Chapter 50
Assessing Future Water Availability Under a Changing Climate in Kabul Basin

Masoud Ghulami, Philippe Gourbesville, and Philippe Audra

Abstract Climate change affects the patterns of precipitation and evapotranspiration and therefore can affect the future water availability and its spatial and temporal distribution. Climate change is also likely to intensify the global hydrological cycle, which can increase the risk of floods and droughts. This study focuses on Kabul basin which lies in the northeast quarter of Afghanistan. It accounts for thirty-five percent of the population's water supply, and has the fastest population growth rate in the country. The main objective of this study is to assess the impacts of climate change on water resources. The climate projections are regionally available at finer resolution. Here in this study the future precipitation data were obtained from the selected models available from the Coordinated Regional Downscaling Experiment (CORDEX) program of the South Asian domain. The APHRODITE precipitation and temperature datasets were also used as observations in the lack of in situ measurements for the data-scarce Kabul basin. The SWAT hydrological model was then developed to understand hydrologic response of the Kabul basin and future projections of water availability under future climate scenarios. The median of the results from all used RCMs suggests an increasing trend in maximum and minimum temperature in the future, as compared to the baseline while the projections for precipitation mainly show a decreasing trend under both RCPs. Based on the results of hydrological modeling, the future runoff would likely increase due to the increased snowmelt in the study area. However lack of infrastructures might lead to further problems due to the possibility of more frequent and extreme floods and droughts.

Keywords Hydrological modeling · Future projections · CORDEX South Asia · Uncertainty

M. Ghulami (✉) · P. Gourbesville · P. Audra
Polytech'Lab, University of Côte d'Azur, 930 route des Colles,
06903 Sophia-Antipolis, France
e-mail: masoud.ghulami@unice.fr

50.1 Introduction

Afghanistan is a semi-arid and mountainous country which faced three decades of conflict. It is one of the most vulnerable countries in the world to climate change as it has very limited capacity to address the impacts of climate change. It has been also considered as a data-scarce region both temporally and spatially with limited capability to measure hydro-meteorological parameters with in situ gauges. The current study focuses on Kabul basin which is surrounded by mountains located in the eastern and central part of the country. The Afghan capital is located in this basin and the main river here is called the Kabul River, which is the most important (although not the largest) river in Afghanistan. Much of the discharge of the Kabul River results from the melting snow accumulating during the winter season in the mountains. However, winter rains, which are common in late winter and early spring, falling on a ripe snow pack in the highlands can greatly augment the flow of the main streams [6].

For hydrological applications, it is essential to quantify precipitation. The availability of satellite-based precipitation products and gridded interpolated datasets provides a great opportunity for those regions suffering from poor spatial and temporal sampling of precipitation. Ghulami et al. [3] tested the estimates from four precipitation products and showed a relatively good detection of precipitation distribution and precipitation amounts for most cases. Their results of continuous and categorical verification statistics suggested that the APHRODITE dataset performed better than other gridded datasets tested for the study basin.

Understanding the impacts of climate variability/changes on different sectors (such as hydropower, irrigation and agriculture, water supply, and sanitation) may lead to more flexible development plans to adapt to these changes and mitigate their impacts. It is an important step which needs to be investigated. Thus, for a country like Afghanistan, in which a majority of its population is engaged in agricultural activities, a lack of understanding about climate change impacts is a very significant problem and needs to be addressed. Therefore, the current study is done to analyze the hydrological response of the Kabul basin and the impacts of climate change on its water resources using the regional scale climate projections of precipitation and temperature.

50.2 Methods

50.2.1 Study Area

The Kabul River includes all Afghan rivers that join the Indus River in Pakistan. The Indus empties into the Arabian Sea of the Indian Ocean. The Kabul basin covers twelve percent of the national territory of Afghanistan, but alone it drains one-fourth

(twenty six percent) of the total annual water flow of the country. As per the information obtained from the Afghanistan Central Statistics Organization (CSO), provinces in the Kabul basin account for thirty five percent of the nation's population, and this region has the fastest population growth rate in the country.

In this study, the Kabul basin has been divided into four main subbasins, which are shown in Fig. 50.1. The total area of the basin is almost 69,269 km^2 and the main subbasins and outlets are described in Table 50.1. Figure 50.2 shows the long-term average of precipitation and temperature values for the basin.
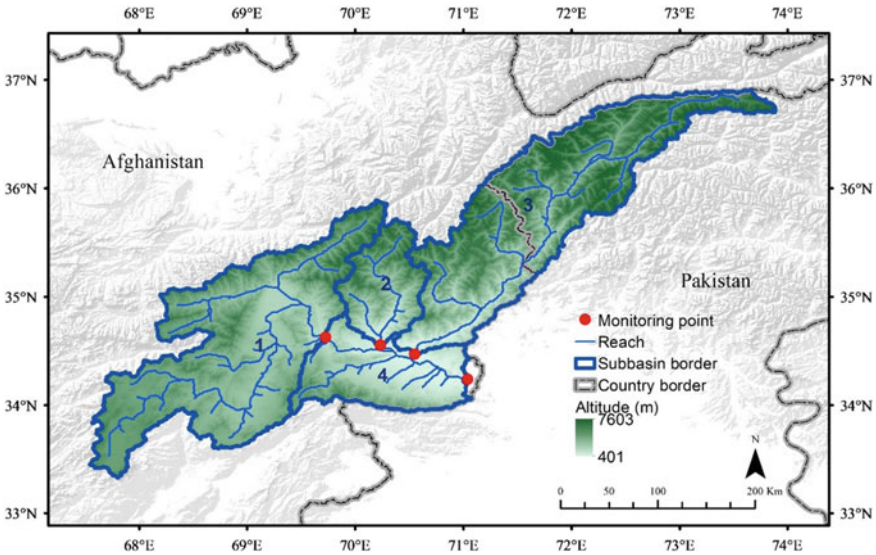

**Fig. 50.1** Location map of Kabul basin, Afghanistan

Table 50.1 Kabul river subbasin characteristics

Subbasin ID from Fig. 50.1	Outlet name	Subbasin area (km^2)	Elevation (m)			Drainage area (km^2)
			Mean	Min	Max	
1	Naghlu	27,838	2,791	978	5,718	27,838
2	Pul-i-Qarghai	6,206	2,820	646	5,420	6,206
3	Pul-i-Kama	25,913	3,433	553	7,603	25,913
4	Dakah	9,312	1,591	401	4,697	69,269

50.2.2 Data Availability

While Afghanistan's meteorological stations were established during the 1950s, once the conflict started, data recording stopped almost everywhere. Data collection activities gradually restarted after 2003. In the lack of long-term surface observations, here in this study, APHRODITE MA (Asian Precipitation Highly Resolved Observational Data Integration Towards Evaluation of water resources, Monsoon Asia (V1101)) was used. APHRODITE MA is an interpolated dataset from rain gauge locations. Depending on availability, between 5,000 and 12,000 rain gauge locations are considered for interpolation. These daily data cover a period of more than 50 years (1951–2007) with a spatial resolution of 0.25°. The interpolation algorithm incorporates orographic correction of precipitation [8].

For this study, a Multi-RCMs approach was used to identify the uncertainty in a climate change model for predictions of future precipitation and temperature for the Kabul basin (Table 50.2).
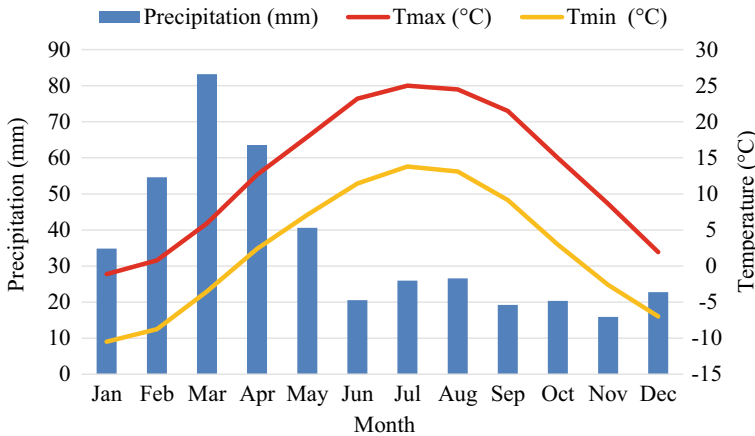
Fig. 50.2 Long-term monthly precipitation and temperature in Kabul basin

Table 50.2 List of CORDEX-RCMs used in this study

ID	RCM	Driving GCMs	Resolution	Contributing institute/country
1	CSIRO-QCCCE	CSIRO-Mk3-6-0	0.5° × 0.5°	SMHI/Australia
2	ICHEC	EC-EARTH	0.5° × 0.5°	SMHI/Sweden
3	MIROC	MIROC5	0.5° × 0.5°	SMHI/Japan
4	MPI-M	MPI-ESM-LR	0.5° × 0.5°	MPI/Germany
5	MPI-M	MPI-ESM-LR	0.5° × 0.5°	SMHI/Germany
6	NCC	NorESM1-M	0.5° × 0.5°	SMHI/Norway
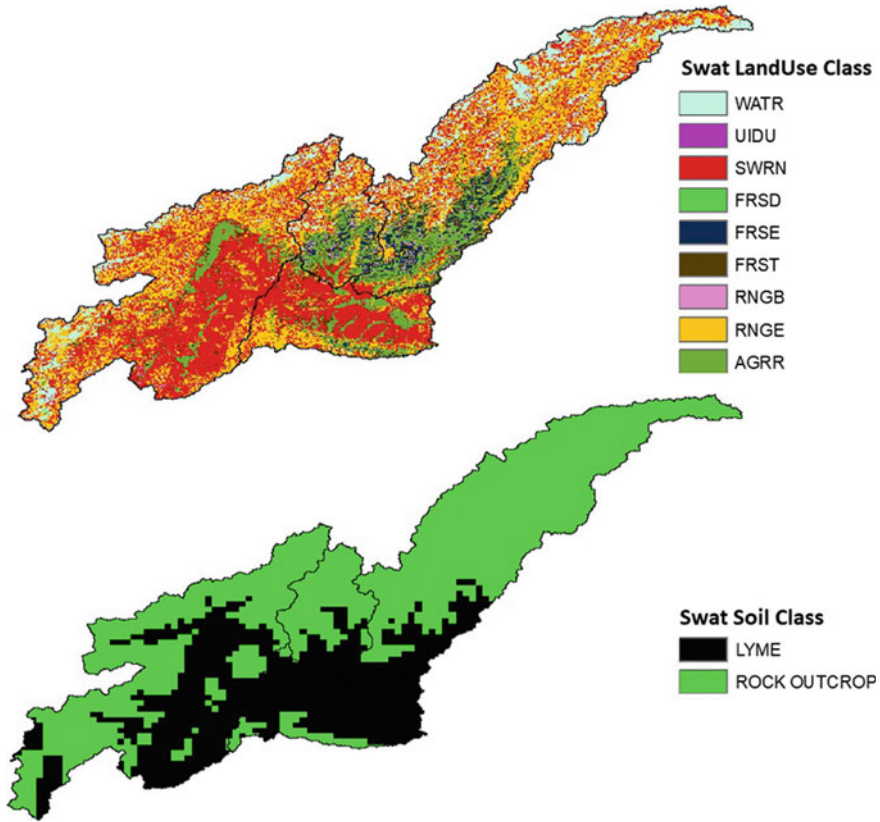
Fig. 50.3 Landuse and soil map of Kabul basin

The landscape features (Fig. 50.3) for hydrological modeling were also obtained from different sources:

– DEM

The 90-m resolution Digital Elevation Model (DEM) was downloaded from the CGIAR-CSI website: http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp. Based on this map, the highest elevation of the Kabul basin is 7603 masl and the lowest is 401 masl.

– Soil

The Harmonized World Soil Database (HWSD), combined with the USDA soil map, was used to specify the soil types of the basin.

– Land use

The Globcover 2009 Map of the European Space Agency (ESA) was applied to specify the different land use and land cover types. For the glacier extent of the basin, the map provided by International Centre for Integrated Mountain Development (ICIMOD) was used.

Table 50.3 Summary of the methods and parameters used by SWAT

Process	Method	Number of parameters
Interception	Water balance	1
Potential evapotranspiration	Monteith (1965), Priestley and Taylor (1972), Hargreaves and Samani (1985)	
Actual evaporation	Richtie (1972)	2
Runoff	SCS-CN (Mockus 1972; Green and Ampt 1911)	5
Infiltration	Water balance	
Inter/return flow	Kinematic model	2
Base flow	Linear reservoir model	5
Percolation to groundwater	Water balance	
River flow routing	Variable storage/Muskingum	3
Snow melting	Degree-day factor method	4
	Total	22

50.2.3 SWAT Hydrological Model

The Soil and Water Assessment Tool (SWAT) is a processed-based, semi-distributed watershed scale simulation model developed initially for the large-scale watersheds [1]. It considers the Hydrological Response Units (HRUs) as model entities. This is done by overlaying the land use, soil and slope layers and finding their unique combinations. The potential evapotranspiration is calculated by Penman-Monteith and runoff estimated with curve number method. A summary of the methods used and parameters required to simulate processes of the water component of SWAT model is shown in Table 50.3 [2].

50.2.4 Downscaling of Climate Data

The delta change approach is a method to downscale global/regional climate model data so that this data may be used as an input for hydrological models and even flood risk assessment for the future. Climate model outputs have inadequacies and a common approach to deal with that issue is the delta change method. This method computes differences between current and future GCM/RCM simulations and adds these changes to the observed time series. The delta change method is the primary future scenario generation technique suggested for use in the U.S. National Assessment. The constraint of this approach is that it is not suitable for non-normal distributions or for analyzing extreme events [7]. Applying the delta change method assumes that GCMs/RCMs more reliably simulate relative changes rather than absolute values [4].

50.3 Results

50.3.1 Future Projections of Precipitation and Temperature

The RCMs' values were compared with their baseline observations (1986–2005) for each month and the changes were calculated for the whole Kabul basin. Figure 50.4 shows the median of all 6 downscaled RCMs. The results suggest an increasing trend in maximum and minimum temperature in the future, as compared to the baseline. The increases for maximum temperature range from +1.05 °C to +3.13 °C under RCP 4.5 and +0.85 °C to +5.83 °C under RCP 8.5. The increases for minimum temperature range from +0.63 °C to +2.94 °C under RCP 4.5 and +0.63 °C to + 5.23 °C under RCP 8.5. The projections for precipitation suggest a decreasing trend in the winter precipitation under both RCPs 4.5 and 8.5 while the summer precipitation in most cases are on the increase.
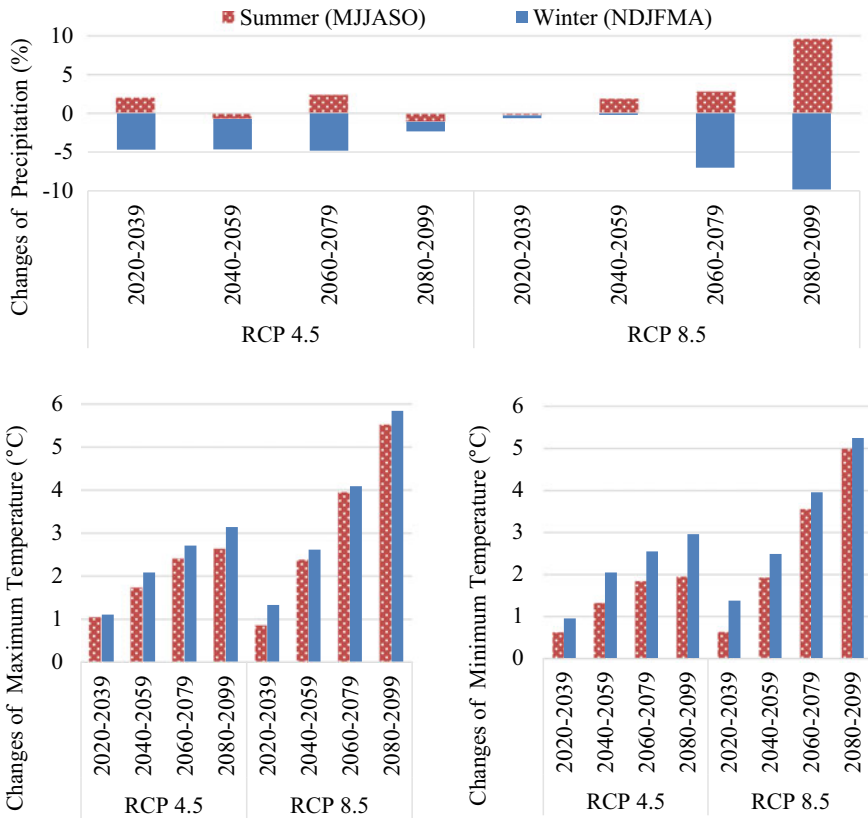
Fig. 50.4 Median of seasonal changes from all downscaled RCMs' data, compared to the baseline

Table 50.4 List of calibration parameters for SWAT model used in this study

Parameter name	Fitted value	Min	Max
TIMP.bsn	0.27	0.23	0.74
SMTMP.bsn	7.38	4.81	8.43
SFTMP.bsn	1.16	−1.07	1.64
CN2.mgt	75.59	74.51	76.84
HRU_SLP.hru	1.12	0.63	1.41
OV_N.hru	0.10	−0.02	0.33
SLSUBBSN.hru	2.47	1.90	3.69
ALPHA_BF.gw	8.70	3.47	9.81
GW_DELAY.gw	50.73	41.97	51.90
SOL_AWC(1).sol	0.20	0.09	0.28
ESCO.hru	0.83	0.64	0.91
SURLAG.bsn	17.02	10.06	20.18
SOL_K(1).sol	1.15	1.12	2.37
GWQMN.gw	2.82	1.85	3.28
PLAPS.sub1	492	−1	498
PLAPS.sub2	−247	−264	79
PLAPS.sub3	−112	−265	78
PLAPS.sub4	11	−170	110

50.3.2 Calibration and Validation of the SWAT Hydrological Model

The input data for the calibration and simulation periods were selected based on the availability of data from 1969–1977. The model has a number of calibration parameters that have to be adapted during the model application. The list of the selected calibration parameters is provided in Table 50.4.

The results of monthly simulations for the calibration period (1969–1977) periods, along with the model's efficiencies, are shown in Fig. 50.5. The red and blue lines represent simulated and observed streamflow discharges, respectively. The results are shown only for the main outlet of the basin at Dakah station. The monthly mean precipitation (blue bars) is given in upper panel. During the calibration period, the model is able to reproduce overall hydrological responses fairly well, on the basis of results given in the graphical and statistical evaluations.
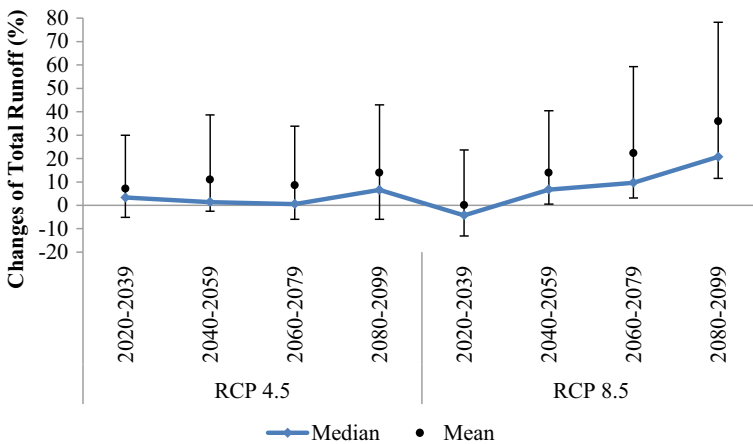
50.3.3 Future Changes of Water Availability

The simulations' results of future runoff were compared with the results of the models for the baseline period of 1986 to 2005. Figure 50.6 shows future runoff for each future time period compared to the baseline under different RCP scenarios based
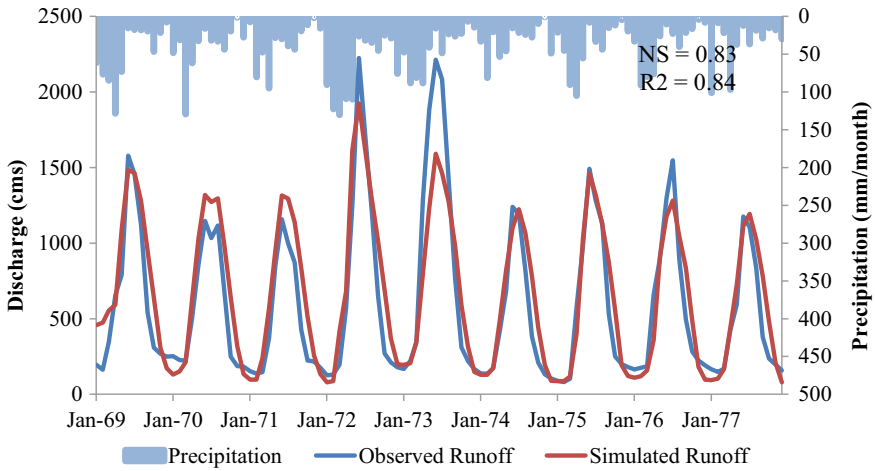
Fig. 50.5 Observed and simulated runoff

Fig. 50.6 Uncertainty in future predicted runoff based on 6 RCMs under RCPs 4.5 and 8.5

on all used RCMs. Overall, the results suggest that future runoffs are very likely to increase. This is mainly due to the increase in temperature which in turn causes an increase in snowmelt. Iqbal et al. [5] studied the impact of climate change on flood frequency and intensity in the Kabul River basin and suggested that the future floods would increase due to an increasing precipitation and higher temperatures, based on most of the climate models, which they used.
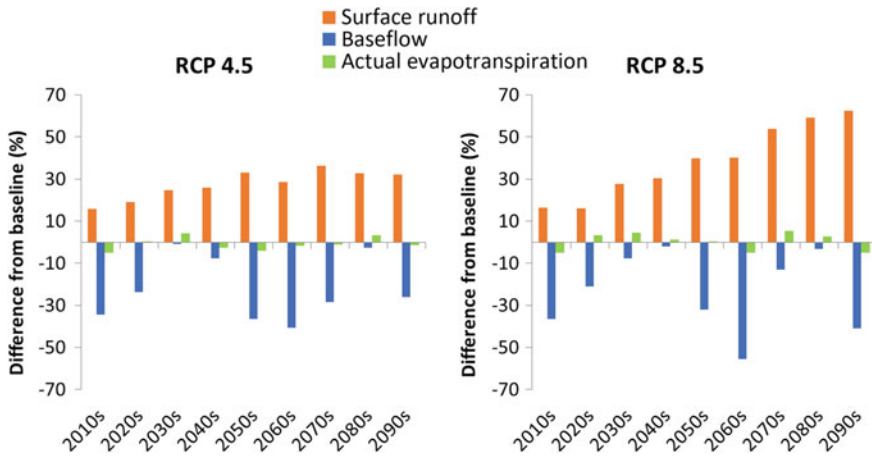
Fig. 50.7 Monthly distribution of future runoff under RCPs 4.5 and 8.5

The predictions for future runoff range between −6% to +43% over the 21st century under RCP 4.5 while these changes are predicted to be within −13% to + 78% under RCP 8.5 for the same period. However, the median values show much lesser range and vary between −4% to +21%.

Figure 50.7 shows the changes in predicted surface runoff and baseflow for the future as well as actual evapotranspiration in the Kabul basin, as compared to the baseline period. The trend shows that though future runoff is increasing, this increase is mainly happening in surface runoff while the baseflow might actually decrease.

50.4 Conclusions

Climate change affects the patterns of temperature and precipitation. As a result, other variables, such as water availability and its spatial and temporal distributions also get affected. The median of the results from all 6 RCMs used in this study, suggests an increasing trend in maximum and minimum temperature in the future, as compared to the baseline. The projections for precipitation suggest a decreasing trend in the winter precipitation while the summer precipitation in most cases are on the increase.

The results of SWAT hydrological model during the calibration period suggest that the model performed well and can be used to reproduce the hydrological response of the basin. As per the predictions, future runoff ranges between −4% and +21%. This increase is mainly due to the increase in temperature and thus the snowmelt.

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