Assessment of the value of regional water conservation services based on SWAT model

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Abstract The quantitative evaluation of water conservation in the Luoyang area can provide a basis for decision-making on regional water resources development and utilization, ecological environmental protection, and economic development planning. Based on the SWAT model and alternative engineering method, the water conservation and its service value in Luoyang region from 2009 to 2018 were assessed and the reasons for their spatial and temporal changes were analyzed. The results show that during the period of 2009–2018, the total water connotation and its service value reached the highest in 2014, with 16,927,100 m³ and 103 million yuan, respectively; the total water connotation and its service value reached the lowest in 2011, with 7,073,500 m³ and 43,224,000 yuan, respectively. Forest ecosystems have a strong water retention and storage capacity, and the highest water conservation and service value. Precipitation is the most important factor influencing water conservation and service value. The value of water-supporting services per unit area of ecosystem in Luoyang area is forest, grassland, arable land, and urban in descending order.

Keywords Alternative engineering method · SWAT model · Water conservation · Value of ecosystem services · Luoyang area

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Introduction

Ecosystem services are the natural environmental conditions and utilities that shape and sustain human survival in ecosystems and ecological processes (Anderson et al., 2017; Bagstad et al., 2013). The concept of ecosystem services reflects the complex interdependence and interconnection of human society and natural ecosystems (Costanza et al., 2017). Natural ecosystems maintain the dynamic balance of the Earth’s living systems and ecological environment by providing services such as ecosystem products and ecosystem functions that guarantee the sustainable development of human societies and ecosystems (Dou et al., 2020). The concept of ecosystem services was first proposed by Paul Ehrlich, and since then, the connotation and specific content of ecosystem services have been improved with the in-depth research of many scholars on ecosystem services (Xiao et al., 2005; Ouyang et al., 2004). Water harvesting refers to the redistribution of precipitation in an ecosystem by intercepting, infiltrating, and storing precipitation through its unique structure at a certain spatial and temporal scale, thus saving water in the ecosystem (Xie et al., 2001). At the regional scale, the water conservation is usually used as an indicator to assess the water conservation function (Liu et al., 2007). The essence of water availability is the capacity of an ecosystem to store precipitation in a specific spatial and temporal scale, i.e., the difference between precipitation and evapotranspiration and streamflow production.

The main water balance–based water conservation simulation methods include distributed hydrology soil vegetation model (DHSVM), soil and water assessment tool (SWAT), variable infiltration capacity (VIC), and integrated valuation of ecosystem services and tradeoffs (InVEST). Among them, InVEST and SWAT models have been widely used for water harvesting. InVEST and SWAT models have been widely used in studies related to the assessment of water-bearing functions. The InVEST model uses precipitation minus actual evapotranspiration as the water yield (Tang et al., 2015) and uses soil properties and surface runoff flow coefficients to finally calculate the water conservation (Bao et al., 2016). However, the model ignores hydrological elements such as groundwater, and there is a large bias in the calculation of the water conservation. The SWAT model subdivides the target watershed into a number of relatively small hydrological response units (HRUs) based on a combination of vegetation, soil, and slope characteristics, and simulates the hydro-physical processes (precipitation, evapotranspiration, groundwater, loam mid-flow, etc.) in the HRUs. The model simulates each HRU individually, thus enabling accurate calculation of water conservation. For example, Fan et al., simulated the water yield and storage in the Teshio River watershed by SWAT, Qiao et al. (2018) used the SWAT model to assess the water conservation function in the Sanjiangyuan area, and Lin et al. (2020) analyzed the daily, monthly, and annual scale water conservation of forests in a discontinuous watershed based on the SWAT model in the Jinjiang River watershed.

Based on the SWAT model of water conservation in the study area, based on the SWAT model and the alternative engineering method, this study evaluates the water conservation and its service value in Luoyang for the first time, and reveals and analyzes the reasons for its temporal and spatial changes. The model was used to quantitatively analyze the contribution of water conservation to the regional ecology. The core issues of this study include the following aspects: (1) Establish a SWAT watershed model, realize the assessment of water conservation and its service value, and identify key areas of water conservation in the study area; (2) estimate different hydrological response units and different land use types, the output contribution of water conservation of different pollution sources, and identify the service value of water conservation in different time periods and land use types, so as to provide a theoretical basis for the comprehensive management and sustainable development of water environment in Luoyang area in the next step. At the same time, it provides decision-making basis for the development and utilization of water resources, ecological environment protection, and economic development planning in other regions.

Overview of the study area

Geographical location

Luoyang City is located in the west of Henan Province, adjacent to Zhengzhou City, the capital of Henan Province in the east, Sanmenxia City in the west, Jiaozuo City across the Yellow River in the
north, and Pingdingshan City and Nanyang City in the south. The terrain is high in the west and low in the east, and the topography is more complex, with 45.5% of the mountains, 40.7% of the hills, and 13.8% of the plains. The area is rich in natural resources, with not only four major mountain ranges such as Funiu, Waifang, Xiong’er, and Xiaoshan, but also major water systems such as the Yellow River, Luo River, Yi River, and Ru River. As one of the birthplaces of Chinese civilization, the eastern starting point of the Silk Road and the center of the Sui-Tang Grand Canal, Luoyang is not only a national historical and cultural city, a famous ancient capital, and a tourist city, but also the deputy center city of the Central Plains City Cluster and the center city of western Henan. As the urbanization process continues to accelerate in recent years, the land utilization rate in the region is increasing year by year, the reserve resources of arable land are getting short, and the contradiction of human-land relationship begins to intensify. Especially in parallel with the socio-economic development, the already fragile ecosystem of the region began to gradually deteriorate, and the conflict between socio-economic development, tourism development, and ecosystem maintenance is increasing. The geographical location map of Luoyang City is as follows (Fig. 1).

Natural resources

Water resources

There are three major river basins in Luoyang City, and there are many water systems in the administrative division because of the many mountains. The average total water resources in Luoyang for many years has reached 2.8 billion m$^3$, of which surface water is the main source, accounting for 90%, and groundwater accounts for 10%. Due to the economic development and industrial development of
Luoyang City over the years, the per capita water resources occupancy is as low as 450\,m$^3$. The flood season in Luoyang City is concentrated in the summer from July to September every year, and the city’s annual average water production modulus is 185,000\,m$^3$/\,(km$^2$\,a).

**Land resources**

Luoyang City is rich in land resources. According to the Statistical Yearbook, Luoyang City’s land resources are 1.52 million \,hm$^2$, of which 75\% are mainly agricultural land, and agricultural land is mainly cultivated land and forest land. The second is the urban construction land in the north, accounting for 12\% of the city’s land resources. The urban construction land is mainly urban residential land and industrial mineral land. The geological structure makes Luoyang rich in minerals, and the developed water system affects the development of Luoyang. Comprehensive factors form the present situation of the distribution of land resources in Luoyang City.

**Hydrological resources**

**Hydrometeorology**

Luoyang City is located at the junction of the three major river basins. The territory is mainly the Yellow River Basin and the Yiluo River Basin. Luoyang has a pleasant climate with four distinct seasons. It is a typical temperate continental monsoon climate. With the influence of global warming, the average temperature in Luoyang has risen by nearly 1 degree, and the precipitation has also increased with the increase of temperature. By 2018, the city’s multi-year average temperature was 14 degrees, the multi-year average precipitation was 630 mm, and the multi-year average humidity was over 60\%.

**Water status**

The total amount of water resources in Luoyang in the past 10 years has shown a trend of declining and then rising. It fell to a minimum of 1.278 billion \,m$^3$ in 2012 and 2013, and then slowly increased. As of 2018, it recovered to 2.172 billion \,m$^3$, which is consistent with the trend of precipitation. Consistently, the precipitation also showed a trend of first decreasing and then increasing, dropping to a minimum of 502.3 mm in 2013.

**Data and methods**

ArcSWAT data construction

The SWAT hydrologic model is a field-scale non-point source pollution model with a physical basis developed by the United States Agricultural Research Institute (USDA-ARS) in the 1990s, and SWAT is used to simulate the effects of land use, soil type, and crops on the loss of water, sediment, and agricultural pollutants from the field (Wang et al., 2003). The SWAT model focuses on simulating the transport and transformation processes of terrestrial surface source pollution and its ecological impacts. The model has three major components: the hydrological cycle module, the soil land erosion module, and the pollutant load module. The SWAT hydrological simulation is performed through 701 equations already 1013 intermediate variables, coupled by relevant equations and subroutines (Dai & Cui, 2009), using a computer programming language for the evolution of the input data and parameters. According to the different running platforms of SWAT, it can be divided into AvSWAT and ArcSWAT, and ArcSWAT version 2012 is used in this study. In this study, a 12.5 \,m resolution DEM was collected and transformed in ArcGIS for projection as well as clipping, filling, and interpolation, and the clipped DEM is shown below (Fig. 2).

Land use plays an important role in HRU delineation and is an indispensable part of the overall SWAT operation. In this study, a land use database of Luoyang area was established, and the land use of Luoyang area spanning 10 years in 2009, 2013, and 2018 with a resolution of 1 \,km was collected through the resource and environment data cloud platform. The map of land use types in different eras in Luoyang area was obtained by clipping and merging, projection transformation, and coordinate transformation of the original data, as follows (Fig. 3 and Table 1).

The soil data input to the SWAT hydrological model includes data on soil types and their spatial distribution in the study area. The properties of the soil data include both physical and chemical levels, with the physical properties playing a major role in the hydrological cycle. The study area is Luoyang area, and the
data source is the 1:1 million resolution soil type data of Luoyang City in 2015 provided by the Institute of Geographical Sciences and Resources, Chinese Academy of Sciences, and the soil type SHAPE file required for the study area is clipped by GIS, and then the projection and coordinate transformation are carried out to get the soil data of this study area. The soil types of Luoyang area are shown below (Fig. 4).

In this study, the area of the generated Luoyang area model based on 12.5 m accuracy DEM is 10.9 × 10³ km², and 15000 ha is used as the threshold value for this watershed delineation, and the whole study area is divided into 25 sub-basins as follows (Fig. 5).

The delineation of spatial units [sub-basins and minimum hydrological units (HRUs)] affects the simulation of runoff, sand content, and nutrients (Arabi et al., 2006). In this study, to ensure the calculation accuracy and speed, and to ensure that a sub-basin has a relatively reasonable HRU, the thresholds for land mile use, soil, and slope division are set at 5%. Finally, the whole study area of Luoyang region was divided into 1456 HRUs after the HRU division.

SWAT model of Luoyang region

The meteorological information for this study was from 2008 to 2018, which was obtained from the local hydrological bureau. 2008 served as a warm-up period for the SWAT model, with simulation dates from January 1, 2009, to December 31, 2018.

In this study, the decision coefficient $R^2$ [Eq. (1)] and the Nash–Sutcliffe simulation efficiency coefficient $Ns$ [Eq. (2)] were used to evaluate the Arc SWAT simulation results, which were calculated as follows:

$$R^2 = \frac{\sum_{i=1}^{n} (o_i - \bar{o})(s_i - \bar{s})^2}{\sum (o_i - \bar{o})^2 \sum (s_i - \bar{s})^2}$$  \hspace{1cm} (1)
where $S_i$ and $O_i$ denote the $i$th simulated and measured data; $O$ and $S$ denote the mean values of all measured and simulated values, respectively.

This SWAT-CUP rate determination uses the SUFI-2 rate determination method to automatically rate the model in Luoyang area. The rate data were selected from Baimasi hydrological station, and the rate period was from January 1, 2012, to December 31, 2018, with 2012 to 2013 as the warm-up period, 2013 to 2016 as the rate period, and 2016 to 2018 as the validation period. The final parameter results and the sensitivity ranking are shown in the following table (Table 2).

The results of the rate determination and validation are shown below (Fig. 6, Table 3).

In the rate period and validation period, the coefficients of determination $R^2$ and $N_s$ of simulated and observed values satisfy $R^2 \geq 0.6$ and efficiency coefficient $N_s \geq 0.5$, and efficiency coefficient $N_s \geq 0.5$, and the simulation results are considered credible.

| Table 1 Area of land use types and their changes in each period |
|-------------------|---------------------|---------------------|---------------------|---------------------|
| Type              | Area statistics for 3 periods | 2009~2013 | 2013~2018 |
|                   | 2009  | 2013  | 2018  | Area of change | Rate of change | Area of change | Rate of change |
| Forests           | 5905.66 | 5898.41 | 5823.15 | −7.25 | −0.12 | −75.27 | −1.28 |
| Arable land       | 6577.45 | 6462.02 | 6486.01 | −115.43 | −1.75 | 23.99 | 0.37 |
| Urban areas       | 929.3  | 995.57 | 1007.25 | 66.27 | 7.13 | 81.68 | 8.2 |
| Watersheds        | 309.09 | 371.33 | 371.61 | −6.03 | −0.4 | 0.28 | 0.08 |
| Grasslands        | 1492.79 | 1486.76 | 1458.42 | −6.03 | −0.4 | −28.35 | −1.91 |
Hydrological cycle calculation

(1) Surface runoff: The calculation of precipitation runoff is the basis for soil erosion, and the SCS algorithm is used to simulate surface runoff in the watershed. The relationship equation is as follows.

\[
\frac{F}{S} = \frac{Q}{P} - I_a
\]  

(3)

The maximum retention \( S \) is spatially closely related to subsurface factors such as land use, soil type, and slope, and can be better determined by introducing \( S \) values with the following equations.

\[
S = \frac{25400}{CN} - 254
\]  

(4)

To express the spatial variability of the watershed, the SWAT model introduces soil moisture correction and slope correction for the SCS model \( CN \) values. The calculation formula is as follows.

\[
CN_1 = CN - \frac{20 \times (100 - CN)}{100 - CN + \exp[2.533 - 0.063 \times (100 - CN)]}
\]  

(5)
where \( CN_1, CN_2, \) and \( CN \) are the CN values at the dry, wet, and normal levels, respectively; \( SLP \) is the average slope of the sub-basin, m/m.

The maximum possible soil water retention, \( S \), with soil moisture can be calculated by the following equation.

\[
S = S_{\text{max}} \left[ 1 - \frac{SW}{SW + \exp(w_1 - w_2 \cdot SW)} \right]
\]  

where \( S_{\text{max}} \) is the maximum possible soil retention during drought, mm, i.e., \( S \) corresponding to \( CN \); \( SW \) is the effective soil moisture, mm; \( W_1 \) and \( W_2 \) are the first and second form coefficients, respectively.

Assuming that the value of \( S \) under \( CN_1 \) corresponds to the soil moisture at the point of shading, and the value of \( S \) under \( CN_2 \) corresponds to the field water-holding capacity, the morphological coefficient can be obtained from the following equation.

\[
w_1 = \ln\left( \frac{FC}{S_2 \cdot S_{\text{max}}} - FC \right) + w_2 \cdot FC
\]

\[
w_2 = \frac{\ln\left( \frac{FC}{1 - S_2 \cdot S_{\text{max}}} - FC \right) - \ln\left( \frac{SAT}{1 - 2.54 \times S_{\text{max}}} \right) - SAT}{SAT - FC}
\]

where \( FC \) is the field water-holding capacity, mm; \( SAT \) is the saturated soil water conservation, mm; \( S_2 \) is the \( S \) value corresponding to \( CN_2 \).

(2) Soil water: Soil water, i.e., water that infiltrates into the soil and is lost by plant uptake or transpira-

### Table 2 Final rate determination results and sensitivity ranking of parameters

| Parameter name | Rate range     | Rate determination optimum | Sensitivity ranking |
|---------------|----------------|---------------------------|--------------------|
| CN2           | \([-0.7, 0.7]\) | 0.314                     | 1                  |
| Esco          | \([0.25, 0.585]\) | 0.413                     | 2                  |
| Gwqmn         | \([10, 500]\)   | 258.47                    | 3                  |
| Sol_Awc       | \([0.03, 0.3]\)  | 0.243                     | 4                  |
| Sol_Z         | \([0.5, 650]\)   | 457.2                     | 5                  |
| EPCO          | \([0.55, 0.75]\) | 0.698                     | 6                  |
| Alpha_Bf      | \([0.028, 0.25]\) | 0.173                     | 7                  |
| Gw_Delay      | \([310, 450]\)   | 415.33                    | 8                  |
| Sol_K         | \([1.30, 1.45]\) | 1.39                      | 9                  |
| CH_K2         | \([2, 6]\)       | 3.21                      | 10                 |
| Revapmn       | \([120, 220]\)   | 171.25                    | 11                 |
| Canmx         | \([20, 55]\)     | 52.655                    | 12                 |
| RCHRG_DP      | \([0.150, 0.465]\) | 0.276                    | 13                 |
| Gw_Revap      | \([0.05, 0.055]\) | 0.051                     | 14                 |

### Table 3 \( R^2 \) and \( N_s \) coefficients for hydrological stations during the rate and validation period

| Rate period | Validation period |
|-------------|-------------------|
| Decision factor \( R^2 \) | Efficiency factor \( N_s \) | Decision factor \( R^2 \) | Efficiency factor \( N_s \) |
| 0.72 | 0.73 | 0.79 | 0.75 |

Fig. 6 Whitehorse temple rate periodic and validation period
tion, can seep into the soil substratum to eventually form groundwater recharge, and can also form runoff and mid-loam flow at the surface. The model uses the dynamic storage method to calculate the flow in the loam. The formula is as follows.

\[ Q_{lat} = 0.024 \times \left( \frac{2 \times SW_{by,excess} \cdot K_{sat} \cdot slp}{\Phi_d \cdot L_{hill}} \right) \]  

(10)

where \( Q_{lat} \) is the lateral flow rate, mm; \( SW_{by,excess} \) is the amount of water about to flow out of the saturated zone, mm; \( K_{sat} \) is the saturated hydraulic conductivity of the soil, mm/h; \( slp \) is the slope, m/m; \( \Phi_d \) is the total porosity of the soil layer; \( L_{hill} \) is the slope length, m.

(3) Groundwater: Groundwater runoff generally exists by way of riverine groundwater and can be extrapolated to and from groundwater storage as well as dry season runoff. The formula is as follows.

\[ Q_{gw,i} = Q_{gw,i-1} \exp(-a_{gw} \Delta t) + w_{rehr} \left[ 1 - \exp(-a_{gw} \Delta t) \right] \]  

(11)

where \( Q_{gw,i} \) is the groundwater recharge on day \( i \), mm; \( Q_{gw,i-1} \) is the groundwater recharge on day \( i-1 \), mm; \( \Delta t \) is the time step, d; \( w_{rehr} \) is the aquifer recharge, mm; \( a_{gw} \) is the surge coefficient.

(4) Evaporation: Evaporation is an important factor that cannot be ignored for a large watershed, including evaporation from water bodies and transpiration from plants and animals. The SWAT model takes full account of evaporation during the hydrological cycle, including evaporation, transpiration, and, to a lesser extent, sublimation of water trapped by the tree canopy and plants. In a necessary part of the evaporative cycle, it is an important pathway for moisture transfer.

Calculation of water conservation capacity and service value based on SWAT model

One of the foundations of SWAT is the water balance, which consists of the processes of precipitation, infiltration, and finally evaporation, as well as the processes of mid-loam flow and runoff circulation. The formula is as follows.

\[ SW_{i} = SW_{0} + \sum_{i=1}^{t} \left( R_{day} - Q_{surf} - E_{a} - W_{seep} - Q_{gw} \right) \]  

(12)

where \( SW_{i} \) is the final water conservation of the soil, mm; \( SW_{0} \) is the preliminary water conservation of the soil, mm; \( R_{day} \) is the final precipitation value, mm; \( Q_{surf} \) is the surface runoff flow, mm; \( E_{a} \) is the total evapotranspiration in the study area, mm; \( W_{seep} \) is the amount of surface runoff, mm; \( Q_{gw} \) is the groundwater conservation on day \( i \), mm.

In addition to providing water for human production and living, the ecosystem can also store water and regulate and replenish surrounding wetland runoff and groundwater volumes. It can reduce the construction of water storage projects such as reservoirs and water diversion projects. The calculation of the functional value of water resources storage is calculated by the alternative engineering method. The formula is as follows.

\[ B_{1} = QS \times P \]  

(13)

where \( B_{1} \) is the water storage (billion yuan), \( QS \) is the potential water storage (billion m\(^3\)), and \( P \) is the cost of obtaining this potential water (reservoir cost per unit of storage) (yuan/m\(^3\)). This study refers to DB11/T1099-2014 Technical Regulations for Ecological Benefit Evaluation of Forestry Ecological Projects, with a \( P \)-value of 6.11 yuan m\(^3\).

Results and discussion

Temporal variation characteristics of water conservation

During the period of 2009–2018, the total water connotation in Luoyang area and its service value changed in the same pattern, both showing an increase and then a decrease. In 2014, the total
volume of water conservation and the value of its services reached the highest level with 16,927,100 m³ and 103 million yuan, respectively; in 2011, the total water conservation and its service value were the lowest, at 7,073,500 m³ and 43,224,000 RMB respectively. The water conservation and service value of the watershed vary dramatically from year to year, and the water conservation varies significantly in windy and dry years (Fig. 7).

Precipitation is an important factor that directly affects the temporal variation of water conservation and its service value (Gong et al., 2017). Based on the relationship between precipitation and water conservation in the watershed, it was found that the water conservation in the study area was significantly and positively correlated with the average annual precipitation in its spatial extent from 2009 to 2018 (Fig. 8), with a Pearson correlation coefficient of 0.63 for both.

Spatial distribution characteristics of water conservation

The spatial distribution of water conservation per unit area was drawn according to the total water conservation of each sub-basin in Luoyang area from 2009 to 2018 (Fig. 9). As can be seen from the figure, the average annual amount of water conservation per unit area in different sub-basins is 448.80 mm, with the high value area (>500 mm) concentrated in the southeastern part of the basin and the low value area (<300 mm) concentrated in the northwestern part of the basin. Further analysis of the causes of the spatial variation of water conservation, in the combined influence of climate, land cover, and topography and other factors in the domain water conservation and water conservation service value is also presented from the southwest to the northeast decreasing spatial distribution characteristics. The main reason is that the upstream area of Luoyang region has high forest coverage, and the forest ecosystem has strong water retention and storage capacity, so the water conservation and its service value are high, while in the downstream area, due to the continuous urbanization, the construction land area accounts for a large proportion, the surface water storage capacity is low, and precipitation is mostly lost in the form of runoff or evapotranspiration, so the water conservation is low.

Water conservation of different ecosystems

Land use type is one of the main influencing factors on water conservation; therefore, the spatial distribution of land use types in Luoyang area was extracted for analysis in this study. The results found that forest land and cropland were the main ecosystem types in the study area, with the sum of the two accounting for
Fig. 8 Correlation between water conservation and precipitation in Luoyang region from 2009 to 2018

\[ y = 0.11x - 531.17 \]
\[ R^2 = 0.867 \]
\[ P = 0.63 \]

Fig. 9 Spatial distribution of average water conservation of sub-regions in Luoyang region, 2009–2018
82% of the total area. The value of water conservation service of different ecosystems has obvious differences, and the order of water conservation service value per unit area from high to low is forest, grassland, arable land, and urban (Table 4). Forests have the highest value per unit of water-holding services, which is determined by the unique structural characteristics of forest ecosystems. After precipitation passes through the forest canopy layer, 14–40% of precipitation is trapped, while the dead leaf layer and soil layer trap and store the remaining part of precipitation, so that most of the precipitation is stored in the forest ecosystem (Zhang et al., 2009; Wang et al., 2018). The area of cultivated land in the study area accounts for about 43% of the watershed area, but the value of water-conserving services per unit is only 45.6% of that of the forest ecosystem. Arable land with slopes greater than 6° in the study area is mainly located in the northeastern and eastern parts of the watershed. The topographic conditions in this area are complex and precipitation is concentrated in summer, while the lower water-retaining capacity leads to frequent soil erosion, and the deteriorating ecological environment poses a great threat to the local ecological security. The scientific return of arable land to forest and grass is conducive to improving people’s living environment and enhancing the water conservation function of the region. The urban ecosystem has the lowest value of water conservation services. In order to maintain the water conservation capacity of the region, the area and layout of land for construction in the city must be reasonably planned. Grassland has a service value of 16,000 yuan-hm-2 per unit of water conservation, which is 1.3 times higher than that of arable ecosystems. However, grassland only accounts for about 8% of the watershed, and thus its contribution to the water conservation function of the watershed is much lower than that of arable land and forest. In order to maintain the water connotation capacity of the region, it is necessary to carry out reasonable planning for the construction land area and layout in the city.

### Discussion

In this study, the SWAT model method was used to simulate the changes of water conservation and its service value in Luoyang area from 2001 to 2019. The results show that the water conservation and service value of Luoyang area fluctuated from 2000 to 2019 due to the influence of precipitation, and the difference of land use types caused obvious differences in water conservation service value between upstream and downstream. Precipitation was significantly and positively correlated with water conservation and service value, i.e., an increase in precipitation was associated with a corresponding increase in water conservation and service value, which is consistent with the findings of Gong Shihan on the factors influencing water conservation of ecosystems in China. In addition to precipitation, land use type differences also have an impact on the water conservation and service value in the watershed. The main manifestations are the value of water conservation services per unit area in the upper reaches of watersheds with high forest cover is 1.6 times that of grassland, 2.2 times that of downstream arable land, and 3.9 times that of urban land per unit area. It shows that there is a significant difference in the water-holding capacity of different land use types.

### Table 4 Value of water-supporting services of different ecosystems

| Ecosystem type | Area share (%) | Unit area water conserved (m³·hm⁻²) | Value of water conservation services per unit area (yuan·hm⁻²) |
|----------------|----------------|-------------------------------------|---------------------------------------------------------------|
| Forests        | 39             | 4316                                | 26370.76                                                      |
| Arable land    | 43             | 1969                                | 12030.59                                                      |
| Urban          | 7              | 1119                                | 6837.09                                                       |
| Grassland      | 8              | 2619                                | 16002.09                                                      |
for example, Liu et al. (2019) found that the water conservation of forest and arable land in the middle and upper reaches of Minjiang River was 2695.77 and 683.85 m$^3$hm$^{-2}$, respectively; Shanshan et al. (2016) found that the water conservation of forest and arable land in Shangluo City, Shaanxi Province was 2966.0 and 1202.1 m$^3$hm$^{-2}$, respectively; in this study, the water conservation of forest and arable land in Luoyang area was 3216.3 and 1069.6 m$^3$hm$^{-2}$. This is mainly due to the large differences in forest types, land conditions, grassland cover, arable land quality, and soil texture in different regions, which in turn lead to divergent findings on the water conservation of the same ecosystem type. At the same time, the differences in research methods and data sources are also the reasons for the different results of water conservation in the same area. Therefore, the results related to the forest water conservation in Luoyang area in this study are reasonable.

Most of the previous studies related to water conservation have used the InVEST model to simulate the water production of different regions or ecosystems as water conservation, ignoring the intermediate hydrological processes such as surface runoff and subsurface runoff, and there is an overestimation of water conservation (Tang et al., 2015). The present study simulates the hydrological processes of precipitation, evaporation, surface runoff, and subsurface runoff in Luoyang based on the mechanistic process model, SWAT, and combines it with the water balance equation, and then calculates the water conservation and its ecosystem service value in Luoyang from 2009 to 2018, and the results are more scientific.

Conclusion

Based on remote sensing data, statistical data, and SWAT distributed hydrological model, this study rates and validates the model with actual runoff measurements from Baimasi hydrological station, and calculates the water conservation of Luoyang area from 2009 to 2018 based on the water balance equation. Also, the value of its ecosystem services was estimated by combining the alternative engineering method. The conclusions are as follows.

1) The average annual total water conservation and water conservation service value of the study area are 12.2 million m$^3$ and 74.5 million yuan respectively, and the average annual total precipitation is about 16.3 million m$^3$. The comparison of the three shows that the Luoyang area plays an important function in water conservation. At the same time, precipitation has a strong influence on water conservation, and the Pearson correlation coefficient between the two reaches 0.63.

2) The value of water conservation services in the Luoyang area has obvious spatial and temporal characteristics. Temporally, the overall trend was first increasing and then decreasing, with the wind-water year reaching 2.3 times the dry-water year; spatially, it decreased from southwest to northeast, with a 2.2 times difference between the 2 unit area averages. Precipitation and land use affect the water-holding function and its spatial distribution pattern.

3) The value of water-supporting services per unit area of ecosystem in Luoyang area is forest, grassland, arable land, and urban in descending order. Among them, the value of water connotation service per unit area of forest is 26,370 yuan-hm$^{-2}$, which is 1.6 times that of grassland, 2.2 times that of arable land, and 3.9 times that of urban land.

4) Since the factors affecting the change of regional ecosystem service values are usually multifaceted, the factors involved in the analysis in this paper are relatively single, and there is a lack of phenomenological description and explanation of attribution in analyzing the evolution of ecosystem service values in the region. However, in general, the results of this paper are representative and can provide a basis for decision-making in regional water resources development and utilization, ecological environmental protection, and economic development planning. In the next step of exploring ecosystem optimization research, we will continue to improve the deficiencies in the paper, with a view to more effective fine management of ecosystem conservation.

Author contribution

Zhang XQ: methodology, investigation, writing-original draft preparation. Chen P: conceptualization, writing-review and editing. Dai SN: methodology, formal analysis. Han YH: conceptualization, writing-original draft preparation.
Availability of data and materials  Datasets and other materials are available with the authors and may be accessible at any time upon request.

Declarations

Ethical approval  This paper does not contain any studies with human participants or animals performed by any of the authors.

Consent to participate  Consent.

Consent to publish  Consent.

Competing interests  The authors declare no competing interests.

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