4. Future Climate Projections over Afghanistan based on CMIP6-GCMs

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The coupled Model Intercomparison Project phase 6 (CMIP6) dataset was used to assess the spatio-temporal projected changes in precipitation and temperature over Afghanistan under latest three SSPs emission scenarios (SSP1-2.6, SSP2-4.5 and SSP5-8.5) for the three period, near future (2020-2044), mid future (2045-2067) and far future (2075-2099). Statistical metric was used for ranking the models to select appropriate GCMs based on their ability to simulate historical monthly average precipitation, maximum and minimum temperature for the period of (1990-2014). Three model namely MPI-ESM1-2-LR, ACCESS-CM2 and FIO-ESM-2-0 were found high ranked models based on past performance for simulating the all three variables. Mean ensemble of selected GCMs revealed an increase in maximum temperature in the range of 1.7-4.5ºC, 2.7-5.3 ºC, and 4.5-6.8 ºC and minimum temperature in the range of 1.8-9.8 ºC, 3.2-9.9 ºC and 5.6-10.7 ºC and average precipitation change in the range of -4.9-10.23%, -2.4-22.6% and -1.4-29.8% under SSP1-2.6, SSP2-4.5 and SSP5-8.5 scenarios, respectively during far future (2075-2099). Northeast of the country (Himalayas region) were projected higher increase in temperature, where, higher change in average precipitation were projected in the south and southwest (desert region) of Afghanistan.

Key Words : *Climate projections, global climate model, CMIP6, Afghanistan line*

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). The change in global GHG releases and socioeconomic is related to the political strategies at national, regional and global levels.

Afghanistan is located in cross road of central and south Asia, has semi-arid to arid climate. Decades of political fighting has faced many different environmental issues, mostly in water sector (Aich et al., 2017). According global climate risk index (2017) ranked 12th most vulnerable to climate change and has already experienced prolonged droughts. i.e. drought 1998-2002 (Sediqi et al., 2019).

In Afghanistan 98 % of water resource is used for agriculture, similarly, more than 80 % of the population get their income from agricultural practices. Therefore, rapid declination of renewable water resources has caused a significant impact on water resources, agriculture and livelihood of the vast populace of the country.

Afghanistan experienced a rapid change in climate in recent years. 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.

Several previous studies conducted to assess the climate change in Afghanistan (Sidiqi et al. 2018, Bokhari et al. 2018) based on Climate Model Intercomparison Project phase 5 (CMIP5) GCMs under different representative concentration pathway (RCP). However no studies have been conducted so far to assess climate change projection in Afghanistan using CMIP6-GCMs.

The objective of the present study is to assess the relative historical performance and future projections of the GCMs of CMIP6 in Afghanistan. Fifteen GCMs based on their availability for the study area are used for this purpose. The capability of the models was assessed in simulating the spatial and temporal variability of climate for annual scale.

2. STUDY AREA AND DATASETS

(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 512000 km².

Afghanistan according to Koppen-Geiger climate classification has divided to different climate zones (Figure 1): from arid desert in the southwest to polar tundra in the northeast of the country. Pular tundra region receive high annual rainfall (>1000 mm) and the arid desert has the least annual rainfall of (100 to 150 mm). On 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).

Afghanistan consists of four seasons. The weather is rainy, snowfall and cold between November and February, while there is no rainfall in the summer between June and August.

(2) Datasets

CRU gridded dataset from the University of East Anglia Climatic Research Unit, was used for assessing GCM's performance in simulating monthly rainfall, Tmax, and Tmin. with resolution of 1.0 × 1.0. CRU was chosen to represent the historical climate of Afghanistan because it showed a high capacity in reproducing the monthly gauge records even better than GPCC product.

Fifteen CMIP6 GCM's were used to assess the future climate projection for three different future scenarios over Afghanistan. The GCMs were selected based on availability of projections of three main climate variables rainfall, Tmax and Tmin, and their availability of future projection for SSP 1-2.6, SSP 2-4.5 and SSP 5-8.5.

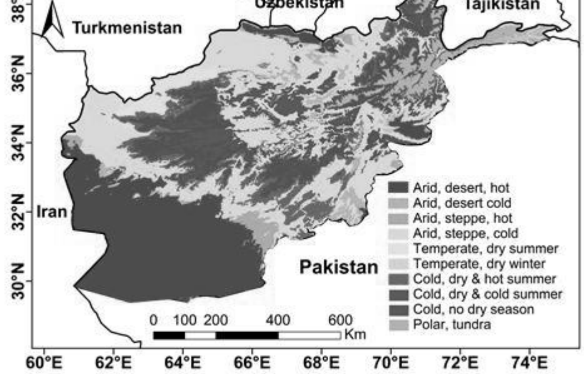


Fig.1 Afghanistan with its different climate zones.

3. METHODOLOGY

In this study, the CMIP6 GCMs were used to replicate the historical annual rainfall, Tmax and Tmin over Afghanistan. CRU gridded dataset was used as a reference to represent the historical climate of the study area, all the GCM simulations were gridded to a common resolution of 1.0°×1.0°. The methods used for the comparison of GCMs are explained below.

(1) GCM Selection

The Kling-Gupta efficiency (KGE) (Gupta et al., 2009) metrics were used to evaluate the association between gridded dataset (CRU) and GCMs and to select an ensemble of GCMs based on their past performance.

KGE range between 1 to - ∞, where 1 indicates a perfect association and can be calculated from equation (1). KGE metrics is a combination of combines Pearson's correlation (r), the ratio of spatial variability and the normalized difference between the gridded dataset (CRU) and each GCM model.

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

where μ_{GCM} and μ_{ref} are the mean, and σ_{GCM} and σ_{ref} are the standard deviation for GCM and CRU data, respectively.

The rating metric (MR) used to find the final rank by the combination the rank of all variables from following equation:

$$MR = 1 - \frac{1}{nm}\sum_{i=1}^{n} rank_i$$

where *i* is the rank of GCM in the ith variables, *n* and *m* are the number of variables and GCM respectively.

(2) Future projections of climate

After the selection of high ranked GCMs, the ensemble of CMIP6 GCM rainfall and temperature projections for SSP scenarios, for three main periods (2020-2044), (2045-2069) and (2075-2099) were compared to that of their reference period (1990-2015) to assess the changes in Afghanistan future climate. The maps were prepared to show the difference in the spatial distribution of rainfall and temperature projections by CMIP6 GCMs.

4. RESULTS

(1) GCM Selection

The performances of CMIP6 GCMs based on KGE metric to reproduce the annual rainfall, Tmax and Tmin are shown in figure 2. The figure presents three radar charts, one for each climate variable. Each radar chart presents the KGE values of each models. The results revealed that based on combination of the rank of all variables using rating metric (RM) equation, FIO-ESM-2-0, ACCESS-CM2 and MPI-ESM1-2-HR has higher KGEs between all models for all three variables.

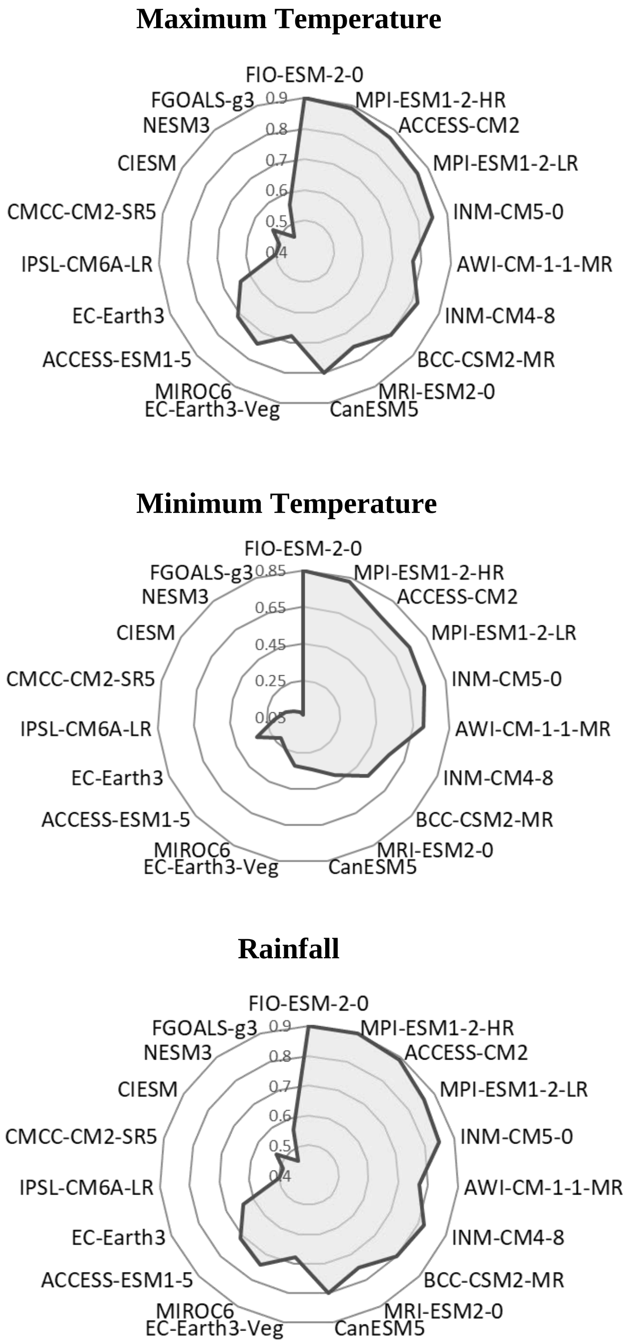


Fig.2 KGE statistical performance results of CMIP6 GCMs in replicating historical annual Tmax, Tmin and rainfall during 1990-2014.

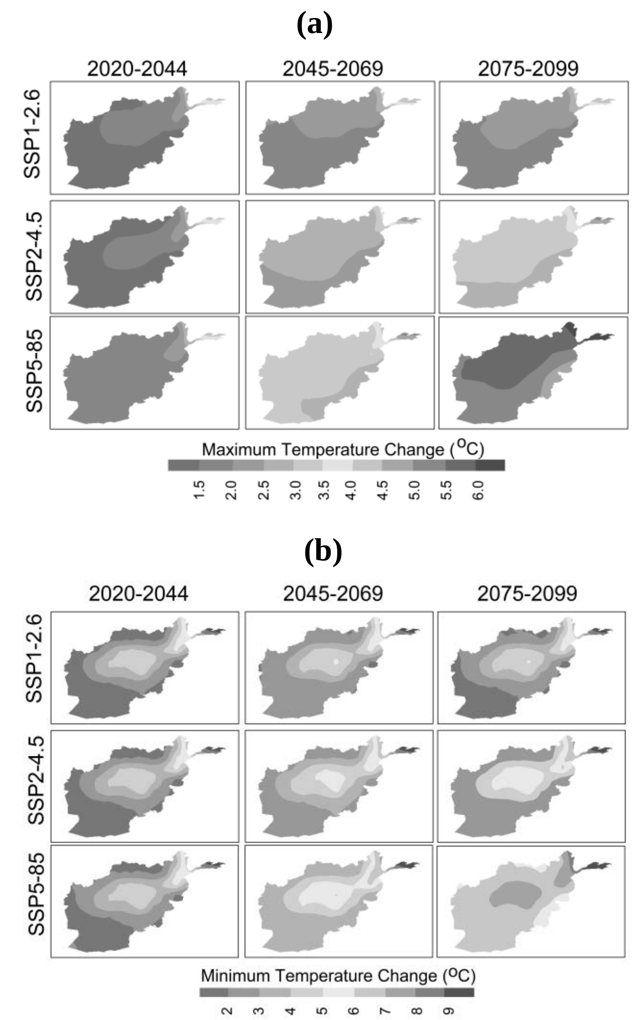
The spatial distribution of bais in Tmax, Tmin and Rainfall in high ranked models are less specially in dry areas (south and southeast regions) compare to other models

(2) Future projections of climate

A multi-model mean ensemble (MME) was formed from the three models with highest KGE. Using the MME, the change in rainfall and temperatures were calculated and presented spatially for three futures (near future 2020-2044, mid future 2045-2067 and far future 2075-2099). compared to the base period (1990 - 2014) for the SSP1-2.6, SSP2-4.5 and SSP5-8.5 emission scenarios.

It is projected that for both Tmax (figure.3a) and Tmin (figure.3b) 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 (figure.3c) was projected to have a positive in the range of (2 to 30 %) and the maximum changes is projected to the southwest of Afghanistan.



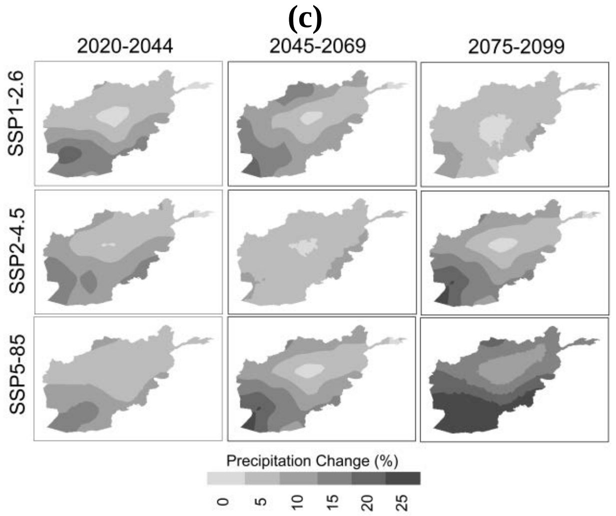


Fig.2 Spatial patterns of change in (a) Tmax (°C), (b) Tmax (°C) and (c) Rainfall (%) over Afghanistan estimated using the MME of CMIP6 for three futures in low (SSP1-2.6), medium (SSP2-4.5) and high (SSP5-8.5) projection scenarios.

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 SSP scenarios.

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