SPATIOTEMPORAL VARIABILITY OF PRECIPITATION AND TEMPERATURE IN AFGHANISTAN BY THE END OF THE 21ST CENTURY

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1. INTRODUCTION

Global Climate Models (GCMs) can be used to predict future climate information. The GCMs project future climate based on different assumptions of future changes of greenhouse gas (GHG) emissions, land use and socio-economy (Taylor et al., 2011; Chen et al., 2014).

Afghanistan experienced a rapid change in climate in recent years. According global climate risk index (2017) its ranked 12th most vulnerable country to climate change and has already experienced prolonged droughts. i.e. drought 1998-2002 (Sediqi et al., 2019).

The mean annual temperature has in the country has increased by 0.13 to 0.29 °C/decade in the last five decades. Understanding possible climate changes are crucial for the country to anticipate future water stress and aridity and their implications in agriculture and the economy.

The objective of the present study is to assess the relative historical performance and to project the CMIP6-GCMs in desert and mountainous regions of Afghanistan. The capability of the models was assessed in simulating the spatial and temporal variability of climate for annual scale.

2. STUDY AREA AND DATASETS

2.1. Study area

Afghanistan considered as a study area in this paper. It is located between latitude 29°- 39°N and longitude 60° - 75°E with an area of around 652000 km² (Nengroo et al., 2012).

Afghanistan according to Koppen-Geiger climate classification has divided to different climate zones (Figure 1). Pular tundra region receive high annual rainfall (>1000 mm) and the arid desert has the least annual rainfall of (100 to 150 mmOn the other hand, northeast region has the lowest mean annual temperature (< -5 °C) and southwest (arid desert) region has the highest mean annual temperature (> 28 °C).

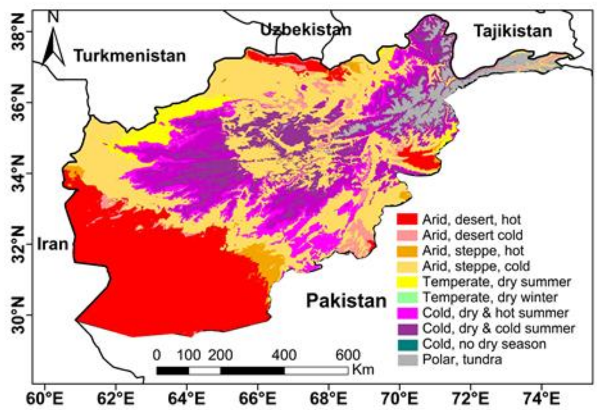

Fig.1 Afghanistan with its different climate zones

2.2. Datasets

Gridded climate data are reliable to use for the climate research in areas where they have insufficient long-term record of climatic observation. CRU gridded dataset from the University of East Anglia Climatic Research Unit, was used for assessing GCM's performance in simulating monthly precipitation (Pr), maximum temperature (Tmax) and minimum temperature (Tmin).

Ninteen CMIP6-GCMs were used to assess the future climate projection for (SSP 1-2.6, 2-4.5 and 5-8.5) scenarios over Afghanistan.

3. METHODOLOGY

3.1. GCM Selection

Past performance approach was used to assess the similarity of GCMs with CRU for the period of 1990 to 2014. In this study Kling-Gupta efficiency (KGE), which is a statistical performance measure, was used to rank the GCM. KGE (Gupta et al., 2009; Kling et al., 2012) metric shows the goodness-of-fit measure and can assess bias, correlation, and variability together between the CRU and each GCM and provides an integrated metric in a range of 1 to $-\infty$ where 1 indicating a perfect match calculated by using equation (1).

$$\boldsymbol{KGE = 1 - \sqrt{(r-1)^2 + \left(\frac{\mu_{GCM}}{\mu_{ref}} - 1\right)^2 + \left(\frac{\sigma_{GCM}/\mu_{ref}}{\sigma_{ref}/\mu_{ref}} - 1\right)^2}} \quad (1)$$

where, r is Pearson's correlation, μ_{GCM} and μ_{ref} are the mean, and σ_{GCM} and σ_{ref} are the standard deviation for GCM and CRU data, respectively.

Final rank of GCMs was derived by a rating metric (*MR*) using equation (5) that refers to the combination of the performance of all climate variables.

$$MR = 1 - \frac{1}{nm}\sum_{i-1}^{n} rank_i \quad (2)$$

where, m refers to the number GCMs, n of variables and i is the rank of each GCM in ith variables. In this study, 3 high ranked GCMs obtained from equation (2) were considered for the generation of ensemble of GCMs

3.2. Projection of rainfall and temperature

Selected GCMs were bias corrected for the references period of (1990-2014) using quantile delta mapping (QDM) bias correction using equation (3) in order to reduce the bias associate with raw GCMs.

$$Q_m(t) = F_0^{-1}\left[F_s[Q_s(t)]\right] \quad (3)$$

where, $Q_m(t)$ and $Q_s(t)$ are ith bias corrected and simulated data from GCM, F_s and F_0^{-1} are Cumulative distribution function (CDF) of raw GCM and inverse CDF of CRU gridded data respectively.

The percentage changes in annual rainfall and the absolute changes in annual maximum and minimum temperature projected for two future periods 2020-2059 and 2060-2099 for (SSP 1-2.6, 2-4.5 and 5-8.5) scenarios.

4. RESULTS

4.1. Selection of GCMs

Figure 2 shows the performance of each GCMs to reproduce the historical Pr, Tmax and Tmin. The ranking of GCM based on each variable are shown in table 2. It can be seen that some of the models ranked very high for one variable and low for another one. Therefore, in order to choose same model for all variables rating metric (MR) were used to rank of all variables. Last column of table 2 shows the overall rank of GCMs for all variables. It is found that ACCESS-CM2, MPI-ESM1-2-LR and FIO-ESM-2-0 are the most suitable model to simulate the historical climate of Afghanistan.

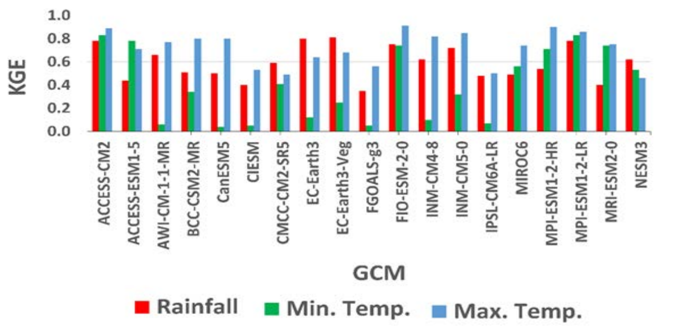

Fig.2 KGE values of GCMs Pr (red), Tmax (blue) and Tmin (green).

Table 2. Overall rank of GCMs (boldface rows indicates selected GCMs).

GCM	Rank based on each variable			MR value	Final Rank
	Rainfall	Max. Temp.	Min. Temp.		
ACCESS-CM2	4	1	2	0.88	1
ACCESS-ESM1-5	16	13	5	0.40	13
AWI-CM-1-1-MR	7	6	16	0.54	7
BCC-CSM2-MR	11	8	10	0.49	8
CanESM5	14	10	18	0.25	16
CIESM	19	17	17	0.07	18
CMCC-CM2-SR5	9	16	9	0.40	14
EC-Earth3	2	14	15	0.47	10
EC-Earth3-Veg	1	11	12	0.60	6
FGOALS-g3	18	19	13	0.02	19
FIO-ESM-2-0	6	2	4	0.79	3
INM-CM4-8	8	7	14	0.47	11
INM-CM5-0	5	5	11	0.61	5
IPSL-CM6A-LR	15	15	19	0.21	17
MIROC6	13	12	7	0.44	12
MPI-ESM1-2-HR	12	3	6	0.63	4
MPI-ESM1-2-LR	3	4	1	0.86	2
MRI-ESM2-0	17	9	3	0.49	9
NESM3	10	18	8	0.37	15

4.2. Projection of climate

Figure 3-5 shows the spatial pattern of the change in Pr, Tmax and Tmin for near future (2020-2059) and far future (2060-2099) under SSP1-2.6, SSP2-4.5 and SSP5-8.5 shared scenarios. It is projected that for both Tmax and Tmin the lowest change will be in SSP1-2.6, near future and southwest of the country and the highest change is projected in SSP5-8.5, far future and northeast of Afghanistan.

On the other hand, the annual rainfall change was projected to have a positive change in the range of (10 to 90 mm) all over the country except in central region.

Maximum and minimum temperature was likely to increase in the range of 1.3 ºC to 5.3 ºC and 1.3 ºC to 5.2 ºC respectively.

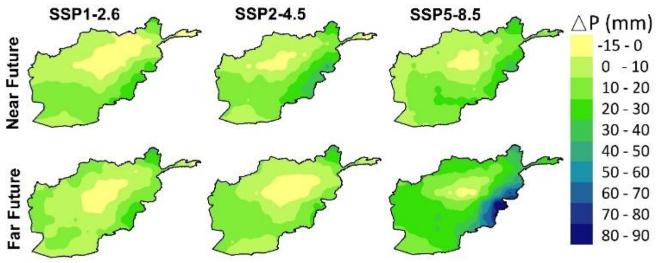

Fig. 3 Spatial patterns in precipitation changes over Afghanistan for the early (2020-2059) and late (2060-2099) periods for SSP1-2.6, 2-4.5, and 5-8.5.

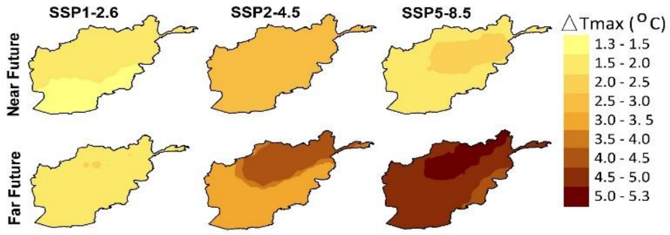

Fig. 4 Same as **Fig. 3**, but for maximum temperature.

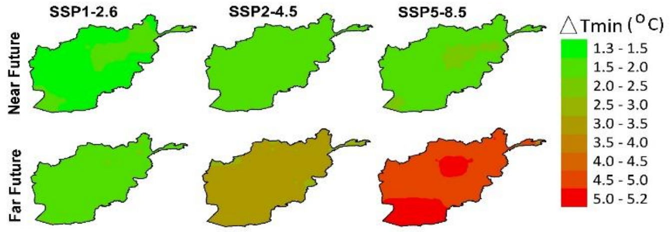

Fig. 5 Same as **Fig. 3**, but for minimum temperature.

5. CONCLUSION

The statistical metric has been conducted in this study to evaluate the performance of CMIP6 GCMs in simulating historical climate. Besides, the MMEs were used to project the future climate for different scenarios. The study revealed a higher increase in rainfall and a significantly large rise in temperature for all SSP scenarios.

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