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ORIGINAL PAPER

GEOSCAPE

Predicting the impact of future climate change on streamflow in the Ugam River watershed

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Abstract

Climate change affects the environment and human life across the planet and it is expected that the negative consequences will be large, especially in developing countries, such as Uzbekistan. The objective of this study was to predict the impact of future climate change on the streamflow of Ugam watershed (Chirchik River Basin (CRB)) using the Soil and Water Assessment Tool (SWAT). The outputs of Coupled Model Intercomparison Project Phase 5 (CMIP5), in combination with Representative Concentration Pathway 8.5, were used as future climate records for the period 2019−2048. The SWAT model was calibrated and validated for the streamflow from Ugam watershed through using the observed daily flow data from 2007 to 2011. The calibrated SWAT model was used to simulate the impact of future climate change on streamflow in the Ugam River for 2019−2048. The results show that the stream discharge is expected to decrease by approximately 42% within thirty years, with a 1.4 °C increase in temperature and 286 mm decrease in precipitation. The peak point for the future period is 40.32 m^3/s in 2037 whereas the lowest discharge, predicted for 2048, accounts for 22.54 m^3/s. Our study enables to understand the impact of climate change on water resources in the Ugam river and to increase the adaptive capacity of water users and managers in the region.

Keywords

Climate change,
Hydrology,
Water Resource Management,
SWAT model,
Chirchik River Basin,
Ugam River watershed

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Highlights for public administration, management and planning:

- According to the analysis of the bias-corrected CMIP5 outputs, the Ugam River Watershed is anticipated to experience a 1.4 °C increase in temperature and 280.1 mm decrease in precipitation during 2019−2048 under the RCP 8.5 scenario.
- The final simulation of the SWAT model depicts possible drop by approximately 42% in the streamflow of the Ugam River watershed in the future period.
- The model was calibrated and validated by setting R2 and Nash-Sutcliffe Efficiency (NSE) as objective functions to test the model performance. To examine the 95PPU of the simulation and observed discharge, the p-factor and r-factor were used.

1 Introduction

1.1 Effects of global climate change

Due to a continuous increase in population and economic activities, the world is still facing barriers concerning securing water resources for basic human needs and development (Jønch-Clausen & Fugl 2010). This has caused increased competition and conflict over limited water resources. According to Cunningham and Cunningham (2013), already 1.1 billion people on our planet have not enough access to drinking water. Climate change causes alteration in the hydrological cycle resulting in inevitable impacts on water resources in different parts of the world (Zhang et al. 2007). These impacts on hydrological processes lead to changes in soil moisture, water temperature, the magnitude of runoff, frequency of flooding and volume of streamflow (Hagemann et al. 2013). These alterations may put aspects of human well-being in jeopardy, including agricultural productivity, energy use, flood control, wildlife management and water supplies.

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Hydrological conditions are distinctive from region to region (Zhang et al. 2007), which makes most regions vulnerable to changes in both temperature and precipitation patterns. The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) predicted an increase of 1.5 °C of global temperature during the 21st century (IPCC 2018). Regarding Central Asian region, according to Solomon et al. (2007), this value probably will reach 3.7°C, leading to a raise of annual evapotranspiration, and shifts in hydrological cycle of the ecosystems (Gosling & Arnell 2013). In addition, due to an increase in temperature, unbalanced atmospheric moisture will cause intense precipitation in one region and severe droughts in another region (Shrestha et al. 2019). According to the UN (2006), without adaptation and mitigation measures, the 2.5°C increase in temperature would result in a 0.5 to 2 % loss in the gross domestic product for each country, whereas in developing countries, such as Uzbekistan, it will cause even more economic damage.

1.2 Climate change and its implication in Uzbekistan

Uzbekistan is one of the arid countries in Central Asia, and the primary consumer of water resources, with about 90% of surface water used for agriculture (World Bank 2013). The agricultural sector is the backbone of the country's economy, and this sector in the country is highly dependent on irrigation (Sorg et al. 2014). Besides this, Uzbekistan is introduced as a downstream water user in Central Asia (Mamatova et al. 2016) and for the country, 85% of the water resources are supplied from neighbouring countries, such as Tajikistan and Kyrgyzstan (UNDP 2016). However, in the last five decades, the mismanagement of transboundary water resources by Central Asian countries has caused a reduction in the water supply for Uzbekistan (Usmanov et al. 2016). After the collapse of the Soviet Union, some countries, such as Tajikistan, opted out from the regional water-sharing agreement between Syrdarya riparian states. Accordingly, the Tajik and Kyrgyz republics agreed to restrict power generation during winter in return for receiving energy resources from their downstream neighbours. However, they started building the Rogun dam as a buffer against energy and economic crisis.

Uzhydromet, as the main hydrological and meteorological service in Uzbekistan, states that the country has already experienced a 1.6°C increase in temperature compared to the past decades (https://www.meteo.uz/). The increase in the annual temperature has reached 0.29°C in a recent decade and diminishing glacial areas to 0.2%–1% were observed annually. There is evidence that the number of hot days with high temperature are increased, and downward trends in precipitation are occurring (Agaltseva 2008), which would influence the water resource availability over the country in the nearest future. Bobojonov and Aw-Hassan (2014) predicted that revenues of local farms in the country would decline up to 2070–2100 owing to temperature risk and water shortage situation.

1.3 Climate change and hydrological modelling

Uzbekistan developed the drought warning system in order to minimize vulnerability and cope with climate risk (Ford et al. 2014). The Dublin Principles claimed that the river basins like Chirchik, are the most suitable geographical unit for planning and managing water resources (WMO 1974). Therefore, watershed management needs to be incorporated into river basin management on the national and regional scales (Holmatov & Lautze 2016). Notably, managing river basins (across both national and regional scales) requires water management institutions and national water policies, as well as technical measures like GIS, followed by climate and hydrological models (Bekchanov & Lamers 2016). They provide water managers with reliable information regarding unforeseen events under uncertain future climate change (Hornidge et al. 2011). During the past two decades, multiple hydrological models were developed all over the world to identify the impact of temperature, precipitation, soil properties, and human activities, on the hydrological cycle and available water resources. According to Devia et al. (2015), a model is defined as a simplified representation of the real world, and the best model can make a better simulation of a real-life system. Different environmental modelling systems require multiple input data, such as rainfall, air temperature, soil characteristics, topography, vegetation, hydrogeology and other physical parameters, in order to make the real-life simulation more reliable and accurate.

Noteworthy, many climate studies have been done through applying different hydrological models, such as Soil and Water Assessment Tools (https://swat.tamu.edu/), and Representative Concentration Pathway (RCP) 2.6–8.5 (The CMIP5 multi-model ensembles, http://cmip-pcmdi.llnl.gov/cmip5/index.html). According to Shrestha et al. (2019), the SWAT simulation pre-

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dicted that a 7-day low flow in the water could go up by roughly 19% during the 21st century under RCP 4.5 and RCP 8.5 in the Miami River. Similarly, the pertinent results of the research conducted in Guijiang river basin showed that the streamflow would slightly change under RCP 2.5 and RCP 4.5, whereas RCP 8.5 discovered a significant change in the future (Jia et al. 2018). In another research, conducted for Kulfo river basin, SWAT model simulation revealed a drop of streamflow accounted for 2.99 % until the 2050s (Demmissie et al. 2018). According to Narsimlu et al. (2013), the outputs of the SWAT model showed that under IPPCC A1B scenarios, the average annual streamflow of Upper Sind River Basin could go up by 16.4 % during 2021–2050, followed by a rise, accounted for 93.5 % during 2071–2098. The research results presented that there was a decrease from 2.5 to 11% in the surface runoff in the Upper Baitarani River basin when the temperature was risen from 1 to 5 °C. However, the increase by 2.5 to 15% in rainfall would cause the surface runoff go up by 6.67 to 43.42% than the past condition. The research conducted in the Amazon River basin, in which MGB-IPH model was used, showed that surface water contributed to 58 % of terrestrial water storage, followed by 27% from soil water and 8% from groundwater (De Paiva et al. 2013). Similarly, Cong et al. (2009) conducted hydrological trend analysis in the Yellow River basin using GBHM model to simulate natural runoff, and the results show that the outgoing discharge was decreased from 1972 to 2005 due to artificial water consumption, like human use. Remarkable research has been undertaken in the Chirchik River Basin (CRB) using the MIKE SHE integrated hydrological model by Usmanov et al. (2016), according to which actual evaporation was observed as the main water loss factor, accounting for average of 821 mm per year.

The pertinent results of the preliminary research show that the impact of future climate change on the streamflow of Ugam Watershed has not been studied yet. Therefore, this research intended to predict hydrological responses under future climate change in Ugam River Basin using Soil and Water Assessment Tools (SWAT). This research further contributes to consolidating the adaptive capacity of water users and managers through generating informative knowledge on the impact of future climate change on water resources in the watershed.

2 Materials and methods

2.1 Study area

The study area, Ugam River watershed rises in the western Tien Shan Mountains and crosses the Sairam Ugam National Park in south Kazakhstan before entering into Uzbek Chirchik valley, northeast of the Tashkent region (Fig. 1). The length of the river basin is approximately 70 km, and basin area is 870 km^2. Annual streamflow of the river is 1.200 million m^3, which makes the river as a main transboundary tributary to the CRB; accordingly, it contributes approximately 20% to the total runoff of the CRB (ERBP 2019). Territory of Kazakh part of Ugam basin covers Sayram-Ugam National Park and one village “Ugam” located within it. Ugam River Basin the Uzbek part of the basin covers Ugam-Chatkal National Park and three urban settlement type villages – Khudjakent, Chevak, and Khumsan. Population in the basin equals 17790 people. Majority of population is living in the Uzbek part of the basin. As in other parts of Uzbekistan, the population here has been growing steadily in recent years. Interestingly, migration played a role in the growth of the population in the Uzbek part of Ugam basin (ERBP 2019).

2.2 Input data

In this research, different climate data observed and projected ones were used to investigate the effect of climate change for the study area. Five yearly (2007–2011) weather records such as daily precipitation (PCP), maximum temperature (Tmax), minimum temperature (Tmin), wind speed (WS), solar radiation (SR) and relative humidity (RH) were obtained from Uzhydromet. These inputs were used in calibration and validation procedures of the SWAT model simulation: 2007 was used as a warmed-up period to decrease model estimation of initial state variables and the model was calibrated for 2008–2009 and validated for the period 2010−2011. Furthermore, 5 yearly (2007–2011) hydrological data at the outlet of the Ugam River watershed, which was also used in the calibration and validation processes, was taken from the hydrology department of Uzhydromet. The statistically corrected climate projection data of the CMIP5, under RCP 8.5, for 30 years, especially daily precipitation, maximum and minimum temperature, wind, and relative humidity were obtained from International Water Management Institute (IWMI) in Tashkent. They were used as future weather records to the SWAT model to simulate the impact of climate change on streamflow in Ugam River watershed (Fig. 2).

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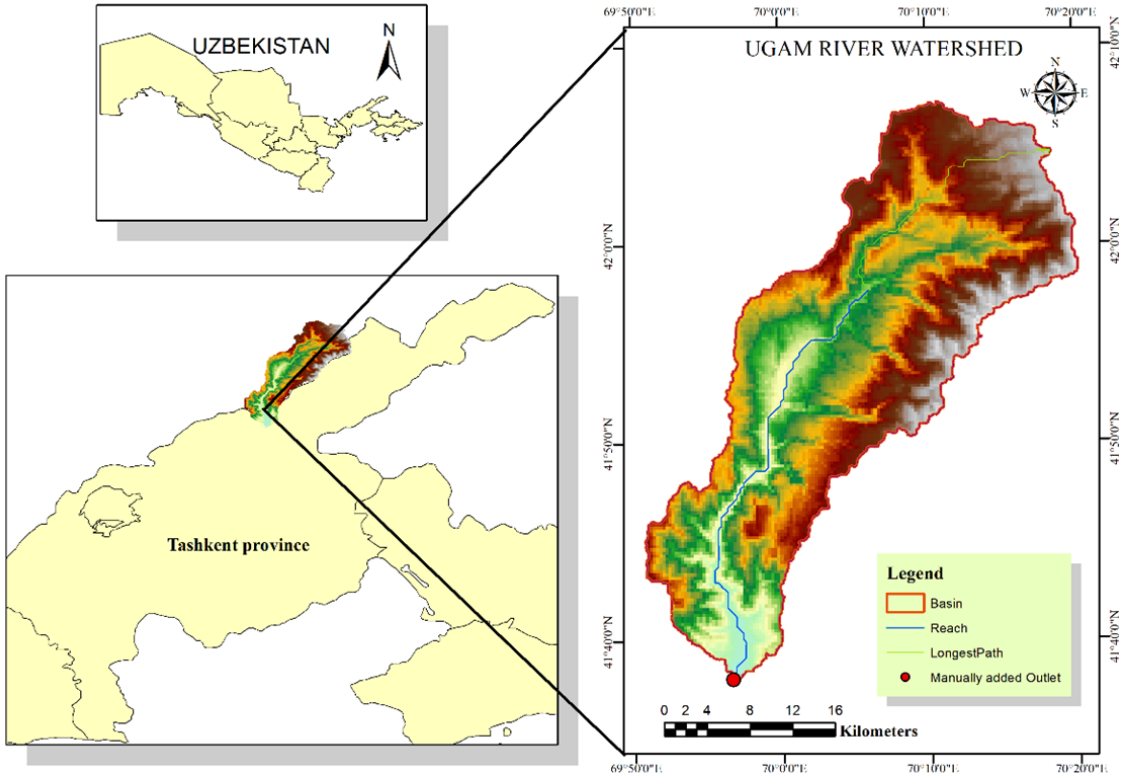


Fig. 1 Study site - Ugam River watershed

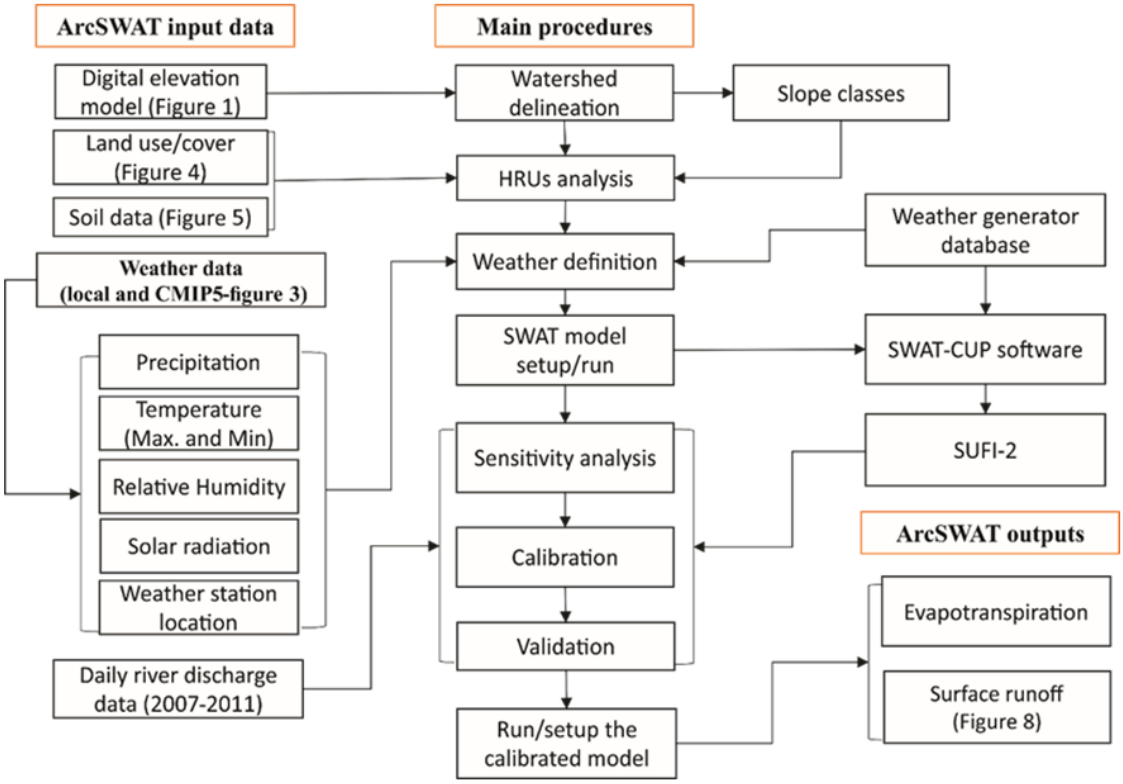


Fig. 2 Process and displaying concept for the ArcSWAT

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Digital elevation model (DEM) with a resolution of 30 meters was obtained from the USGS (earthexplorer.usgs.gov), used to delineate the watershed, as well as stream network and stream characteristics in the ArcSWAT2012. Considering changes in land use cover over the passing time, two versions of MODIS (Land cover type 2: Annual, University of Maryland-UMD classification), with a resolution of 500m, were obtained from the USGS website. The land use/land cover map for 2008 was used in the SWAT model simulation for 2007−2011 towards calibration and validation, whereas the land use/land cover map for 2018 was used for the future simulation. The study area is covered by five different land use/land cover classes, with agriculture land use as major one. Soil data with a resolution of 30 meters was acquired from the FAO soil database, and necessary corrections and projections for the Soil and Land Use map were performed in GIS software. In this study, no threshold options were selected due to a small percentage of the classes in both land use and soil maps, which was aimed at keeping key landscape features of the watershed. In this research, Clay (Ge43-3a-3953), Clay-Loam (I-Bc-2c-3085), Loam (I-Bh-c-3969) and Loam (I-Xk-2c-3978) were used (Table 1).

Table 1 Soil characteristics of the Ugam River Watershed

#	Soil characteristics	Soil textural classes			
		CLAY	CLAY\ LOAM	LOAM	LOAM
1	Soil codes	Ge43-3a-3953	I-Bc-2c-3085	I-Bh-c-3969	I-Xk-2c-3978
2	Soil moist bulk density (Mg/m^3) layer 2	1.6	1.1	1.3	1.5
3	Potential crack volume of the soil profile	0.5	0.5	0.5	0.5
5	Available water capacity of the soil layer (mm H2O/mm)	0	0.071	0.071	0.071
6	Saturated hydraulic conductivity (mm/hr), average Ksat	1.5	6.2	3.1	1
7	Soil hydrology group	C	C	D	D

2.3 Methods

2.3.1 Trend analysis

Trend analysis was employed to see the periodic changes of the past climate and the future climate in the study area. By means, three-decade historical weather data and climate projection data derived from CMIP5, especially precipitation and temperature were analysed using the least squares method in Microsoft Excel.

2.3.2 Scenario analysis

Scenario analysis has been applied in many climate and hydrology studies. IPCC recently introduced new climate scenario, Representative Concentrative Pathway (RCP). This is modelling of global climate having different RCP scenarios as known as RCP 2.6, RCP 4.5, RCP 6.5 and RCP 8.5. In this study, RCP 8.5 was selected to see how future climate would possibly unfold under the exclusion of substantial measures. RCP is a scenario with high greenhouse gas emissions, business as usual scenario (Van Vuuren et al. 2011).

2.3.3 SWAT model

The SWAT is a physically based hydrological model, which has an interface with ArcGIS software. In this research, ArcSWAT 10.2 version, compatible with ArcGIS 10.3, was used. The SWAT has two phases: 1) land phase of the hydrological cycle and 2) water phase of the hydrological cycle. For this study, the water phase, the process of water movement through the stream network, was selected. Furthermore, in the SWAT model, the Penman-Monteith model was used to calculate potential evapotranspiration (Shrestha et al. 2019). The Curve Number (CN) was employed, which requires daily precipitation data, to compute the total volume of surface runoff.

2.3.4 SWAT model setup, calibration and validation

The SWAT model was set up and run from 2022 to 2048 in daily time steps through considering a 3-year warm-up period (2019–2021). The model was calibrated twice at the outlet of the the Ugam watershed by setting R2 and Nash-Sutcliffe Efficiency (NSE) as objective functions to test the model performance (Abbaspour 2015). The first calibration was performed using observed streamflow for four years from 2008 to 2011, and the second one was

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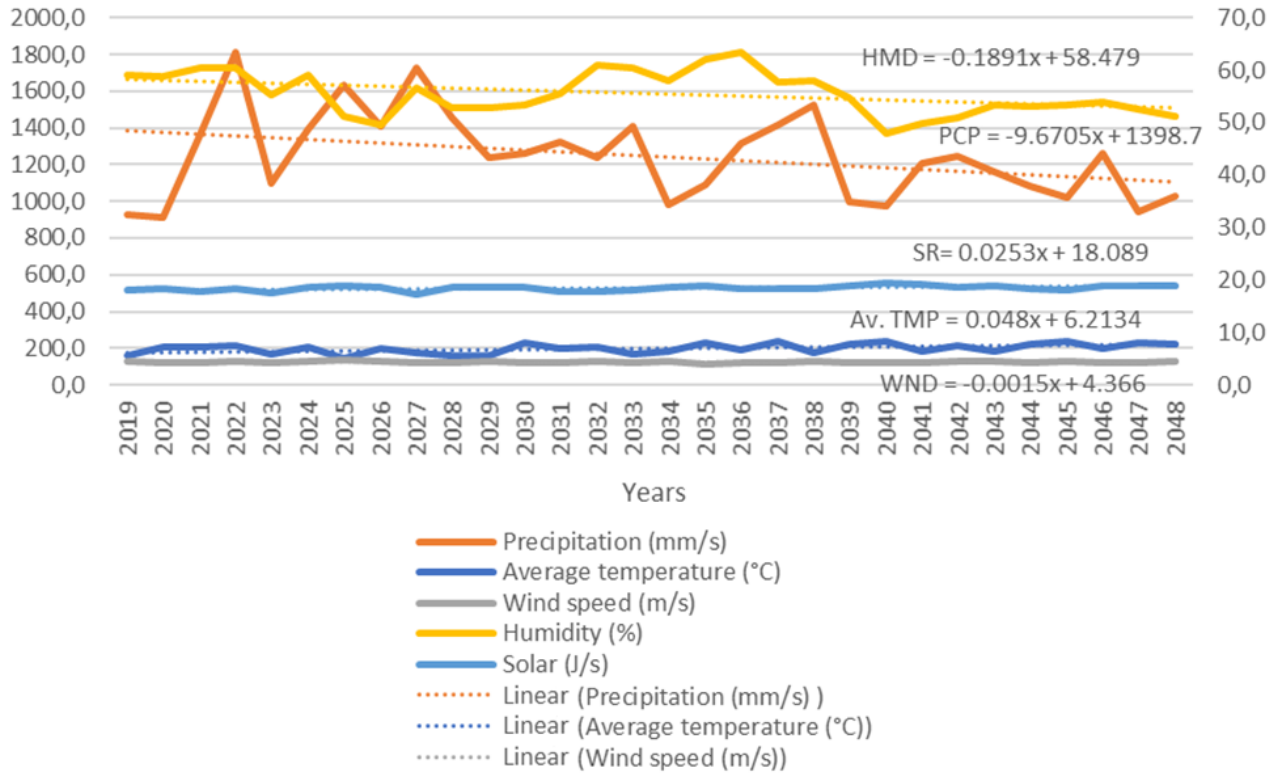


Fig. 3 Climate projection of CMIP5 under RCP 8.5 for the period of 2019-2048 (The CMIP5 multi-model ensembles, source: http://cmip-pcmdi.llnl.gov/cmip5/index.html)

done for two years from 2008 to 2009. The reason behind performing calibration twice was to see whether a five-year calibration could be representative for a two-year calibration, and the results of two calibration periods were quite similar. Therefore, a two-year calibration was used for further model simulation in this study. Noteworthy, the rest of the observed streamflow data (2010–2011) was used in the calibration of the SWAT model. For calibration and validation of the model, the automated SWAT Calibration and Uncertainty Program (SWAT-CUP) was used; a semi-automatic model algorithm, Sequential Uncertainty Fitting version 2 (SUFI-2) was employed to find the most appropriate model parameters. In this semi-automatic model algorithm, five iterations, each to have 500 simulations, were carried out in the calibration, whereas one iteration with 500 simulations was enough in the validation of the model (Abbaspour 2015). In calibration, p and r factors were employed: p-factor is the percentage of the measured data bracketed by 95PPU, which shows model's ability to capture uncertainty, whereas r-factor measures quality of calibration and the thickness of the 95PPU.According to (Abbaspour 2015), 1 and 0 should be the target on p and r factors in the absence of errors and other uncertainties. In sensitivity analysis, objective functions such as t-test, t-stat were used to get statistics of parameter sensitivity (Abbaspour 2015).

3 Results

3.1 Climate projection

The outputs of the CMIP 5 climate model for Central Asia were used as the records of future climate in combination with the RCP 8.5 scenario. The section is followed by the analysis of temperature (average, minimum and maximum), precipitation, wind and relative humidity for 2019–2048 (CMIP5 ensemble). The outputs of CMIP5 for RCP

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8.5 are plausible due to its coarse-scale so they do not have exact accuracy. Hydrological models require finer-scale climate data, therefore, biased-corrected CMIP5 projections obtained from IWMI were used. According to the analysis of the CMIP5 outputs, the Ugam River is anticipated to experience the lowest temperature in 2025 with 5.1°C and the highest temperature in 2043 with 8.5°C. Overall, during the thirty years, the temperature over the basin will slightly increase by 1.4 °C (Fig. 3). The average annual precipitation was estimated to decrease by 280.1 mm in thirty years, with the lowest trend would be 914.3 mm in 2020, followed by the highest one, 1814.9 mm, in 2022. Additionally, annual average wind over the Ugam Watershed was projected to be 4.3 m/s during 2019–2048, followed by 56% annual average relative humidity for the same period.

3.2 Calibration, Validation and Sensitivity

For calibration and validation, the ArcSWAT model was run for 5 years (at daily time step) from 2007 to 2011. The first year (2007) was taken as a warm-up period to make sure that there were no effects from the initial conditions in the model.

The Ugam watershed, at 865.2744 km^2, was delineated from the DEM (Fig. 1). The area has further been divided into 55 hydrological response units based on land-cover classes (Fig. 4) and soil types (Fig. 5). There are the following land-cover classes, which cover a certain area in the watershed, such as Rang-Grasses (769.3 km^2), Agriculture Land-Generic (78.1 km^2), Residential (5.8 km^2) and Southwestern US Arid Range (12.1 km^2). Table 1 illustrated that the watershed consisted of four soil classes, and soil moist bulk density was 1.6, 1.1, 1.3 and 1.5 Mg/m3 for Clay (Ge43-3a-3953), Clay_Loam (I-Bc-2c-3085), Loam (I-Bh-c-3969) and Loam (I-Xk-2c-3978), respectively. The potential crack volume of the soil layer, total soil volume, which is important for predicting surface runoff and infiltration, was 0.5 for all soil classes, whereas average Ksat was calculated as 1.5 mm/hr for Clay, followed by Clay-Loam with 6.2 mm/hr, Loam (I-Bh-c-3969) with 3.1 mm/hr, and Loam (I-Xk-2c-3978), accounted for 1 mm/hr.

The ArcSWAT simulation outputs showed that simulated values of Potential evapotranspiration (PET) were 678.4 mm, following surface runoff 328.97mm and evaporation and transpiration (ET) of 260.6 mm for the period. Notably, streamflow was underestimated from 2007 to 2011 in the model. For instance, the relation (R2) between simulated and observed streamflow was very low, accounting for 0.1036. Furthermore, the multiple regression analysis was performed and as a result, the p-value and standard error were 1.49E-36 and 29.73, respectively (Table 3), which were not acceptable. Because the accepted value of p should be close to zero. Therefore, calibration and validation were performed to decrease potential errors in the model output and reach the best simulations.

3.3 Justification of the two-year calibration

Calibration for the SWAT model was carried out from 2008 to 2009. Before, calibration was done from 2008 through 2011. A lack of daily climate data in the governmental repository for another five years limited the process of calibration. Therefore, calibration for two years, from 2008 to 2009, was done to see whether the outcomes would be similar to each other or not. Consequently, the two-year calibration showed almost the same statistics as the five-year calibration when tested. For example, the R2 accounted for 0.58 in the five-year analysis while it was 0.56 in the two-year analysis. As can be observed, there was a negligible difference between these analyses. Another interesting point is that p and r factors were 0.39 and 0.31, respectively in the five-year calibration. Whereas p factor was the same observed as the five-year calibration and r factor was a bit higher, 0.35 in the two-year calibration than the five-year calibration. Finally, yet importantly, other statistical indicators were close to each other in both calibration periods. Fig. 6 illustrates the comparison of calibrated discharges with observed discharges at a monthly time step. The best simulations from the two-year calibration were overlaid with the best simulation from the five-year calibration. Trends for the best simulations of both calibration periods were akin to the observed trend. Therefore, the two-year calibration was taken, and their new parameters were used for further research.

3.4 The calibration and validation results of the SWAT model for 2008–2009

During the two-year calibration, the number of parameters, namely runoff curve number, base flow alpha factors (days), groundwater delay (days) and threshold depth of water in the shallow aquifer (mm), were used to run required iterations. In total, five iterations, each with 500 simulations, were undertaken to reach the objective function (the target R2 of 0.5).In the fifth iteration, the objective function was reached at 0.56 (Table 2), and the best parameters (fitted value), which were to be used in the future SWAT simulation, were identified (Table 3).

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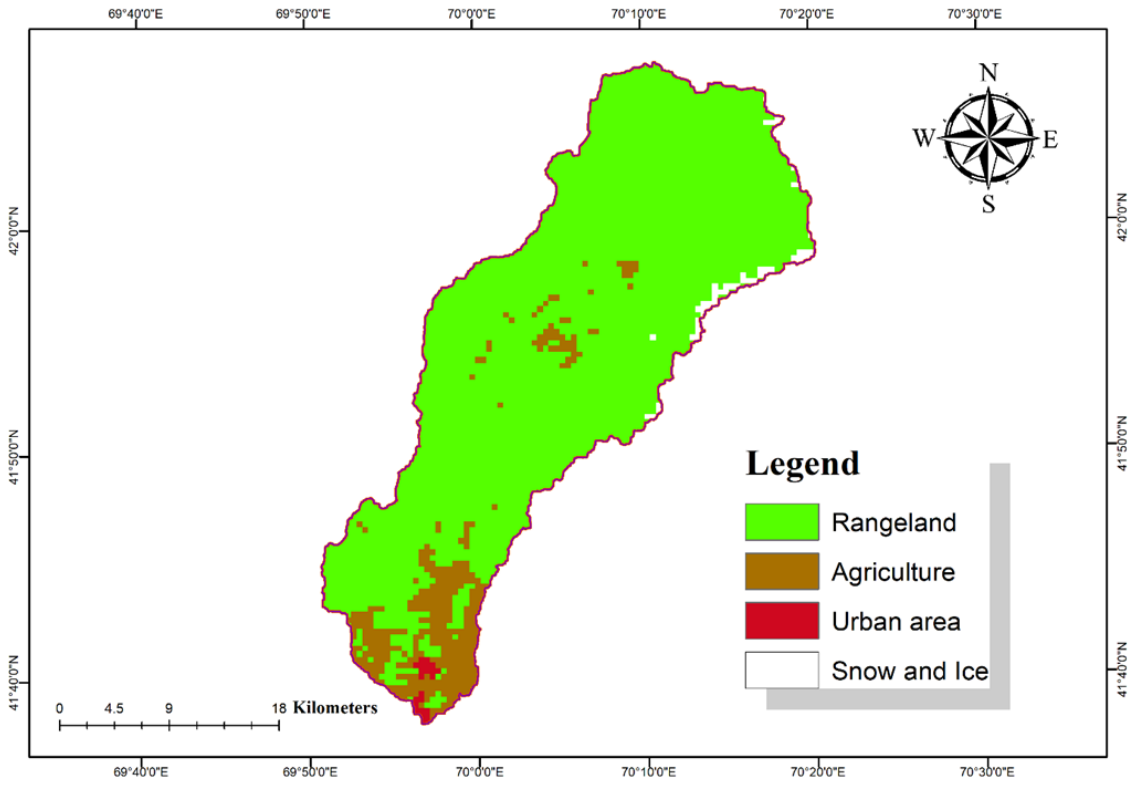


Fig. 4 Land use and land cover map for 2010 according to MODIS satellite image classification

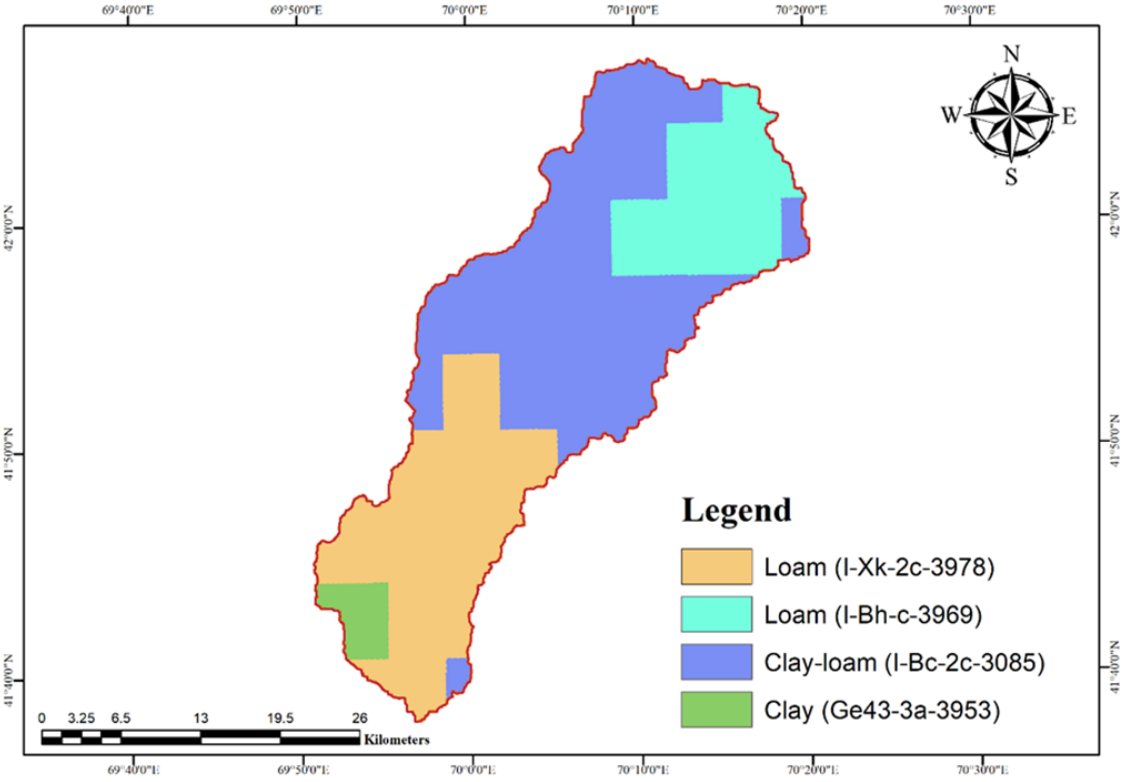


Fig. 5 Soil map extracted from FAO soil database

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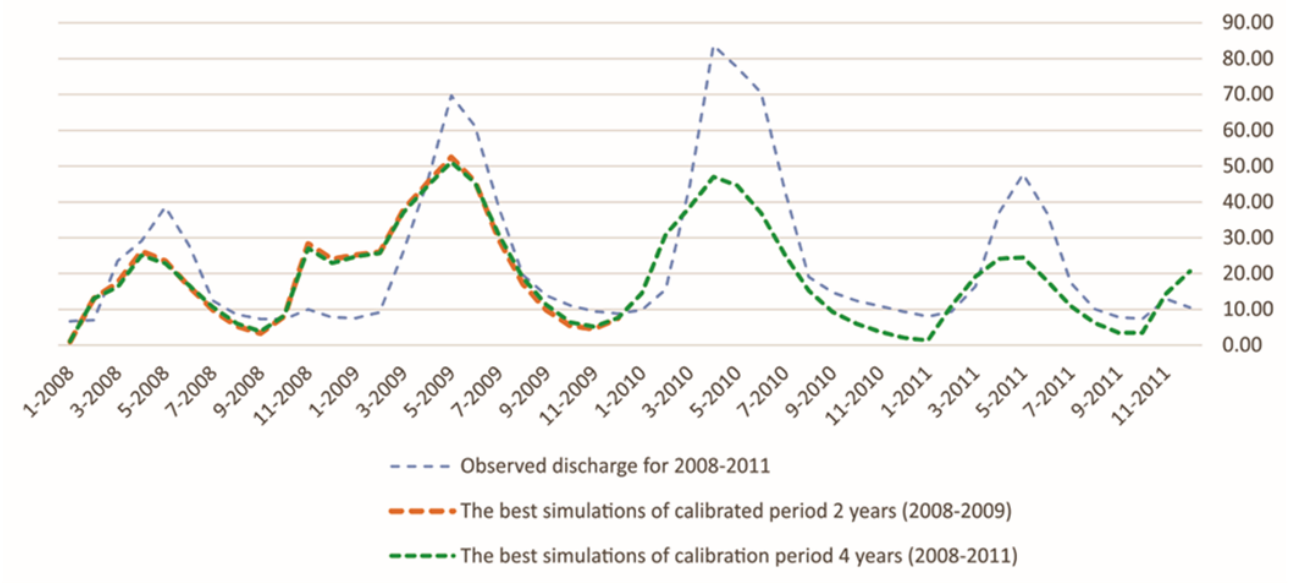


Fig. 6 The comparison of calibrated discharge with observed discharge

Table 2 Comparison of five-year and 2-year calibrations

The name of statistical indicators	Four-year calibration	Two-year calibration
R2	0.58	0.56
p-factor	0.39	0.39
r-factor	0.31	0.35
Nash-Sutcliffe coefficient (NS)	0.53	0.55
Mean simulated flow out (Mean observed flow out)	18.99 (23.76)	20.08 (21.14)
Standard Deviation of simulated flow out (Standard Deviation of observed flow out)	14.81 (21.63)	15.61 (18.24)

In the next step, in order to examine how the parameters used in the calibration were sensitive, the global sensitivity analysis was accomplished (Table 4). As a result, the runoff curve number, accounted for 7.69 mm in the t-stat test, followed by base flow alpha factors with 17.33 days, groundwater delay with 8.32 days, and threshold depth of water in shallow aquifer 0.15 mm. Whereas only the threshold depth of water in shallow instituted by 0.88 and the rest was 0.

Fig. 7 demonstrates the model uncertainties expressed as a 95% prediction uncertainty (95PPU) which was derived from the model inputs like climate, soil and land use. To examine the 95PPU of the simulation and observed discharge, the p-factor and r-factor were used. Correspondingly, these factors made up 0.39 and 0.35 (Table 2). This denotes a high risk of uncertainty in the model inputs and outputs. In some cases, the space between the best simulation and observed discharge lies on 95PPU coverage and this reflects on the value of the r-factor. While the p-factor stood for that 39% of measured data was enclosed by 95PPU. To perform the validation, the parameters in the last iteration of the calibration and observed discharge data for 2010–2011 were used. Only one iteration was accomplished, and the results derived from this were slightly worse than the calibration period. For example, R2 and NS which were underestimated in the validation, were 0.39 and 0.47, whereas the r-factor was higher, accounting for 0.72 followed by a p-factor of 0.58 (Table 5).

Table 3 The best parameters of after the last iteration of the calibration

#	Parameter's name	Parameter definition	Fitted value	Min value	Max value
1	r__CN2.mgt	Runoff curve number (mm)	0.69	0.36	0.73
2	v__ALPHA_BF.gw	Base flow alpha factors (days)	0.02	0.13	0.30
3	v__GW_DELAY.gw	Groundwater delay (days)	28.92	6.89	103.32
4	v__GWQMN.gw	Threshold depth of water in a shallow aquifer (mm)	2.06	1.56	2.45

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Table 4 Sensitivity analysis and determination of the best and effective parameters of the model

#	Parameter Name	Parameter definition	t-Stat	P-value
1	R__CN2.mgt	Scs runoff curve number	7.69	0
2	V__ALPHA_BF.gw	Base flow alpha factors (days)	17.33	0
3	V__GW_DELAY.gw	Groundwater delay (days)	8.32	0
4	V__GWQMN.gw	Threshold depth of water in a shallow aquifer (mm)	0.15	0.88

Table 5 The comparison of the calibration and validation results

#	The name of statistical indicators	Calibration	Validation
1	R2	0.56	0.39
2	p-factor	0.39	0.58
3	r-factor	0.35	0.72
4	Nash-Sutcliffe coefficient (NS)	0.55	0.47

3.5 SWAT model performance

The calibrated ArcSWAT model was used to simulate the impact of future climate on streamflow in the Ugam watershed for 2019–2048, with three years as a warm-up period. The calibrated model used the same inputs as in the calibration, including the DEM with resolution 30 meters (Fig. 1) and soil datasets (Fig. 5). However, land use/cover 2018 (Fig. 7) and climate data (2019–2048), were modified for the future period. There are the following land-cover classes, which cover a certain area in the watershed, such as Rang-Grasses (769.3 km^2), Agriculture Land-Generic (79.7 km^2), Urban area (4.6 km^2) and South-western US Arid Range (10.1 km^2). In 2018-land use, it can be seen, that the agricultural area was increasing whereas, the urban area was decreasing.

Fig. 8 depicts the simulated discharge at the Ugam outlet point derived from the SWAT model over Ugam stream of CRB for the future period of 2019–2048. Overall, the stream discharge is expected to decrease by approximately 42% within thirty years. The peak point for the period was 40.32 m^3/s in 2037. Whereas the lowest one is predicted to be in 2048, accounting for 22.54 m^3/s. The regression equation depicts that discharge would fall by 23.32 m^3/s during the study period.

Fig. 9 demonstrated that the model outputs for the hydrological variables in Ugam watershed for 2019–2048. Within the thirty years, potential evapotranspiration is simulated to reach 978.9 mm per year, while actual (ET) are predicted to be 217.6 mm. Furthermore, the average precipitation in the simulated period is expected to reach 1270 mm, which would result in 127.91 mm surface runoff. The simulated results for lateral and return flow to the stream channel are predicted to be 139.7 mm and 749.78 mm, respectively (Fig. 9). The model outputs show that temperature stress days for plant growth are expected to reach 150.36 days, followed by water stress days at 43.94 for the period.

3.6 Discussion

The outputs of CMIP5 in combination with RCP 8.5 and RCP 8.5 was selected in our research to see the inevitable climate impacts under no substantial measures. However, Christensen and Lettenmaier (2006) used 11 GCMs in combination with IPCC SRES A2 and B1 for 2010–2039. In that research, the mean average temperature and precipitation were calculated, and the results for temperature were A2 ranging from 1.2 to 4.4°C, followed by B1 scenarios ranging from 1.3 to 2.7°C. For the precipitation, the ranges were −1 to −2% for the A2 scenario, and from +1 to −1% for the B1 scenario. In our research, we calculated average temperature and the sum of precipitation for 2019–2048, and the results ranged from 5.1 to 8.5 °C for temperature, followed by precipitation with a range of 91mm to 1814.9 mm.

The SWAT model was employed to simulate the impact of future climate change on hydrological resources in the study area. The SWAT model was then acclimatized in the context of the chosen study area by taking the local climate data, serving as an input. During the execution of the SWAT model, MODIS-DEM images were used which had 250 by 250 meters of spatial resolution. This is a bit coarse of a resolution, restricting the expected results in terms of detailed data, which was reflected in the overestimation of the rate of potential runoff. Narsimlu et al. (2013) studied the impact of future climate on water resources in the Sind River using the SWAT. The model was calibrated for 1992–2000 and the result was 0.73 for p-factor, followed by r-factor 0.42, R2=0.82 and NS=0.8. For the validation period (2001–2005), they were 0.42, 0.36, 0.96 and 0.93. The model simulation for the future period of 2021–2050 showed the streamflow would increase by 16.4%. Another research was conducted by Shrestha et al. (2019) in Miami river watershed,

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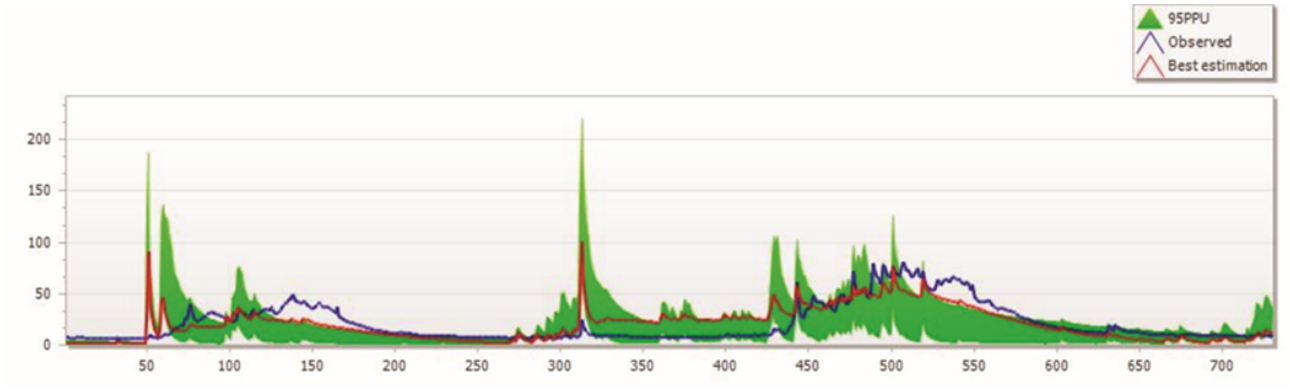


Fig. 7 Observed and simulated time series with 95% probability band (Latin hydrometric station)

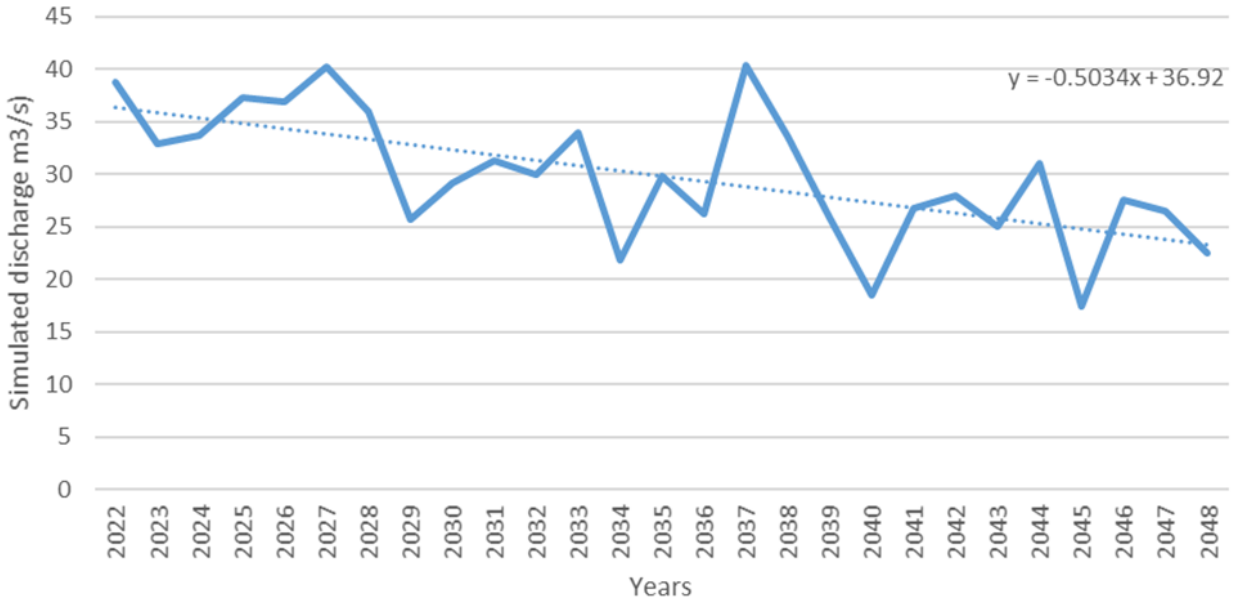


Fig. 8 Simulated discharge at Ugam outlet for Ugam River watershed during 2022–2048

in which CMIP5 climate models in combination with RCP 4.5 and 8.5 as climate input for the SWAT model were used. The performance indicators NSE, R2, PBIAS, and RSR for monthly flows at the outlet were found to be 0.86, 0.89, 2.68%, and 0.38, respectively during the calibration period. During the validation period, figures were 0.83, 0.86, 0.82%, and 0.41, correspondingly and the result showed that the watershed streamflow would increase by 19%.

However, in our research the calibration (2008–2009) and the validation (2010–2011) processes were executed as required according to Abbaspour (2015). After having done all past and future analyses of the climate variables, the calibration was performed to optimize the model performance by searching for the best parameters. The calibration also illustrated modest values for the objective function (R2) and the model performance function (NS). The main findings of the calibration were the best parameters and fitted values, serving to run the future simulation. It is assumed by these findings that the executed five iterations in the calibration give a proper result that can be reached the objective function. The outputs of the uncalibrated SWAT model for the baseline period showed relatively low significance in comparison with the observed discharge.

As a result, for calibration, the objective function, which was set for R2=0.5, was fully surpassed at 0.56. Values for p-factor and r-factor were 0.39 and 0.35. This means that our results had 39% of potential uncertainty that was likely expected

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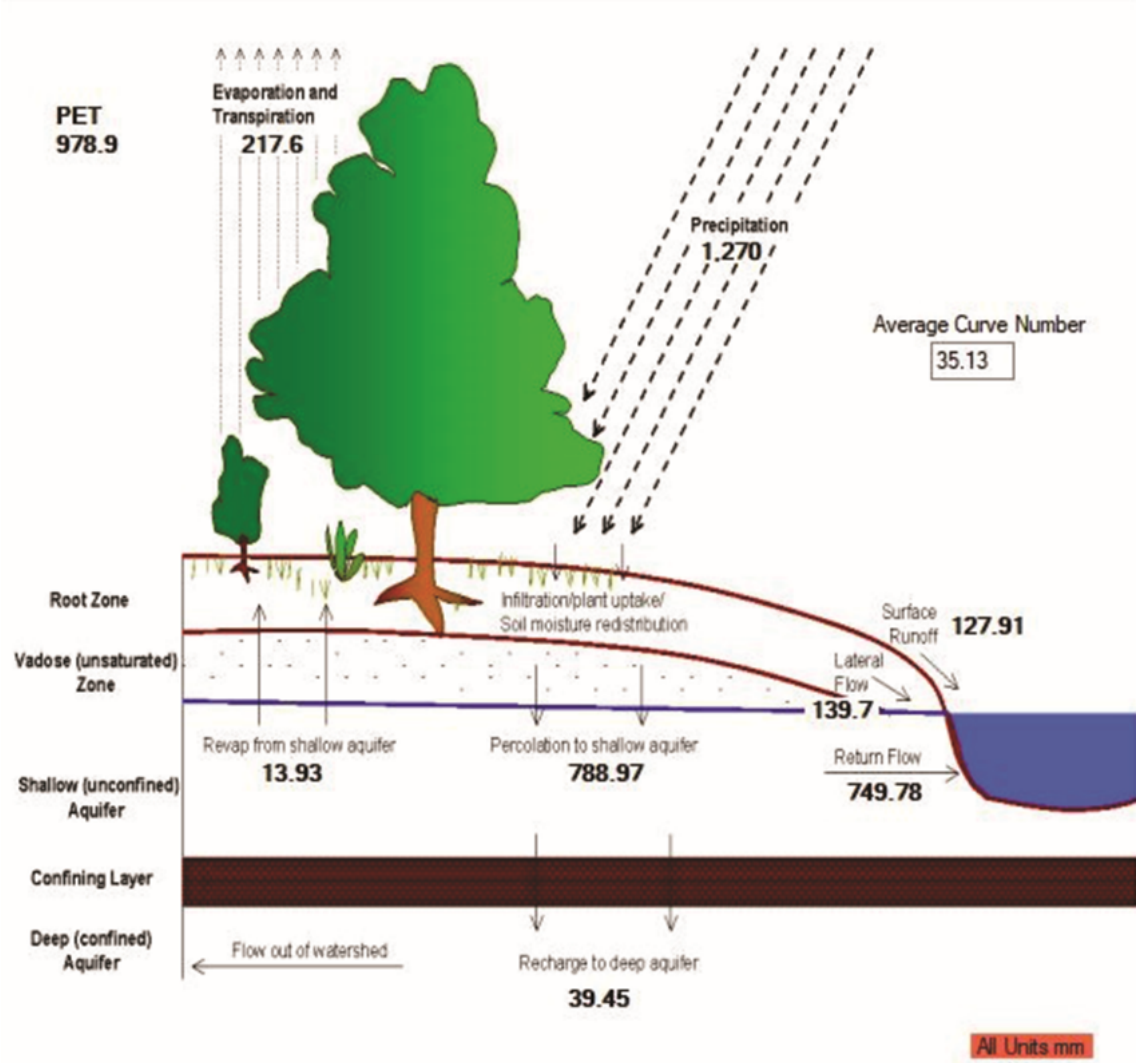


Fig. 9 The ArcSWAT model outputs for hydrological cycle of the Ugam River watershed

to be 35%. According to validation, the value for R2 did not fully reach an estimated threshold (0.5). Interestingly, the values for p-factor and r-factor were considerably different as observed in calibration processes, accounting for 0.58 and 0.72, respectively. The output of validation had somewhat worse circumstances on uncertainties to compare with the output results of calibration

In the final run of the ArcSWAT model, the potential area of land use categories experienced some changes. Amongst them, the agricultural area increased, due to massive land-owning for agricultural purposes such as cattle farming which took place on the natural rangeland. The final simulation also depicted some possible drop by approximately 42% in the amount of the observed discharge in the long term. This might result in pinpointing the probability of water stress that the study area might suffer in the calculated future period. The drop in the observed discharge revealed some numeric data on the potential stress days in the Ugam River watershed. Those were temperature stress days for plant growth, expected to be 150.36 days, and water stress days, accounted for 43.94 for the future. Temperature stress days might lead to an increase in the rate of the current evapotranspiration in the Ugam watershed, negatively affecting available surface water resources. Water stress days are also perceived to have the negative influences on the agricultural sector, especially on productivity. Summarizing all, according to the IPCC report (2014), the geographical location of Uzbekistan lies in the arid zone, which is vulnerable to changes in future climate. Additionally, the main rivers passing through Uzbekistan are considered as transboundary rivers, which may generate unexpected transboundary issues on water distribution during the water shortage period foreseen in the fu-

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ture. For this reason, it is strongly advised by the international governments to use hydrological models like the SWAT model to promote integrated water resources management, considering all interests of Central Asian countries (Hornidge et al. 2011). The main findings of this study could be served as a considerably attentive input to the initiatives of the government of Uzbekistan on water management in the future.

4 Conclusions

According to IPCC AR5, the future climate is anticipated to have increased temperature and decreased precipitation in the Central Asian region, especially in countries located in arid zone, and our research results for the future period showed the expected trends with respect to changes in climate variabilities. In the next thirty years, the temperature in the Ugam watershed is forecasted to increase; meanwhile the precipitation is expected to decline. This analysis served to get better insights into possible changes in the future climate in the study area. Afterwards, the calibrated and statistically validated outputs, serving as an input to the SWAT model were used for the future simulation and accordingly, streamflow in the Ugam watershed is foreseen to decrease for the next three decades. Because, using the SWAT model we predicted a decrease in the amount of precipitation and an increase in the rate of the air temperature. Predicted dynamics of the climate variables are assumed to be caused by the high rate of emissions, indicated in RCP 8.5 scenario. Overall, the SWAT model gave a moderate contribution on this issue. According to the targeted objective function, we got a modest value, which exceeded the objective function with performing five iterations. Of course, if additional iterations were executed, the value standing for the objective function would be extreme for the case study.

The following recommendations were proposed, which derived from the outcomes of the current research and identified drawbacks in discussion for the future research. Firstly, it is recommended to calibrate and validate the model using more than 2 years to reach the best values for objective functions. For this purpose, it is advised to collect more data such as climate and observed discharge from multiple weather and gauging stations as possible in the existing sampling locations. In addition, using more relevant parameters with appropriate ranges for calibration is recommended. Secondly, it is recommended to use the local land-use map instead of the global land-use map to increase the accuracy of the model outputs and accordingly, it is advised to create own land-use map by using detailed land classes and observing study area. Last, but not least, it is recommended to use a local soil map to model studies on the hydrological cycle to get better results possibly derived from the model instead of the world soil from the global open datasets. In this case, it is advised to use the local soil atlas to create the local soil map.

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