PROJECTION OF SPATIOTEMPORAL CHANGES IN PRECIPITATION OF AFGHANISTAN FOR DEFFERENT SHARED SOCIOECONOMIC PATHWAYS SCENARIOS

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DEDICATION

This dissertation dedicated to my parents who have always been an incredible source of support and encouragement through my entire study life, and my beloved wife who eased this journey to be happened with her genuine love and encouragement. And to my brother and sisters whom I am proudly grateful for having them in my life. Also this work is dedicated to all my friends and each individual who contributed towards my Master Study. Rahimi couldn't have been a success without your genuine support and prayers.

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ABSTRACT

The spatially inhomogeneous changes in precipitation due to global warming emphasizes the need for assessment of precipitation changes at regional scales. Such assessment is particularly important for Afghanistan where a majority of the population is engaged in agriculture and thus, assessment of the impacts of climate change on precipitation characteristics is paramount for sustainable development of the country. With the release of new global climate model (GCM) simulations for recently conceptualized shared socioeconomic pathways (SSP) scenarios, it is become important to evaluate the changes the precipitation for new scenarios for streamlining the existing policies derived based on earlier scenarios. In this study, six GCMs for Coupled Model Intercomparison Projects Phase 6 (CMIP6) are used for projection of spatiotemporal changes in precipitation of Afghanistan for five SSP scenarios, ssp119, ssp125, ssp245, ssp370 and ssp585. The climate change factor was estimated to assess the changes in precipitation for two future periods, near (2020–2059) and far (2060–2099) future at a spatial resolution of 1.0°. The results revealed a large heterogeneity in changes in annual and seasonal precipitation of Afghanistan. Large variability in precipitation projections using different GCMs was also noticed. The multi-model ensemble (MME) mean projection of precipitation revealed increase in annual precipitation in the northeast and decrease in the southwest, which indicates wet region will be wetter while the dry region will be drier. However, the precipitation was projected to increase almost the entire country for higher temperature rise scenarios. Overall, winter temperature was projected to decrease more, up to -30% in the southwest while an increase in summer precipitation in the southwest. Changes in annual precipitation were projected to decrease with time. The highest decrease was projected by nearly -20% for ssp585 in the far future and the highest increase in the northwest nearly by 20%, also in the far future.

ABSTRAK

Perubahan curahan hujan secara tidak homogen akibat pemanasan global menekankan bahawa perlunya penilaian mengenai perubahan curahan pada skala serantau. Penilaian ini sangat penting terutamanya bagi Afghanistan di mana majoriti penduduk terlibat dalam aktiviti pertanian, lantas, penilaian mengenai kesan perubahan iklim terhadap ciri-ciri curahan hujan adalah amat penting untuk pembangunan negara yang lestari. Dengan adanya keluaran simulasi model iklim global (GCM) yang baru untuk senario laluan sosioekonomi bersama (SSP), adalah penting untuk menilai perubahan curahan hujan untuk senario baru bagi menyelaraskan dasar yang ada yang diturunkan berdasarkan senario sebelumnya. Dalam kajian ini, enam GCM untuk Projek Antara-Perbandingan Model Gandingan Fasa 6 (CMIP6) digunakan di dalam unjuran perubahan spatiotemporal terhadap curahan hujan di Afghanistan untuk lima senario SSP iaitu, ssp119, ssp125, ssp245, ssp370 dan ssp585. Faktor perubahan iklim dianggarkan untuk menilai perubahan curah hujan untuk dua tempoh masa hadapan, iaitu masa hadapan jangka pendek (2020-2020) dan jangka panjang (2060-2099) dengan resolusi spasial 1.0°. Hasilnya menunjukkan ketidakseragaman yang besar dalam perubahan hujan tahunan dan bermusim di Afghanistan. Variasi yang besar di dalam unjuran curahan menggunakan GCM yang berbeza juga telah dikenalpasti. Purata unjuran curahan model kumpulan berganda (MME) mendedahkan berlakunya peningkatan curahan hujan tahunan di timur laut manakala penurunan di barat daya, yang menunjukkan kawasan basah akan bertambah basah sementara kawasan kering akan bertambah kering. Bagaimanapun, curahan hujan diunjurkan untuk meningkat bagi seluruh kawasan negara bagi senario suhu yang semakin tinggi. Secara keseluruhan, suhu pada musim sejuk diunjurkan berlakunya penurunan yang lebih, sehingga -30% di barat daya manakala peningkatan curahan hujan sewaktu musim panas juga di kawasan barat daya. Perubahan pada curahan hujan tahunan telah diunjurkan akan berlakunya penurunan seiring dengan masa. Penurunan yang paling tinggi diunjurkan hampir -20% untuk ssp585 pada masa hadapan jangka panjang dan peningkatan yang paling tinggi iaitu hampir 20% di timur laut, juga untuk masa hadapan jangka panjang.

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LIST OF ABBREVIATIONS

CMIP	-	Coupled Model Intercomparison Projection
SSP	-	Shared Socioeconomic Pathways
RCP	-	Representative Concentration Pathways
CCF	-	Climate Change Factor
MME	-	Multy Model Ensemble
GPCC	-	Global Precipitation Climatology Centre
CRU	-	Climate Research Unit
PDF	-	Probability Distribution Function
PET	-	Potential Evapotranspiration
RPs	-	Return Periods
SPEI	-	Standardized Precipitation Evapotranspiration Index
UTM	-	Universiti Teknologi Malaysia

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CHAPTER 1

INTRODUCTION

1.1 Overview

Warming atmosphere due to anthropogenic emissions is altering rainfall and temperature at different scales in various regions both globally (Alexander *et al.*, 2006) and regionally (Sheikh *et al.*, 2015; Klein Tank *et al.*, 2006; Shrestha *et al.*, 2017; Purnadurga et al., 2018; Tong et al. 2019). Changing climate modified the frequency, severity, spatial extent, length, and timing of precipitation (Pour et al., 2018; Ahmed et al., 2019). Physical systems and social and economic sectors have been harshly influenced by varying degrees to these changes. Therefore, changes in precipitation have received considerable interest across the globe for planning mitigation of climate change impacts (Nashwan and Shahid 2019; Ahmed et al., 2018).

The changes in precipitation have been analysed at a global, regional, and national scale (Shiru et al., 2019; Alamgir et al., 2019; Salman et al., 2017). The studies reported a large divergence in the trends of precipitation in different parts of the world (Sa'adi et al., 2017; Khan et al., 2019). The impacts of the changing precipitation have also found to affect differently in different regions. The countries with high population density, less adaptation capability, vulnerable ecology and more ignorant population will be affected more by the changes in precipitation (Shahid et al., 2016; Shiru et al., 2019).

Afghanistan is one of the most vulnerable countries of the world to climate change (Atef et al., 2019; Qureshi, 2020). The 2017 Global Adaptation Index ranked Afghanistan as the 11th most vulnerable country worldwide to climate change (Chen et al., 2015; Sediqi et al., 2019). The fragile arid environment, frequent natural hazards, high population density, and agriculture-based feeble economy along with other factors have made the country highly vulnerable to climate change (Akhundzadah et al., 2020; Mehrad, 2020). In the past 60 years, the temperature of

Afghanistan has increased by nearly 2°C, which is likely to continue in the future. The warming of climate caused a declination of rainfall by 30% since 1960 (Akhundzadah et al., 2020). Changes in precipitation caused more frequent and severe droughts in the country in recent years (Qutbudin et al., 2019). The country experienced one of the most prolonged recorded droughts in the world during 1998–2002. During the 40 years of conflicts, many water infrastructures were demolished all over the country which made the water sector of the country highly vulnerable to climate change (Mahmoodi, 2008; Mack et al., 2013; Iqbal et al., 2018). A country where a significant part of the population is engaged in agriculture, assessment of the impacts of climate change on precipitation characteristics is paramount for sustainable agricultural development (Přivara and Přivarová, 2019; Frotan et al., 2020).

Studies also reported an increase in floods in Afghanistan due to the temperature rise (Frotan et al., 2020; Azizi and Asaoka, 2020). For example, Frotan et al. (2020) evaluated the impacts of climate change on surface water resources of Afghanistan's northern river basin. They reported that discharge from this basin is 12% higher than in the late 20th century, even though annual precipitation has decreased. This is mainly due to an increase in snowmelt volume, and the main source of inputs in this basin has shifted to snowmelt due to climate change. Quantification of the changes in precipitation is important to understand possible changes in water availability, different kinds of hydrological hazards, and hydro-environment of a region. Evaluation of such changes is highly important for Afghanistan for developing planning and climate change risk reduction (Figure 1.1).

Despite the enormous importance of climate change projections of Afghanistan for adaptation planning and economic development, only a few studies have been conducted in the country. Aich et al. (2017) projected climate of Afghanistan from reanalysis and coordinated regional climate downscaling experiment (CORDEX)-South Asia simulations for two Coupled Model Intercomparison Projects Phase 5 (CMIP5) scenarios, RCP4.5 and RCP8.5. They reported that despite the high uncertainty with regard to precipitation projections, it is apparent that the increasing evapotranspiration is likely to exacerbate Afghanistan's already existing water stress. Sidiqi et al. (2018) projected climate of Kabul River basin of Afghanistan using Global climate models (GCMs) of CMIP5 for two RCP scenarios (RCP 4.5 and RCP 8.5). They reported that the mean annual temperature in the basin to increase by 1.8°C, 3.5°C and 4.8°C by the 2020s, 2050s and 2080s respectively. The mean annual precipitation is projected to increase whereas monthly precipitation is expected to increase and decrease according to the months for the whole river basin, under both scenarios, by 2100. Azizi and Asaoka (2020) projected climate of northeast Afghanistan using CMIP5 GCMs and RCP scenarios for the assessment of the impact of climate change on snow distribution and river flows in a snow-dominated mountainous watershed in the western Hindukush–Himalaya, Afghanistan. They reported alteration of high-altitude stream sources in the Hindukush Mountains and reduce the amount of water reaching downstream areas.

Figure 1.1 People fled from hilly villages after they had lost their owned livestock and farmland for hydrological hazards. (Adopted from BBC-News)

GCMs, primarily used for studying spatial and temporal changes in future climate on a global scale employs mathematical equations derived from physical principles to simulate atmospheric circulation and global climate. A large number of GCMs has been developed by different climate groups. The GCMs are continuously upgraded to improve their reliability and spatial resolution by adopting new physical processes and consistent data. Intergovernmental Panel on Climate Change (IPCC) coordinates the updates through Coupled Model Intercomparison Projects (CMIP). The CMIP6 is the upcoming version consists of state-of-the-art GCMs with a broader range of experiments to provide a wider variety of scientific questions (O'Neill et al., 2016). CMIP6 also differs from earlier phases in terms of new future scenarios known as shared socioeconomic pathways (SSPs) which were derived based on different socioeconomic assumptions (Cannon, 2020; Wu et al., 2019; Tian and Dong, 2020; Xin et al., 2020).

The objective of the present study is to use CMIP6 GCMs for the projections of spatiotemporal changes in precipitation in Afghanistan for different SSP scenarios to understand the possible least changes in rainfall and its variability due to the rise of global temperature. Six CMIP6 models released so far which have projections for five SSP scenarios, ssp119, ssp125, ssp245, ssp370 and ssp585.were used. The ssp119 and ssp126 are considered the maximum rise of global mean temperature by 1.5 and 2.0°C at the end of the century or mild temperature rise scenarios. The ssp245 is considered as moderate temperature rise scenarios while ssp370 and ssp585 are considered as high-temperature rise scenarios. The GCMs were re-gridded to a common resolution to provide information on spatiotemporal changes in precipitation for future periods. The results presented in the article have the potential to be used for adaptation planning for building a climate-resilient society in Afghanistan.

The report is organized as follows. A short description of the climate of Afghanistan and the data used in the present study are given in the next section. The methods used for spatiotemporal changes in precipitation of Afghanistan are given next. The results obtained including the spatial variability of precipitation and distribution of precipitation for two future periods, 2020-2059 and 2060-2099 compared to the base period 1971-2010 are presented next. Finally, conclusions made from the study area provided.

1.2 Problem Statement

Afghanistan is frequently ranked among the countries most vulnerable to climate change due to a combination of low adaptive capacity and high exposure to climate fluctuations. Over the past four decades, armed conflict has destroyed the country's infrastructure, damaged its institutions, and led to widespread poverty and underdevelopment, which collectively underpin Afghanistan's vulnerability and lack of adaptive capacity to climate change (Figure 1.2).

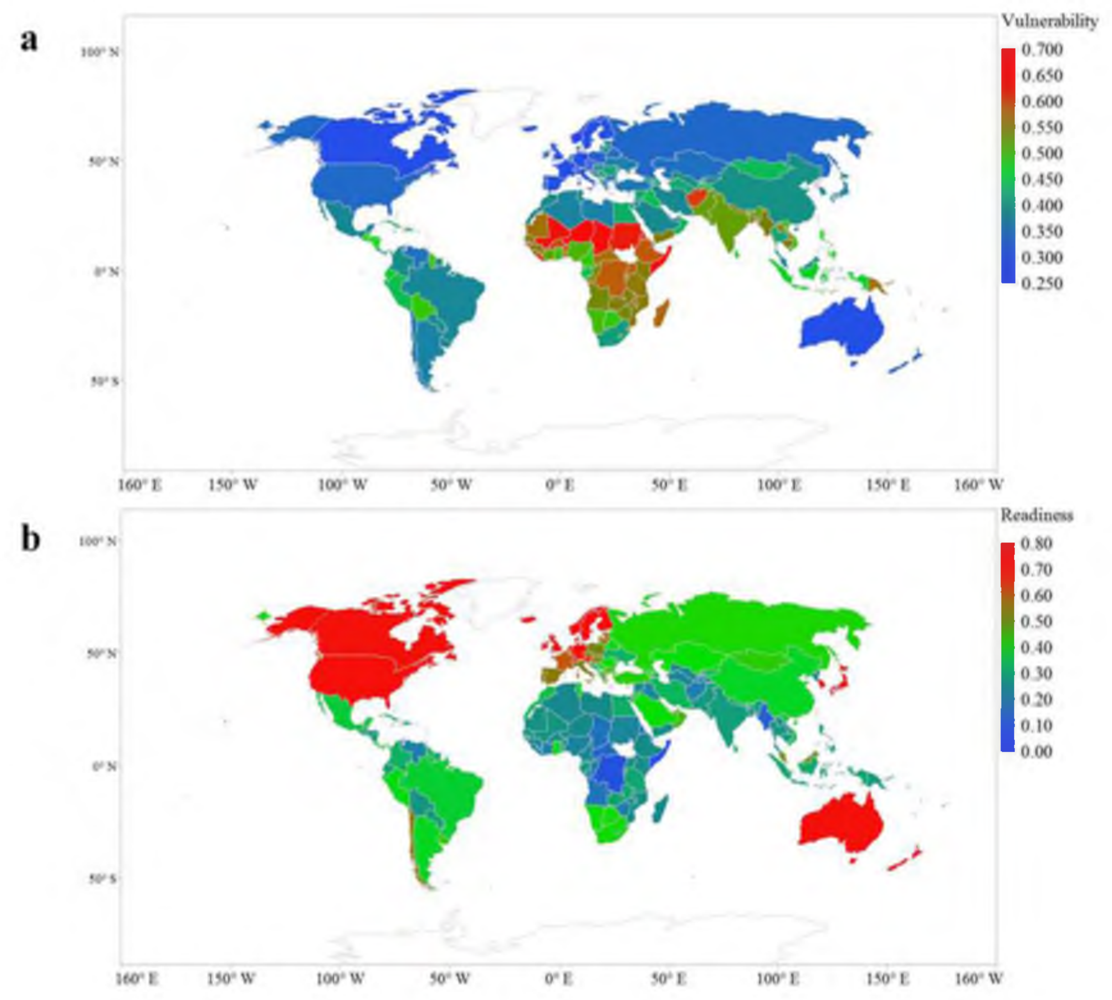

Figure 1.2 showing geographical mean of vulnerability and adaptation readiness indicators of climate change. (a) Vulnerability [mean range: 0.25–0.70]; (b) readiness [mean range: 0.00–0.80] (Adopted from: Sarkodie and Strezov, 2019)

The population and the economy are almost completely dependent on agricultural production, particularly subsistence farming and key sectors, including water, energy, agriculture, are among the most vulnerable to climate change. The country is regularly hit by extreme weather or climatic events, causing substantial economic damage and loss of lives, showing that even today Afghanistan is not sufficiently adapted to the current climate (Figure 1.3).

Figure 1.3 localized floods caused by heavy rainfall, increased in mountainous and hilly area in north and dry and bare plateau in south (Adopted from https://www.wfp.org/)

Afghanistan being a semi-arid to arid area is prone to droughts and prolonged droughts are commonly occurring in the country. The country receives an insufficient precipitation of between 200 – 400 mm per annum (Reddy and Saranya, 2017) indicating the significance of natural resource management and requirement of adaptation and mitigation measures against climate change. The changing climate in the country will significantly affect most rural communities where water, soil, forests, and grazing areas are very essential factors (Atef et al., 2019)(Figure 1.4). The climate change impacts on water resources have been reported in Afghanistan e.g. impaction of the glacier and snowmelts feeding the Kabul River which has caused an increase in a trend; shifting the river basins seasonal monsoons (Atef et al., 2019).

Figure 1.4 water shortages worsen in rural areas as precipitation pattern altered (Adopted from http://blogs.wsj.com/)

According to United Nation (2018) report the worst drought in recent history, that hit two out of three provinces in Afghanistan, has destabilized the lives of tens of thousands of civilians, some of whom have already been displaced, United Nation reported. The United Nation has predicted that over two million people are expected to become severely food insecure in the coming period in Afghanistan. Among the most vulnerable are women and children (Figure 1.5).

Climate of Afghanistan is changing in the line of global climate change. However, there are very limited study on climate change in Afghanistan, the studies in nearby countries revealed changes in precipitation and rises in temperature in the region. Changes in mean and variability of climate significantly changes the probability of extremes. Therefore, it can be clearly anticipated that global warming induced climate change will cause an increase in hydro-climatic extremes in Afghanistan and make aggravate the existing condition.

Figure 1.5 Destabilized people due recent drought in Afghanistan (http://www.xinhuanet.com/).

It is anticipated that the changes in climate have changed the characteristics of precipitation in Afghanistan. However, due to high diversity of climate and various patterns of the changes in climate in different regions and seasons, the impact of climate change would have a different impact on precipitation patterns in different parts of the country. Therefore, the release of global climate model (GCM) projections for new scenarios namely, shared socioeconomic pathways (SSPs) emphasizes the need of re-evaluation of climate change projections and the spatially inhomogeneous changes in precipitation due to global warming emphasizes the need for assessment of spatiotemporal changes in precipitation. Besides, there is a large uncertainty in precipitation projections which is require to quantify for better decision making to streamline the existing adaptation measures.

1.3 Research Goal

1.3.1 Research Objectives

The general objective of the study is to use couple model intercomparison project phase 6 (CMIP6) GCMs for the projections of spatiotemporal changes in precipitation in Afghanistan for different shared socioeconomic pathway (SSP) scenarios.

(a) To re-grid the GCM precipitation simulations into a common resolution of $1.0° \times 1.0°$ using bilinear interpolation method.

(b) To generate the multi-model ensemble mean (MME) precipitation time series by averaging the simulations of different GCMs.

(c) To estimate the climate change factor (CCF) as the difference between the historical simulation and future projections of GCMs.

(d) To use the climate change factor to compute the changes in ensemble mean precipitation for the future periods.

1.3.2 Scope of the study

The scope of the study are outlined below:

(a) The study mainly focuses on the development of a statistical modelling for the assessment of precipitation projection in data scarce arid regions of the world under climate change scenarios. The projection developed in the present study for the modelling of annual and seasonal precipitation is verified through its application within the geographical boundary of Afghanistan.

(b) CMIP6 GCMs are recently being used for studying future climate change scenarios. Numbers of GCMs are available in CMIP6 suits, nevertheless six GCMs including CanESM3, EC-Earth3-Veg, GFDL-ESM4, IPSL-CM6A-LR, MIROC6 and MRI-ESM2-0 are employed in the present study for the generation of climate change scenarios.

(c) Various linear and non-linear methods have been proposed for downscaling precipitation. In the present study, two robust state of art data mining models, namely, random forest (RF) and support vector machine (SVM) models have been used to downscale the output of GCMs and project precipitation.

1.3.3 Significant of the study

Afghanistan presents a number of specific challenges in terms of climate change assessment. Precipitation projections for Afghanistan require significant refinement due to the lack of availability of reliable historic meteorological records. Complex topography in Afghanistan also means that local variations in response to global warming, particularly precipitation, are likely to be large and many areas may vary from the regional trends. It is expected that the assessment of the impacts of climate change on precipitation characteristics is paramount for sustainable agricultural development and viable for hydrological disaster mitigation. The couple model intercomparison project phase 6 (CMIP6) GCMs for the projections of spatiotemporal changes in precipitation in Afghanistan for different shared socioeconomic pathway (SSP) scenarios developed in this study can be used to assist decision makers to streamline the existing adaptation measures.

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