Mean Temperature (°C) Variations for Pakistan - 2050-2074 Vs 1980-2004 (RCP8.5) – (a) Global variation trend for models' mean, (b) **bcc-csm1-1** Model output, (c) **GFDL-CM3** Model output, (d) **HadGEM2-ES** Model output

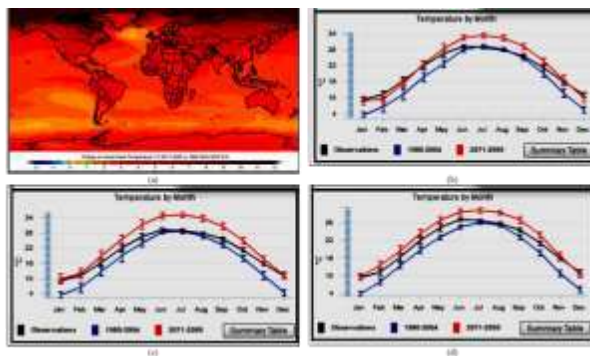


Figure 4: Mean Temperature (°C) Variations for Pakistan - 2071-2095 Vs 1980-2004 (RCP8.5) – (a) Global variation trend for models' mean, (b) **bcc-csm1-1** Model output, (c) **GFDL-CM3** Model output, (d) **HadGEM2-ES** Model output

Table 1 lists the various parameters of analysis like RMSE, bias and changes for these models.

Table 1: Summary of models' process parameters and annual changes in Temperature simulation

Country	Pakistan		Variable	Temperature		
Observed value (1980-2004)		20.52±0.50	°C	Time Period	Annual Mean	
Model	Annual RMSE	1980-2004	Bias	Change		
				2025-2049	2050-2074	2071-2095
Bcc-csm1-1	3.76	17.49±0.52	-3.03	1.50	3.23	4.49
GFDL-CM3	3.71	17.31±0.64	-3.21	2.35	4.48	6.57
HadGEM3-ES	3.65	17.26±0.43	-3.26	1.82	3.76	5.40

*Trend of Simulated changes in Precipitation:*

Figure 5 shows variation in precipitation simulated for 2025-2049 period, for the study area, by using models mentioned above. Figure 5(a) is a global picture of change in mean precipitation (mm/day) expected during 2025-2049 as compared to 1980-2004 (RCP8.5) for the mean of models. A change of 0.04 mm/day is fore-seen for the mean of all 26 models. Figures 5(b), (c) and (d) indicate changes of -4.35% (-0.02mm/day), 8.70% (+0.05 mm/day) and 10.87% (+0.13 mm/day) during the

simulation period of 2025-2049 as compared to base modelled period of 1980-2004 for bcc-csm1-1, GFDL-CM3 and HadGEM2-ES models, respectively.

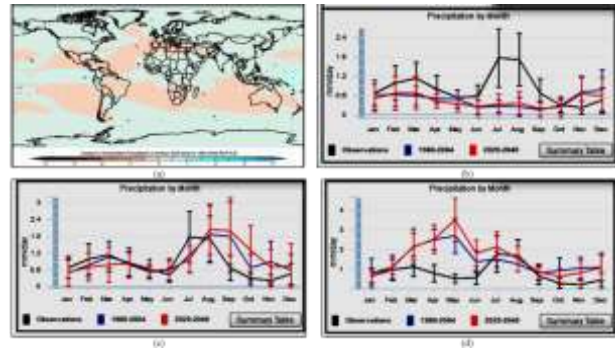


Figure 5: Mean precipitation (mm) Variations for Pakistan – 2025-2049 Vs 1980-2004 (RCP8.5) – (a) Global variation trend for models' mean, (b) **bcc-csm1-1** Model output, (c) **GFDL-CM3** Model output, (d) **HadGEM2-ES** Model output

Figure 6 shows variation in precipitation simulated for 2050-2074 period, for the study area, by using models mentioned above. Figure 6(a) is a global picture of change in mean precipitation (mm/day) expected during 2050-2074 as compared to 1980-2004 (RCP8.5) for the mean of models. A change of 0.05 mm/day is fore-seen for the mean of all 26 models. Figures 6(b), (c) and (d) indicate changes of 5.32% (+0.04 mm/day), 9.57% (+0.09 mm/day) and 8.51% (+0.09 mm/day) during the simulation period of 2050-2074 as compared to base modelled period of 1980-2004 for bcc-csm1-1, GFDL-CM3 and HadGEM2-ES models, respectively.

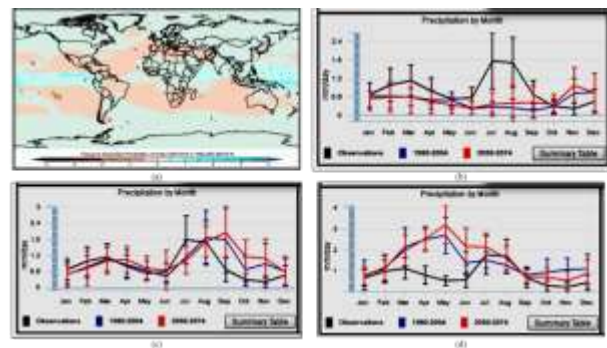


Figure 6: Mean precipitation (mm) Variations for Pakistan – 2050-2074 Vs 1980-2004 (RCP8.5) – (a) Global variation trend for models' mean, (b) **bcc-csm1-1** Model output, (c) **GFDL-CM3** Model output, (d) **HadGEM2-ES** Model output

Figure 7 shows variation in precipitation simulated for 2071-2095 period, for the study area, by using models mentioned above. Figure 7(a) is a global picture of change in mean precipitation (mm/day) expected during 2071-2095 as compared to 1980-2004 (RCP8.5) for the mean of models. A change of 0.06 mm/day is fore-seen for the mean of all 26 models. Figures 7(b), (c) and (d) indicate changes of 8.97% (+0.05mm/day), 6.21% (+0.08mm/day) and 8.97% (+0.13 mm/day) during the simulation period of 2050-2074 as compared to base



modelled period of 1980-2004 for bcc-csm1-1, GFDL-CM3 and HadGEM2-ES models, respectively.

Table 2 lists the various parameters of analysis like RMSE, bias and changes for these models.

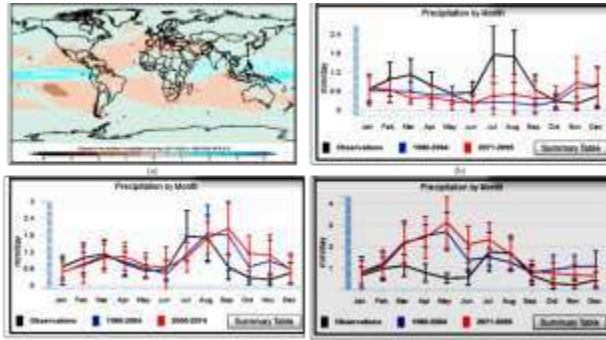


Figure 7: Mean precipitation (mm) Variations for Pakistan – 2071-2095 Vs 1980-2004 (RCP8.5) – (a) Global variation trend for models' mean, (b) bcc-csm1-1 Model output, (c) GFDL-CM3 Model output, (d) HadGEM2-ES Model output

Table 2: Summary of models' process parameters and annual changes in Precipitation simulation

Country	Pakistan			Variable	Precipitation	
Observed value (1980-2004)	0.82±0.17		mm/day	Time Period	Annual Mean	
Model	Annual RMSE	1980-2004	Bias	Change		
				2025-2049	2050-2074	2071-2095
Bcc-csm1-1	0.68	0.46±0.14	-0.36	-0.02	0.04	0.05
GFDL-CM3	0.45	0.94±0.19	0.12	0.05	0.09	0.08
HadGEM3-ES	0.97	1.45±0.17	0.63	0.13	0.09	0.13

## V. Conclusions and Recommendations

In this study, from the results of three models, it is firstly observed that temperature variation is expected to range from 1.5-2.35 °C during 2025-2049, 3.23-4.48 °C during 2050-2074, and 4.49-6.57 °C during 2071-2095. Taking the average of the three models, this change is 1.89°C, 3.82°C and 5.49°C for the simulated periods of 2025-250, 2050-2074 and 2071-2095, respectively, with reference to modelled values for the base period (1980-2004).

Secondly, it is observed that precipitation variation is expected to be 3.31%, 8.16% and 9.45% when worked as average for above three models during simulated periods of 2025-250, 2050-2074 and 2071-2095, respectively.

It is recommended that further study be made by using results of other models' data also.

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Climate change studies are important to understand trend of change(s) of various parameters and to help policy makers to plan and execute future water projects.