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Quantitative impacts of climate change and human activities on the runoff evolution process in the Yanhe River Basin

Yingxin Lian [a,1], Miao Sun [a,1], Jichao Wang [a], Qinghua Luan [b], Mengyan Jiao [a], Xining Zhao [c,**], Xuerui Gao [c,*]

[a] College of Water Resources and Architectural Engineering, Northwest A&F University, Yangling, Shaanxi, 712100, China
[b] Hebei University of Engineering, School of Water Conservancy and Hydroelectric Power, Taiji road19#, Handan, Hebei Province, China
[c] Institute of Soil and Water Conservation, Northwest A&F University, Yangling, Shaanxi, 712100, China

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ABSTRACT

Since 1999, the surface vegetation coverage in the Yanhe River Basin has undergone constant change. The ecological environment in the basin has improved partially; however, water scarcity remains a critical issue for the Loess Plateau. The current quantitative analysis of runoff evolution affected by climatic and anthropogenic elements in the study area is insufficient. To evaluate the influence of anthropogenic elements and climatic variation on runoff evolution, we used the SWAT hydrological model to study key hydrological processes under different simulation scenarios along the river basin in this study. Overall, the runoff volume of the Yanhe River Basin showed a significant downward trend, although different trends were observed over different periods. Runoff declined from 1981 to 1998 and increased after 1998. A comparative analysis of three different scenarios shows that climate change contributes approximately twice as much to runoff evolution as land use changes. Climate change causes runoff to decrease by 65.64%, whereas land use change causes runoff to increase by 34.36%. The decrease in runoff in small watersheds is primarily due to climatic factors, whereas vegetation restoration is beneficial to the increase in runoff in small watersheds. The research results will be valuable in comprehending the quantitative influence of climatic and anthropogenic factors on the hydrological evolution of the Yellow River Valley.

1. Introduction

The improvement of water resources in the Yellow River basin will be conducive to the development of regional ecological environment, and directly promote the healthy development of social economy in the region (Wang et al., 2016; Nicoll and Brierley, 2016). Human activities and climatic variation are the primary factors affecting streamflow evolution (Mukherjee et al., 2019). Climate change affects the terrestrial water circulation system through variations in temperature, precipitation, and other factors, thereby affecting the hydrological runoff process. Anthropogenic activities have correspondingly increased with the domestic economy growth, altering the original land use type, structure, and land cover mode. The influence of anthropogenic activities on the hydrologic cycle and water balance are in constant flux. Afforestation, restoration of farmland to forest, construction of hydraulic structures, large-scale activities such as irrigation and drainage, and urbanization and industrialization inevitably affect the land cover type to varying degrees and influence the hydrological processes and water resources. This is known as the land utilization/cover change (LUCC) effect on water circulation (Usman et al., 2015). Anthropogenic activities affect hydrology via LUCC, water-soil retention measures, rainwater storage engineering, and changes in the flow generation mechanisms in the basin underlayer. In this paper, the influence of anthropogenic activities mainly refers to the variations in LUCC caused by afforestation.

Sloping farmland is the principal form of farmland in the Yellow River watershed, and its land utilization structure is quite irrational (Gao et al., 2016). Furthermore, sloping farmland is prone to water and soil erosion. The annual water loss per Mu is up to 2,040 m^3, resulting in increasingly barren land and a delicate ecological balance. The Yellow River watershed experiences subtle climatic variations (Jiang et al.,

* Corresponding author.
** Corresponding author.
E-mail addresses: Zxn@nwsuaf.edu.cn (X. Zhao), gaoxuerui666@163.com (X. Gao).

[1] these authors contributed equally to this work.

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2018). Global warming has resulted in precipitation decrease and evaporation increase in the Yellow River watershed, and drought is exacerbated. By 2030, evaporation in inland river areas is expected to increase by approximately 15%, which will far exceed the increase in precipitation (Brutsaert et al., 2017). This will result in a reduction of the gross volume of water resources, exacerbating the disequilibrium of supply and demand. It has been demonstrated that actual runoff of Yellow River watershed has continuously declined since the 1980s due to surface acidification and a general decrease in watershed precipitation (Zhao et al., 2017). A decline in runoff will generate a sequence of environmental problems, e.g., degradation of aquatic ecology downstream, increase of the inundation threat and waterlogging disasters, and shortage of domestic, industrial, and agricultural water (Shi and Wang, 2015).

The Yellow River watershed is the dominant watershed area of Northwest and North China, and is one of the regions with the most drastic transformations in hydrological features (Gao et al., 2016). Anthropogenic activities and recent climate change have become the most influential constraints affecting ecological restoration. To further resolve the issue of water scarcity in the Loess Plateau, quantitative separation of the influence of anthropogenic factors and climatic variation on streamflow evolution is imperative. In recent years, domestic and foreign researchers have conducted substantial research on this issue. Wu et al. (2017) considered that climatic and anthropogenic factors have diverse impacts on different watersheds during the same period and on the same watershed during different periods. In the Shiyang River watershed, a relatively arid area in northern China, the influencing factors of climate change account for ≥64% of the change in runoff due to decreased rainfall and increased evapotranspiration (Huo et al., 2008). However, in the Dongjiang River of southern China, the effects of anthropogenic activity and climatic factors on runoff evolution were found to be almost identical (Lin et al., 2012). Many scholars have studied the effects of anthropogenic and climatic factors on streamflow evolution in diverse regions of Yellow River watershed. Anthropogenic and climatic influences on streamflow in the Beiluo River watershed were analyzed using measured and simulated natural streamflow information. The results show that climatic transformation is the principal factor resulting in decreased streamflow in the Beiluo River Basin in recent years (Yang, 2011). However, in the Huangshui River watershed, anthropogenic factors played a leading role in reduced runoff, with a contribution rate of up to 64.54% (Zhang et al., 2014). Similarly, the dominant factors contributing to the prominent decline in streamflow in the midstream over the past 60 years were anthropogenic, including the implementation of water–soil retention measures, operation of hydraulic engineering, and consumption of water resources (Zheng et al., 2010). Thus, in diverse regions of the Yellow River watershed, the runoff responses to climatic factors and anthropogenic influences are different.

The loess hill and gully region is semi-arid area. It occupies the highest proportion of land area on the Loess Plateau. The Yanhe River lies in the midstream of the Yellow River. It is in the middle loess hill and gully region of the Loess Plateau. The main characters in the watershed are the greatest water scarcity and soil erosion (Guo et al., 2016). The vegetation coverage conditions and land utilization pattern in the Yanhe River Basin have changed significantly since 1999 when the farmland afforestation project was implemented (Peng et al., 2010). However, currently, research on the mechanism of hydrological effects on the Loess Plateau under a changing environment (such as climatic variations and anthropogenic factors) is still insufficient, especially regarding the quantitative influence of the water cycle; this requires further research and discussion. Therefore, it is important to conduct targeted research in the Yanhe River Basin. This may form a reference for understanding the mechanisms influencing the hydrological processes in a larger region.

Due to the complexity of the mechanisms of climatic variation and anthropogenic factors affecting the water cycle and the interrelationships among the influencing factors, the simple water balance model cannot accurately simulate the water cycle process in a changing environment, and is often unable to effectively separate the influence of any two factors on the elements of the water cycle. The hydrological model refers to a mathematical model for describing the hydrological process, which has good prospects for application in the problems of climatic variation and hydrology (Peterson et al., 2009; Karlsson et al., 2016). Double cumulative curve method (DMC), SCS curve method, VIC model, and SWAT model have been the most widely used of these hydrological models. The SWAT model is a distributed hydrological simulation tool with great potential for the simulation of long-term surface runoff, non-point source pollution, and hydrological response in changing environments, and has been widely used globally (Zhao et al., 2016). In previous studies, the simulation tool was proven to be applicable in arid and semi-arid regions, including the Yellow River region in China (Gao et al., 2020).

Climatic data from the Yan'an and Ansai stations were collected and the climatic change trends were analyzed. The hydrological model (SWAT) was verified using runoff observation data of the local hydrologic station. The watershed hydrological model was used to simulate the runoff process from 1980 to 2012. The intention was to determine the runoff evolution trend in diverse climatic and land utilization conditions to effectively distinguish the quantitative influences of climatic variation and anthropogenic elements on runoff. The anthropogenic activities in this research are different from other studies. The effects of anthropogenic elements on runoff in this study is mainly consider the change of land use/land cover after afforestation and the implement of Grain for Green Project. By calculating and comparing the runoff simulation results of three different scenarios, the quantitative influences of climatic variation and anthropogenic elements on the streamflow of Yanhe River basin were revealed.

2. Materials and data

2.1. Study area

The Yanhe River is a tributary of the Yellow River with a geographic location of 36°21–37°19′ N and 108°38′–110°29′ E, which is located in the middle region of the Yellow River (see Fig. 1). The length of the Yanhe River is approximately 286.9 km, with a drainage area of approximately 7725 km^2. The typical climate of the area is characterized by arid and windy springs with alternating cold spells and changing temperatures. The mean annual precipitation is 520 mm, 70% of which occurs in the rainy season, gradually decreasing from upstream to downstream. The mean annual streamflow volume in the basin is 2.89 million m^3. The primary soil type in the Yanhe River Basin is yellow soil,

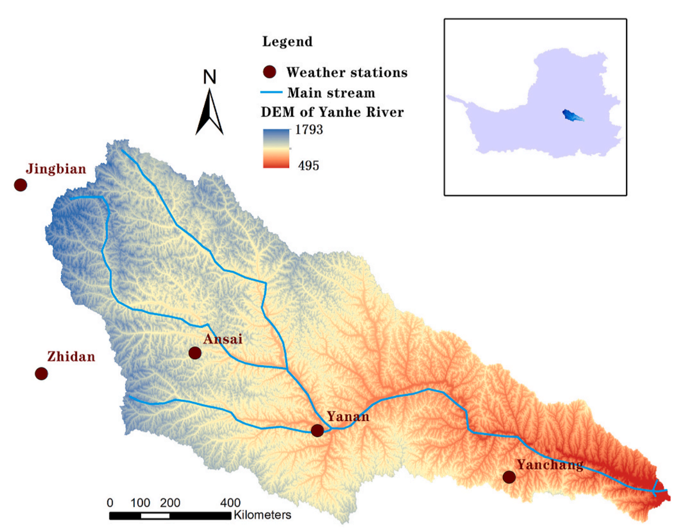

Fig. 1. Map of the Yanhe River Basin.

comprising 85% of the soil. The remainder consists of small amounts of scattered red soil, silt, and black soil. There are 14 principal vegetation species in the Yanhe Basin, and vegetation coverage increases from north to south. The land utilization patterns include forest, agricultural, and grassland.

2.2. Data

Land utilization information, soil data, measured hydrologic runoff data, and climatic information were collected in this study for analysis and simulation.

1) Land-use data, from 1980 until 2010, were obtained from the National Earth System Science Data Sharing Infrastructure (http://www.geodata.cn).
2) Soil information was obtained from the China Soil Database (http://gis.soil.csdb.cn/).
3) Ganguyi Hydrographic Station is a control hydrographic station in the research basin. The hydrological model was corrected and validated using monthly measured streamflow information obtained from the local water authority from 1980 to 1990.
4) r.The meteorological information (1980–2012) was downloaded from the China Meteorological Science Data Sharing Service Center (CMDC), including daily average air pressure, precipitation, sunlight duration, evaporation, etc. The Yan'an and Ansai meteorological stations are in the research area.

3. Methodology

3.1. Mann–Kendall test

The non-parametric Mann–Kendall (M–K) test was used to evaluate the significance of monotone trends in the time series of climatic and hydrological information. It is a frequently used trend test method (Yue et al., 2002). It is used to evaluate the variation trend of annual average precipitation, temperature, sunlight, and evaporation. The calculation method of the standardized test statistic Z is explained in the research of Donald and Mohamed (2002).

3.2. Methods for distinguishing the effects of land utilization and climatic variation on runoff

To distinguish the impacts of land utilization/cover and climatic elements on the runoff process, three scenarios were set in this study. S1 was used as the reference period (1981–1999), as the conversion of farmland to forest project began in 1999. There were few anthropogenic activities to transform land use types during this period, and therefore, it was considered that there was no anthropogenic influence in S1. S1 used land-use information from 1980 and meteorological information from 1981 to 1999. Subsequently, in the S2 scenario, the land utilization map of 1980 in the S1 scenario was replaced by that of 2010, while the other climatic parameters remained unchanged. In the S2 scenario, the runoff process was only affected by human activity. Finally, we set the simulation period to S3, which used meteorological information from 2000 to 2012 and land-use information for 2010. In the S3 scenario, the regional runoff process was affected by both climatic changes and underlying surface transformation.

The contribution of climatic variations and land-use transformation to streamflow evolution under the three scenarios is calculated as follows (Wang et al., 2010):

$$\Delta R_L = R_{S2} - R_{S1} \tag{1}$$

$$\Delta R_C = R_{S3} - R_{S2} \tag{2}$$

$$\Delta = |\Delta R_L| + |\Delta R_C| \tag{3}$$

$$\mu L = \frac{|\Delta R_L|}{\Delta} \times 100\% \tag{4}$$

$$\mu C = \frac{|\Delta R_C|}{\Delta} \times 100\% \tag{5}$$

where ΔR_L and ΔR_C represent the runoff change volume caused by land use transformation and climatic variation, respectively; R_{S1}, R_{S2}, and R_{S3} represent the runoff in scenarios S1, S2, and S3, respectively; and μL and μC represent the contribution ratio of land utilization transformation and climatic element to runoff evolution, respectively.

3.3. SWAT model

SWAT is a geographical information system (GIS)-based distributed watershed hydrological model and a tool for soil water assessment. Since the introduction of the model, it has been rapidly developed and applied, undergoing continuous improvement in recent years. In previous studies, the SWAT model has shown good applicability to arid and semi-arid regions.

The GIS interface facilitates the definition of watershed hydrological features and the simulation of hydrological units. The SWAT model is initialized with spatial distribution data such as topography, land use/vegetation cover, soil, land management, and meteorological information.

3.4. SWAT calibration and validation

3.4.1. Model setup

Based on the meteorological data from 1981 to 1999, the land utilization information of 1980 and the hydrological elements of the Yanhe River, a SWAT project was built as the base period (Scenario 1). With the establishment of the database, SWAT automatically divided the basin into 48 sub-basins and 770 HRUs by loading the DEM information, soil information, and land use/cover map of the Yanhe River watershed. After the basin was divided, we calculated the HRU of the study area through superposition analysis of land utilization, soil characteristics, and other factors. Together with previous work, we used the meteorological information to simulate the streamflow process.

3.4.2. Model calibration and validation

This study adopted the sequential uncertainty fitting program (SUFI-2) developed by Abbaspour et al. (2015) in the calibration and uncertainty programs to carry out uncertainty analysis of new theoretical methods and improve simulation accuracy.

The SUFI-2 algorithm reflects the uncertainty in the adjustment process of the calibration parameters, which is an optimization method of parameter estimation. The multivariate uniform distribution in the parameter hypercube was used to describe the parameter uncertainty, and the 95% predicted uncertainty band (95 PPU) of the output variable at the levels of 2.5% and 97.5% was used to quantify the output uncertainty. First, the SUFI-2 algorithm assumes a relatively large parameter fill-in space. Then, the range of uncertainties is gradually reduced while monitoring the changes in P and R. Each time the parameter range is changed, the sensitivity matrix and covariance matrix are recomputed. The parameters are then updated, and the next step is performed to bring the simulation value closer to the measured value. The most sensitive parameters are illustrated as in Table 1.

For model calibration and validation, the observed and simulated data sets were compared and evaluated using Nash–Sutcliffe efficiency (NS) and the coefficient of correlation (R^2) (Veith et al., 2007).

Table 1
Sensitivity parameters corrected for overall sensitivity analysis.

Order	Parameter	Best Parameters	t-Stat	p-Value
1	CN2	0.14	1.52	0.14
2	AL PHA_BF	0.83	1.43	0.16
3	GWQMN	1734.25	−1.84	0.07
4	GW_REVAP	0.22	−0.3	0.77
5	ESCO	0.15	1.37	0.18
6	OV_N	0.16	2.96	0.01
7	SLSUBBSN	170.64	4.45	0
8	EPCO	0.7	1.36	0.18
9	CN_N2	0.31	3.62	0
10	CN_K2	0.002	7.71	0
11	ALPHA_BNK	0.027	3.17	0
12	SOL_AWC	19.85	2.83	0.01
13	SOL_K	12.14	−17.1	0
14	SOL_BD	0.46	−2.19	0.04

4. Results

4.1. Climatic element analysis

Linear regression method was applied to analyze the variation trend of meteorological factors including the annual average precipitation, air temperature, sunlight duration, and evaporation in the Yanhe River Basin for a 30 years period beginning in 1980. The M–K trend test method was applied to calculate the Z value to explore the significance of the trend of meteorological factors. Fig. 2 shows the respective variation tendency of climatic factors during the past three decades.

Fig. 2 illustrates that at a 99% confidence level ($|Z| > 2.32$), the mean annual temperature displayed a significant upward trend ($Z = 4.33$). Meanwhile, at a 95% confidence level ($|Z| > 1.64$), the sunshine duration also showed an evident upward trend ($Z = 2.2865$) and increased at a rate of 8.56 h/year. The annual precipitation tended to decrease ($Z = -1.3135$) at a 90% confidence level ($|Z| > 1.28$). The average annual evapotranspiration in the Yanhe River Basin presented a modest upward trend ($Z = 0.1242$).

4.2. Land utilization transformation analysis

In this research, land use/cover data from 1980 to 2010 were applied in the simulation to analyze the influence of land utilization/cover transformation on the streamflow evolution in the research region. Comparing the land utilization/cover conditions of 1980 and 2010, there was an evident change in the proportion of grassland, forest land, and agricultural land after the enablement of afforestation project in the Yanhe River region (see Fig. 3). In 1980, agricultural land was the major land utilization pattern, accounting for 72.63% of the basin area. Forest land and farmland accounted for only 19.08% and 4.35% of the area, respectively. The proportions of bare land and water were small (0.9% and 3.04%, respectively). With the return of farmland to forest and grassland, from 1980 to 2010 agricultural land, bare land, and water dropped by 4312.68 km^2, 29.14 km^2, and 150.77 km^2, respectively, whereas forest land and grassland both showed substantial growth (Table 2). The percentage of agricultural land, bare land, and water in the Yanhe River watershed dropped to 15.94%, 0.52%, and 1.06%, respectively, whereas forest land and grassland accounted for 44.59% and 37.89% in 2010. Consequently, grassland replaced agricultural land as the principal land usage type in the Yanhe River Basin in 2010. In

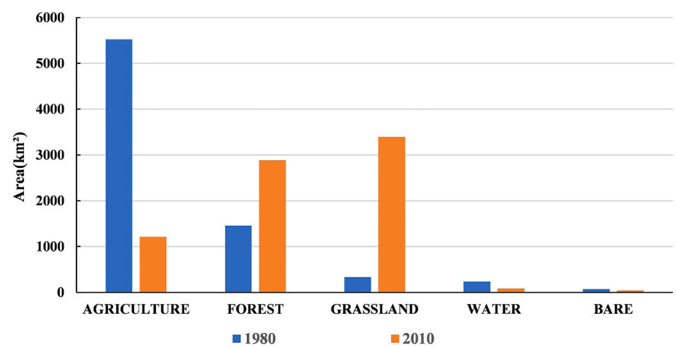

Fig. 3. Comparison of land use types in 1980 and 2010 in the Yanhe River Basin.

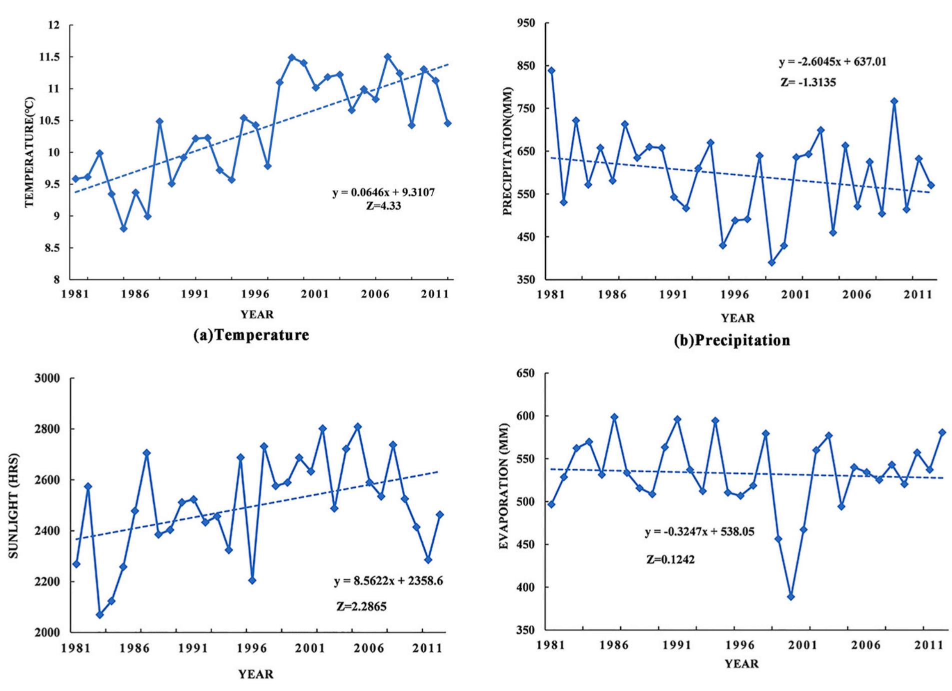

Fig. 2. Trends of the climatic factors.

Table 2
Land use/cover transformation in 1980 and 2010.

Land use	1980		2010		(km^2)
	Area (km^2)	Ratio (%)	Area (km^2)	Ratio (%)	
AGRICULTURE	5524.83	72.63	1212.15	15.94	−4312.68
BARE LAND	68.64	0.9	39.5	0.52	−29.14
FOREST	1451.53	19.08	2881.28	37.89	1429.75
GRASSLAND	330.75	4.35	3391.46	44.59	3060.71
WATER	231.56	3.04	80.79	1.06	−150.77

accordance with the changes in land utilization form and structure, the Sloping Land Conversion Program and Grain for Green Project significantly influenced ecological conservation and improvement of the region, and contributed to the protection of water resources.

4.3. Runoff variation analysis

According to the measured hydrological streamflow data during 1981–2012, linear regression method was used to analyze the streamflow variation trend in the study area.

In Fig. 4 (a), the average annual runoff showed a slight downward trend ($Z = -1.162$), decreasing slowly at a rate of 1.1445 m^3/s. Fig. 4(b) shows the runoff variation trend before and after the reforestation project implementation. Before 1999, the average annual runoff showed an evident downward trend ($Z = -3.53$) at a 99% confidence level ($Z < 2.32$). On the contrary, the average annual runoff showed a clear upward trend ($Z = 2.38$) after 1999 when the project was implemented.

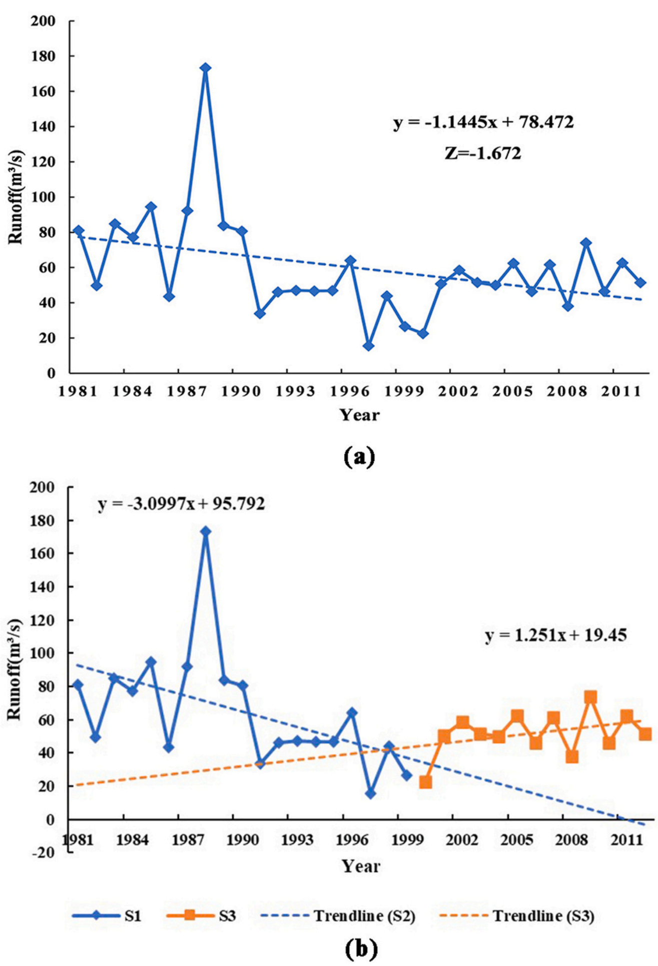

Fig. 4. Runoff change during 1981–2012.

Using the average annual runoff analysis result, we compared the two scenarios (S1, S3) with the simulated scenario (S2) to analyze the cause of this phenomenon.

4.4. Model calibration and validation

Due to limitations in the available hydrological data, the observed monthly streamflow data of the study area from 1991 to 2005 were not obtained. Thus, the hydrological data of 1981–1985 were applied to calibrate the model, and data from 1986 to 1990 were applied to validate the simulation tool. The monthly runoff simulation values of the Ganguyi Hydrological Station in S1 were calibrated and verified, and the comparisons between simulated and observed streamflow volumes are presented in Figs. 5 and 6. At monthly scale, the R^2 and NS of the calibration period were 0.84 and 0.55, respectively. In the verification period the values were 0.71 and 0.6, respectively. The results revealed that the simulated value conforms with the measured value, and the evaluation coefficient predicted by the model meets the evaluation criteria. The results of the model simulation can provide an effective reference value for research of the quantitative impact on streamflow evolution in the study area.

4.5. Quantitative effect of climate and land utilization variation in the Yanhe River region

According to previous studies, the decline of precipitation and the rise of temperature are possible climatic factors affecting runoff decrease in the watershed. As the precipitation decreased from 1980 to 2012, the flood season in S3 was drier than in S2, and the runoff in S3 was also generally less than that in S2, as shown in Fig. 7. Therefore, precipitation variation is the major climatic factor driving runoff evolution.

To express the influence of land utilization transformation on runoff evolution more intuitively, we subtracted the simulation results of S1 and S2. These results are shown in Fig. 8, which indicates that there is an evident runoff change in almost every flood season (between July and September). Due to the implementation of the project, the land cover type in the study area has undergone tremendous change, influencing the runoff evolution. For land use/cover type change, the greater the rainfall, the greater the runoff evolution.

To further analyze the respective effects of anthropogenic activity and climatic factors on runoff evolution quantitatively, this study compared the simulated runoff of S1 vs. S2 and S2 vs. S3, and calculated the results according to equation (7). The consequence is given as bellow.

Table 3 shows that under the circumstance of land use/cover transformation (S1 vs. S2), the runoff in the study area increased by 106 m^3 after the implementation of the project. The 34.36% increase in runoff was attributed to land-use transformation (human activities). In contrast, the runoff in the study area decreased by 65.64% under the

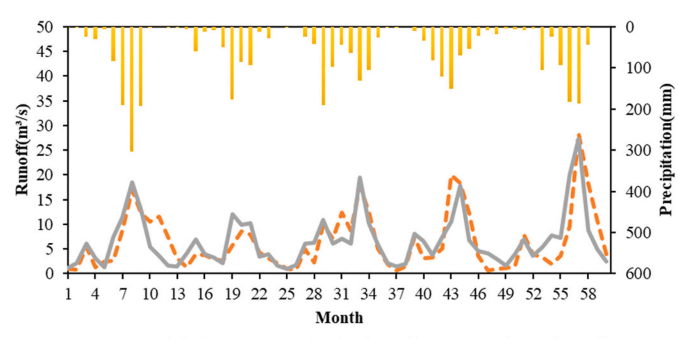

Fig. 5. Comparison of streamflow in the calibration period (1981–1985) at Ganguyi Station.

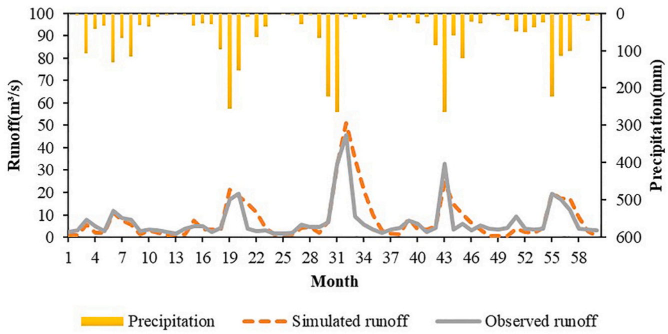

Fig. 6. Comparison of streamflow in the validation period (1986–1990) at Ganguyi Station.

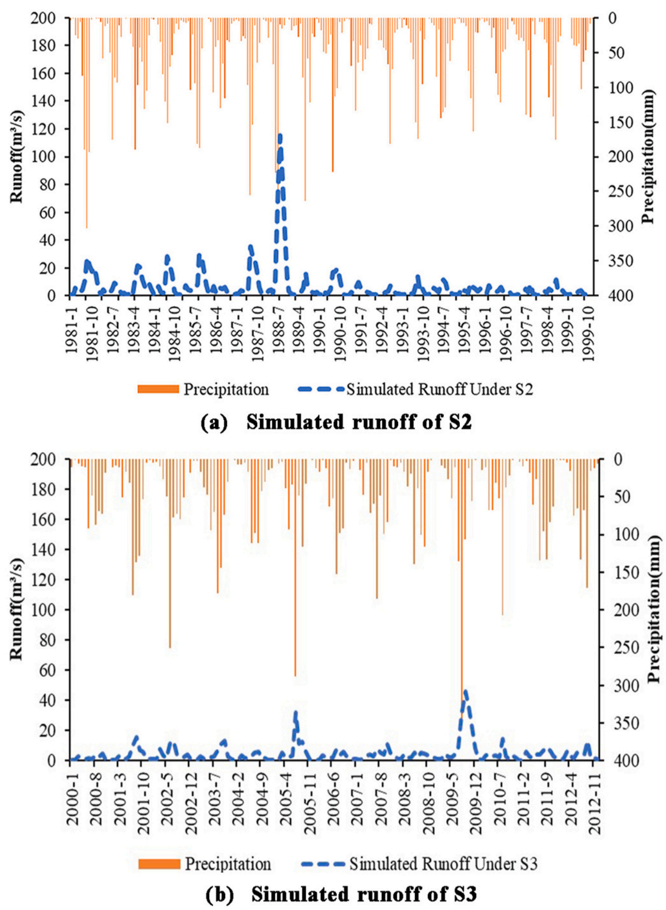

Fig. 7. Monthly simulated runoff in climate scenarios S2 and S3.

climate change condition (S2 vs. S3).

In general, the runoff change is complicated and affected by diverse factors. We focused on climatic variations and anthropogenic factors and quantitatively researched the effects of the disparate factors on streamflow evolution. Climatic variation and LUCC caused a 65.64% decrease and 34.36% increase in runoff change, respectively. Climatic factors had a major impact on runoff evolution, which almost doubled the contribution ratio of land use. Among all climatic factors, precipitation played a leading role in influencing runoff evolution. Therefore, to improve water–soil retention of the similar area, the impacts of climatic factors (especially precipitation) and anthropogenic factors on the runoff process should be considered synergistically in future water resource management.

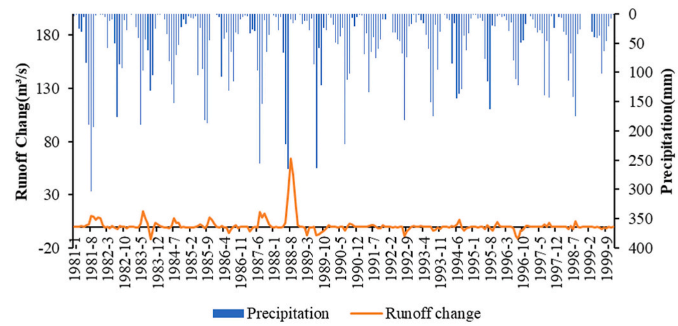

Fig. 8. Monthly simulated runoff change in land-utilization change scenarios S1 and S2.

Table 3
Quantitative effect of human & climate factors on runoff.

Region	Land use change	
The Yanhe River Basin	ΔR_L (10^8 m^3)	μR_L
	0.01	34.36%
	Climate change	
	ΔR_C (10^8m^3)	μR_C
	−0.02	−65.64%

5. Discussion

Recently, with the transformation of land use types, large-scale engineering construction, urbanization, rapid expansion, and other intense human activities, hydrological elements have undergone significant changes. This has resulted in increased pressure on water resource security and has posed many challenges to the regional hydrological cycle and water resource security. In this study, the hydrological response mechanism under changing environments was studied using a hydrological simulation tool. In the Yanhe River watershed, we quantitatively isolated the effects of anthropogenic activity and climatic factors on runoff evolution. Therefore, this research may be a reference of quantifying the influence of various factors on hydrologic process and understanding the evolution of streamflow more accurately in the Loess Plateau region in the future changing environment with climate change and increasing human activities. Other scholars have also conducted relevant studies on the factors affecting runoff evolution in the Yanhe River region.

Sanim et al. (2019) analyzed the effects of anthropogenic and climatic factors on streamflow in the Arys and Keles River watersheds (Kazakhstan). The results illustrated that the main reason for the decrease of annual runoff in the two basins is anthropogenic elements, and the decrease percentages range from 59% to 99%. The grassland area showed a sharp decline in both watersheds. From 1976 to 2015, the water requirement of cultivated land irrigation and residents in densely populated areas increased continuously, which led to the increasing water consumption in the basins.

Using 1952–1994 as the baseline period, Qiu et al. (2011) quantitatively researched the effect of precipitation variation and anthropogenic elements on streamflow evolution during 1995–2008. The results showed that the precipitation and runoff from 1995 to 2008 decreased by 11.1% and 27.3%, respectively. The impact ratio of precipitation variation and anthropogenic element to runoff reduction was 46.2% and 53.8%, respectively.

Similar to the study area in the research of Sanim et al. (2019), the Yanhe River is also in an arid and semi-arid region, but runoff is affected by human activities that are quite different from those described in Sanim's study. The effects of anthropogenic activity in Yanhe River watershed are mainly afforestation and artificial reforestation. The anthropogenic influences in Arys and Keles River basins include increased irrigation intake, increased domestic water consumption, and reduced vegetation coverage area. The change trends of runoff under the influence of different human activities differ significantly. The consequence of the research maybe useful for the future water resources protection and management in view of the current situation of the Loess Plateau.

Compared with the research consequence of Qiu et al., anthropogenic activities in Yanhe mainly consider the change of land use after afforestation. The percentage of agricultural land, bare land, and water in the Yanhe River watershed dropped to 15.94%, 0.52%, and 1.06%, respectively, whereas forest land and grassland accounted for 44.59% and 37.89%, respectively, in 2010. In addition, the calculation time period is different. Therefore, the streamflow in the Yanhe River region has increased under the influence of anthropogenic factors. The results show that vegetation restoration measures are beneficial to the increase in runoff.

The other reason for the inconsistency between the conclusions of this study and those of other studies may be the adoption of different periods of meteorological information and land-use data in the research process as well as the difference in research methods. In contrast to other studies, this study used runoff data from 1980 to 1990 for calibration and verification of the hydrological tool and used land use data from 1980 to 2010 and meteorological data from 1980 to 2012 to quantify the effects of different elements on streamflow process. In addition, the uncertainty of model parameters could contribute to inconsistent output results in contrast with other studies. In the application of watershed hydrological models, climatic variation scenarios, and anthropogenic activity scenarios, the uncertainty of climate models, hydrological models, and downscaling methods were not given sufficient consideration. Additional research is required to quantify these uncertainties to assess the future influence of climatic and anthropogenic elements on the hydrological cycle more rationally and comprehensively.

6. Conclusions

The SWAT model was applied to distinguish the quantitative the effects of anthropogenic activity (LUCC) and climatic factors on runoff evolution in this research. The primary conclusions are as follows:

(1) In the three decades from 1980 to 2010, the climatic condition had transformed significantly in the study watershed. The temperature showed an increase trend, whereas the precipitation gradually decreased. Meanwhile, the sunshine duration increased at a rate of 8.56 h/year. The average annual evapotranspiration presented a subtle escalating trend.

(2) After the implementation of the project, the land utilization/cover status of the watershed changed prominently. The percentage of agricultural land, bare land, and water in the Yanhe River Basin dropped to 15.94%, 0.52%, and 1.06%, respectively, whereas the forest land and grassland both showed substantial growth trends, which accounted for 44.59% and 37.89%, respectively, from 1980 to 2010. Consequently, in 2010, grassland replaced agricultural land to become the dominant land utilization form in the Yanhe River watershed.

(3) Streamflow in the study area presented an overall downward trend significantly from 1980 to 2010, although it showed different trends during different periods. The streamflow demonstrated a decreasing tendency from 1981 to 1998, but showed an increase from 1998 to 2010.

(4) The anthropogenic factors and climatic variation in the watershed significantly affected the runoff process. Through the comparative analysis of three different scenarios, the results showed that climate change contributed approximately twice as much to runoff as land utilization. Climate variation led to a 65.64% decrease of watershed streamflow, whereas land utilization transformation led to a 34.36% augmentation. The consequence indicate that climatic variation may be the principal element causing runoff decline, anthropogenic factors are beneficial to the increase in runoff.

(5) The change trends of runoff under the influence of different human activities differ significantly. The effects of anthropogenic activity considered in this research are mainly afforestation and artificial reforestation. The consequence indicate that vegetation restoration measures and the enablement Grain for Green are beneficial to the increase in runoff.

Author contributions

Research Design and Organization, X.G.; Data Processing and Writing—Original, J.W and M.J.; Data Interpretation, Draft modification, Writing—Review, Editing and revising, Y.L. and M.S.; Data Preparation, Q.L.; Supervision and Funding Acquisition, X.G. and X.Z. All authors have read and agreed to the published version of the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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