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Projecting Future Temperature using CMIP5 GCMs over Transboundary Gomal River Basin

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***Abstract*—** Temperature is a key driving force in hydrological cycle, defining the extent of climate change. It causes the alteration in hydrological cycle process, limiting and intensifying the rainfall, increasing the rate of evapotranspiration and changes the crop pattern and duration over a region. Its future analysis is utmost to cope with negative effects of climate change over a specified region. This study also investigates, the future temperature pattern over Gomal River Basin (GRB). To undertake the study, downscaled daily temperature data of four General Circulation Models (GCMS) namely; bcc_csm1_1_m, mpi_esm_mr, ncar_ccsm4 and ncc_noresm1_m and their ensemble mean were first compared and validated with observed data for the period of 1980-2005. After that, temperature was projected for the mid-century (2020-2060) for the Representative Concentration Pathways (RCPs) 4.5. The analysis were carried out based on the four seasons; winter (December-February), spring (March-May), summer (June-August) and autumn (September-November). The results indicate that, the basin temperature was accurately predicted by the ensemble mean of the four GCMs with R^2 value of 0.9. All the GCMs projected a warming in future in all seasons. Winter warming is more compared to other seasons. Proper adaptation strategies are needed to cope with the adverse impacts of global warming in the basin.

Keywords— Temperature, Climate Change, CMIP5, GCMs, GRB

I. Introduction

Mean surface air temperature is an important meteorological parameter which influences hydrological cycle causing evaporation from water bodies and occurrence of precipitation. It plays an important role in the germination and growth of the crops. It cause droungts and floods by altering precipitation patterns [1]. Higher temperature over a region is the feature of global warming. The global average temperature has increased by an average of 0.85 °C during 1800–2012 relative to 1961–1990 [2] and 0.74 °C (1906.-.2005) [3]. Over Southeast Asia, the mean annual temperature would rise by about 3.2 °C under RCP 8.5 [4] while over East Asia it is projected to likely increase by 0.98 °C and 4.06 °C for low and high emission scenarios respectively. Also, an increase of 10-15 % in summer precipitation was projected. at the end of 21st century in the East Asia [5]. Across South Asia region, the daily mean temperature would rise by 2.9 °C in 2046-2075 comparative to 1976-2005 [6]. In Pakistan, the 21st century temperature would increase by around 6.7 °C under RCP 8.5 [7]. This increase is higher in the northern parts and smaller in the southern parts. This increase in the temperature has caused the change in the bowing and sowing seasons of crops, movements of the inhabitants.

General Circulation Models (GCMs) included in the Coupled Model Inter-comparison project, Phase 5 (CMIP5) are the most advance tools to analyze future global warming and its effects on different socio-economic sectors such as agriculture, industries, tourism and hydropower generation ([8], [9], [10], [11]). Due to this reason different researches across the world are using the output of these GCMs in climate change impacts studies. Detailed information on the experimental design of GCMs included in the CMIP5 are given by [12]. In this study four GCMs namely; bcc_csm1_1_m, mpi_esm_mr, ncar_ccsm4 and ncc_noresm1_m and their ensemble were used to project temperature in the mid-21st century (2020-2060) using RCP 4.5 for the transboundary GRB.

II. Data and Methodology

A. Study Area

The GRB is a transboundary river basin shared between Pakistan (76%) and Afghanistan (24%) (Figure 1). The basin area is 34167 km2 and the runoff generated from the basin contributes to the Gomal Zam Dam constructed on the Gomal River at Khajuri Katch in Pakistan. The average annual temperature over the basin is 12.7 °C and average annual precipitation is 228 mm. There are two major rivers in the basin, namely; Gomal River and Zhob River. These both rivers drain the basin into Gomal Zam Dam, which is a sole sources of water supply to the lands and community living downstream in the command area. The rise in temperature will affect the precipitation pattern and hence the water availability to the Dam affecting the socio-economic wellbeing of the community. Hence its future quantification is necessary to mitigate and adopt to the impacts of climate change.

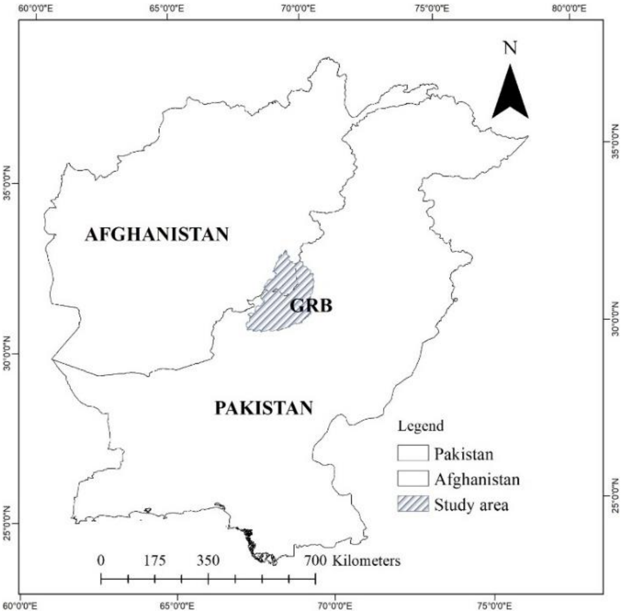

Figure 1. Location Map of Gomal River Basin (GRB)

B. *Temperature Data*

In this study, four GCMs from 5th Couple Model Inter-comparison Project (CMIP5) of the Intergovernmental Panel on Climate Change (IPCC) was used. Downscaled data of the four GCMs (Table 1) and its ensemble mean were downloaded from http://ccafs-climate.org/ at the four stations covering the basin. Observed data for the period of 1980-2005 at Dera Ismail Khan station was obtained from Pakistan Meteorological Department. To select best GCM, the GCMs historical data was compared with the observed data. For future analysis, the daily data of the GCMs were transformed into four seasons, namely winter, spring, summer and autumn.

TABLE 1. DETAILS OF GCMS USED IN THIS STUDY

GCM	Organization/Institute	Model ID	Resolution (Lat x Long) °
bcc_csm1_1_m	Beijing Climate Center (Climate System Model)	BCC	2.7906 x 2.8125
mpi_esm_mr	Max Planck Institute of Meteorology	MPI-ESM	1.8653 x 1.875
ncar_ccsm4	National Center for Atmospheric Research, USA	NCAR	0.9424 x 1.25
ncc_noresm1_m	Norwegian Climate Centre, Norway	NCC	1.8947 x 2.5

C. *Methodology*

The methodology consists of comparing and validating the GCMs data by comparing the data with the observed data. For this purpose, the GCMs data were compared at four stations (S1, S2, S3 and S4) (Table 2) using Pearson Correlation Coefficient (r) (Equation 1) and Root Mean Square Error (RMSE) (Equation 2). Then descriptive statistic (Equation 3-4) was applied to quantify the future temperature in the Mid of 21st Century (2020-2060).

TABLE 2. LOCATION OF STATIONS USED TO PROJECT FUTURE TEMPERATURE OVER THE GRB

S.No.	Station	Coordinates (Lat x Long)°
1	S1	32.40 x 68.97
2	S2	31.53 x 69.19
3	S3	31.53 x 68.38
4	S4	30.84 x 68.25

1. Pearson Correlation Coefficient (r)

$$r = \frac{\sum_{i=1}^{n}(O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2}\sqrt{\sum_{i=1}^{n}(P_i - \bar{P})^2}} \quad \text{(II. 1)}$$

Where "O" is the observed and "P" is the GCM data

2. Root Mean Square Error (RMSE)

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(O_i - P_i)^2}{n}} \quad \text{(II. 2)}$$

3. Statistical Mean ($\bar{X}$)

$$\bar{X} = \frac{\sum_{i=1}^{N} X_i}{N} \quad \text{(II. 3)}$$

where, X is the data point and N is the total number of data points.

4. Standard Deviation (σ)

$$\sigma = \frac{\sqrt{\sum(X - \overline{\overline{X}})}}{n} \quad \text{(II. 4)}$$

where, $\bar{X}$ is the mean of the data set and n is the number of data points.

III. RESULTS AND DISCUSSIONS

A. *Validation of GCMs*

The results of the statistical test applied for the validation of GCMs with the observed data are presented in the Table and Figure. All the four GCMs have good correlation with observed data. The correlation coefficient (r) value ranges from a minimum of 0.90 to a maximum of 0.95 for station S1 while it ranges from 0.89 to 0.95 for station S2. The GCM ncc_noresm1_m has higher value of "r" while bcc_csm1_1_m has lower value of "r" compared to other GCMs at all the four stations. The RMSE value ranges from a minimum of 15.66 to a maximum of 21.65. On average, the minimum values of RMSE were observed for ncar_ccsm4 while the maximum values of RMSE were observed for mpi_esm_mr. Compared to the individual GCM, the ensemble means of all the GCMs indicate a strong correlation with the observed data. Also, the RMSE showed lowest values for the ensemble mean at all stations. Hence, the ensemble mean is the most suitable for future analysis as it predicts the basin accurate climate in terms of temperature.

B. *Projections of Fuutre Temperature*

1) *Winter Temperature*

The results of winter temperatures projected in the 2020-2060s are presented in the Table 4. The results were compared with the observed historical temperature for the period of 1980-2005. The average mean observed temperature over the basin is 1.0 °C in winter. The results indicate that the mean temperature over the basin will increase in future. At S4, highest warming was observed compared to other stations. For bcc_csm1_1_m, the mean temperature is projected to increase by 4 °C at S1 and 8.26 °C at S4. Least warming were projected by the GCM mpi_esm_mr which is 3.62 °C at S1 and 7.85 °C at S4 compared to the historical observations. The ensemble means also show warming in winter temperature which is highest at S4.

TABLE 3. STATISTICAL RESULTS OF THE VALIDATION OF THE GCMS WITH THE OBSERVED DATA

Station	bcc_csm1_1_m		mpi_esm_mr		ncar_ccsm4		ncc_noresm1_m		Ensemble Mean	
	r	RMSE	r	RMSE	r	RMSE	r	RMSE	r	RMSE
S1	0.90	18.7	0.91	19.20	0.90	16.70	0.92	19.35	0.95	18.31
S2	0.89	20.3	0.91	21.65	0.91	17.10	0.92	21.53	0.95	19.97
S3	0.90	15.6	0.91	17.13	0.90	15.87	0.92	16.65	0.96	16.11
S4	0.89	20.3	0.91	21.65	0.91	16.60	0.92	18.35	0.95	18.33

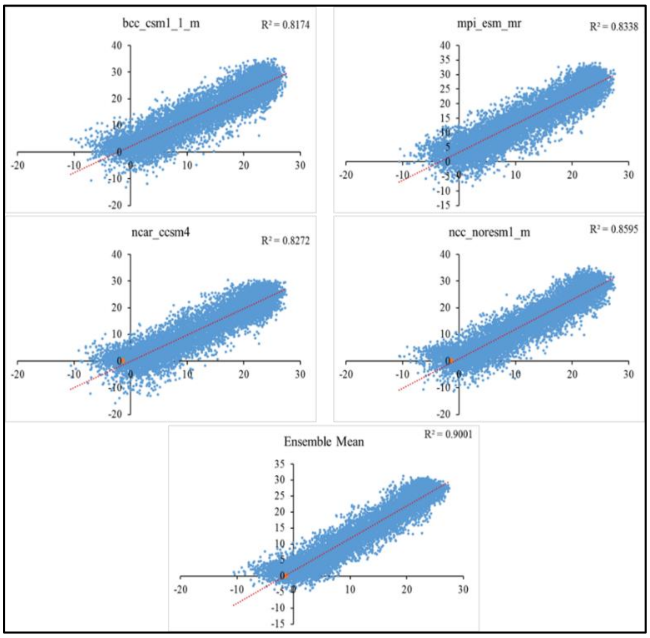

Figure 2. Comparison of GCMs and its ensemble mean with the observed data for the period of 1985-2005

TABLE 4. PROJECTIONS OF WINTER TEMPERATURE IN THE MID-21ST CENTURY OVER THE GRB

Station	Observed	bcc_csm1_1_m	mpi_esm_mr	ncar_ccsm4	ncc_noresm1_m	Ensemble Mean
S1	1.0	5.37	4.62	4.85	5.38	5.89
S2	1.0	5.56	4.89	4.98	5.25	5.96
S3	1.0	6.20	5.60	5.72	5.88	6.64
S4	1.0	9.26	8.59	8.85	9.66	8.88

2) *Spring Temperature*

Spring temperatures also show warming in the future (Table 5). The mean historical temperature over the basin is 12.4 °C. compared to the historical, the bcc_csm1_1_m shows an increase of 1.37 °C at S1 while 8.04 °C at S4. The least projected increase were observed for ncar_ccsm4 which is 1.19 °C at S1 and 7.91 °C at S4. The results of the ensemble means of the GCM also show warming in the basin in spring season.

TABLE 5. PROJECTIONS OF SPRING TEMPERATURE IN THE MID-21ST CENTURY OVER THE GRB

Station	Observed	bcc_csm1_1_m	mpi_esm_mr	ncar_ccsm4	ncc_noresm1_m	Ensemble Mean
S1	12.4	13.77	13.70	13.59	13.68	14.46
S2	12.4	16.96	17.05	16.79	16.90	17.71
S3	12.4	17.47	17.74	17.35	17.44	18.31
S4	12.4	20.44	20.65	20.31	21.22	20.36

3) *Summer Temperature*

The results of the historical and projected summer temperature are presented in the Table 6. The mean summer temperature over the basin is 22.9 °C. in future the highest warming were projected by the mpi_esm_mr while the lowest warming were projected by ncar_ccsm4. The bcc_csm1_1_m GCM results indicate that temperature will increase by 0.81 °C at S1 while .10 °C at S4. The ensemble mean of the four GCMs used also indicate warming in summer season. This warming is highest at S4 which is 6.30 °C.

TABLE 6. PROJECTIONS OF SUMMER TEMPERATURE IN THE MID-21ST CENTURY OVER THE GRB

Station	Observed	bcc_csm1_1_m	mpi_esm_mr	ncar_ccsm4	ncc_noresm1_m	Ensemble Mean
S1	22.9	23.71	24.14	23.53	23.83	24.46
S2	22.9	25.73	26.36	25.58	25.83	26.47
S3	22.9	26.95	27.71	26.74	27.18	27.88
S4	22.9	29.00	29.71	28.75	29.85	29.20

4) *Autumn Temperature*

The results of the autumn temperature is shown in the Table 7. The mean observed temperature is 13.4 °C. results indicate a warming in future in autumn season. The projected increase at S1 for bcc_csm1_1_m, mpi_esm_mr, ncar_ccsm4 and ncc_noresm1_m is 1.32 °C, 1.49 °C, 1.38 °C and 1.44 °C respectively. The results of the ensemble mean indicate that temperature will increase by 1.85 °C at S1 and 6.54 °C at S4 in the mid-21st century.

TABLE 7. PROJECTIONS OF AUTUMN TEMPERATURE IN THE MID-21ST CENTURY OVER THE GRB

Station	Observed	bcc_csm1_1_m	mpi_esm_mr	ncar_ccsm4	ncc_noresm1_m	Ensemble Mean
S1	13.4	14.72	14.89	14.78	14.84	15.25
S2	13.4	16.61	16.82	16.61	16.71	17.13
S3	13.4	17.38	17.60	17.41	17.58	17.97
S4	13.4	19.80	19.95	19.81	20.35	19.94

CONCLUSIONS

The main objective of this study was to project temperature in the mid-21st century (2020-2060) over the transboundary Gomal river basin using CMIP5 GCMs for the RCP 4.5. GCMs were first validated with the observed data for the period of 1980-2005. It was found that ensemble mean of the four GCMs used performed well with "r" value of 0.95. Projected results of all the GCMs used indicate a warming in future in all seasons. The winter warming is more compared to other seasons. The ensemble means of the GCMs indicate that on average the winter, summer, spring and autumn temperatures will increase by 7.5 °C, 7.9 °C, 6.0 °C and 6.5 °C respectively. this rise in temperature will significantly affect precipitation patterns with increase rate of evapotranspiration in the basin. Hence, planner and managers are required to adopt strategies to minimize the adverse impacts of global warming and climate change on agriculture and socio-economic activities of the communities in the basin.

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