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RESEARCH ARTICLE

Impact of climate change and human activities on economic values produced by ecosystem service functions of rivers in water shortage area of Northwest China

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Abstract
Climate change and human activities are affecting the ecological health of rivers and the economic value of its ecosystem services. Taking water quantity as the intermediate variable, we proposed a quantitative calculation method for the impact of climate change and human activities on the economic value produced by the ecosystem service functions of rivers. The framework mainly consists of three steps: firstly, we quantitatively determined the changes in the amount of water coming from rivers due to climate change and human activities; secondly, combining the theory of resource and environmental economics to calculate the economic value generated by ecological service functions of rivers; finally, we quantitatively identified and analyzed the impact of climate change and human activities on the economic value produced by the ecosystem service functions of rivers. Taking Baoji section of Weihe River (BSWR) as an example, we quantitatively analyzed and calculated the impact of climate change and human activities on the economic value produced by ecosystem service functions of rivers. The main conclusions of this paper are as follows: in recent 52 years, the economic value produced by the ecosystem service functions of rivers decreased by 3.57 billion yuan due to the climate change and human activities; the total economic value has been reduced by an average of 68 million yuan per year. This useful work can not only reveal the impact of climate change and human activities on the economic value of ecosystem services of rivers but also can provide an important basis for the reasonable management model of water resource of ecosystem of rivers watershed.

Keywords Climate change and human activities · Economic values · Ecosystem service functions · Baoji section of Weihe River · Northwest China

Introduction

Climate change and human activities will have an impact on the economic value of service functions of rivers ecosystems in water shortage area of Northwest China. Water resources in rivers not only have economic functions that can promote socio-economic development (Gopal 2016; Xu et al. 2016; Gómez et al. 2014) but also have ecological functions that can maintain human daily life and river ecological health (Yue et al. 2018; Yang and Yang 2014), and these economic and ecological functions can produce corresponding economic value (Cheng et al. 2019; Gopal 2016). In recent years, in order to continuously pursue the direct economic benefits for themself, and they built more and more water conservancy projects and forced conversion of river water resources (mainly refers to the conversion of ecological water into economic water) (Pang et al. 2013), coupled with the impact of climate change on river water resources in Northwest China in recent years (Wu et al. 2017; Zhan et al. 2014b; Zhang et al. 2012b; Piao et al. 2010), leading to changes in the ecosystem service functions of rivers and their economic value. And this impact is often negative in Northwest China, which lead to the loss of some ecosystem service functions in rivers and its economic value to be severely reduced. Therefore, we urgently need to determine the impact of climate change and human activities on the economic value generated by the ecosystem service functions of rivers.

In recent years, many important research reports on the impact of climate change and human activities on runoff coming from rivers (Van Vliet et al. 2016; Grafton et al. 2013;

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Vörösmarty et al. 2000) and the economic value of ecosystem service function of rivers have already been issued (Yue et al. 2018; Sonia Akter et al. 2014). Such as, Piao and co-workers (Piao et al. 2010) made a detailed description of climate change in northwest China and a quantitative description of the impact of climate change on the water resources; Huang and his co-workers (Huang et al. 2015) studied the impact of human activities on the Weihe River which is a typical river in northwest China, and they found that human activities had the greatest impact on the runoff change; Yue and her co-workers (Yue et al. 2018) analyzed the ecological service functions of environmental base flow and used the theory of economics of resources and environment to calculate the economic value produced by ecological service functions of environmental base flow. Ecosystem service functions of rivers are closely related to the amount of water resources coming from rivers (Xu et al. 2016; Gopal 2016), so climate change and human activities will inevitably have a certain impact on the economic value of ecosystem service functions of rivers. However, up till the present moment, few research reports on the impact of climate change and human activities on the economic value of ecosystem service functions of rivers have been published and it is difficult to understand the impact of human activities and climate change on the economic value of the ecological service functions of river ecosystems and to provide the rational management of water resources.

Based on the above problems, our objective in this paper is to establish a calculation model to qualitatively determine the impact of climate change and human activities on the economic values of ecosystem service functions of rivers in water shortage area of Northwest China. Taking the BSWR as the example, we use this framework to determine the impact of climate change and human activities on the economic values produced by the ecosystem service functions of rivers in BSWR. This useful work can not only reveal the impact of climate change and human activities on the economic value of service functions of rivers ecosystem but also it can provide a quantitative and important basis for the reasonable management of water resource coming from rivers ecosystem.

Methods

The quantitative determination of the impact of climate change and human activities on the economic value produced by ecosystem service functions of rivers is mainly focused on changes in water resources due to the climate change and human activities, respectively. Therefore, firstly, we needed to determine quantitatively the impact of climate change and human activities on the water resources of rivers in water shortage area of Northwest China; secondly, we quantitatively calculated the economic value and unilateral economic value produced by the ecosystem service functions of rivers; finally, we quantitatively determined the impact of climate change and human activities on the economic value produced by the ecosystem service functions of rivers, respectively; the specific calculation steps are as follows.

Amount of change of water resources coming from rivers in a certain period

The amount of change of the water resources coming from rivers in the water shortage area of Northwest China is mainly derived by the factors of climate change and human activities (Piao et al. 2010; Grafton et al. 2013; Zhao et al. 2013). Meanwhile, the total amount of change of water resources coming from rivers derived by the factors of climate change and human activities refers to the amount of change of water resources coming from rivers between two different time points of a certain period, as shown in formula (1).

$$\Delta W = W_{t2} - W_{t1}, \quad (1)$$

Where ΔW refers to the amount of change of water resources coming from rivers during a certain period of time, one hundred million m^3; W_{t1} refers to the amount of water resources coming from rivers in t1 time, one hundred million m^3; W_{t2} refers to the amount of water resources coming from rivers in t2 time, one hundred million m^3.

Climate change, human activities, and amount of water resources coming from rivers

We used the product of the total reduction of river water resources and the contribution ratio of climate change and human activities in recent years to determine the reduction of river water resources due to the climate change and human activities, respectively. Therefore, we firstly need to obtain the contribution ratio of the climate change and human activities, respectively, and then obtain the amount of contribution of the climate change and human activities on the reduction of water resources respectively, as shown in the following steps.

Contribution ratio of climate change and human activities to the change of water resources

They are many qualitative determination methods of contribution ratio of climate change and human activities to the change of water resources (Yang et al. 2017; Jiang et al. 2015; Zhan et al. 2014a, b; Guo et al. 2014). So far, there is no recognized method for the impact of climate change and human activities on surface runoff, and there are many research methods, and each has its own advantages and disadvantages (Binbin et al. 2018; Shrestha et al. 2017; Pieri et al. 2017). And we mainly explained three research methods, which includes hydrological model, elasticity coefficient method, and cumulative slope method. The methods, its description, and its source are as shown in Table 1.

Contribution of climate change and human activities to the change of water resources

The amount of water resources coming from the rivers in water shortage area of Northwest China is mainly derived by the impact factors of climate change and human activities (Dey and Mishra 2017; Teegavarapu 2013; Zhang et al. 2013; Wu et al. 2014). That is to say, the change in the amount of the climate change and relatively unreasonable human activities will continuously affect the amount of water resources coming from the rivers (Ribes et al. 2013; Zhao et al. 2013; Ye et al. 2013; Piao et al. 2010). Change in the amount of the water resources coming from rivers is a product of contribution ratio of climate change and human activities to water resources and the amount of change of water resources come from rivers during a certain period of time, as shown in the following formula (2).

$$\Delta W_{CC} = \alpha \times \Delta W; \Delta W_{HA} = \beta \times \Delta W, \quad (2)$$

Where ΔW_{CC} refers to the amount of water resources changed with climate change in the study area, one hundred million m^3; ΔW_{HA} refers to the amount change of water resources due to the human activities in the study area, one hundred million m^3; αandβ refer to the contribution ratio of climate change and human activities to the total change of water resources, respectively, %.

Economic value produced by the ecosystem service functions of rivers

Economic value produced by the ecosystem service functions of rivers mainly includes the ecological economic values produced by the ecosystem service functions of rivers and economic value produced by the economic water coming from rivers (Cheng et al. 2019; Yue et al. 2018; Gopal 2016; Xie et al. 2015), and the calculation of two economic values are as follows.

Ecological economic values produced by the ecosystem service functions of rivers

Ecological economic value produced by the ecosystem service functions of rivers is obtained by the product of total amount of water coming from rivers which was used for ecological water use and the economic value produced by the unilateral ecological water, as shown in Eq. (3).

$$V_{EEV} = W_{EL} \times v_{EEV}, \quad (3)$$

Table 1 Qualitative determination methods of contribution ratio of climate change and human activities to the change of water resources respectively

Methods	Brief description	Sources
Hydrological model	Accurately divided the reference period and the impact period of human activities based on the abrupt position of runoff. The meteorological data of the impact period of human activities were input into the model to restore the natural runoff without land use change during the impact period of human activities, and the contribution of human activities to runoff changes and contribution of climate change to runoff changes were calculated. The change of runoff before and after the mutation is used to calculate contribution rate of climate change and human activities.	Yunyun et al. 2018; Yang et al. 2017; Li et al. 2016; Jiang et al. 2012 Zhang et al. 2012a, b
Elasticity coefficient method	The reference period and the impact period of human activities are divided according to the location of runoff mutation. Using the meteorological data and the fixed formula of impact period of human activities to restore surface runoff during impact period of human activities. Finally, the formula is used to calculate contribution rate of climate change and human activities to runoff change.	Liu 2014; Guo et al. 2014
Cumulative slope method	The cumulative slope change rate comparison method is used to distinguish impact of climate change and human activities on runoff. The slope of the fitted straight line before and after the mutation is calculated by plotting the cumulative runoff, cumulative precipitation, and cumulative evapotranspiration curves for many years. Precipitation and cumulative evapotranspiration	Jiang et al. 2015; Zhan et al. 2014a, b; Yang et al. 2014; Liu 2014

Table 1 (continued)

Methods	Brief description	Sources
	change rates before and after the abrupt change.	

Where V_{EEV} refers to the ecological economic values produced by the ecosystem service functions of rivers, one hundred million yuan; W_{EL} refers to the amount of water coming from rivers used for ecological water use, one hundred million m^3; and v_{EEV} refers to the economic values produced by the unilateral ecological water, yuan/m^3.

According to the specific rivers conditions in water shortage area in Northwest China, Yue and co-workers (Yue et al. 2018) identified the basic ecological functions that ecological flow of rivers, the main function includes the water purification, maintaining biodiversity, avoiding dried-up rivers, sustaining wetland ecosystems, nutrient transport, maintaining soil fertility, hydrologic cycle, geology, sediment transport, fishery production, recreation and landscapes and improving quality of life, and they considered that these functions are independent of each other. In this paper, we use the calculation method of the economic value generated by the ecological flow reported by Yue et al. (2018), and we also assumed that the change in the ecological economic value generated by the ecological service function of rivers is mainly determined by the change of the water volume. And the economic values produced by the unilateral ecological water use was calculated by the equivalent factor method (Yue et al. 2018), as shown in formula (4).

$$v_{EEV} = \frac{V_{EEV}}{W_{EEV}} = \frac{C \times S}{W_{EEV}}, \tag{4}$$

Where W_{EEV} refers to the total water requirement of ecological water use, m^3; C refers to the equivalent factor, yuan/hm^2; and S refers to the water surface area of the ecological water use, hm^2.

Economic value produced by economic water coming from rivers

The economic value produced by the economic water coming from rivers is obtained by the product of total amount of water coming from rivers which was provided for the economic sectors and the economic value produced by the unilateral economic water, as shown in Eq. (5).

$$V_{SEV} = W_{EN} \times v_{SEV}, \tag{5}$$

Where V_{SEV} refers to the economic value produced by the economic water use coming from rivers, one hundred million yuan; W_{EN} refers to the amount of water resources which used for economic water use, one hundred million m^3; and v_{SEV} refers to the unilateral economic value produced by the economic water use, yuan/m^3.

The economic benefits produced by the unilateral economic water use was calculated through using the Cobb-Douglas production function (Gao et al. 2018; Kaenchan and Gheewala 2016), as shown in formula (6) and (7).

$$Y = A_O \times (1+\lambda)^t \times K^{\alpha} \times L^{\beta} \times W^{\gamma}, \tag{6}$$

$$v_{SEV} = \frac{\partial Y}{\partial W} = \gamma \times \frac{Y}{W}, \tag{7}$$

Where Y refers to the economic output, Yuan; A_0 refers to the constant variable, dimensionless; λ refers to the coefficient of technological progress, dimensionless; t refers to the time series, year; K refers to the capital investment, yuan; α refers to the all capital output elasticity, dimensionless; L refers to the labor input, person; β refers to the labor output elasticity, dimensionless; W refers to the amount of the economic water use, 10^8 m^3; and γ refers to the water resource output elasticity, dimensionless.

Total economic values produced by the ecosystem service functions of rivers

Total economic values produced by the ecosystem service functions of rivers is the sum of the ecological economic value produced by the ecosystem service functions of rivers and the economic value produced by economic water coming from rivers, as shown in Eq. (8).

$$V_{TEV} = V_{EEV} + V_{SEV}, \tag{8}$$

Where V_{TEV} refers to the total economic values produced by the ecosystem service functions of rivers, one hundred million yuan.

Case study

Research area

A case study was used to determine the impact of climate change and human activities on the economic value of ecological service functions of rivers in the BSWR (mainly refers to the section between the Linjicun and Weijiabao Hydrological Station, see Fig. 1), which is the largest tributary of the Yellow River of China. The BSWR is located among the middle of Shaanxi Province. The administrative area mainly includes the most parts of Xianyang and Baoji City (see Fig. 1). The head of the Linjiacun diversion canal is located next to the Linjiacun hydrological station. It has

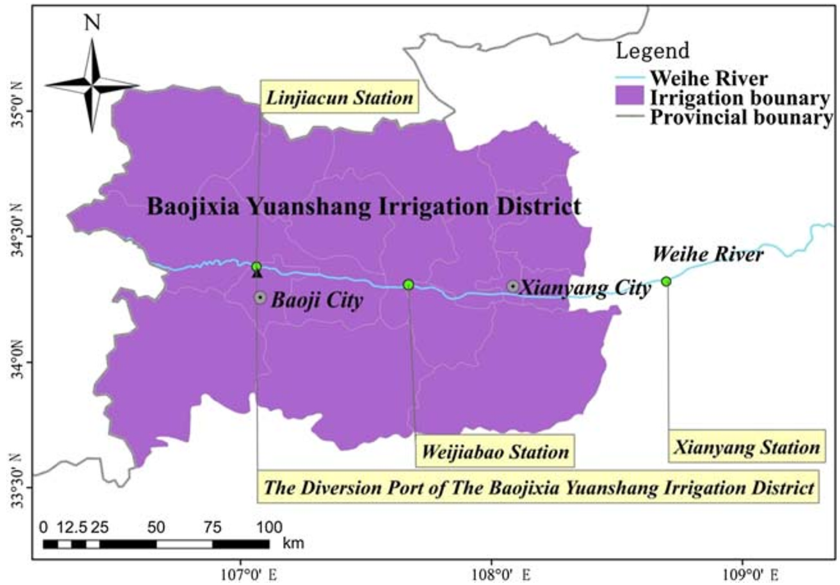

Fig. 1 Location of the Baoji section of the Weihe River and Baojixia Yuanshang Irrigation District (Cheng et al. 2019)

changed the flow direction and usage of water resources. Most of the water resources are used to irrigate crops in Baojixia Yuanshang Irrigation District (BYID). In the form of flood irrigation, water waste is more serious. In recent years, climatic factors such as precipitation and evaporation in the BSWR have changed. The amount of surface water resources has also changed drastically (Huang et al. 2015), showing a significant downward trend (Chang et al. 2015; Guo et al. 2014). The water resources in the BSWR have intensely declined due to human activities and climate change and the unreasonable water resource management model (large amount of water resources used for agricultural irrigation) has caused the losses of some ecological functions in the BSWR (Lin and Li 2013) and may lead to the change in the economic value produced by the ecosystem service functions of rivers. Therefore, we urgently need to study the reduction of economic value produced by ecosystem service functions in the BSER due to climate change and human activities, respectively.

The data used in this paper mainly come from “People’s Republic of China Hydrological Yearbook”, “Shaanxi Statistical Yearbook”, and “Water Statistical Yearbook of Shaanxi”.

Scenario design of water management model

The change amount of surface water resources in the BSWR due to human activities and climate change can be used for ecological water use and economic water use. Therefore, we have set up a water resource management scenario, and we used percentages to express water use in both two sectors, as shown in the following Table 2.

Determination of change in surface runoff and contribution ratio

Guo et al. (2014) used the Mann-Kendal model to find the variation points of runoff in the BSWR, and they found that the major variation years mainly occurred in 1971 and 1991; Wang et al. (2019) analyzed change of runoff of the BSWR with the cumulative anomaly method, and found that the main year of variation mainly occurred in 1970 and 1990. Therefore, we selected the years that must include 1970, 1971, 1990, and 1991. Therefore, we chose 1960–2009 as the total period of determination of impact of the climate change and human activity on the economic value produced by the ecosystem service functions of rivers.

We used the 1960s as the reference time point, and calculated the changes in the runoff from 1960s to the 1990s and 2000s respectively in the section of the Weihe River; the calculation results are shown in Table 2. Furthermore, we calculated the change rate of runoff coming from the Weihe River from 1960s to the 1990s and 2000s respectively; the calculation results are shown in Table 3.

Many scholars used many different calculation methods to calculate the contribution ratio of human activities and climate change to the surface runoff in the BSWR (Guo et al. 2014; Hou et al. 2011; Zhan et al. 2014a, b). And the calculation results of contribution ratio of climate change and human activities are shown in Table 4.

From Table 3, we can see that different scholars agreed that the main reason for the largest contribution of water resources change in the Weihe River Basin is human activity (Zhan et al. 2014a, b; Gao et al. 2014). The impact of climate change is

Table 2 Water allocation planning of ecological and economic water use

Type		Ecological water use (%)	Economic water use (%)
Water allocation planning	1	100	0
	2	90	15
	3	75	25
	4	50	50
	5	25	75
	6	15	90
	7	0	100

relatively smaller than the impact of human activities. In addition, there are some differences in the contribution ratio obtained by different methods for determining the contribution ratio of runoff reduction. Each method has its own advantages and disadvantages compared to other models (Binbin et al. 2018; Shrestha et al. 2017; Pieri et al. 2017); the calculation results of each research method cannot be the most accurate contribution ratio, so we must take a relatively recognized contribution ratio of impact of the climate change and human activities on the reduction of amount of water resources in the BSWR, respectively.

Guo et al. (2014) and Hou et al. (2011) believed that the impact of the human activities on reduction of runoff reached more than 85%, and also the data periods they used were mainly 1972–1991 and 1971–2009; Zhan et al. (2014a, b) used the data from 1958 to 2009 to analyze the impact of human activities on reduction of runoff, and they believed that the impact of human activities on the reduction of water resources in the Weihe River Basin is more than 65%. Gao et al. (2014) considered that human activities have a greater impact on the reduction of water resources in the Weihe River Basin over time, that is to say, the impact of human activity was small before 1971. So we believe that the calculation results of Zhan et al. (2014a, b) are relatively reasonable, so we use the contribution ratio of reduction of runoff coming from the report of Zhan et al. (2014a, b) and using the improved elastic coefficient method (Zhan et al. 2014a, b).

Therefore, we choose average value of results of contribution ratio of the report that had been issued by Zhan et al. (2014a, b), that is to say, the contribution ratio of climate change and human activities on the reduction of water resources coming from the BSWR are 25% and 75%, respectively.

Results and discussions

Impact of climate change and human activities on the economic value of rivers

In order to eliminate the impact of the grain prices and inflation on the agricultural economic benefits and the economic value of river ecological flows in different years, we uniformly adopted the unilateral agricultural economic benefits and economic value of unilateral ecological flows in 2009. Gao and her co-workers (Gao et al. 2018) used the C-D production function method to study the agricultural economic benefits generated by the agricultural irrigation water use in the BYID, and the unilateral agricultural economic benefit in 2009 was 1.23 yuan/m^3. Yue et al. (2018) adopted the results reference method to study the economic value in the Baoji section of the Weihe River, and ecological economic value generated by the unilateral ecological flow in 2009 is 2.60 yuan/m^3. The contribution ratio of climate change and human activities on the reduction of water resources coming from the BSWR are 25% and 75%, respectively. Based on the different water resources management (see the "Scenario design of water management model" section), we calculated the amount of reduction of the economic value produced by the ecosystem services of rivers due to the climate change and human activities and respectively, as shown in Fig. 2.

Table 3 Rate and amount of change of runoff coming from Weihe River over a certain period of time (Relative to 1960s)

Period	Runoff (10^8 m^3)	Change rate of runoff (%)	Change amount of runoff (10^8 m^3)
1960s	31.23	0.00	0.00
1970s	22.13	− 29.13	− 9.10
1980s	22.75	− 27.15	− 8.48
1990s	15.11	− 51.62	− 16.12
2000–2009	12.85	− 58.85	− 18.38

Table 4 Contributions ratio of climate change and human activities to the change of runoff over a certain period of time, respectively

Items	Climate change (%)	Human activities (%)	Period (Years)	Sources and method
Contributions ratio	22–29	71–78	1958–2008	Zhan et al. 2014a, b (Improved elasticity method)
	13.82	86.18	1971–2009	Hou et al. 2011 (Double cumulative slope method)
	14.60	85.40	1972–1991	Guo et al. 2014 (Cumulative slope method)
	Less than 35	More than 65	1958–2008	Zhan et al. 2014a, b (SIMHYD model)

In the past 52 years, the total economic value produced by the ecosystem service functions of the BSWR decreased by 3.57 billion yuan due to the combination of climate change and human activities. The total economic value decreased by an average of 0.89 and 2.678 billion yuan due to climate change and human activities, respectively. At the same time, the total economic value produced by the ecosystem services functions of the BSWR has been reduced by an average of 68 million yuan per year due to climate change and human activities. The total economic value is reduced by an average of 17 and 51 million yuan per year due to the climate change and human activities, respectively.

In addition, we can see that the use of different water resources management models will also cause a certain impact on the total economic value produced by the BSWR. The economic value produced by the ecological flow in the river basin is greater than the economic value generated by agricultural irrigation water use. The loss of economic value caused by ecological flow is more than double the economic loss of all agricultural irrigation use.

In conclusions, the impact of human activities on the economic value produced by the ecosystem service functions of rivers is quite more than the climate change' impact in the BSWR, that is to say, human activities are the main reason that the economic value produced by the ecosystem service functions of rivers continuously reduced in recent 52 years; it mainly reflected in not proper management of water resources and change of land use in the BSWR (Li et al. 2016; Liu 2014; Lin and Li 2010).

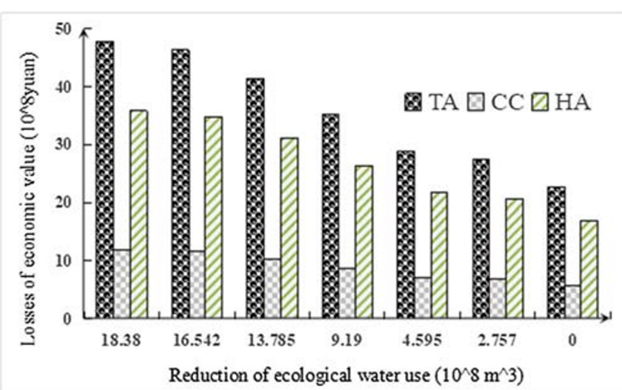

Fig. 2 Losses of the economic value of ecosystem services functions due to climate change and human activities and respectively. TA refers to the losses of the economic value of ecosystem services functions of rivers due to climate change and human activities; CC refers to the losses of the economic value of ecosystem services functions due to climate change; HA refers to the losses of the economic value of ecosystem services functions due to human activities

Limitation and trends analysis of calculation model

Although we quantitatively research on the impact of the combination of climate change and human activities on the economic value produced by the ecosystem service functions of rivers in BSWR, the calculation model also need to be improved accurately. There are two defects and so we should do something for the two defects in the following aspect.

1. Climate change and human activities will not only have a certain impact on water volume, but will also affect some ecosystem services functions of rivers (Piao et al. 2010; Whitehead et al. 2009; Delpla et al. 2009), and also this paper uses water changes as intermediate variables to determine the impact of human activities and climate change on the economic value produced by ecosystem service functions of rivers; however, we did not consider these. For example, human activities and climate change have affected the river water quality or crop yield, and then further affected the water quality purification function or affected the economic benefits produced by the agricultural irrigation water, which inevitably led to a decrease in the economic value of the ecosystem service functions of rivers. As there is less research in this area of the Weihe River Basin, so we did not cover this aspect. We should try to include these elements in later studies.
2. Different methods for determining the contribution ratio of the climate change and human activities on water resource changes may cause some differences in contribution rates of climate change and human activities (Shrestha et al. 2017; Pieri et al. 2017), which in turn may lead to differences in the calculation of reduction of the economic value due to the climate change and human activities. The contribution ratio of climate change and

human activities on the reduction of water resource in this paper are 25% and 75%, respectively. However, other scholars have adopted different methods to obtain the contribution rates of climate change and human activities on reduction of water resource in Baoji section of the Weihe River. There is a large difference in the contribution ratio used (Huang et al. 2015), and we cannot judge who is right and who is wrong. Further, the differences in contribution ratio will affect the change of the economic value produced by the ecosystem services functions of rivers due to the climate change and human activities. Therefore, the model of change of the economic value produced by the ecosystem service functions of rivers due to the climate change and human activities will need to be further improved on the basis of improvement of contribution ratio of the climate change and human activities on reduction of water resources in water shortage area of Northwest China.

Conclusions

Taking the water quantity as the intermediate variable, we proposed a quantitative calculation method for the impact of climate change and human activities on the economic value of ecosystem service functions of rivers. Taking BSWR as an example, we can obtain the following conclusions: (1) In past 52 years, the total economic value produced by the ecosystem service functions of the BSWR decreased by 3.57 billion yuan due to the climate change and human activities. The total economic value decreased by an average of 0.89 and 2.678 billion yuan due to the climate change and human activities, respectively. (2) At the same time, the total economic value has been reduced by an average of 68 million yuan per year, and the total economic value is reduced by an average of 17 and 51 million yuan per year due to the climate change and human activities, respectively. (3) We have analyzed the model defects, and we should add the impact of climate change and human activities on some functions in the later research process, not only through the impact of water volume, and try to adopt reasonable climate change and human activities contribution ratio. The study of this model can provide a basis for the rational management of water resources.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

Binbin H, Chengyuan H, Ruonan L et al (2018) Research progress on the quantitative methods of calculating contribution rates of climate change and human activities to surface runoff changes [J]. J Nat Resour 33(5):899–910 (in Chinese)

Chang J, Wang Y, Istanbulluoglu E et al (2015) Impact of climate change and human activities on runoff in the Weihe River basin, China. Quat Int 380-381:S1040618–21400192X

Cheng B, Li H, Yue S, Huang K (2019) A conceptual decision-making for the ecological base flow of rivers considering the economic value of ecosystem services of rivers in water shortage area of Northwest China. J Hydrol 578:124126

Delpla I, Jung AV, Baures E, Clement M, Thomas O (2009) Impacts of climate change on surface water quality in relation to drinking water production. Environ Int 35(8):1225–1233

Dey P, Mishra A (2017) Separating the impacts of climate change and human activities on streamflow: a review of methodologies and critical assumptions. J Hydrol 548:278–290

Gao ZY, Li HE, Z Q et al (2018) Analysis of irrigation benefit of Baoji gorge Irrigation District using ridge regression of C-D production function. Agric Res Arid Areas 36(06):39–46 (in Chinese)

Gómez CM, Pérez-Blanco CD, Batalla RJ (2014) Tradeoffs in river restoration: flushing flows vs. hydropower generation in the Lower Ebro River, Spain. J Hydrol 518:130–139

Gopal B (2016) A conceptual framework for environmental flows assessment based on ecosystem services and their economic valuation. Ecosyst Serv 21:53–58

Grafton RQ, Pittock J, Davis R, Williams J, Fu G, Warburton M, Udall B, McKenzie R, Yu X, Che N, Connell D, Jiang Q, Kompas T, Lynch A, Norris R, Possingham H, Quiggin J (2013) Global insights into water resources, climate change and governance. Nat Clim Chang 3(4):315–321

Guo A, Chang J, Huang Q et al (2014) Quantitative analysis of the impacts of climate change and human activities on runoff change in Weihe Basin. J Northwest Northwest A&F Univ 042(008):212–220 (in Chinese)

Hou QL, Bai HY, Ren YY et al (2011) Analysis of variation in runoff of the main stream of the Weihe River and related driving forces over the last 50 years. Resourc Sci 33(8):1505–1502 (in Chinese)

Huang SZ, Huang Q, Chen YT (2015) Shengzhi H , Qiang H , Yutong C, 2015. Quantitative Estimation on Contributions of Climate Changes and Human Activities to Decreasing Runoff in Weihe River Basin, China [J]. Chin Geogr Sci (05):49–61

Jiang SH, Ren LL, Yong B et al (2012) Analyzing the effects of climate variability and human activities on runoff from the Laohahe Basin in northern China. Hydrol Res 43(1/2):3–13

Jiang C, Xiong L, Wang D et al (2015) Separating the impacts of climate change and human activities on runoff using the Budyko-type equations with time-varying parameters[J]. J Hydrol 522:326–338

Kaenchan P, Gheewala SH (2016) Cost-benefit of water resource use in biofuel feedstock production. J Clean Prod 142(PT.3):1192–1199

Li YY, Chang JX, Wang YM et al (2016) Spatiotemporal responses of runoff to land use change in Wei River basin. Trans CSAE 32(15): 232–238 (in Chinese)

Lin QC, Li HE (2010) Influence and guarantee on ecological basic flow of Weihe River from Baojixia water diversion. J Arid Land Resourc Environ 24(11):114–119 (in Chinese)

Lin QC, Li HE (2013) Analysis on impacts of climate changes and Baojixia water diversion on Wei river runoff. J Hydroelectric Eng 32(3):71–75 in Chinese

Liu W (2014) Hydrological simulation and runoff response analysis based on SWAT model [D]. Northwest University, Xi'an (in Chinese)

Pang A, Sun T, Yang Z (2013) Economic compensation standard for irrigation processes to safeguard environmental flows in the Yellow River Estuary, China. J Hydrol 482:129–138

Piao S, Ciais P, Huang Y, Shen Z, Peng S, Li J, Zhou L, Liu H, Ma Y, Ding Y, Friedlingstein P, Liu C, Tan K, Yu Y, Zhang T, Fang J (2010) The impacts of climate change on water resources and agriculture in China. Nature 467(7311):43–51

Pieri L, Rondini D, Ventura F (2017) Changes in the rainfall-streamflow regimes related to climate change in a small catchment in northern Italy. Theor Appl Climatol 129(3/4):1075–1087

Ribes A, Decharme B, Alkama R et al (2013) Anthropogenic influence on multidecadal changes in reconstructed global evapotranspiration. Nat Clim Chang 3(1):59–62

Shrestha NK, Du XZ, Wang JY (2017) Assessing climate change impacts on fresh water resources of the Athabasca River basin, Canada. Sci Total Environ 601:425–440

Akter S, Grafton RQ, Merritt WS (2014) Integrated hydro-ecological and economic modeling of environmental flows: Macquarie Marshes, Australia[J]. Agricultural Water Management 145:98–109

Teegavarapu RSV (2013) Climate change-sensitive hydrologic design under uncertain future precipitation extremes. Water Resour Res 49(11):7804–7814

Van Vliet MTH, Wiberg D, Leduc S et al (2016) Power-generation system vulnerability and adaptation to changes in climate and water?resources [J]. Nature Climate Change 6(4)

Vörösmarty CJ, Green P, Salisbury J et al (2000) Global water resources: vulnerability from climate change and population growth. Science 289(5477):284–288

Wang FY, Duan KQ, Fu SY et al (2019) Partitioning climate and human contributions to changes in mean annual streamflow based on the Budyko complementary relationship in the loess plateau, China. Sci Total Environ 665:579–590

Whitehead PG, Wilby RL, Battarbee RW et al (2009) A review of the potential impacts of climate change on surface water quality. Hydrol Sci J 54(1):101–123. https://doi.org/10.1623/hysj.54.1.101

Wu Y, Cheng D, Yan W, Liu S, Xiang W, Chen J, Hu Y, Wu Q (2014) Diagnosing climate change and hydrological responses in the past decades for a minimally-disturbed Headwater Basin in South China. Water Resour Manag 28(12):4385–4400

Wu L, Wang S, Bai X, Luo W, Tian Y, Zeng C, Luo G, He S (2017) Quantitative assessment of the impacts of climate change and human activities on runoff change in a typical karst watershed, SW China. Sci Total Environ 601-602:1449–1465

Xie G, Zhang C, Zhang C et al (2015) The value of ecosystem services in China. Nat Sci 37(9):1740–1746 (in Chinese)

Xu ZX, Peng DZ, Pang B et al (2016) Theoretical basis and calculation method for ecological base flow for rivers: Case study in the Guanzhong Reach of the Wei River [M]. Science Press, Beijing (in Chinese)

Yang W, Yang ZF (2014) Integrating ecosystem-service tradeoffs into environmental flows decisions for Baiyangdian Lake. Ecol Eng 71:539–550

Yang HB, Qi J, Xu XY et al (2014) The regional variation in climate elasticity and climate contribution to runoff across China. J Hydrol 517:607–616

Yang LS, Feng Q, Yin ZL, Wen X, Si J, Li C, Deo RC (2017) Identifying separate impacts of climate and land use/cover change on hydrological processes in upper stream of Heihe River, Northwest China. Hydrol Process 31(1–5):1100–1112

Ye X, Qi Z, Jian L et al (2013) Distinguishing the relative impacts of climate change and human activities on variation of streamflow in the Poyang Lake catchment, China. J Hydrol 494(12):83–95

Yue S, Li H, Cheng B, Gao Z (2018) The value of Environmental Base flow in water- scarce basins: a case study of Wei River basin, Northwest China. Water 10(7):848

Yunyun L, Chang J, Wang Y et al (2018) Spatiotemporal response mechanism of runoff to climate change in the Wei River Basin [J]. J Basic Sci Eng 26(3):502–514 (in Chinese)

Zhan CS, Jiang SS, Sun FB et al (2014a) Quantitative contribution of climate change and human activities to runoff changes in the Wei River basin, China. Hydrol Earth Syst Sci 18(8(2014-08-19)) 11(2): 2149–2175

Zhan C, Zeng S, Jiang S, Wang H, Ye W (2014b) Integrated approach for partitioning the effect of climate change and human activities on surface runoff. Water Resour Manag 28(11):3843–3858

Zhang A, Fu G, Wang B et al (2012a) Assessments of impacts of climate change and human activities on runoff with SWAT for the Huifa River basin, Northeast China. Water Resour Manag 26(8):2199–2217

Zhang AJ, Zhang C, Fu GB et al (2012b) Assessments of impacts of climate change and human activities on runoff with SWAT for the Huifa River basin, Northeast China. Water Resour Manag 26(8): 2199–2217

Zhang CQ, Zhang B, Li WH et al (2013) Response of streamflow to climate change and human activity in Xitiaoxi river basin in China. Hydrol Process 28(1):43–50

Zhao G, Mu X, Peng T et al (2013) Climate changes and their impacts on water resources in semiarid regions: a case study of the Wei River basin, China. Hydrol Process 27(26):3852–3863