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Modelling Rainfall-Runoff Process of Kabul River Basin in Afghanistan Using ArcSWAT Model

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Abstract: Kabul River Basin is the most populated and an important source of water resources in Afghanistan. The Soil and Water Assessment Tool (SWAT) model, together with the ArcGIS and SWAT-CUP, is employed to predict the runoff in the basin. Nine years of meteorological and hydrological data are employed in the study. The DEM, the soil cover, and the land use/cover data are downloaded from the available global database. The ArcGIS based soil classification, the land use/cover, the elevation, the drainage, and the slope distribution maps of the basin are generated. The meteorological data from 18 different stations and the hydrological data from 7 different stations are obtained from the Ministry of Energy and Water of Afghanistan. The basin is divided into 48 sub-basins with a total number of 770 hydrological response units (HRUs). The sensitivity analysis results revealed that the flow characteristics of KRB are highly influenced by the groundwater and snowmelt. The model is calibrated using the data from 2010 to 2014 and validated employing the data from 2015 to 2017 at seven different hydrological stations. The SWAT-CUP is successfully used to calibrate the model for predicting monthly and daily runoffs. The calibrations and validations for the seven stations are achieved, on the average, with the correlation coefficient (R) of 0.78 (for daily flows) and 0.82 (for monthly flows), respectively. Total water yield in the basin is estimated to be 432.9 mm/year, corresponding to 31 176 Mm^3/year, hardly meeting the demand of 26 512 Mm^3/year in the basin.
Keywords: Rainfall-Runoff modeling; SWAT model; SWAT-CUP; Kabul River Basin; Water Yield.

1. Introduction

Kabul River Basin covers the second largest area, possesses substantial water resources and inhabits dense population in Afghanistan. Hence, the planning and management of water resources in this basin becomes a crucial task. The climate change effects in recent decades has caused sudden floods and prolonged droughts hindering the water resources availability. In order to make a sound understanding of the water resources in the basin, the runoff potential study of the basin is carried out using the SWAT model.

The SWAT model has been employed by many researchers for prediction of water yield. Binger et al. [1] utilized it in Goodwin Creek Basin in Mississippi to look at the impacts of basin subdivision on simulated runoff. Peterson and Hamlett [2] used the SWAT model for simulation of base flow in Ariel Creek Basin in Pennsylvania with a catchment area of 39.4 km^2. They suggested that the model can adequately handle the estimation of flow rate on a monthly and yearly basis. Manguerra and Engel [3] focused on the key parameterization issues of runoff prediction using the SWAT model, concentrating on how to enhance model performance without restoring time-consuming and arbitrary parameter calibration. Liew et al. [4] utilized the SWAT model to assess runoff in Little Washita River Experimental Watershed in Oklahoma under changeable climatic conditions. They suggested that the model can provide a suitable simulation for hydrological studies linked to the effects of climate changes on water budget and water availability. Tripathi et al. [5] applied the SWAT model together with generated rainfall data to analyze runoff in a small agrarian catchment in India. Garbrech et al. [6] used the SWAT model to simulate monthly runoff reaction to rainfall predictions in a small basin located in central Oklahoma. The results of that study concluded that the preceding hydrological conditions and precipitation forecasts make a wide range of runoff responses. Rostamian et al. [7] applied the SWAT model for runoff modeling in two different watersheds, Beheshtabad and Vakan, in central Iran covering areas of 3860 km^2 and 3198 km^2, respectively. The SWAT model was used for a selected portion of River Drina Basin in Europe with an area of 20000 km^2 in order to calculate cumulative runoff [8]. That study suggested that the SWAT model is particularly suitable during rainy and dry seasons and that it can be used positively for rainfall-runoff transformation in yearly and multi-year simulations. Vu et al. [9] computed runoff in Dak Bla River Watershed in Vietnam with the help of five high-resolution rainfall gridded datasets using the SWAT model. According to the study, the SWAT model can be used properly for gridded data set to simulate runoff in the regions where reliable observation data are not available. Shivhare et al. [10] implemented the SWAT model in Tapi sub-basin (Burhanpur Watershed) in India to evaluate surface runoff. The SWAT model with daily meteorological input data was run for a time period of four years (1992 to 1996) and the output result was examined at a monthly time step. The study, conducted by Worku et al. [11], studied the effect of land use /land cover change on the runoff in Beressa Watershed in Ethiopia by applying the SWAT model. Available data from 1980-1999 and 2000-2014 were used in the calibration and validation by SWAT-CUP software. That research concluded that the change in land use/land cover can have an important impact on the runoff yield. Another study ([12]) utilized the SWAT model for the agriculture river basin (Berkeri Shah River Basin) in Madhya Pradesh, India. Accessible 12 years of monthly and daily hydrological data (1995-2008) with one year of the warm-up period were provided to the model. The entire basin was divided into 11 main sub-basins. The SWAT-CUP with the SUPI-2 algorithm was used to calibrate and validate the model. The study concluded that the accuracy of the SWAT model is highly dependent on the high resolution gridded precipitation data or more accurate measured meteorological data. Duru et al. [13] applied the SWAT model in Ankara River Basin in Turkey to predict streamflow. Accessible 13 years of streamflow data both on a daily and monthly basis were used for the calibration and validation purposes. Rohtash et al. [14] conducted a study using SWAT for the analysis of the rainfall-runoff modeling processes of the Chaliyr River Basin at Kuniyil, India, covering an area of 2013 km^2. The entire watershed was divided into 15 sub-basins, and 103 hydrological response units were created through watershed delineation. The SWAT-CUP was used to calibrate the model. Jimeno-Saez et al. [15] applied the Artificial Neural Network (ANN) and SWAT models for estimating daily streamflow in two watersheds located in Peninsular Spain with contrasting climatic conditions of Atlantic and Mediterranean. The results of that study show that the SWAT has a better performance in estimating very low values of streamflow. Ashish et al. [16] conducted a study in an ungauged watershed Rupen located in Gujrat, India to evaluate the rainfall-runoff tendencies. Remote sensing data and GIS together with the SWAT model were applied to create a proper rainfall-runoff model of the study area. The model was run for a time period of 17 years including 14 years of warm-up period and the runoff of each sub-basin was predicted on a monthly and annual basis. The study concluded that the SWAT model is a useful tool to evaluate discharge and runoff and other hydrological components in the ungauged river basin of semi-arid regions.

There have been recently few studies applying the SWAT model for assessing the runoff in some portions of Kabul River Basin. Bromand [17] applied the SWAT model with local and global meteorological data to estimate water availability and sectoral water demand for Kabul River Basin. He carried out the calibration on a monthly basis using the data from 2008 to 2012 only at three different hydrological stations (Dakah, Nawabad, and Shukhi). Since the KRB covers a large area, there is a need to estimate the runoff at more stations for more realistic predictions. Ayoubi and Kang [18] performed a study in Panjshir sub-basin located in Kabul River Basin. They applied the SWAT model with two types of local land cover data (1993 and 2010) to investigate the impact of land-use changes on the surface runoff. The SWAT-CUP software was used to calibrate the daily data from 2010 to 2012 and to validate the data from 2012 to 2013 in a single upstream station (Shukhi Station). According to [18], the urbanization, barren land growth, deforestation, and snowmelt were the largest contributors to surface runoff. Only a single sub-basin is considered in [18] who calculated the short-term daily runoff. Ayoubi and Dongshik [19] utilized the SWAT model in Ghurband and Panjshir sub-basins located in Kabul River Basin with local and global weather data to simulate streamflow and to estimate water balance in these sub-basins for freshwaters and irrigations. The SWAT-CUP was used to calibrate the available data from 2010 to 2012 and to validate one year of data from 2012 to 2013 on a monthly scale at three different hydrological stations (Omerz Station, Pul-Ashwa Station, and Shukhi Station). The local land cover data for 2010 and global soil data were used in the model. In [19], the weather data from the global and local stations were used and the model was calibrated and validated with limited data only for some stations located in the upstream part of the basin. Aawar and Khare [20] implemented the SWAT model to the sub-basin of the Kabul River Basin in order to predict future streamflow and climate change impact on the runoff. Available monthly runoff data for a time period of 7 years (2003 to 2010) were used for the calibration and from 2010 to 2018 were used for the validation processes. The result of that study indicates that streamflow can be significantly affected by the changes in climate variability, soil type, and land use/land cover. In [20], a small part of the Kabul River Basin is considered, the runoff is estimated only for one station (Istalif Station), and the model was calibrated and validated only on a monthly basis.

In general, previous studies applied the models with short periods of data and/or with gridded weather data in some sub-basins of Kabul River Basin. They mostly calibrated and/or validated the models with the data measured at just one, two, or three stations on a monthly or daily basis. There are, on the other hand, about 31 meteorological and hydrological stations in Kabul River Basin. This study employed the long term (2009-2017) local weather data at 18 main local meteorological stations distributed all over the whole Kabul River Basin. The model was calibrated and validated using the runoff data measured at seven different hydrological stations located both in the upstream and downstream parts of the basin.

This study focuses on the rainfall-runoff modeling in Kabul River Basin using the ArcGIS based SWAT model. The main purposes of the present study are: (1) to determine the most sensitive parameters that affect the catchment flow, (2) to estimate the monthly and daily flows of the basin from the available meteorological data, and (3) to determine the total amount of surface runoff and water yield in the basin.

2. Kabul River Basin

Afghanistan is one of the non-coastal countries with a total area of around 652 000 km^2 located in South Central Asia (Figure 1). It is a rugged land with an average elevation of 1100 m above mean sea level (msl) varying from 150 m to 8000 m. One-quarter of the country 's land lies 2500 m above msl. About three-quarters of the country's land is covered by mountains and hills, while wetlands and river valleys are located in the north and south. Mostly desert areas of the country are located in the south-eastern part.

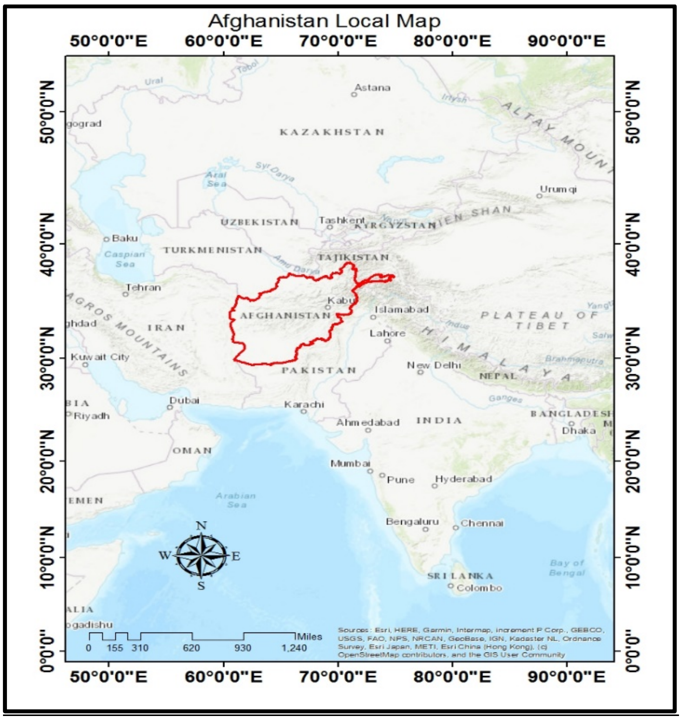

Figure 1. Map of Afghanistan

Hindu Kush and Himalayan-Pamir mountains divide the country from west to east. The southern part of the country is covered by the mountains of Suleiman and Karakoram, which are the main source of water, and farming [21]. Based on the geographical characteristics of Afghanistan, the country is divided into five major river basins as Hilmand, Harirod-Murghab, Northern, Panj Amo and Kabul (Figure 2).

Hilmand River, with a total length of 1300 km and storage capacity of 6.5 billion cubic meters, originates from the central area of Hindu Kush Mountains next to the headwaters of Kabul River [22].

Helmand River water is usually supplied from Upper Helmand Region and it is exposed to heavy snowstorms in the winter. Hari Rod River is another main source of water covering a drainage area of 40 000 km^2. The river runs westward from the main source located 250 km to the west of Kabul. Northern River Basin with a total catchment area of 75 000 km^2 is another major source of water. It originates from Hindu Kush mountains and moves in the northward until joining with Amu Darya River which is one of the largest rivers in Central Asia, covering a drainage area of approximately 309 000 km^2 with a storage capacity of 24 billion cubic meters. The total length of the river is approximately 2540 km rationing the water between Afghanistan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan.

Kabul River Basin (KRB) is located between latitudes 33° N and 37° N, and longitudes 67° E and 74° E (Figure 3). It originates from the central upland at an average elevation of 6000 m above msl and extends to the eastern valley at an average elevation of 400 m above msl. The KRB, with a total length of 700 km, of which 560 km is in Afganistan, and a catchment area of 72000 km^2 emanates from the central part of Hindu Kush Mountains located approximately 100 km in the west of Kabul [22]. The storage capacity of the KRB is estimated to be 22 billion cubic meters. The river flows from the eastern direction toward Kabul and finally to Pakistan joining with Indus River in the east of Peshawar city. Its key river branches are Laghman Alingar, Panjsher, Logar, and Kunar rivers. The basin is divided into 7 sub-basins as Alingar, Kunar, Kabul, Shamal, Gomal, Ghorband Wa Panjsher, and Chak Wa Logar Rod (Figure 3). Of 34, 13 provinces of the country are located in the KRB and it is the fastest-growing population area inhabiting about 35% of Afghanistan's population.

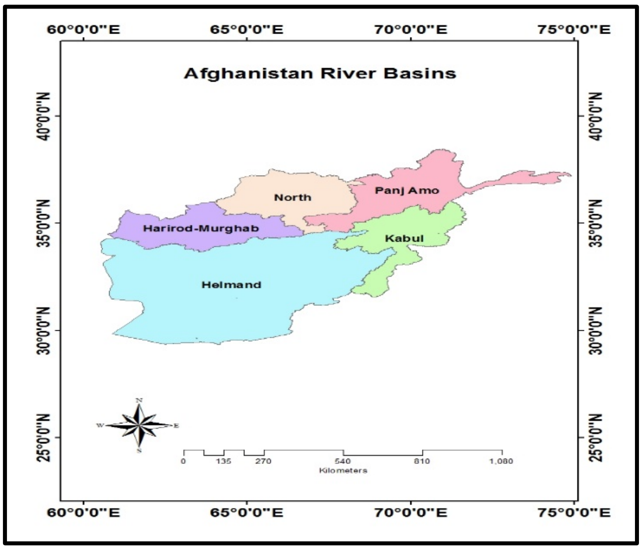

Figure 2. Afghanistan river basins

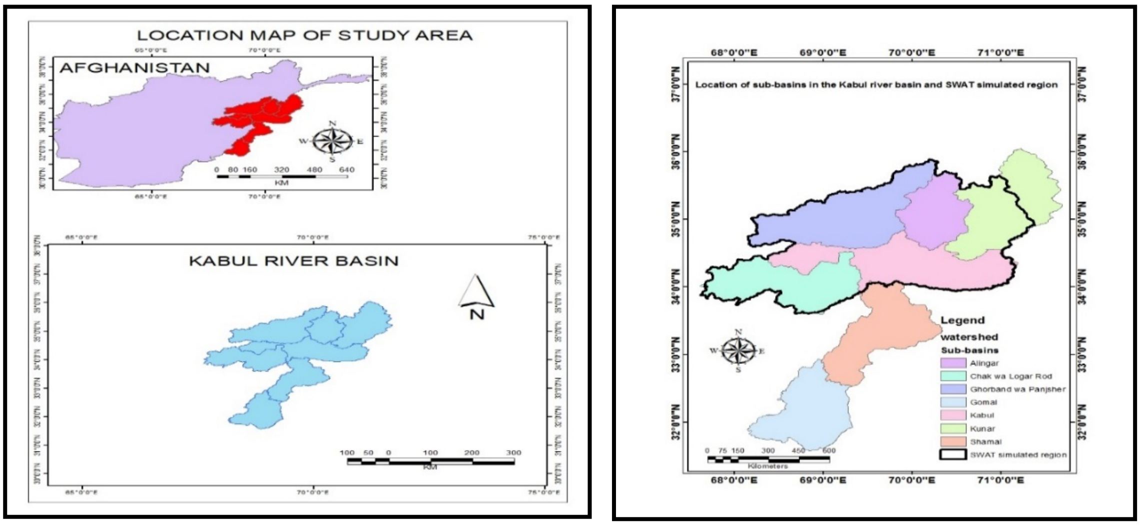

Figure 3. Kabul River Basin

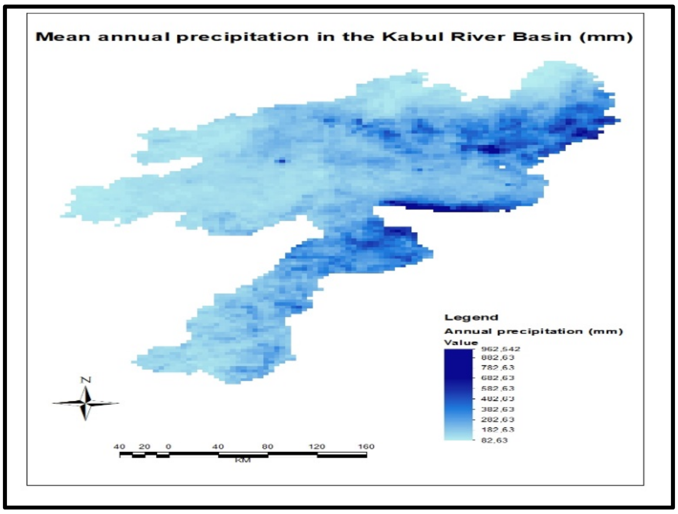

Figure 4. Mean annual precipitation in Kabul River Basin from 2010-2017

The basin is located under semi-arid and continental type climate conditions with cold winters and hot summers. The average yearly rainfall in the basin is estimated to be 530 mm (see Fig. 4), and the average yearly temperature is recorded as 9 ^oC. The maximum temperature of the basin can reach up to 48 ^oC in the downstream part of the basin in Nangarhar region. The basin provides water to around 13 million people for their critical daily needs, as well as for agricultural and power generation purposes. Some hydropower dams were developed in the basin, such as Jabul Saraj Dam, Surobi Dam, Mahipar Dam, Naghlu Dam and Darunta hydropower station [23].

3. Data

3.1 Digital Elevation Model (DEM)

The Digital Elevation Model (DEM) is an essential part of the rainfall-runoff modeling by the SWAT. The DEM describes the elevation of all points and the area between different points at a specific resolution. A DEM file could be used to represent the characteristics such as the altitude, slope length, steepness and relief ratio of streams of different basins. DEM file with a resolution of 30 m by 30 m was downloaded from the DIVA-GIS website (https:/www.diva-gis.org/gdata) for the entire country territory. The downloaded DEM file contained a number of gaps that were filled in by the ArcGIS spatial analysis tools. The projected DEM was used in the SWAT model for the purpose of watershed delineation, drainage area, flow direction, flow accumulation, stream generation along the basin, rivers, and subbasin parameters. The topography of the KRB represented by the DEM ranges from 387 m to 5718 m above msl, with an average elevation of 2480 m (see Figure 5). The northern, northwestern, and some parts of the northeastern regions of the study area have high elevation ranges, while the eastern regions have a low elevation range (Fig.5).

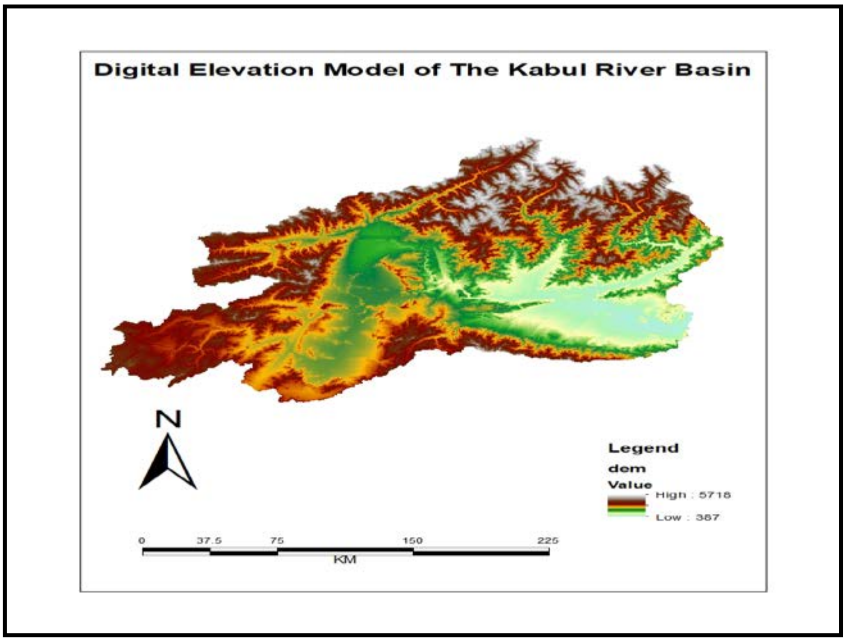

Figure 5. Digital elevation model of Kabul River Basin

3.2 Soil and Land Use/Land Cover Data (LULC)

The SWAT model database requires data on the soil types, along with their properties such as the moisture content, soil texture, conductivity, and bulk density. A digital soil map of the world in the shapefile format was downloaded from the Food and Agriculture Organization (FAO) GeoNetwork website (http://www.fao.org/geonetwork/srv/en/metadata.show%3Fid=14116) at 1:5.000.000 scale, containing 28 major soil groupings, subdivided into the second level of 153 soil units [24]. Based on the FAO soil classification map, the KRB contains six major soil groups, as presented in Figures 6.

The LULC classification map is an integral part of SWAT rainfall-runoff modeling and it is a critical factor influencing surface runoff within a watershed. LULC map could be used to classify vegetation types that affect the local hydrological processes. A digital Map of the Asia Land Cover in a GeoTIFF format provided by the United States Geological Survey Land Cover Institute (USGS-LCI) (https://archive.usgs.gov/archive/sites/landcover.usgs.gov/global_climatology.html) was used to derive the land cover classification map of the KRB. Accordingly, the KRB has thirteen different land-use classes namely, Barren or Sparsely Vegetated, Croplands, Deciduous Needle leaf Forest, Evergreen Needle leaf Forest, Grasslands, Mixed

Forests, Shrublands, Permanent Wetland, Savannas, Snow and Ice, Urban, Water, and Woody Savannas as shown in Figure 7.

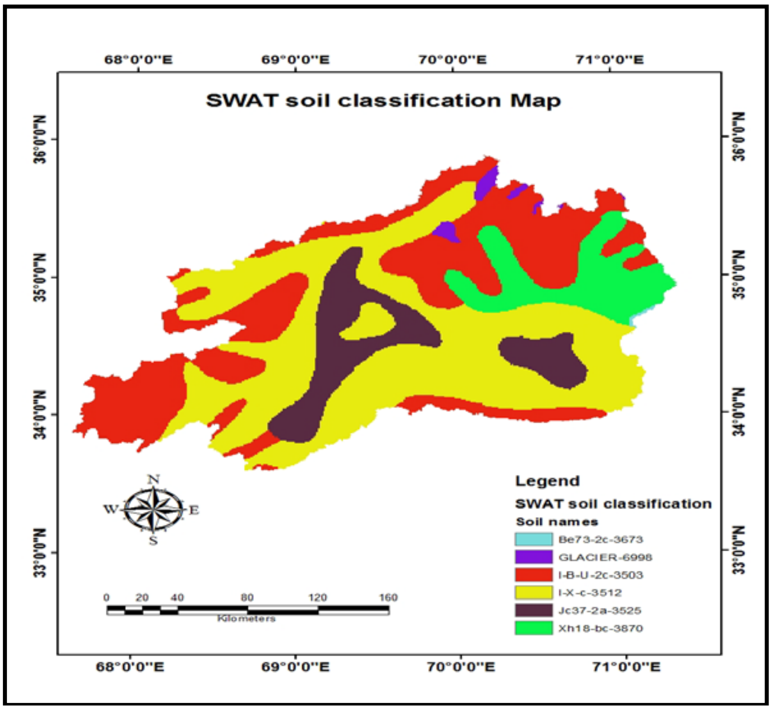

Figure 6. Soil classification map of Kabul River Basin

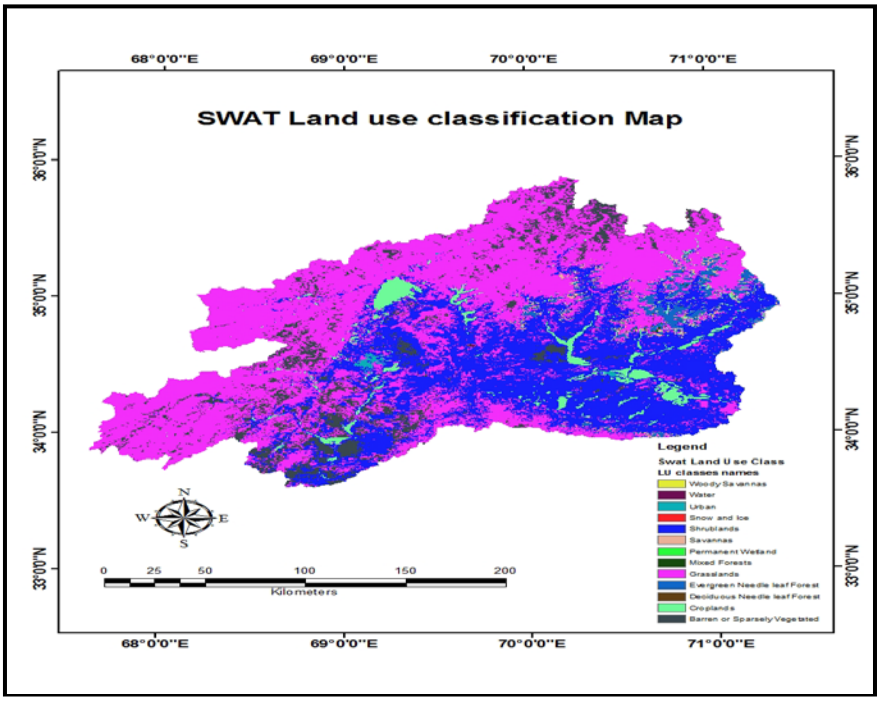

Figure 7. Land use map of Kabul River Basin

Shrublands and Grassland are the most extensive land cover in the basin, accounting for about 33% and 51% of the total basin area, respectively. Barren or Sparsely Vegetated is the third extensive land cover in the basin occupying 8.7 % of the total basin area (Figure 8).

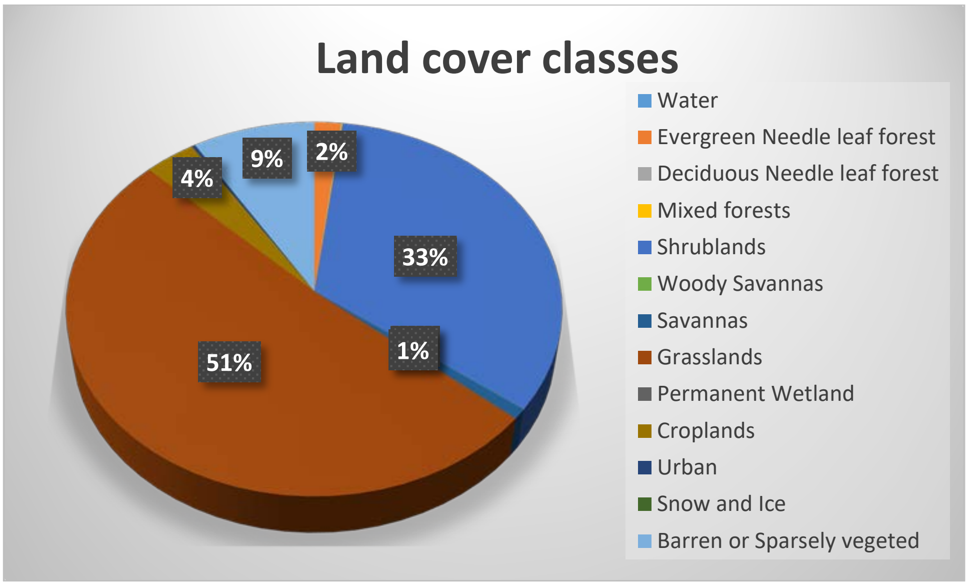

Figure 8. Land cover % of Kabul River Basin

3.3 Drainage map of the KRB

The first step in setting up a SWAT model is the delineation of the watershed. After setting up the model and defining the projected coordinate system of the DEM file for the study area (Kabul River Basin), the DEM-based flow direction and concentration process is performed to generate the drainage network taking into account the various outlets. For the defined sub-basins outlets, the entire basin is divided into 48 different sub-basins. Figure 9 shows the drainage map of the study area in which SWAT considers different outlets for each sub-basin. The seven hydrological stations are also shown in Figure 9.

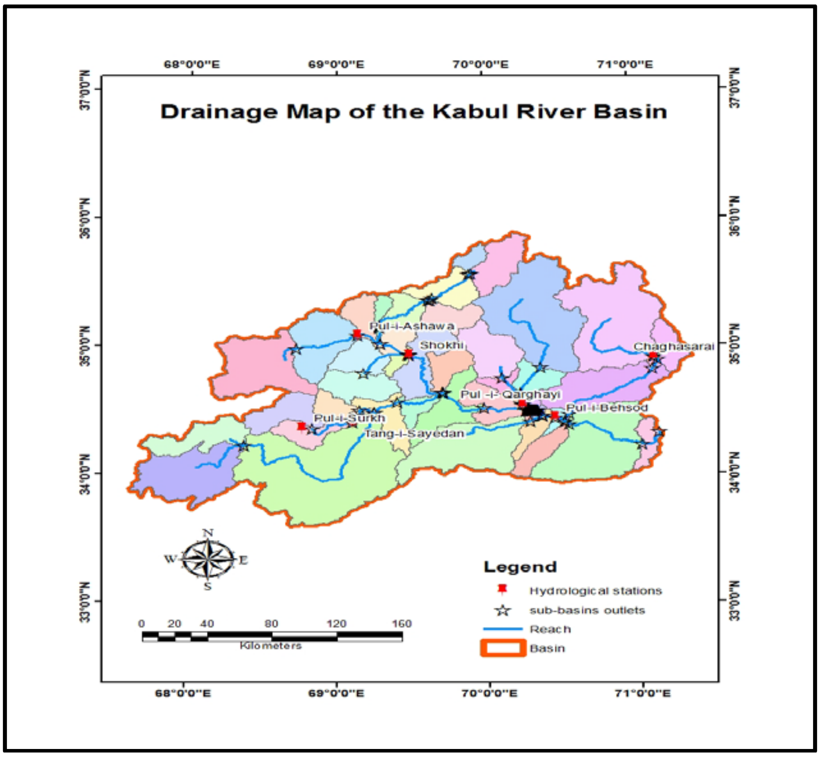

Figure 9. Drainage map of Kabul River Basin and locations of seven hydrological basins

3.4 Hydrologic Response Unit (HRU) analysis

The hydrological response units (HRUs) are defined as parts of a subbasin that contains unique land use, soil, and management attributes. The SWAT model divides the basin area into sub-basins and each sub-basin into several HRUs. The model calculates variables like runoff individually for each HRU and then combines them to assess the overall loading from the sub-basin.

Dividing the basin into regions of unique land use, soil, and slope combinations allow us to examine differences in evapotranspiration and other hydrological conditions at different land covers, soils, and slopes. For the HRU analysis process, the SWAT model requires land use, soil, and slope as input parameters. Land use and soil maps of the study area are fed into the model and it is reclassified for the defined soil and land cover classes. In the slope theme, three different slope classes under the multiple slope option are selected for the entire basin, ranging from 0 - 15%, 15% - 30%, 30% - 45% and 45% - 99% as shown in Figure 10. After successfully reclassifying and overlying the land use, soil, and slope datasets, the model created 770 HRUs with a unique combination of land use, soil and slope with an overlap of 99.98 % basin boundaries.

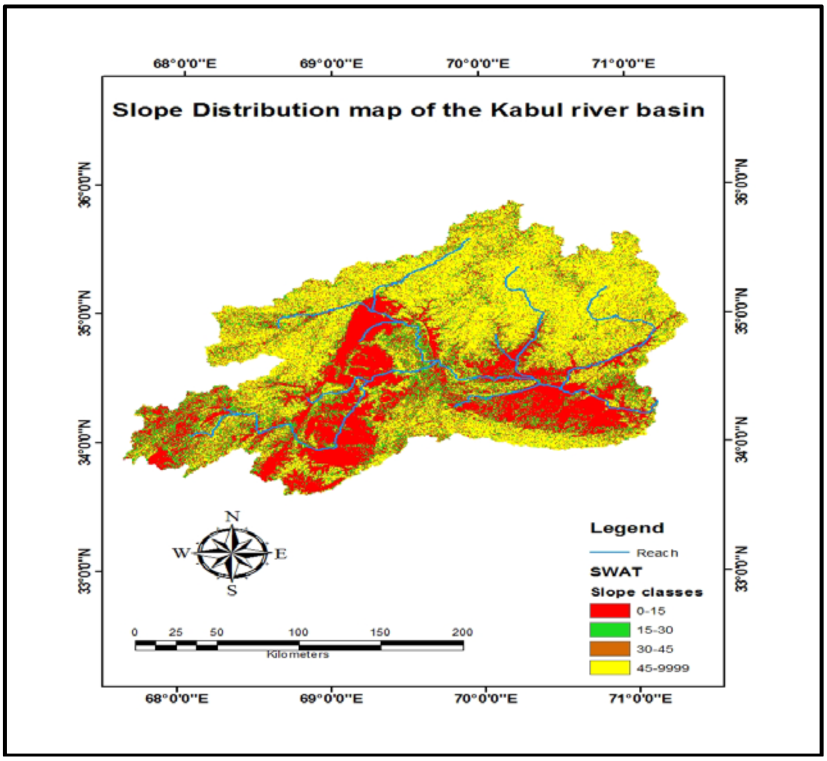

Figure 10. Slope distribution map of Kabul River Basin

3.5 Meteorological and hydrological data

In this study, 18 weather stations were selected for the study area (Table1). The daily and monthly meteorological (rainfall, maximum and minimum temperature) and hydrological data were obtained from the Ministry of Energy and Water of Afghanistan. Most of the stations in the KRB located in the plain area below the msl of 2480 m. Meteorological data measured at the 18 stations from 2009 to 2018 and hydrological data measured at 7 stations (see Table 1) from 2010 to 2017 were used in the present study. Table 1 and Figure 11 show the locations of meteorological and hydrological stations and the drainage areas of the stations in the study area. As seen in Table 1, Dakah has larger drainage area of 67 370 km^2 while Qala-i-Malek has smaller drainage area of 69 km^2.

Table 2 presents the summary of precipitation and runoff statistics. The maximum precipitation is observed at Bagh-i-Lala station with 233 mm while the minimum is observed at Keraman, Khawak, Omarz, and Qala-i-Malek with 0.001 mm. Maximum runoff, on the other hand, is observed at Pul-i-Behsod with 531.3 m^3/s while the minimum runoff is observed at Tang-i-Sayedan with 0.002 m^3/s. Variation in precipitation is significant at stations Bagh-i-Omomi and Tang-i-Gulbahar while there is less variation at station Pul-i-Kama. Runoff variation is significant at stations Shokhi and Pul-i-Behsod while this variation is less at Pul-i-Surkh and Tang-i-Sayedan (see Table 2).

Table 1. Meteorological and hydrological data

	Meteorological data period 2009-2018			Hydrological data period 2010-2017	
Stations	Latitude	Longitude	Elevation (m)	Stations	Drainage Area (km^2)
Pul-i-Kama	34.46870556	70.55703056	558	-	26005
Naghlo	34.63726389	69.71703611	998	-	26046
Pul-i-Qarghayi	34.54697778	70.24248889	643	Pul-i-Qarghayi	6155
Bagh-i-Omomi	35.14879722	69.28754167	1587	-	205
Tang-i-Gulbahar	35.14879722	69.28868333	1625	-	3565
Bagh-i-Lala	35.15176111	69.22051111	1698	-	485
Pul-i-Ashawa	35.08880000	69.14188611	1624	Pul-i-Ashawa	4020
Qala-i-Malek	34.57745833	69.97010278	2211	-	69
Asmar	34.91500833	71.20171667	832	-	19960
Chaghasarai	34.90926944	71.12883611	847	Chaghasarai	3855
Dakah	34.23070556	71.03855	419	-	67370
Doabi	35.34829722	69.61877222	2059	-	789
Keraman	35.28355278	69.65692778	2232	-	110
Khawak	35.56481111	69.89494167	2405	-	369
Omarz	35.375825	69.64085278	2042	-	2240
Nawabad	34.81969167	71.12031944	796	-	23960
Payin-i-Qargha	34.55253889	69.03574444	1970	-	1970
Pul-i-Surkh	34.36684167	68.76965278	2216	Pul-i-Surkh	1305
Shokhi	34.93616667	69.48439444	1374	Shokhi	10850
Pul-i-Behsod	34.442347	70.459831	555	Pul-i-Behsod	36980
Tang-i-Sayedan	34.408975	69.10441111	1870	Tang-i-Sayedan	1625

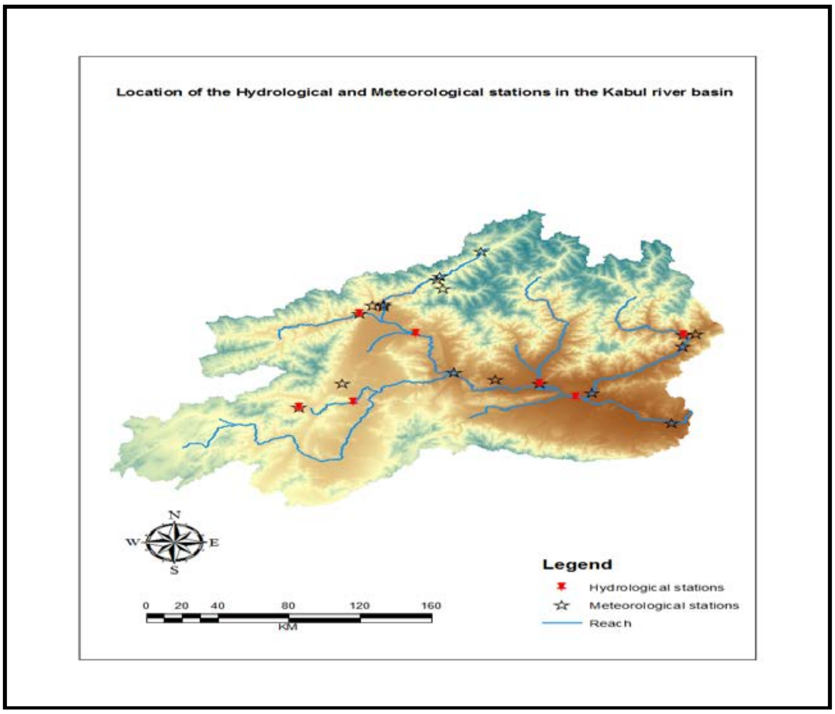

Figure 11. Meteorological and hydrological stations in Kabul River Basin

4. Models

4.1 Soil and Water Assessment Tool (SWAT) model

The SWAT, developed by the USDA-ARS, has been widely used for the prediction of water, sediment, and pesticide yields in large and complex catchments. The SWAT model divides the basin area into sub-basins and each sub-basin into several Hydrological Response Units (HRUs). The model calculates variables such as runoff and sediment individually for each HRU and combines them to assess the overall loading from the sub-basins. HRUs have been defined as parts of the subbasin that contains unique land use, soil, and management attributes [25]. The SWAT model uses the water balance equation.

$$SW_t = SW_0 + \sum_{i=1}^{t} \left(R_d - Q_s - E_a - W_{seep} - Q_g\right) \tag{1}$$

where; SW_t is the final soil water content (mm), SW_o is the initial soil water content (mm), R_d is the quantity of precipitation (mm), Q_s is the quantity of surface runoff (mm), E_a is the quantity of evapotranspiration (mm), W_{seep} is the amount of infiltrated water reaching the vadose region (mm), and Q_g is the quantity of return flow (mm).

The SWAT model uses Equations (2) and (3) to simulate surface runoff and peak runoff rates.

$$Q = \frac{(R - I)^2}{(R - I + S)} \tag{2}$$

$$q_p = \frac{CiA}{3.6} \tag{3}$$

where; Q is surface runoff volume (mm), R is the precipitation depth (mm), I is initial abstraction (mm), S is the retention parameter (mm), q_p is the peak runoff rate (m^3/sec), C is the runoff coefficient, A is the area of the basin (km^2), and *i* is the intensity of precipitation (mm).

Table 2. Precipitation and runoff statistics at gauging stations

	Rainfall Statistics (2009-2017)				Runoff Statistics (2010-2017)			
Stations	Max Rainfall (mm)	Min Rainfall (mm)	Mean Rainfall (mm)	Standard Deviation (mm)	Max runoff (m^3/s)	Min runoff (m^3/s)	Mean runoff (m^3/)	Standard Deviation (m^3/s)
Pul-i-Kama	114.4	0.003	16	20.6	-	-	-	-
Naghlo	186	0.1	24.33	30	-	-	-	-
Pul-i-Qarghayi	134	0.21	22.2	27.3	288.66	2.42	58.66	68
Bagh-i-Omomi	195.3	0.6	37.21	49	-	-	-	-
Tang-i-Gulbahar	194.5	0.0012	38	47.2	-	-	-	-
Bagh-i-Lala	233	0.002	39.20	51.8	-	-	-	-
Pul-i-Ashawa	207.7	0.003	32	41	116	3.86	23	24
Qala-i-Malek	159	0.001	31.20	33.11	-	-	-	-
Asmar	140.2	2.03	38	32.2	-	-	-	-
Chaghasarai	152.3	0.5	37.6	32.2	242	2.56	45.30	52.2
Dakah	119.5	0.002	20/76	23.3	-	-	-	-
Doabi	174	0.4	30	36.2	-	-	-	-
Keraman	167.4	0.001	29.35	33	-	-	-	-
Khawak	138	0.001	23.55	29.7	-	-	-	-
Omarz	164.4	0.001	29	35.55	-	-	-	-
Nawabad	127	1	36	31.20	-	-	-	-
Payin-i-Qargha	145.5	0.1	30.47	34.5	-	-	-	-
Pul-i-Surkh	131.5	0.117	27	29.5	30.36	0.080	4.78	5.98
Shokhi	-	-	-	-	439	24.5	101.6	106
Pul-i-Behsod	-	-	-	-	531.3	25	152	122
Tang-i-Sayedan	-	-	-	-	34.36	0.002	4.19	6.72

For simplicity in real application, the retention parameter (S) is defined by the dimensionless parameter CN (curve number), as expressed by Eq. (4):

$$S = 25.4\left(\frac{100}{CN} - 10\right) \tag{4}$$

Generally, the initial abstraction (I) is approximated as 0.2S. In this case, the general equation of the surface runoff volume can be expressed by Eq. (5):

$$Q = \frac{(R - 0.2S)^2}{(R + 0.8S)} \quad (5)$$

The surface runoff only takes place when precipitation depth (R) is greater than initial abstraction (I), (R>I). The details on SWAT can be obtained from [25].

The SWAT model is preferred since it is easily available online. It can freely and easily downloaded and be used. It is a comprehensive model which can integrate surface and subsurface processes such as rainfall-runoff, sedimentation, groundwater flow, water quality etc. and climate change [26]. It is capable of simulating such events in different spatial and temporal scales. Its main weakness is that the HRU is represented as constant (non-spatial variation). It ignores the flow and pollutants routing between HRUs. Also, wide range of data is required for the model [26]. The more details of strengths and weaknesses of the SWAT model can be obtained from [26].

4.2 SWAT-CUP

The SWAT Calibration and Uncertainty Program (SWAT-CUP) is a computer-based widely used program developed for the purpose of calibration and sensitivity analysis of the SWAT model. This program contains different methods such as the Sequential Uncertainty Fitting (SUFI2), Particle Swarm Optimization (PSO), Generalized Likelihood Uncertainty Estimation (GLUE), Parameter Solution (ParaSol) and Markov Chain Monte Carlo (MCMC) for optimization under several objective functions. More information on the SWAT-CUP can be found in [27].

5. Model application

5.1 Sensitivity analysis

A complex hydrological model can be influenced by different parameters whose values are not precisely defined. These kinds of parameters can be optimized by calibrating the model outputs, where the calibration process is mostly supported by the sensitivity analysis. This analysis makes it easier to select the important and effective parameters for the model calibration by specifying the parameters that represent the higher sensitivity of the model outputs related to the model input variation. The SWAT-CUP utilizing the SUFI2 is used in the present study for the sensitivity analysis. The ranks of the sensitive parameters are obtained according to the objective function of Nash-Sutcliffe Efficiency (NSE); the greater is the absolute value of t-state and the smaller is the P-value, the more sensitive becomes the parameter [27]. Of initially considered 22 parameters, 15 were determined as sensitive, as presented in Table 3. Among these 15, GWQMN.gw (shallow aquifer threshold water depth), SMTMP.bsn (snow melt base temperature), SFTMP (snowfall temperature), SMFMN (snow minimum melting rate), and GW_DELAY (groundwater delay) were found to be the most sensitive ones (see Table 3). The sensitivity analysis results revealed that the flow characteristics of KRB are highly influenced by the groundwater, snowmelt, sub-basins, and management practices.

5.2 Model calibration and validation

In this study, two-third of the observed runoff data with one year of the warm-up period is used for the calibration (2010-2014) and the data from 2015 to 2017 are used for the validation at the 7 stations (see Figure 9). The model is calibrated both on monthly and daily time scales by the SWAT-CUP with 300 iterations for each parameter. The error measures for the calibrations at the 7 stations are summarized in Table 4. The correlation coefficients (R) values are, on the average, around 0.81, the NSE values are, on the average, 0.64 and the RSR (the ratio of root mean square error (RMSE) and the standard deviation of observed data) values are around 0.62 indicating successful calibration.

The calibrated SWAT model is then applied to predict the runoff at the 7 stations for the period of 2015-2017 at monthly and daily basis time scales. Figures 12 and 13 present the scatter plots showing the measured versus observed runoff data at the seven stations during the validation stage at monthly time and daily time scales, respectively. As seen in Figure 12, the model made good predictions at the stations, especially for Pul-i-Ashawa, Pul-i-Qarghayi, Shokhi and Pul-i-Surkh stations. The related error measures are presented in Table 4 with high R and NSE and low RSR values.

Figure 13 presents the scatter plots of observed versus predicted daily runoff values at the 7 stations for the validation stage. The related error measures are presented in Table 4.

Table 3. Determined 20 sensitive parameters for the model calibration

Parameter Name	Parameter Name in SWAT-CUP	t-Stat	p-Value	Sensitivity rank
Treshold depth of water in the shallow aquifer required for return flow to occur (mm)	V_GWQMN.gw	-19.098	0.0000000000	1
Snow melt base temperature (°C)	V_SMTMP.bsn	7.210	0.0000000001	2
Snowfall temperature (°C)	V_SFTMP.bsn	4.494	0.0000119941	3
Minimum melt rate for snow during the year (mmH_2O/day-°C)	V_SMFMN.bsn	-4.163	0.0000471042	4
Groundwater delay (days)	V_GW_DELAY.gw	-3.168	0.0016987948	5
Temperature lapse rate (°C/Km)	V_TLAPS.sub	-3.000	0.0034288905	6
Snow pack temperature lag factor	V_TIMP.bsn	-1.952	0.0523239401	7
Threshold depth of water in the shallow aquifer for "revap" to occur (mm)	V_REVAPMN.gw	1.672	0.0956043043	8
Saturated hydraulic conductivity (mm/hr)	R_SOL_K(..).sol	1.599	0.1108312706	9
Soil evaporation compensation factor	R_ESCO.hru	-1.597	0.1111735301	10
Maximum melt rate for snow during year (mmH_2O/day-°C)	V_SMFMX.bsn	-1.496	0.1362217862	11
Surface runoff lag time	V_SURLAG.bsn	-0.701	0.4838570727	12
Available water capacity of the soil layer (mmH_2O/mmSoil)	R_SOL_AWC(..).sol	-0.657	0.5111224422	13
Baseflow alpha factor (days)	V_ALPHA_BF.gw	-0.509	0.6111016232	14
Groundwater "revap" coefficient	V_GW_REVAP.gw	-0.429	0.6681511110	15

Table 4. Calibration and Validation statistics values at Kabul River Basin

	Monthly time scale						**Daily time scale**					
	Calibration			**Validation**			**Calibration**			**Validation**		
Station	R	NSE	RSR	R	NSE	RSR	R	NSE	RSR	R	NSE	RSR
Pul-i-Ashawa	0.85	0.71	0.54	0.85	0.63	0.61	0.81	0.59	0.64	0.85	0.63	0.61
Pul-i-Behsod	0.81	0.60	0.64	0.82	0.61	0.62	0.79	0.45	0.74	0.75	0.51	0.70
Pul-i-Qarghayi	0.79	0.53	0.68	0.84	0.69	0.56	0.72	0.48	0.72	0.92	0.44	0.75
Shokhi	0.82	0.67	0.58	0.84	0.65	0.59	0.77	0.59	0.64	0.80	0.61	0.62
Pul-i-Surkh	0.79	0.60	0.63	0.92	0.81	0.43	0.71	0.47	0.73	0.69	0.40	0.77
Tang-i-Sayedan	0.84	0.66	0.58	0.80	0.63	0.61	0.82	0.57	0.51	0.79	0.55	0.50
Chaghasarai	0.81	0.65	0.59	0.81	0.48	0.72	0.77	0.60	0.63	0.80	0.43	0.76

* NSE: Nash-Sutcliffe Efficiency, RSR: it is defined as the ratio of root mean square error (RMSE) and the standard deviation of observed data, R: Correlation coefficient.

As seen in Figure 13 and Table 4, the model made good predictions of the runoff at the stations, especially at Pul-i-Ashawa and Pul-i-Qarghayi stations. The daily runoff predictions at Pul-i-Surkh stations seems poor. The reason may be there are two dams (Chak-e-Wardak and Shah-wa-Arus hydropower and irrigation dams) and large irrigational area near this station.

Figures 14 and 15 present the temporal simulations of the measured monthly runoff and measured daily runoff at seven stations, respectively at both the calibration and validation stages. Overall, the model gives satisfactory results for both calibration and validation steps. As seen in Figure 14, the model successfully simulates the observed monthly runoff at stations Pul-i-Ashawa, Pul-i-Qarghayi, Pul-i-Surkh and Tang-i-Sayedan. It captures the trend, high and low values. It underestimated the monthly runoff values especially at stations Pul-i-Behsod, Shokhi, Chaghasarai. According to Figure 15, the daily runoff simulations are good for all the stations except Shokhi and Chaghasarai stations where there is underestimation. This underestimation may be because of the post monsoon land use/cover behavior in which there is high infiltration and less soil water content or it may be related to the existence of reservoirs or dams within the basin, which are not included in the modelling due to the lack of information. Furthermore, there is a high degree of uncertainty on the withdrawal of groundwater in this intense agricultural area.

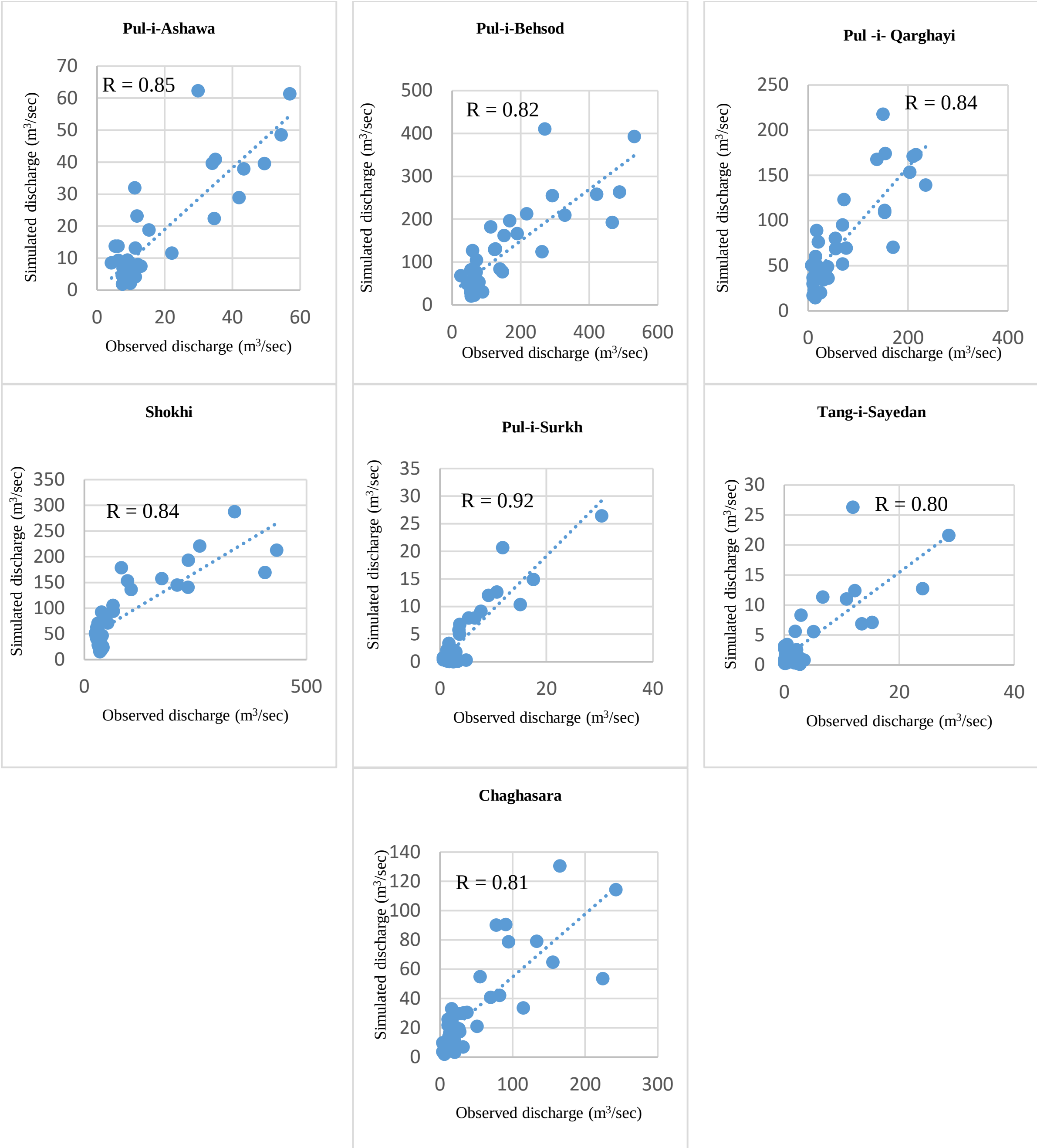

Figure 12. Comparison of measured and predicted monthly runoff (Validation stage)

The water balance components of the KRB estimated by the model indicates that the evaporation and transpiration, and the potential evapotranspiration are estimated to be 52.6 mm/year and 59.6 mm/year, respectively as shown in Table 5. The total amount of water yield which is defined as the aggregate sum of water leaving the hydrological response units and entering the principle channel from 2009 to 2017 is estimated as 432.9 mm/year (see Table 5).

The uses of water in the Kabul river basin are divided into three categories; controlled or managed water use, beneficial water use, and non-beneficial water use. The controlled water use is classified into three groups as irrigation, domestic and livestock water uses. Most of the amount of controlled water is used for the purpose of irrigation, about 7100 million m^3. In addition to controlled water use, the lands that are used for the rangeland account for the largest water usage with nearly 41% of the total water use in the basin. The estimated breakdown of various uses and the ratios to the total water consumption are shown in Table 6. Referring to Tables 5 and 6, the total water uses in the KRB is 26 512 Mm^3/year, where the model estimated water yield for the whole KRB is around 31 176 Mm^3/year and the total surface runoff estimated by the model is 16 272 Mm^3/year. As the KRB is the most populated and agriculture area, the runoff water yield in the basin may not be sufficient to meet the demand. Furthermore, the region's weather records indicate that low winter rainfall occurs at least once in every 10 to15 years in two sequential years. The last under-average years across the country were 1963-1964, 1966-1967, 1970-1972, 1999-2001. Besides, many droughts were recorded over the period from 2002 to 2011 that have had a major effect on the agriculture and livestock sector. Droughts like that of 2004 effected the cereal crops which decreased by 43%, about 3.06 million tons compared to the high cereal production yield in 2003. Considering all these adverse effects, it is clear that there is a need for the development of optimal water resources management strategies for the KRB.

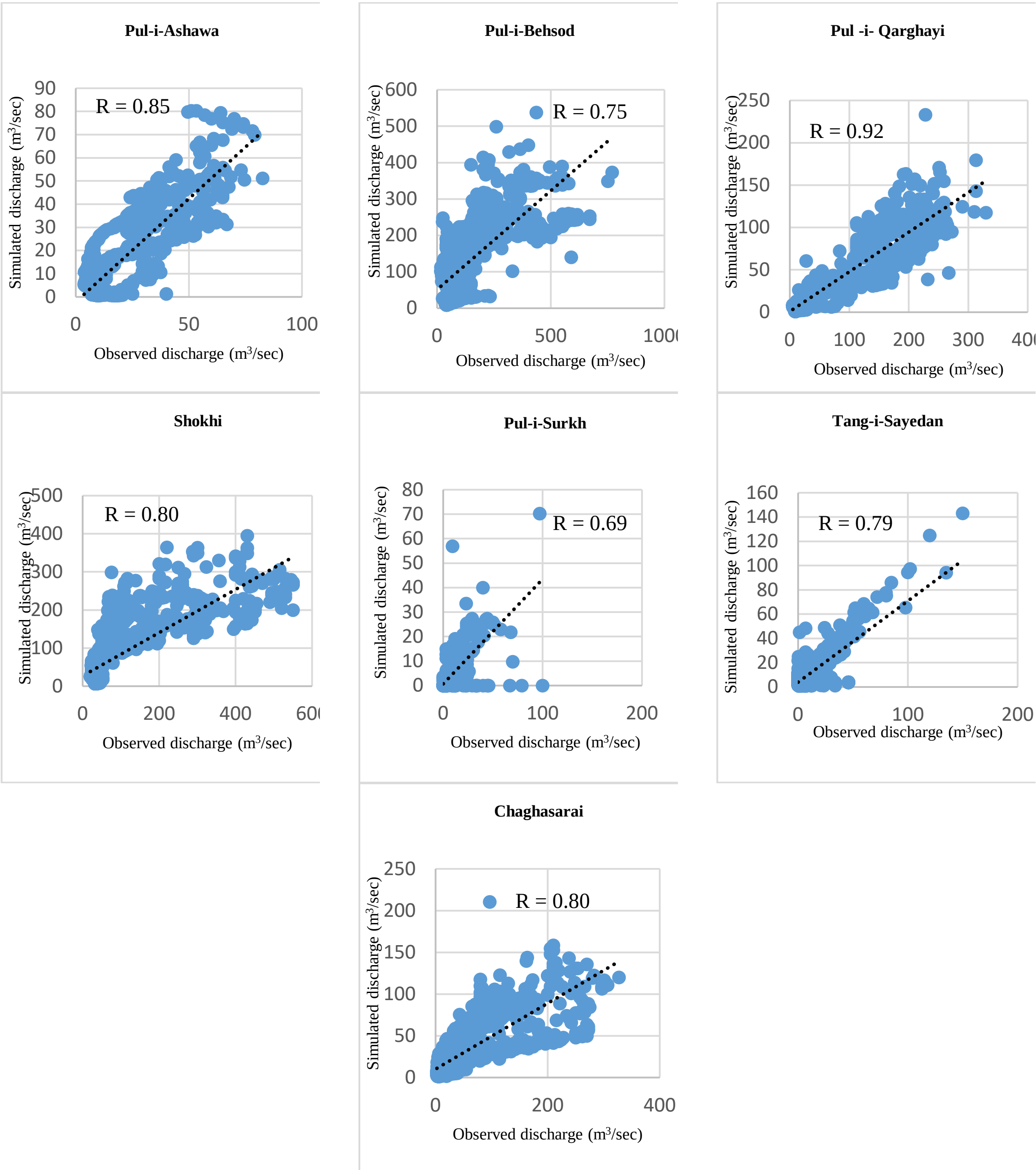

Figure 13. Comparison of measured and predicted daily runoff (Validation stage)

6. Conclusions

The rainfall-runoff modeling of the KRB is conducted using the ArcSWAT model. The basin is divided into 48 sub-basins with a number of 770 hydrological response units (HRUs). The SWAT-CUP is successfully used to calibrate the model for predicting monthly and daily runoffs at seven different hydrological stations. The sensitivity analysis results revealed that the flow characteristics of KRB are highly influenced by the groundwater and snowmelt parameters. The successful simulations of the runoff at the seven basins indicate that the SWAT model can be confidently employed for the runoff assessment at the KRB at daily and monthly time scales for long periods of time. It can be an effective modelling tool for the planning and management of water resource resources at the KRB. This study can contribute to the assessment of runoff and it can be used to make decisions for proper planning, designing, and management of the water resources in Kabul River Basin.

Finally, the following findings with respect to the SWAT model are also concluded in this study:

1) The SWAT model is a useful tool that can help to accurately estimate various water balance components.

2) The SWAT model is useful in many aspects, such as the analysis of watershed hydrology, and identification of hydrologically sensitive parameters.

3) The SWAT model can be applied to investigate the climatic, spatial, and temporal changes occurring within a basin.

4) To improve the SWAT model performance, the meteorological stations should be improved, both in terms of quality and quantity. It is therefore highly recommended that a good network of both hydrological and meteorological stations should be established at the basin, including, the upstream part.

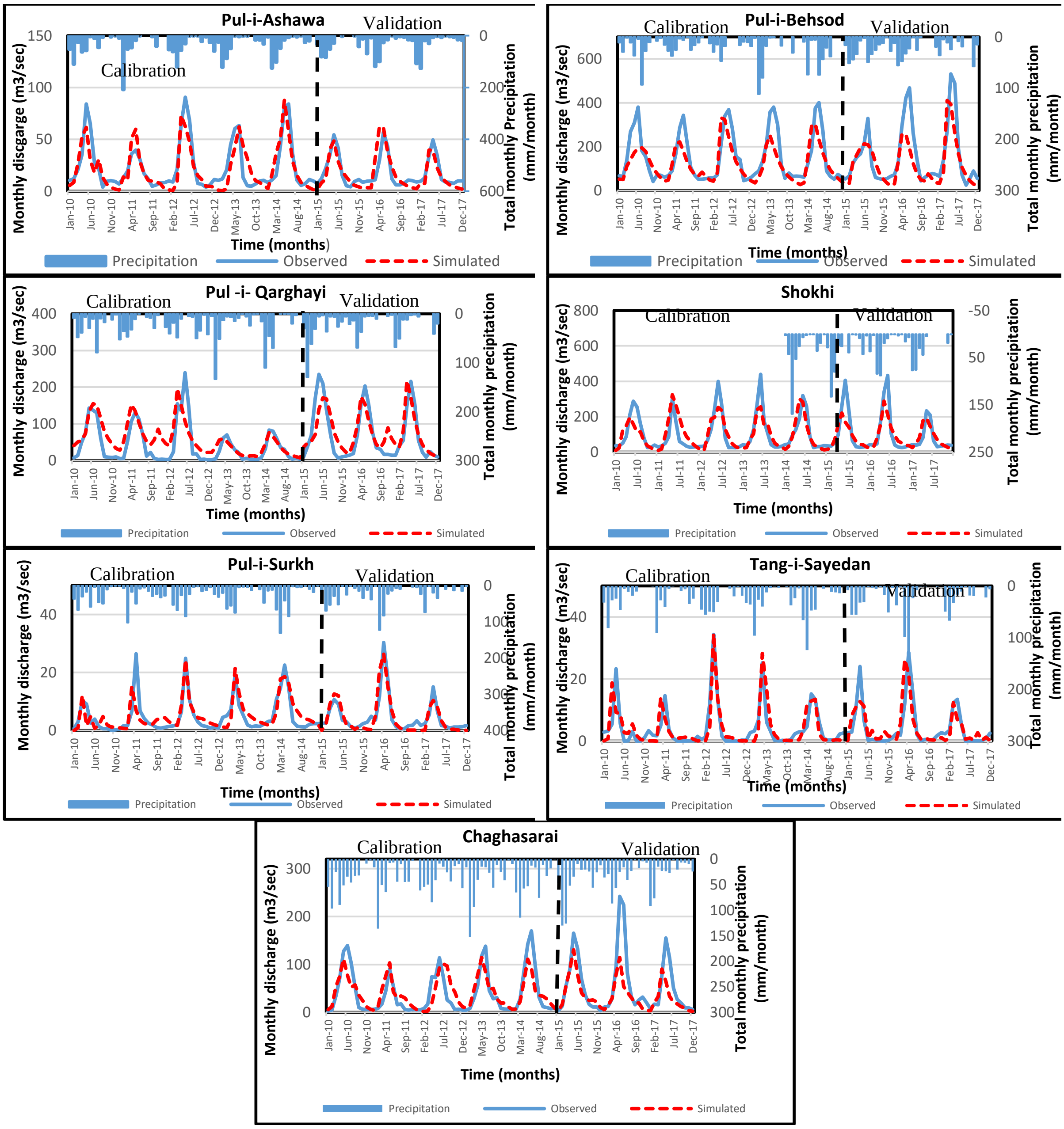

Figure 14. Comparison between observed and simulated monthly runoff during calibration (2010-2014) and validation (2015-2017) stages at seven stations

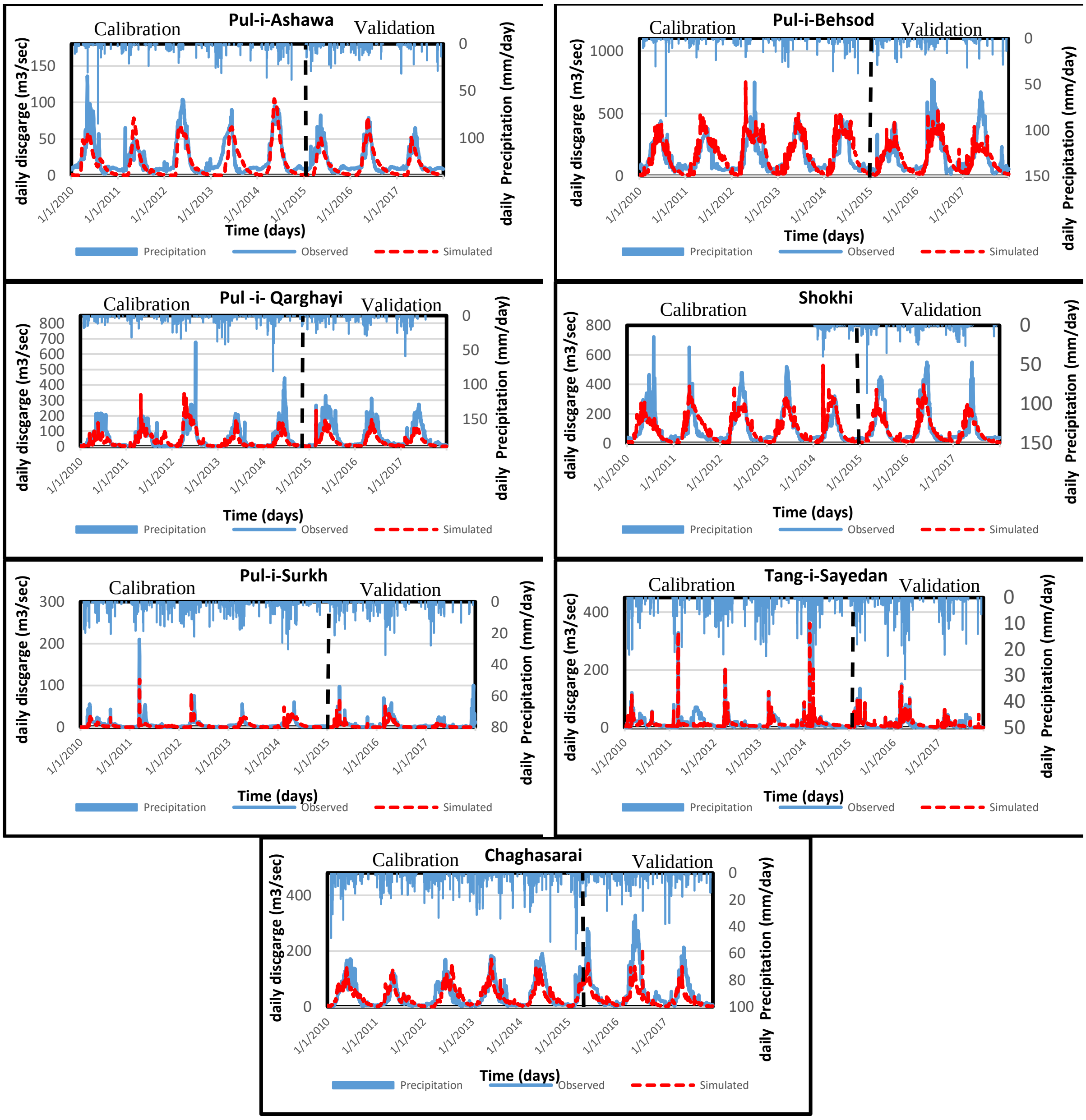

Figure 15. Comparison between observed and simulated daily runoff during calibration (2010-2014) and validation (2015-2017) stages at seven stations

Table 5. Average monthly hydrological components for the study area over the period 2009 to 2017

Month	Surface runoff (mm)	Lateral runoff (mm)	Water Yield (mm)	ET (mm)	PET (mm)
1	8.63	2.39	18.49	0.53	0.55
2	24.55	5.65	40.4	1.37	1.53
3	36.07	8.84	65.68	3.89	4.45
4	15.58	9.88	54.37	6.52	7.32
5	4.56	6.07	41.1	9.46	10.21
6	1.13	2.18	24.8	6.73	7.48
7	1.62	1.08	15.45	8.88	10.09
8	2.63	1.4	11.88	7.29	8.64
9	106.02	1.15	83.36	5.1	6.16
10	2.03	1.75	37.32	2.11	2.37
11	3.19	2.7	11.77	0.64	0.68
12	20	1.5	28.26	0.12	0.12

Table 6. Uses of water in Kabul River Basin (Source: FAO and Ministry of Energy and Water)

Water Use Type	Use sub-Type	Use Purpose	Mm^3	Percent (%)
Controlled Water Use	Irrigation	Irrigated Crops	6442	24.3
		Irrigated Fruits	468	1.8
		Vine-Yards	174	0.7
	Domestic use	Urban Population	137	0.5
		Rural Population	60	0.2
	Livestock	Cattle	15	0.1
		Horses/donkeys	3	0.00
		Sheep/Got	38	0.1
Beneficial Water Use	Utilized Land Use	Rain-fed Crops	64	0.2
		Forest and Shrubs	4014	15.1
		Rangeland	10853	40.9
Non Beneficial Water Use	Unutilized Land Use	Barren Land	2157	8.1
		Sand cover	27	0.1
		Built Up Area	219	0.8
	Losses from water bodies	Perennial waterbodies	310	1.2
		Temporary waterbodies	505	1.9
		Snow cover	1026	3.9
TOTAL water uses			26512	

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