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Separation of the Impact of Landuse/Landcover Change and Climate Change on Runoff in the Upstream Area of the Yangtze River, China

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Abstract
Landuse/landcover change (LULCC) and climate change (CC) impacts on streamflow in high elevated catchments are very important for sustainable management of water resources and ecological developments. In this research, a statistical technique was used in combination with the Soil and Water Assessment Tool (SWAT) to the Upstream Area of the Yangtze River (UAYR). Different performance criteria (e.g., R^2, NSE, and PBIAS) were used to evaluate the acceptability of the model simulation results. The model provided satisfactory results for monthly simulations in the calibration (R^2; 0.80, NSE; 0.78 and PBIAS; 22.3%) and the validation period (R^2; 0.89, NSE; 0.75 and PBIAS; 19.1%). Major landuse/landcover transformations from 1990 to 2005 have occurred from low grassland to medium grassland (2%) and wetlands (0.9%), bare land to medium grassland (0.2%), glaciers to wetland (16.8%), and high grassland to medium grassland (5.8%). The results show that there is an increase in average annual runoff at the Zhimenda station in UAYR by 15 mm of, which approximately 98% is caused by climate change and only 2% by landuse/landcover change. The changes evapotranspiration are larger due to climate change as compared to landuse/landcover change, particularly from August to October. Precipitation and temperature have increased during these months. On the contrary, there has been a decrease in evapotranspiration and runoff from October to March which depicts the intra-annual variations in the vegetation in the study area.

Keywords Climate change · Land cover · Land use change · Mann Kendall · Qinghai Tibet · SWAT model · Yangtze River

1 Introduction

Changes in hydrological processes caused by anthropogenic activities like landuse/landcover change and climate change have resulted in multiple environmental problems (Li et al. 2019; Mittal et al. 2016; Wang and Cheng 2001b; Wang et al. 2007b, 2014; Yang

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et al. 2019; Zhang et al. 2019, 2016). Rapid urbanization and human activities have a significant impact on landuse and landcover (Zhou et al. 2013). Landuse/landcover change (LULCC) and climate change (CC) ultimately have adverse effects on sustainable development and water resources planning and management (Tekleab et al. 2014).

Many researchers investigated the impacts of LULCC on hydrological processes across the world (Asl-Rousta et al. 2018; Chen et al. 2014; Gong et al. 2019; Marhaento et al. 2017a; Martínez-Salvador and Conesa-García 2020; Nadalromero et al. 2016; Setti et al. 2020; Tian et al. 2014; Wang et al. 2014; Woldesenbet et al. 2017; Zuo et al. 2016). These studies focused on the changes in hydrological processes within river basins using hydrological models (Fossey et al. 2016; Marhaento et al. 2017b; Sajikumar and Remya 2015). Some studies used hydrological models in combination with traditional statistical methods (like Mann Kendall and regression analysis) (Wagner and Waske 2016; Woldesenbet et al. 2017; Xiaolian 2014; Yan et al. 2013, 2017; Zhang et al. 2014). These studies showed the impacts of landuse/landcover changes on hydrological systems for at basin level. However, few studies have paid attention to the attribution of changes in runoff (Yan et al. 2017; Zuo et al. 2016).

Recently some researchers concluded that impacts of LULCC and CC on streamflow in different regions differed due to variations in soil type, topography, anthropogenic activities, and climatic conditions (Chang et al. 2014; Wang et al. 2017; Zuo et al. 2016). Brun and Band (2000) stated that human developments increased streamflow and high floods, whereas it decreased variability in streamflow. Brandes et al. (2005) and Kim et al. (2002) found an increase in the extent of impermeable land cover which led to different impacts on baseflow and runoff. Moreover, Shi et al. (2014) evaluated that the rise in grassland has a negative impact on streamflow in downstream areas compared to upstream areas of the Luanhe River basin in China. Similarly, (Zuo et al. 2016) and Yan et al. (2017) concluded that LULCC has spatially varying effects on streamflow of the Loess Plateau of China. Henceforth, the impacts of LULCC on the hydrological cycle may differ among various regions with distinctive hydrological characteristics.

The impacts of LULCC and CC on runoff were evaluated by for instance (Hu et al. 2015; Karlsson et al. 2016; Ma et al. 2009; Marhaento et al. 2018; Tomer and Schilling 2009). They reported that changes in landuse/landcover play a vital role in the variation of runoff, especially in subtropical areas. However, Chung et al. (2011) concluded that runoff changes significantly more due to climate change compared to landuse/landcover in the Anyangcheon watershed in Korea. Li et al. (2012) found that LULCC mainly influences runoff as compared to CC. Changming et al. (2003) and Daofeng et al. (2004) described that the runoff is primarily affected by CC in the source regions of the Yellow River. Wang et al. (2018) reported more significant impacts of LULCC on runoff as compared to CC in the Yangtze River delta. Therefore, it is evident from these studies that the impacts of LULCC and CC in different study areas replicate that different river basins experienced different impacts of climate change and landuse/landcover change due to differences in landuse/landcover and other geographical characteristics. Therefore, there is a need to conduct a study in the study area that evaluates the main factors contributing to streamflow changes. Therefore, this study separates the impacts of climate change and landuse/landcover change on streamflow in the Upstream Area of the Yangtze River (UAYR).

Floods frequently occurred in the Yangtze River basin, causing lives and property losses (Ge et al. 2013; Wang et al. 2015; Wei et al. 2013a). The assessment of future changes in streamflow for this river basin is very important for the strategic planning and management of water resources. Therefore, the quantification of LULCC and CC impacts on runoff in the source regions of the Yangtze River is critical to investigate the flow regime behavior due to climatic variability and landcover transformations. In this research, the Upstream Area of the Yangtze River (UAYR) was simulated using the semi-distributed physically-based Soil and Water Assessment Tool (SWAT). The main focus was on the separation of the impact of landuse/landcover change (LULCC) and climate change (CC) on runoff by using the statistical technique "One Factor at A Time" (OFAT) combined with the SWAT model. The questions addressed in this research were; a) how has the climate and landuse/landcover changed from 1985 to 2016? and b) what are their relative contributions to the runoff in UAYR? Though, the novelty of this study to address these questions is defined as 1); the application of a statistical conceptual framework and a semi-distributed hydrological model in UAYR, 2); to suggest the modeling approach to assess the importance of climate change and landuse/landcover change for runoff changes in the UAYR and 3); to understand the dominant factor which controls the runoff in the UAYR.

2 Material and Methods

2.1 Study Area

The Yangtze River is the world's third and china's longest river with a drainage length of 6300 km. The Upstream Area of the Yangtze River (UAYR) is located in the middle of the Qinghai Tibetan Plateau between longitudes 90°30′ E–97°15′ E, and latitudes 32°30′ N–35°50′ N. The total area of the UAYR is 137,000 km^2 upstream of Zhimenda gauging station (Ahmed et al. 2020b), which is 17% of the area of the Qinghai Tibetan Plateau. There are 753 glaciers, which contribute 20% of the total runoff volume of the entire Yangtze River (Mao et al. 2016). The landcover consists of medium grassland, natural forest, natural lakes, permafrost, and seasonally frozen soils (Dong et al. 2002; Wang and Cheng 2001a; Wang et al. 2007a; Yang et al. 2002). There has been an increasing trend during 1964-2014 in the temperature variables (i.e., maximum, minimum, mean temperature, and diurnal temperature range); however, this increase is more pronounced in high elevated areas as compared to lower elevations in the UAYR (Ahmed et al. 2020a). Precipitation has also increased by 1.3 mm year^{-1} for the Zhimenda sub-basin (Ahmed et al. 2020b). The river flow at Zhimenda hydrological station is mainly influenced by precipitation variations (Ahmed et al. 2020b). Daily climatic data were collected from the China Meteorological Department and monthly streamflow data from the Yangtze River Authority.

2.2 Modified Mann-Kendall Test and Sen's Slope Estimator

The Modified Man-Kendall (MMK) test (Yue and Wang 2004) and Sen's slope estimator (Sen 1968) were used for the detection and quantification of trends in hydro-meteorological variables, respectively. The significant values of ρk were used for calculation of a correction factor $\frac{n}{n_s^*}$.

$$\frac{n}{n_s^*} = 1 + \frac{2}{n(n-1)(n-2)} \times \sum_{k=1}^{n-1}(nk-k)(n-k-1)(n-k-2) \tag{1}$$

where "n" is the number of observations, "n_s*" is the "effective number of observation counts for autocorrelation", and *"k"* is the autocorrelation function for the rank of the observations. Details of the MMK test are provided in Yue and Wang (2004) and details of Sen's slope estimator in Sen (1968).

2.3 Soil and Water Assessment Tool (SWAT)

SWAT is a semi-distributed hydrological model developed by (Arnold and Fohrer 2005). It has been widely applied to simulate and predict hydrological processes by using the water balance principle with varying soil and land use types and management strategies in large and complex basins (Abbas and Xuan 2019; Chung et al. 2011; Jin et al. 2019a, b; Karlsson et al. 2016; Li et al. 2019; Oliveira et al. 2019). It can also be used in small agricultural watersheds to simulate soil erosion and loss (Hussain et al. 2019). SWAT divides a basin into its several sub-basins, and each sub-basin is further divided into several hydrological response units (HRUs). An HRU is a homogeneous combination of landuse/landcover, soil, and slope of the catchment The SWAT model calculates the water balance for each HRU and accumulates outflows from all HRUs at the outlet level of the basin. The water balance equation and more detailed explanation is provided in Abbaspour et al. (2007), and Zhang et al. (2019).

The SCS-CN (Soil Conservation Service-Curve Number) method was used for estimating surface runoff using daily rainfall, while evapotranspiration was calculated by the Penman-Monteith equation and flow routing with the Muskingum method in SWAT. The ArcGIS SWAT (ArcSWAT-2012) model was applied to the UAYR, and the study area was divided into 17246 HRUs and 790 sub-basins (Fig. 1). Figure 2 shows the data sets

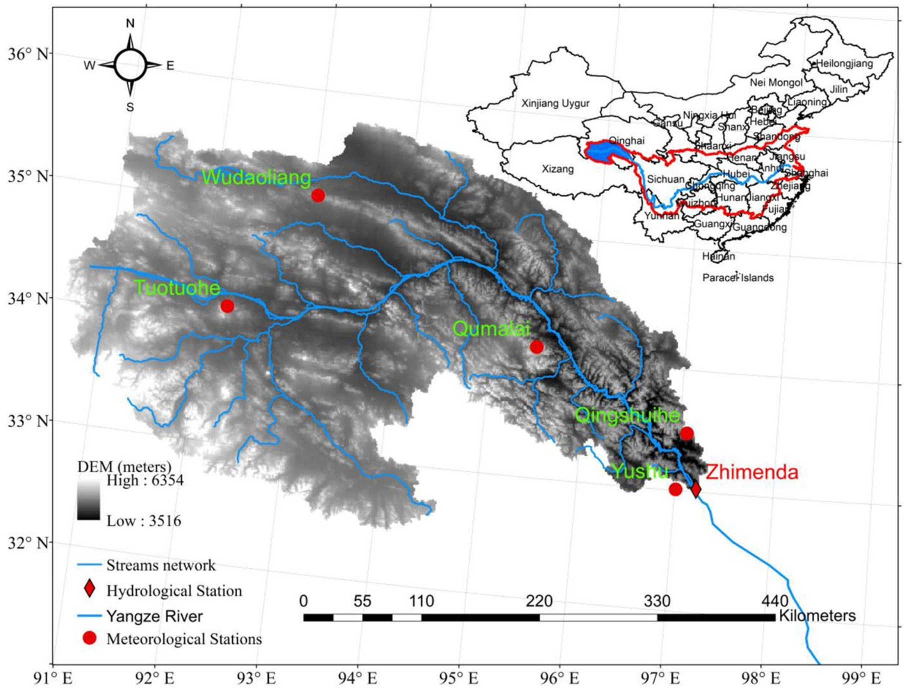

Fig. 1 Study area with hydro-meteorological stations in the Upstream Area of the Yangtze River (UAYR)

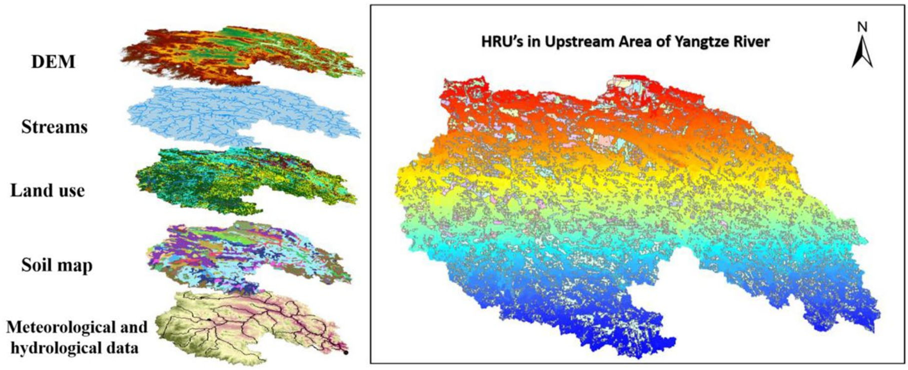

Fig. 2 SWAT modeling input raster and forcing data sets

required as input for the SWAT model simulation. The SWAT model input database used for this study is provided in Table 1.

2.4 Model Calibration and Validation

The monthly streamflow data of Zhimenda station from 1985-2000 are used for calibration and the data from 2001-2016 for validation. The spin-up period is from 1980-1984. The auto-calibration tool, SWAT-CUP with the Sequential Uncertainty Fitting version 2 (SUFI-2) algorithm, was used for calibration (Abbaspour 2013). The model was calibrated repeatedly with eight iterations and 500 simulations for each iteration on a daily basis. First, the initial ranges of the parameters were determined, and iterations were carried out until the optimal values of each parameter were obtained. The calibration was carried out to achieve acceptable values of the coefficient of determination (R^2) as objective function, and additionally the Percentage bias (PBIAS) and Nash-Sutcliffe Efficiency (NSE) as evaluation criteria in the calibration and validation period (Moriasi et al. 2007).

$$R^2 = \frac{\left[\sum_{i=1}^{N}(Q_{OBS,i} - Q_{MEAN}) - (Q_{OBS,i} - Q_{MEAN})\right]^2}{\sum_{i=1}^{N}\left(Q_{OBS,i} - Q_{MEAN}\right)^2 \sum_{i=1}^{N}\left(Q_{SIM,i} - Q_{MEAN}\right)^2} \tag{2}$$

$$PBIAS = \frac{\sum_{i=1}^{N}\left(Q_{SIM,i} - Q_{OBS,i}\right)}{\sum_{i=1}^{N} Q_{OBS,i}} \times 100 \tag{3}$$

$$NSE = 1 - \frac{\sum_{i=1}^{N}\left(Q_{OBS,i} - Q_{SIM,i}\right)^2}{\sum_{i=1}^{N}\left(Q_{SIM,i} - Q_{MEAN}\right)^2} \tag{4}$$

where $Q_{OBS,i}$, Q_{MEAN}, and $Q_{SIM,i}$ are observed, mean observed, and simulated flows, respectively. The NSE defines the scattering of observed and simulated values on a 1:1 scale line on a graph, while a value of 1 is the best fit (Nash and Sutcliffe 1970). Negative and positive values for the percentage bias (PBIAS) represent the model's under and over-estimation, whereas a value of zero is the ideal condition (Moriasi et al. 2007).

Table 1 SWAT Input Database

Data Type	Description	Available Sources	Data Period / Resolution
Climate data	Temperature (Maximum, Minimum, Mean), Relative Humidity, Windspeed, Solar Radiations and Precipitations	China Meteorological Administration (CMA)	Daily observed data (1980-2016)
Hydrological data	Monthly Streamflow data	Yangtze River Basin Authority	Monthly observed data for Zhimenda gauging station (1980-2016)
Digital Elevation Model (DEM)	SRTM	The China Archive http://www.igsnrr.ac.cn	1:250,000
Landcover/Landuse map raster	Landsat TM/ETM	Data Center for Resources and Environmental Sciences Chinese Academy of Sciences (RESDC)	1:100,000
Soil map raster	Harmonized World Soil Database V 1.2 (HWSD) which is 30 arc-second databases	Food and Agriculture Organization (FAO) of the United Nations.	1:1,000,000

2.5 Scheme for Separation of Climate Change and Landuse/Landcover Change Impacts

Climate change and Landuse/Landcover change are two largely independent factors (Zhang et al. 2008), and both of these might cause changes in the hydrological response of a river basin. To separate the impact of CC and LULCC on runoff, we adopted the "One Factor at A Time" (OFAT) approach (Yang et al. 2017a, b). Figure 3 presents the streamflow responses to landuse/landcover change and climate change. Changes in streamflow due to CC for two landuse/landcover patterns (L1 and L2) are ΔQ_{C1} and $\Delta Q_{C2.}$ ΔQ_{C1} will be closer to ΔQ_{C2} when there is a smaller change in landuse/landcover (ΔL), i.e., a smaller difference between L1 and L2. The average of ΔQ_{C1} and ΔQ_{C2} is used to denote the impact of CC on hydrological processes (ΔQ_C). Similarly, changes in hydrological components due to landuse/landcover changes under climatic conditions C1 and C2 are $\Delta Q_{L1,}$ and $\Delta Q_{L2,}$ respectively. The average of ΔQ_{L1} and ΔQ_{L2} denoted as ΔQ_L represents the change due to LULCC. Equation (7) describes the total change in the flow regime (ΔQ).

$$\Delta Q_C = \frac{1}{2}(\Delta Q_{C1} + \Delta Q_{C2}) = \frac{1}{2}(Q_{C2}^{L1} - Q_{C1}^{L1}) + (Q_{C2}^{L2} - Q_{C1}^{L2}) \quad (5)$$

$$\Delta Q_L = \frac{1}{2}(\Delta Q_{L1} + \Delta Q_{L2}) = \frac{1}{2}(Q_{C1}^{L2} - Q_{C1}^{L1}) + (Q_{C2}^{L2} - Q_{C2}^{L1}) \quad (6)$$

$$\Delta Q = \Delta Q_L + \Delta Q_C = Q_{C2}^{L2} - Q_{C1}^{L1} \quad (7)$$

Meteorological data for the periods 1980-2000 (C1) and 2001-2016 (C2) were selected in this study. The landuse/landcover maps of 1990 and 2005 represent the landuse/landcover patterns for the two periods, namely L1 and L2, respectively. In Fig. 3; C_1 (1985-2000), C_2 (2001-2016), L_1 (1990), and L_2 (2005) are the climate and landuse/landcover input in two periods. ΔC and ΔL are the climate change and the land use/cover change during the two periods. The hydrological component (i.e., runoff or evapotranspiration) values at point A, B, C, and D are Q_{C1}^{L1}, Q_{C1}^{L2},Q_{C2}^{L2}, and Q_{C2}^{L1}, respectively. A

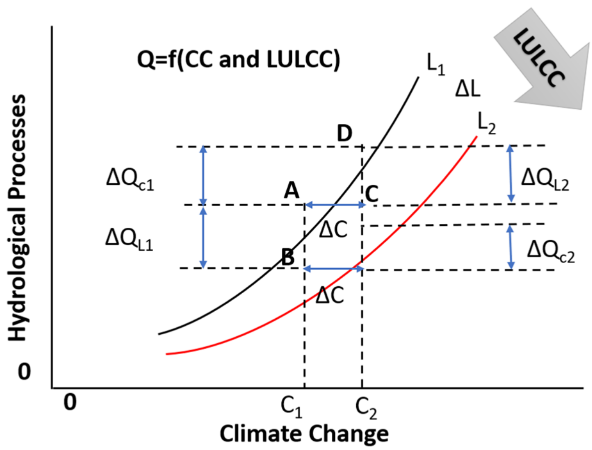

Fig. 3 A schematic diagram of separating the effects of climate change and landuse change on hydrological processes. (modified from Yang et al. (2017a, b)

calibrated SWAT model was applied to each of the four scenarios derived from these two climate data periods and two landuse/landcover maps (Fig. 4).

3 Results and Discussion

3.1 Changes in Hydrological and Meteorological Variables

The annual mean streamflow at Zhimenda hydrological station, total annual precipitation, and annual mean temperature was derived from monthly time series. Decadal trend magnitudes of these hydro-meteorological variables during 1980–2016 are shown in Fig. 5. A decreasing insignificant ($P>0.05$) trend for annual precipitation was found during the first decade (1980-1990), whereas all other decades showed significantly ($P<0.05$) increasing trends. The highest increase was found during the 2000-2010 period (89.3 mm per decade), followed by 85.2 mm per decade during the 2011-2016 period.

For annual mean air temperature, during 1980-1990, 1990-2000, and 2010-2016 decades, a decreasing trend was found, while for 2000-2010, an increasing trend was observed. Insignificant ($P>0.05$) trends were found during 1980-1990 and 1990-2000, whereas during the 2000-2010 and 2010-2016 decades, significant trends in mean temperature were observed. A significant trend of 1.32 ℃ per decade during 2000-2010 and -0.70 ℃ per decade occurred during 2010-2016.

Annual streamflow decreased during 1980-1990 and 2011-2016 decades, while for 1990-2000 and 2000-2010, it increased. The significantly increasing trend rate was 91.7 m^3 sec^{-1} $decade^{-1}$ during 2000-2010, and a significantly decreasing trend with a magnitude of -129.9 m^3 sec^{-1} $decade^{-1}$ was observed during 2010-2016.

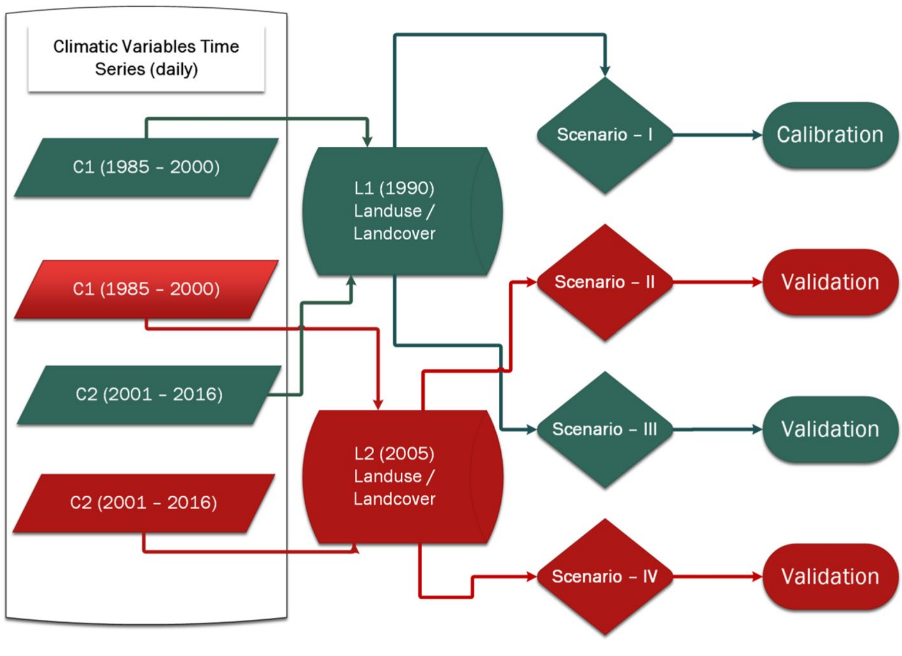

Fig. 4 Schematic diagram adopted for SWAT modelling results of all scenarios

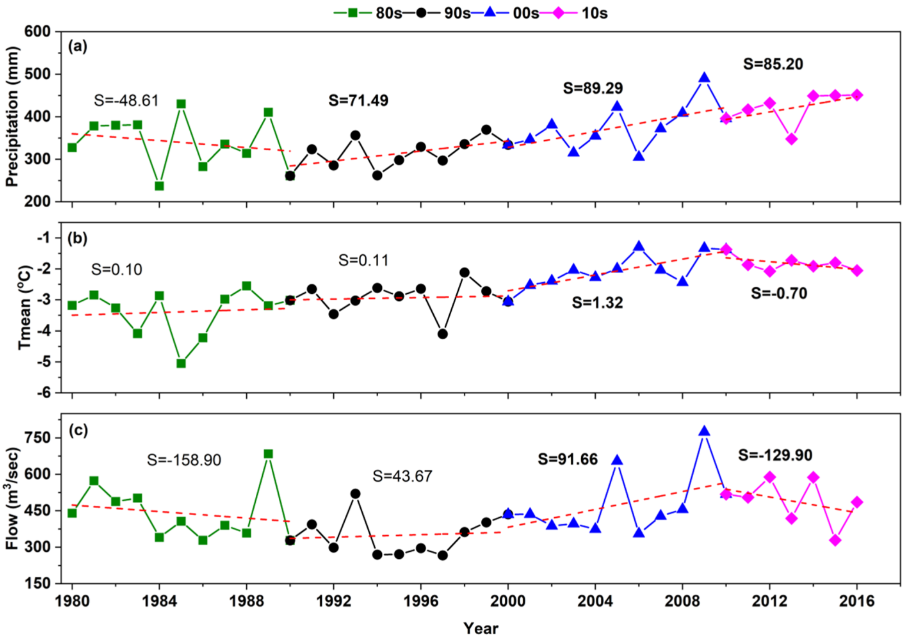

Fig. 5 Temporal changes in annual precipitation (mm/decade), temperature (℃/decade) and runoff (m^3/sec/decade) from 1980 – 2016. S denotes the trend magnitude per decade whereas bold values represent a significant at 0.05 confidence level

The MMK test was carried out for the entire study period to analyze statistical reliability, and the results are presented in Table 2. The monthly precipitation significantly increased ($P<0.05$) in February, May, June, October, and November, whereas it decreased significantly in December. On the other hand, temperature found significantly increasing trend throughout the year and the magnitude of this rising trend was larger during the winter months (January, February, and December) compared to the rest of the year. Mean monthly flows showed insignificant trends during May, July, and December, while for the rest of the year, they have a significantly increasing trend (Table 2).

3.2 Changes in Landuse/Landcover

Table 3 and Fig. 6 show the landuse/landcover changes (LULCC) in the Upstream Area of the Yangtze River (UAYR) between 1990 and 2005. The dominant landuse/landcover was low grassland with more than 45% coverage. Bare land is the second dominant landuse/landcover in both periods, covering about 24%. Medium grassland, water, high grassland, and wetlands are the other significant landcover types in the UAYR (Table 3). The landuse/landcover during 1990 was compared to the landuse/landcover in 2005, and it was found that the area with low grassland, water, high grassland, shrub, and sparse woodland has decreased by 105 km^2, 87 km^2, 78 km^2, 19 km^2, and 4 km^2, respectively. Moreover, the area with medium grassland, bare land, and wetland has increased by 113 km^2, 84 $km^2$and 46 km^2, respectively.

Table 2 Modified Mann Kendall test statistic results of precipitation, mean temperature and streamflow during 1980-2016

	Precipitation (mm)		Temperature (°C)		Streamflow (m^3/sec)	
Month	**Z**	**Trend / Decade**	**Z**	**Trend / Decade**	**Z**	**Trend / Decade**
Jan	-0.48	-0.05	6.08	**0.78**	3.00	**4.2**
Feb	2.5	**0.22**	9.83	**0.92**	3.09	**2.7**
Mar	0.13	0.01	7.89	**0.36**	2.92	**3.7**
Apr	1.43	0.68	6.25	**0.46**	4.03	**14**
May	7.40	**4.49**	8.49	**0.32**	1.92	14.6
Jun	8.58	**4.46**	7.68	**0.42**	3.55	**35**
July	1.80	6.01	12.47	**0.57**	-0.28	-16.7
Aug	4.58	**6.21**	12.07	**0.56**	3.30	**97.8**
Sep	1.03	1.23	6.06	**0.45**	2.84	**82.4**
Oct	4.54	**2.09**	6.86	**0.38**	2.21	**46.4**
Nov	4.9102	**0.36**	6.0268	**0.48**	3.32	**19.3**
Dec	-2.4353	**-0.19**	7.0196	**0.62**	1.49	3.70

Bold values show the significantly increasing/decreasing trends at a 5% confidence level

A LULCC transformation matrix is presented in Table 4 and Fig. 7, which shows the transformations of the different landuse types. Keeping in view the objective of this study, we focused on the transformation of the major landuse/landcover changes. These major landuse/landcover changes may have significant impacts on hydrological processes. This analysis showed that high grassland has changed to bare land (603.6 km^2), low grassland (559.1 km^2), and medium grassland (351.28 km^2), which can be attributed to large-scale deforestation programs in early 2000 (Liang et al. 2015). Bare-land has increased mainly by the transformation from low grassland (5182.7 km^2), medium grassland (2433. 8 km^2), and water (943.9 km^2). Feng et al. (2015) reported that the changes in unused land were caused by climate change.

Table 3 Changes in landuse and landcover in the Upstream area of the Yangtze River (USYZ) between 1990 and 2005

Landuse /Landcover	1990s		2005s		Change	
	Area (km^2)	**Area (%)**	**Area (km^2)**	**Area (%)**	**Area (km^2)**	**Area (%)**
Dry land	55	0.040	62	0.04	7	0.005
Natural Forest	21	0.015	21	0.02	0	0.000
Shrub	355	0.25	336	0.24	-19	-0.014
Sparse woodland	106	0.08	102	0.07	-4	-0.003
High grassland	4127	2.94	4049	2.88	-78	-0.056
Medium grassland	26536	18.91	26649	18.99	113	0.081
Low grassland	63534	45.28	63429	45.21	-105	-0.075
Water	6745	4.80	6658	4.74	-87	-0.062
Glacier	1187	0.84	1212	0.86	25	0.018
Settlement	13	0.009	15	0.01	2	0.001
Bare land	33867	24.14	33951	24.20	84	0.060
Wet land	3761	2.68	3807	2.71	46	0.033

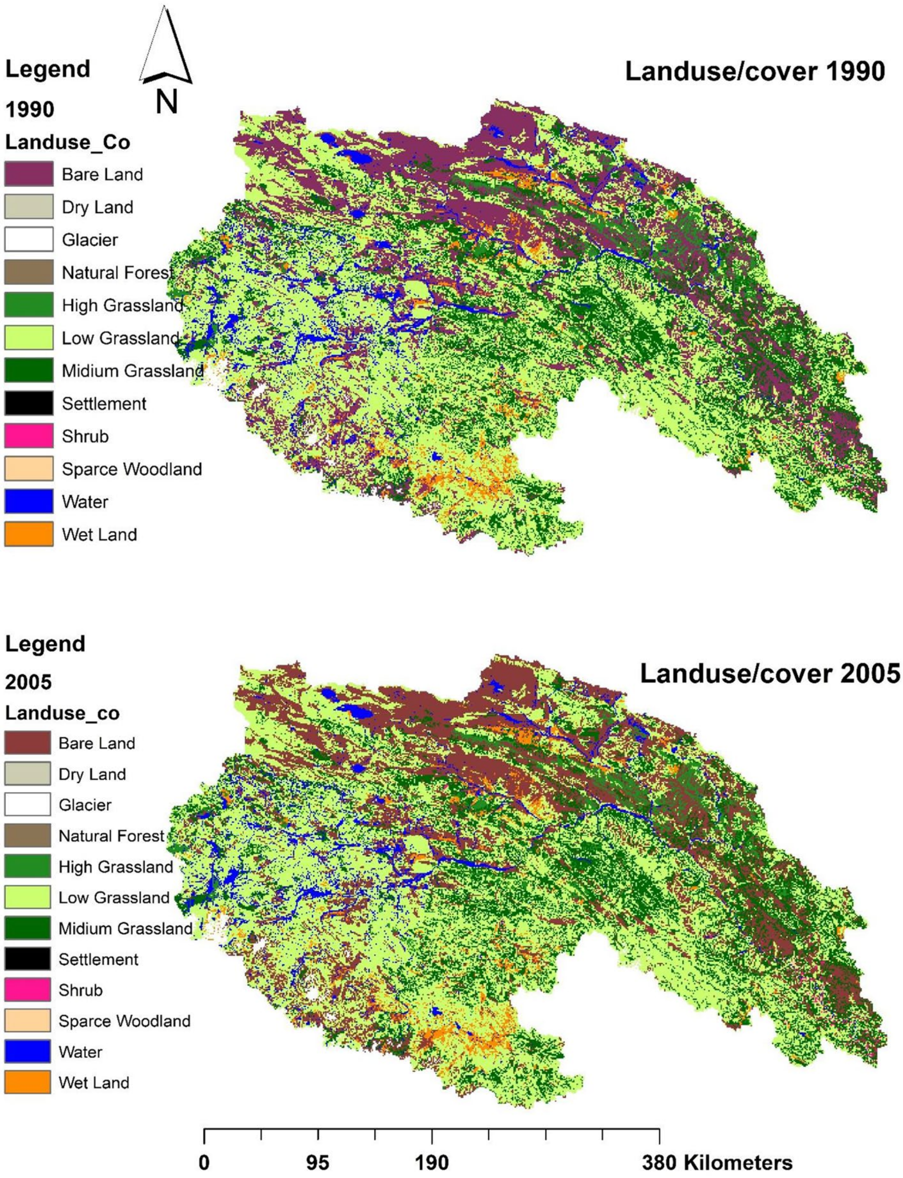

Fig. 6 Land use/cover pattern for 1990 and 2005 in the Upstream Area of the Yangtze River (UAYR)

Dominant landuse/landcover transformations, having changed particular landuse types with more than 15 km^2 from 1990 to 2005, are presented in Table 5. These dominant landuse changes were mainly from low grassland to medium grassland, low grassland and sparse woodland to wetlands (unused land), high grassland to medium grassland, and medium grassland to water. Most of these changes will ultimately increase the canopy cover, which leads to more transpiration, interception, and less streamflow.

Table 4 Landuse/landcover transformation matrix from 1990 to 200 in USYZ

		Landuse/ Landcover 2005 (km^2)												
	Transformation Matrix	**Bare Land**	**Dry Land**	**Glacier**	**Natural Forest**	**High Grassland**	**Low Grassland**	**Medium Grassland**	**Settlement**	**Shrub**	**Sparse Woodland**	**Water**	**Wet Land**	**Grand Total**
Landuse/ Land-cover 1990 (km^2)	**Bare Land**	24079	3	149	1	604	5170	2489	1	31	8	929	393	33856
	Dry Land	0	14	0	0	0	22	14	0	2	0	2	0	54.28
	Glacier	135	0	845	0	4	132	11	0	0	0	4	37	1168
	Natural Forest	2	0	0	9	0	1	8	1	0	0	0	0	20
	High Grassland	640	1	4	0	2404	554	388	0	0	0	55	21	4068
	Low Grassland	5183	20	175	0	559	48514	7433	3	93	17	1936	979	64912
	Medium Grassland	2434	7	6	8	351	7328	14936	5	113	25	390	239	25841
	Settlement	1	3	0	0	0	2	5	0	0	1	1	0	12
	Shrub	12	6	0	1	5	87	140	4	73	3	8	0	340
	Sparse Woodland	5	0	0	1	0	14	38	0	7	42	0	0	105
	Water	944	6	2	1	42	2027	339	0	2	3	2718	105	6189
	Wet Land	448	0	14	0	36	933	231	0	0	0	85	1819	3565
	Grand Total	33882	60	1196	20	4004	64786	26030	13	320	99	6128	3592	140135

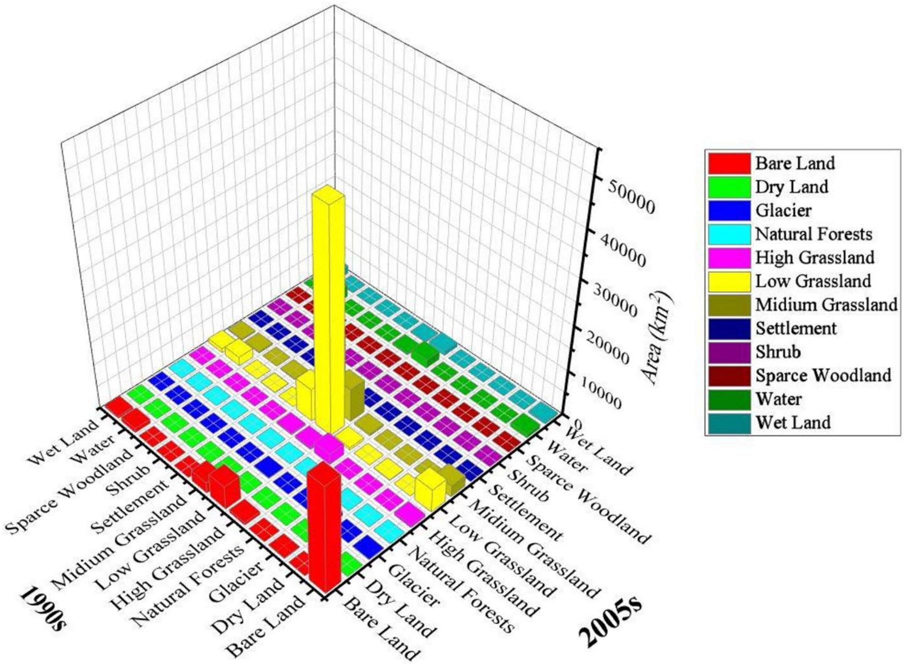

Fig. 7 Transition of landuse/landcover from 1990 to 2005 in UAYR

3.3 Model Calibration and Validation

Simulated runoff is overestimated (e.g., in August 1989 and August 1993) and underestimated (e.g., in August 2005 and September 2014) during peak flows (Fig. 9). The monthly R^2, NSE, and PBIAS values for the calibration period (1985-2016) are 0.80, 0.78, and 22.3%, respectively, and for the validation period (2001-2016), the R^2, NSE, and PBIAS values are 0.83, 0.75 and 19.1%, respectively (Fig. 8, Table 6). These results indicate that the SWAT model is a robust simulation tool that can be used to simulate hydrological processes and to assess climate change and landuse change impacts in the upstream area of the Yangtze River. The results presented in Table 6

Table 5 Major landuse/landcover transformations from 1990 to 2005 in USYZ

Major LULCC Transformations	Net Changed Area (km^2)	Area changed (%)
Low Grassland to Medium Grassland	104.5	2.0
Bare Land to Medium Grassland	54.9	0.2
Medium Grassland to Water	51.2	2.1
Low Grassland to Wet Land	45.8	0.9
High Grassland to Medium Grassland	36.9	5.8
Glacier to Wet Land	22.8	16.8
Sparse Woodland to Wet Land	20.1	427.4
Bare Land to Shrub	18.2	0.1

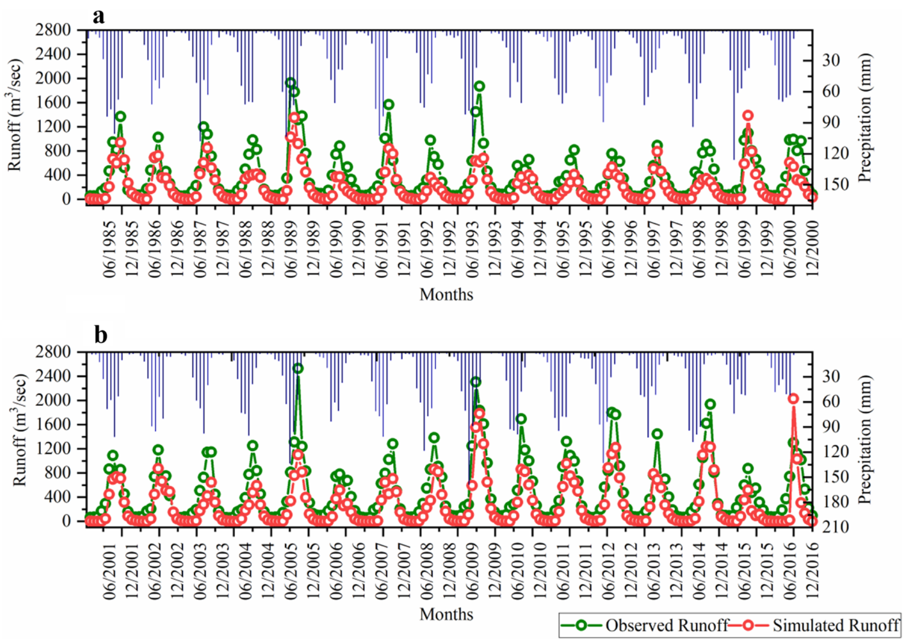

Fig. 8 Monthly observed and simulated runoff and observed precipitation during (**a**) Calibration period (1985-2000), (**b**) Validation period (2001-2016))

indicate that the water balance and the basic rainfall-runoff relationships, including the intra-annual variabilities, are well captured. The results of selected performance criteria are within the range of "good performance," as classified by Moriasi et al. (2007) and provided in Table 7.

3.4 Impacts of Climate Change and Landuse/Landcover Change on Runoff

In this study, the impacts of climate change (CC) and landuse/landcover change (LULCC) on streamflow were determined using simulated results rather than observed data (Yang et al. 2017a). Table 8 presents the simulated streamflow for all four scenarios, as described in the methodology section. It shows the combination of different LULCC and CC impacts for 1990 and 2005. The impact of climate change on runoff was estimated by using Eq. (5) using the differences between scenario I and II, and scenario III and IV. The results show an increase in runoff by 15 mm, which is approximately 98% of the change in average annual runoff at Zhimenda station in UAYR. The LULCC impact on runoff was estimated by using Eq. (6). The results reveal that landuse/landcover change also increased runoff, but by only 0.3 mm, which accounts for approximately 2% of the change in average annual runoff in UAYR. These findings reveal that the impact of climate change is much larger as compared to landuse/landcover change in the UAYR.

The intra-annual variations in ET and runoff are presented in Fig. 9. It is noteworthy that there is a significant increase in ET and runoff from August to October, while there is a remarkable decrease in ET and runoff values in May to July due to climate change

Table 6 Optimal values with their ranges for sensitive parameters used in calibration

Sr. No.	Parameters	Optimal Value	Min. Value	Max. Value
1.	r__CN2.mgt	-0.5	-0.7	0.2
2.	v__ALPHA_BF.gw	0.4	0	1
3.	v__GW_DELAY.gw	30	70	150
4.	v__GWQMN.gw	0.9	0	2.5
5.	v__SMFMX.bsn	8	6	23
6.	v__SMFMN.bsn	2.5	5	14
7.	v__SMTMP.bsn	2	0	8
8.	v__SFTMP.bsn	1	-6	2
9.	v__TIMP.bsn	0.6	0	1
10.	v__ESCO.hru	0.95	0	1
11.	v__HRU_SLP.hru	0.5	0	1
12.	r__SOL_K().sol	0.1	-0.5	1
13.	r__SOL_BD().sol	1.25	-0.3	1
14.	v__SNOCOVMX.bsn	58	0	200

CN2 Moisture condition SCS curve number, *ALPHA_BF* Baseflow recession constant, *GW_DELAY* Groundwater delay coefficient (days), *GWQMN* Threshold water level in shallow aquifer for base flow (mm), *SMFMX* Melt factor for snow in June (mm H2O/˚C-day), *SMFMN* Melt factor for snow in December (mm H2O/˚C-day), *SMTMP* Snow melt base temperature (˚C), *SFTMP* Snowfall temperature (˚C), Snowpack temp lag factor, *ECSO* Soil evaporation compensation factor, *HRU_SLP* average slope steepness, *SOL_K* Saturated hydraulic conductivity (mm/h), *SOL_BD* Soil bulk density (g/cm-3), *SNOCOVMX* Areal snow coverage threshold at 100%. "v" and "r" at the start of each parameter represents parameter value is "replaced a given value" and "multiplied by (1+ a given value)" respectively

(Fig. 9a). However, the lowest values of ET and runoff are observed in June. Precipitation and temperature have also significantly increased during these months (i.e., May-July). The ET values are positively correlated with the runoff changes due to CC from August to October. The variations in ET and runoff due to LULCC are shown in Fig. 9b. ET and runoff values are gradually increasing from May to September, however they are decreasing from October to March, which illustrates the intra-annual variations in the vegetation in the study area. Moreover, ET and runoff are also positively correlated from May to September as it is the growing season in the study area.

These increasing and decreasing values of runoff and evapotranspiration are a clear representation of intra-annual variations of precipitation. During the study period, the transformation of landuse/landcover from lower grassland to medium grassland and wetland could have led to an increase in evapotranspiration (Yang et al. 2017a). The impact of climate change on runoff is higher as compared to landuse/landcover change, which is inconsistent with the findings of (Hu et al. 2015; Karlsson et al. 2016; Ma et al. 2009; Tomer and Schilling 2009).

They investigated that changes in landuse/landcover play a vital role in the variation of runoff, especially in (sub)tropical areas. However, Changming et al. (2003) and Daofeng

Table 7 Performance criteria results for calibration and validation of SWAT model

Period	R^2	NSE	PBIAS
Calibration (1985-2000)	0.80	0.78	22.3%
Validation (2001-2016)	0.83	0.75	19.1 %

Table 8 Simulated average annual precipitation (mm), runoff (mm) and under different Climate Change (CC) and Landuse/Landcover change (LULCC) scenarios

Scenarios	Climate data	Landuse/ Landcover	Precipitation (mm)	Runoff (mm)	ΔQ due to CC and LULCC (mm)		Runoff change Percent%
S1	1985-2000	1990	330.2	52.9	-	-	-
S2	1985-2000	2005	331.3	53.4	ΔQ_C	15.0	98
S3	2001-2016	1990	376.6	68.1	ΔQ_L	0.3	2
S4	2001-2016	2005	376.6	68.3	ΔQ	15.3	100

et al. (2004) concluded that runoff is mainly affected by climate change in the source regions of the Yellow River, and this is similar to the findings of this study for the upstream area of the Yangtze River. The findings of Wang et al. (2018) in the delta area of the Yangtze River are also consistent with the findings of our study. It is evident from these studies that these two factors (landuse/landcover and climate) resulted in different impacts on hydrological processes in various study areas depending on the spatial heterogeneity of these factors and the characteristics of the study areas (size, slope, soil types, etc.).

This study reveals that the results of the separation of climate change and landuse/landcover change impacts on runoff were more accurate and acceptable (Hu et al. 2015; Wei et al. 2013b). A comprehensive approach that combines the effects of landuse/landcover and climate change is essential to assess the impact on hydrological processes. The

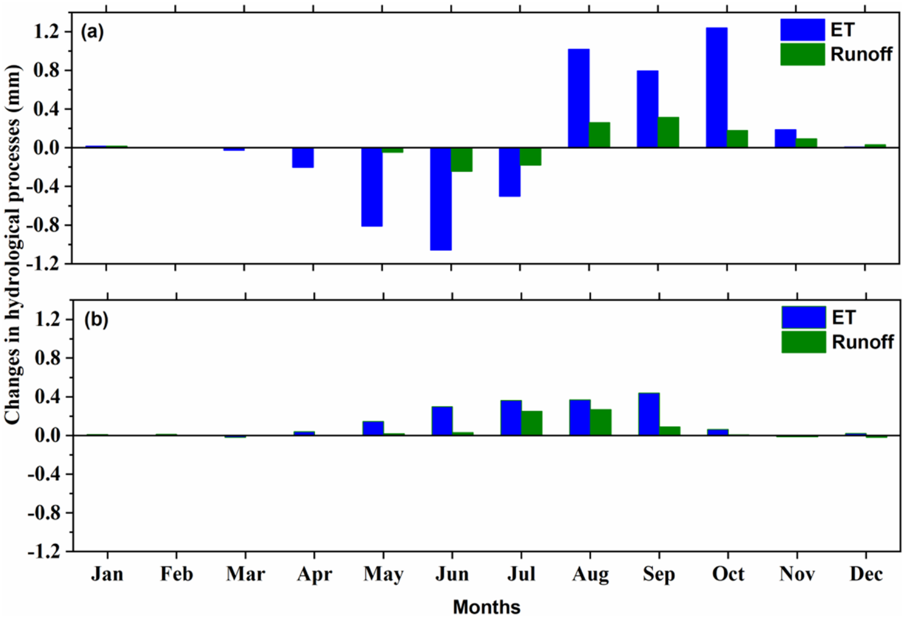

Fig. 9 Monthly changes in the evapotranspiration and runoff due to (**a**) Climate change, (**b**) Landuse/Landcover change

various uncertainties may affect the modeling results and the identification and separation of impacts. For example, parameter selection is an important source of uncertainty in most hydrological models, which may affect the separation (Li et al. 2009; Tian et al. 2014). Moreover, selecting the appropriate hydrological model will also affect the results (Karlsson et al. 2016). It is preferable to use multiple models in future studies to analyze the separation of climate change and landuse/landcover impacts on runoff.

4 Conclusion

In the present study, the SWAT model was used to separate the impacts of climate change and landuse/landcover change on runoff in the Upstream Area of the Yangtze River (UAYR). This research combines the robustness of the SWAT model for the separation of the two driving factors and statistical approaches. The main conclusions achieved from this study are:

- There has been an increase in average annual runoff at Zhimenda station in UAYR of 15 mm in the period 1985-2016, where approximately 98% of the change has been caused by climate change and only about 2% has been caused by landuse/landcover change.
- There has been a significant increase in evapotranspiration (ET) and runoff from August to October, while there has been a remarkable decrease in ET and runoff values in May to July due to climate change.. Precipitation and temperature have also significantly increased during these months.
- Simulated runoff is overestimated (e.g., in August 1989 and August 1993) and underestimated (e.g., in August 2005 and September 2014) during peak flows. The Objective function (R^2) was 0.80 and 0.83 for calibration and validation period, respectively. In addition, NSE and PBIAS found 0.78, 22.3 % (for calibration) and 0.75 and 19.1% (for validation) respectively.

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Authors Contributions N. Ahmed designed the research, highlighted the problem, formulated the research plan. N. Ahmed., M.J. Booij, S. Xiangyang, and F. Hussain analyzed the data. G. Wang., M.J. Booij helped in interpretation of results and supervised the study. M.J. Booij and G. Nabi helped in the model development and analysis of results. Original draft was written by N. Ahmed. whereas; G. Wang., M.J. Booij, and G. Nabi, reviewed the draft paper. N. Ahmed., G. Wang. and M.J. Booij finalize the research paper. G. Wang also provide the financial resources and also supervised this study. All authors confirm the final version of paper for submission to journal. All authors have read and agreed to the published version of the manuscript.

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Availability of Data and Materials The digital elevation model, soil raster map and the software (SWAT Mode) used in this study is freely available and can be accessed from the websites given in data section of the manuscript. The climatic parameters and streamflow data is the property of China Meteorological Department and Yangtze River Authority, respectively and can be requested to these departments via official channels.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no conflict of interest.

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