Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Assessment of the Value of Regional Water Conservation Services Based on SWAT Model

Xianqi Zhang
North China University of Water Resources and Electric Power
Peng Chen (632642579@qq.com)
North China University of Water Resources and Electric Power
Shengnan Dai
North China University of Water Resources and Electric Power
Yonghua Han
North China University of Water Resources and Electric Power

Research Article

Keywords: Alternative Engineering Method, SWAT model, Water conservation, Value of Ecosystem Services, Luoyang area

Posted Date: January 28th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1208076/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

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

Xianqi Zhang[a,b,c] , Peng Chen [a,*],Shengnan Dai[d],Yonghua Han[e]
[a]*Water Conservancy College, North China University of Water Resources and Electric Power, Zhengzhou 450046, China*
[b]*Collaborative Innovation Center of Water Resources Efficient Utilization and Protection Engineering, Zhengzhou 450046, China*
[c]*Technology Research Center of Water Conservancy and Marine Traffic Engineering, Henan Province, Zhengzhou 450046, China*
[d] *Henan Zhong Hui Engineering Consulting Co., Xinxiang 453000, China*
[e] *Yellow River Water Conservancy Commission Sanmenxia reservoir hydrology and water resources bureau, Sanmenxia 47200, China*
***Corresponding authors**: Peng Chen. Email: 632642579@qq.com;phone: +86-135-9257-0528
Authors:
Xianqi Zhang. E-mail: zxqi@163.com; phone: +86-158-3719-7937
Peng Chen. E-mail: 632642579@qq.com;phone: +86-135-9257-0528
Shengnan Dai. E-mail: 454448121@qq.com;phone: +86-189-3733-3871
Yonghua Han. E-mail: 1491849399@qq.com;phone: +86-177-4046-1012

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 m^3 and 103 million yuan, respectively; the total water connotation and its service value reached the lowest in 2011, with 7,073,500 m^3 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

1 Introduction

Ecosystem services are the natural environmental conditions and utilities that shape and sustain human survival in ecosystems and ecological processes[1,2,3,4]. The concept of ecosystem services reflects the complex interdependence and interconnection of human society and natural ecosystems [5,6,]. 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 [7,8,9]. 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 [10,11,12,13]. 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 [14]. At the regional scale, the water conservation is usually used as an indicator to assess the water conservation function [15]. 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) etc. 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 [16] and uses soil properties and surface runoff flow coefficients to finally calculate the water conservation [17]. 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 Fei et al. [18] used the SWAT model to assess the water conservation function in the Sanjiangyuan area, and Lin Feng et al. [19] 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.

Numerous studies have shown that the SWAT model has good applicability in different regions. Therefore, based on the SWAT model and alternative engineering method, this paper assesses the water conservation and its service value in the Luoyang region from 2009 to 2018, and analyzes the reasons for its spatial and temporal changes, so as to provide a theoretical basis for the next comprehensive water environment management and sustainable development in the Luoyang region. At the same time, it provides decision-making basis for other regional water resources development and utilization, ecological environmental protection and economic development planning, etc.

2 Overview of the study area

Luoyang City is located in the western part of Henan Province, close to Zhengzhou City, the capital of Henan Province, to the east, Sanmenxia City to the west, Jiaozuo City across the Yellow River to the north, and Pingdingshan City and Nanyang City to 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.

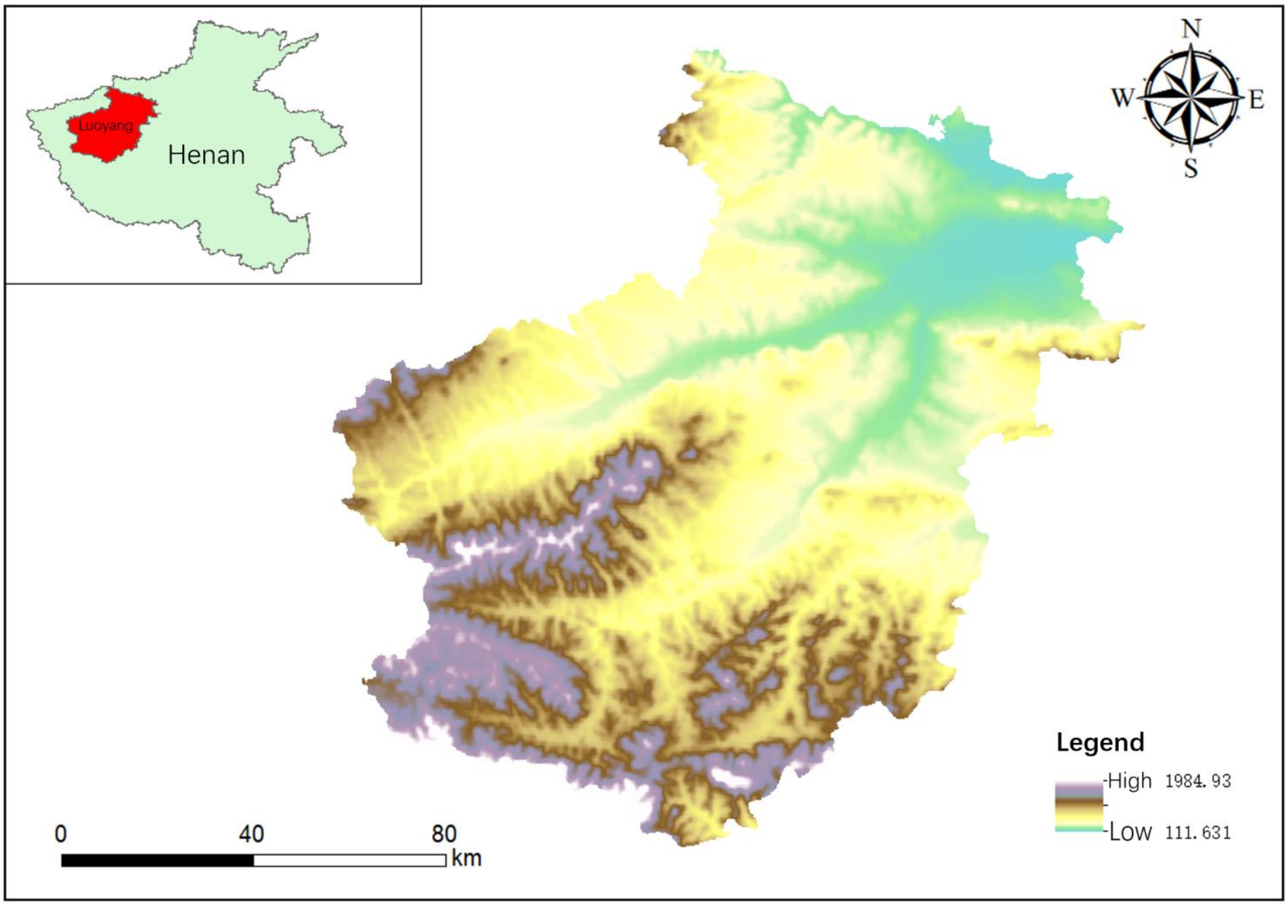

Figure 2-1 Geographical location map of Luoyang City

3 Data & Methods

3.1 ArcSWAT data construction

The SWAT hydrologic model is a field-scale nonpoint 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 [20]. 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 [21], 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 12.5m resolution DEM was collected and transformed in ArcGIS for projection as well as clipping, filling and interpolation, and the clipped DEM is shown below.

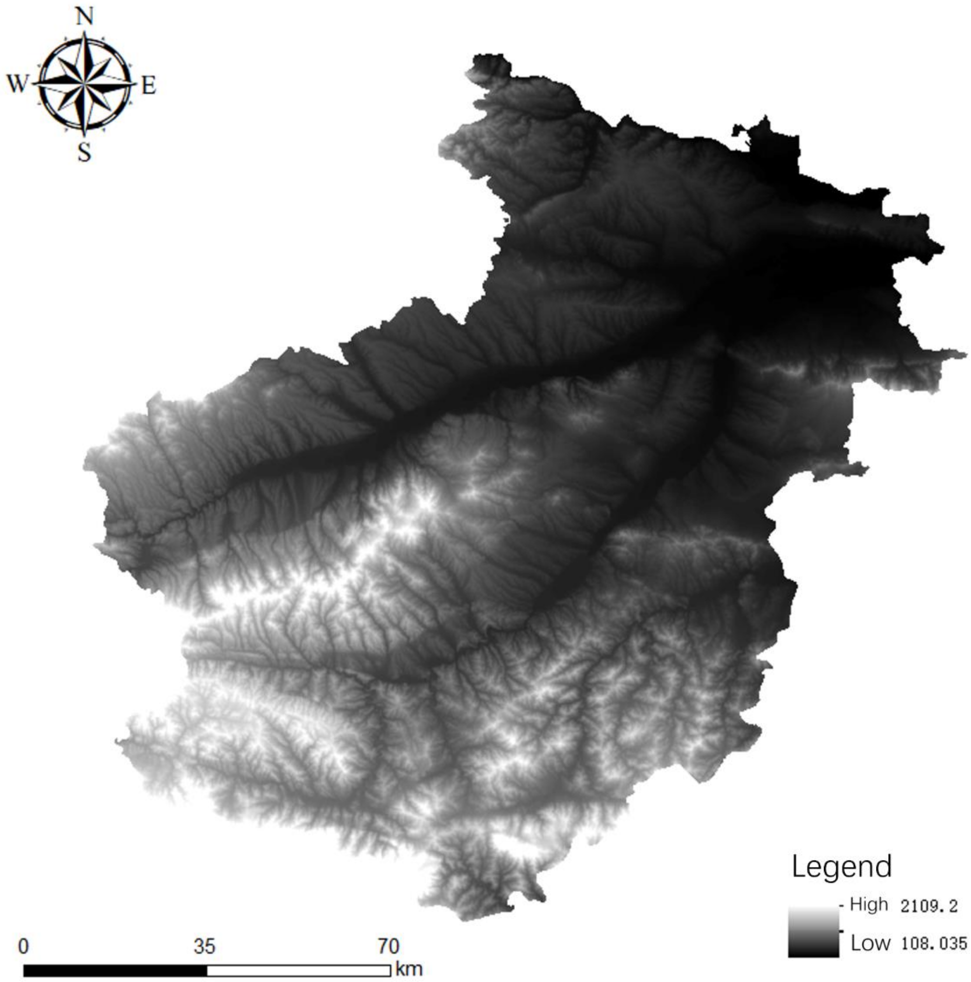

Figure 3-1 12.5m DEM map of Luoyang City

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.

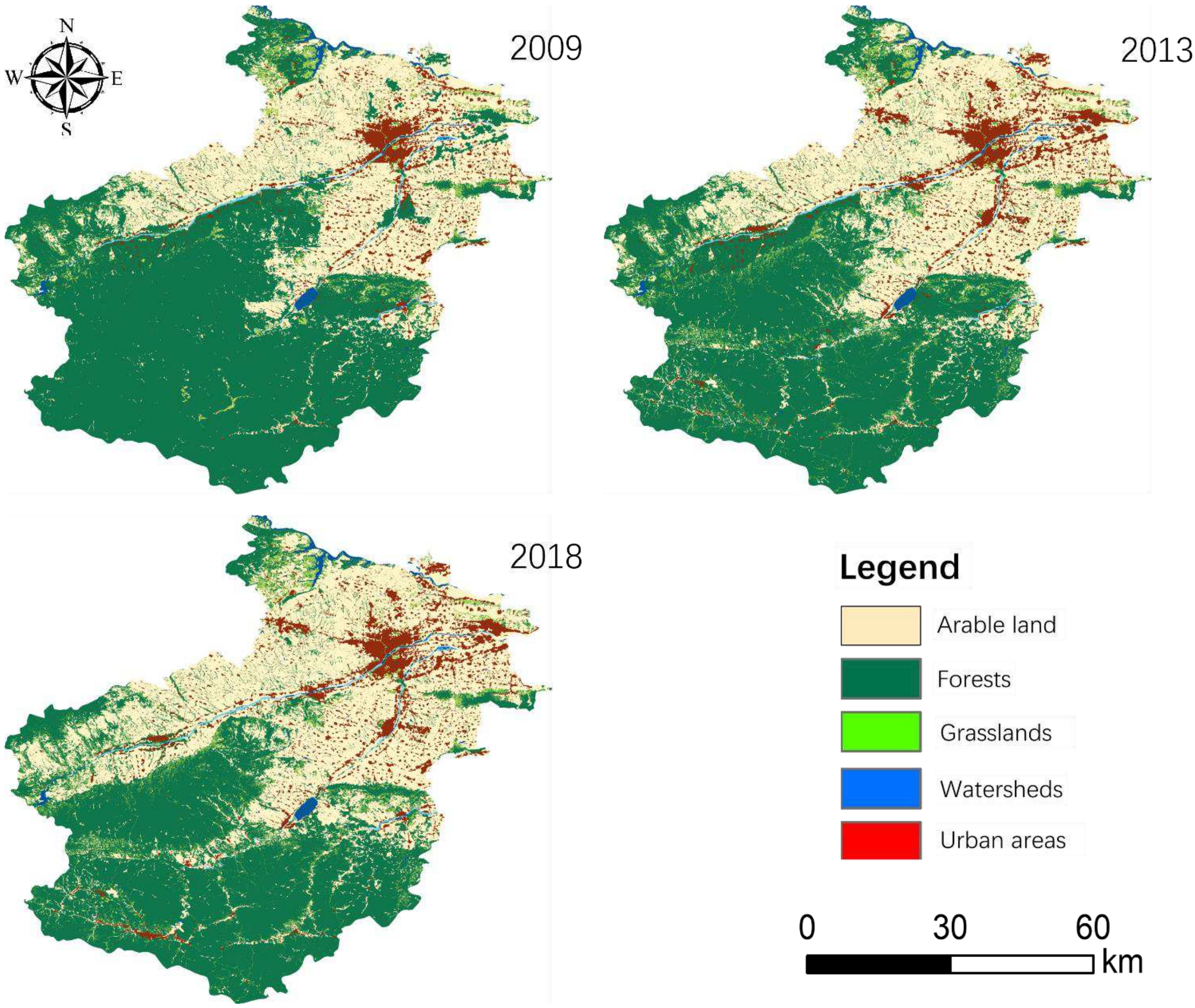

Figure 3-2 Land use in Luoyang City

Table 3-1 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	62.24	20.14	0.28	0.08
Grasslands	1492.79	1486.76	1458.42	-6.03	-0.4	-28.35	-1.91

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.

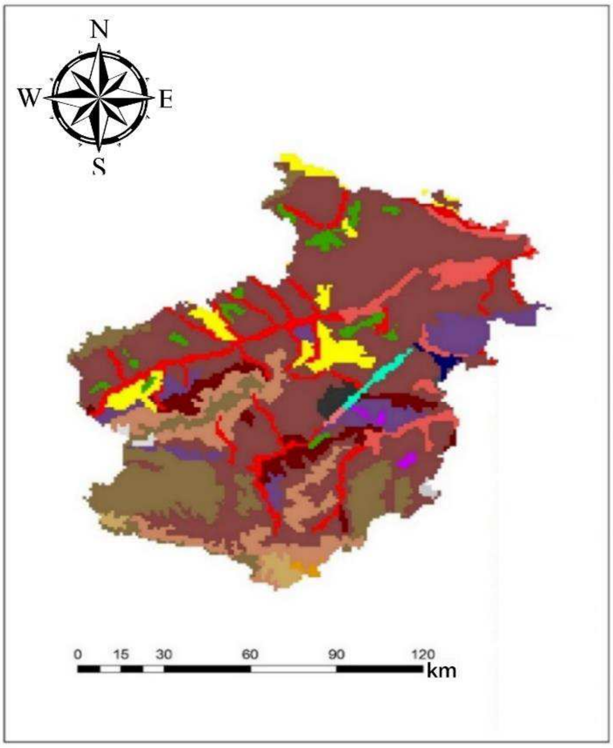

Figure 3-3 Soil type map of Luoyang City

In this study, the area of the generated Luoyang area model based on 12.5m accuracy DEM is 10.9x103km^2, and 15000ha is used as the threshold value for this watershed delineation, and the whole study area is divided into 25 sub-basins as follows.

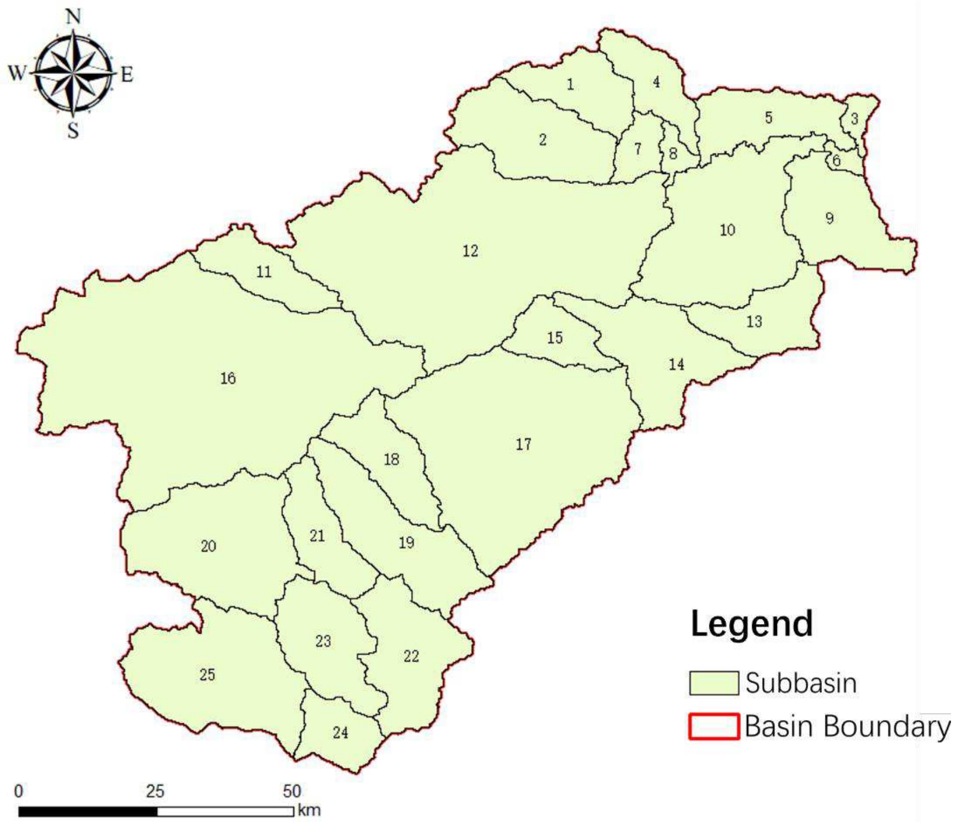

Figure 3-4 Number and location of each sub-basin

The delineation of spatial units [sub-basins and minimum hydrological units (HRUs)] affects the simulation of runoff, sand content and nutrients [22]. 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.

3.2 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:

$$R^2 = \frac{\left[\sum_{i=1}^{n}(o_i - o)(s_i - s)\right]^2}{\sum(o_i - o)^2 \sum(s_i - s)^2} \qquad (1)$$

$$N_s = 1 - \frac{\sum_{i=1}^{n}(o_i - s_i)^2}{\sum_{i=1}^{n}(o_i - o)^2} \tag{2}$$

where: *Si, Oi* denote the ith 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 3-2 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

The results of the rate determination and validation are shown below.

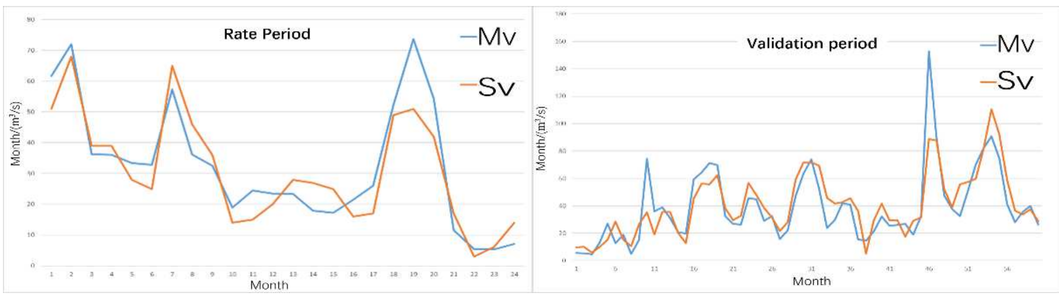

Figure 3-5 Whitehorse Temple Rate Periodic and Validation Period

Table 3-3 R^2 and Ns coefficients for hydrological stations during the rate and validation period

Rate Period		Validation period	
Decision factor R^2	Efficiency factor Ns	Decision factor R^2	Efficiency factor Ns
0.72	0.73	0.79	0.75

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

3.3 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.

$$F/S = Q/P - I_a \tag{3}$$

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.

$$S = \frac{25400}{CN} - 254 \tag{4}$$

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.

$$CN_1 = CN - \frac{20 \times (100 - CN)}{100 - CN + \exp[2.533 - 0.063 \times (100 - CN)]} \tag{5}$$

$$CN_2 = CN \cdot \exp[0.0636 \times (100 - CN)] \tag{6}$$

where: *CN1*、*CN2* 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.

$$S = S_{\max}\left[1 - \frac{SW}{SW + \exp(w_1 - w_2 \cdot SW)}\right] \tag{7}$$

Where: S_{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 , 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.

$$w_1 = Ln\left(\frac{FC}{S_2 \cdot S_{\max}} - FC\right) + w_2 \cdot FC \tag{8}$$

$$w_2 = \frac{\ln\left(\frac{FC}{1 - S_2 \cdot S_{\max}{}^{-1}} - FC\right) - \ln\left(\frac{SAT}{1 - 2.54 \times S_{\max}{}^{-1}} - SAT\right)}{SAT - FC} \tag{9}$$

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 transpiration, 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.

$$Q_{lat} = 0.024 \times \left(\frac{2 \times SW_{ly,excess} \cdot K_{sat} \cdot slp}{\Phi_d \cdot L_{hill}}\right) \tag{10}$$

Where: Q_{lat} is the lateral flow rate, mm; $S_{wly,excess}$ 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; S_{lp} is the slope, m/m; Φ_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.

$$Q_{gw,i} = Q_{gw,i\text{-}1} \exp(-a_{gw} \triangle t) + w_{rehrg}[1 - \exp(-a_{gw} \triangle t)] \tag{11}$$

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; Δt is the time step, d; W_{rehrg} 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, transpiration from plants and animals, etc. 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. A necessary part of the evaporative cycle, it is an important pathway for moisture transfer.

3.4 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.

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \tag{12}$$

Where: SW_t is the final water conservation of the soil, mm;

SW_o 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.

$$B_1 = QS \times P \tag{13}$$

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-m3.

4 Results & Discussion

4.1 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 (Figure 4-1).

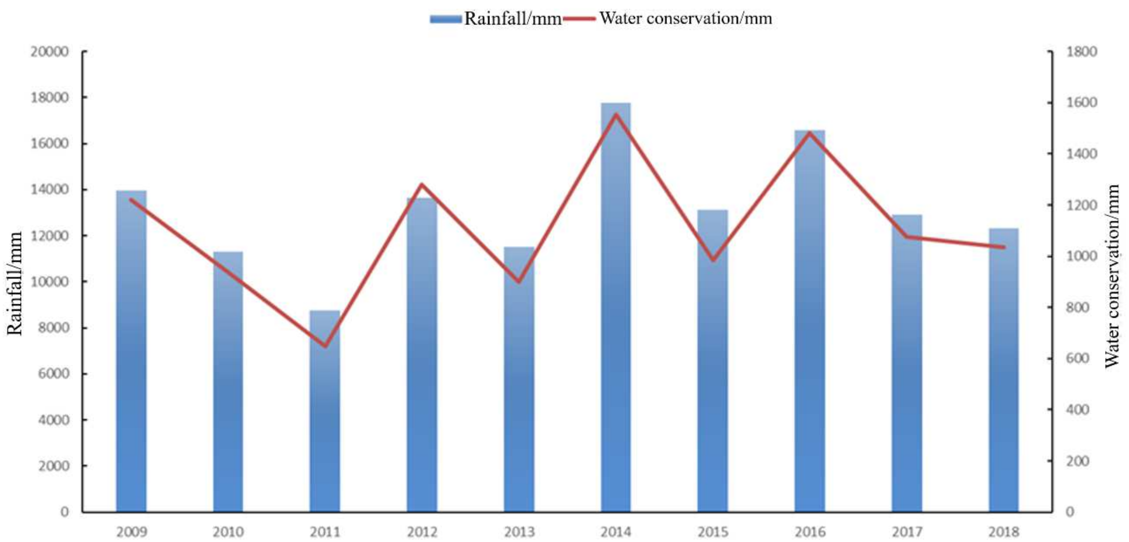

Fig. 4-1 Water conservation and rainfall in Luoyang area

Precipitation is an important factor that directly affects the temporal variation of water conservation and its service value [23]. 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 (Figure 4-2), with a Pearson correlation coefficient of 0.63 for both.

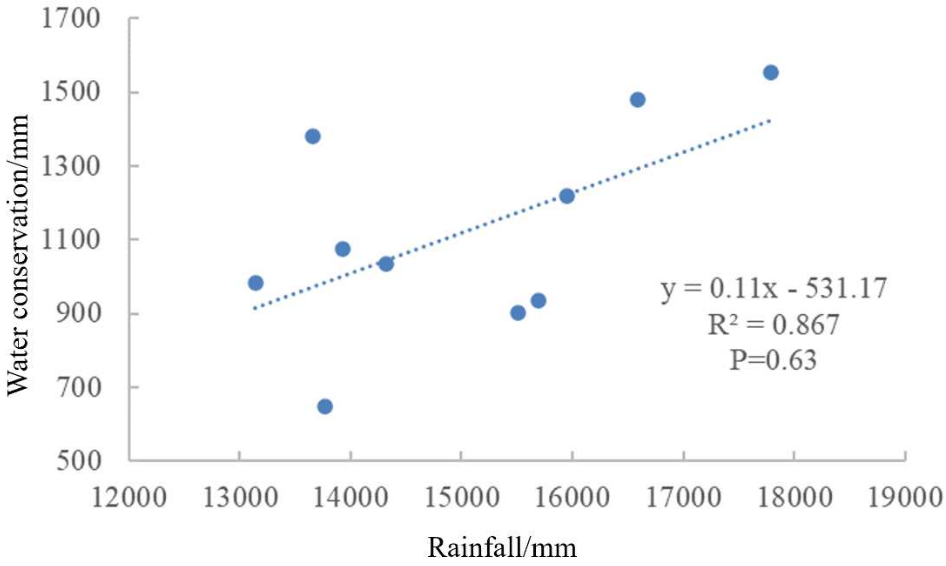

Figure 4-2 Correlation between water conservation and precipitation in Luoyang region from 2009-2018

4.2 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 (Figure 4-3). As can be seen from the figure, the average annual amount of water conservation per unit area in different sub-basins is 448.80mm, with the high value area (>500mm) concentrated in the southeastern part of the basin and the low value area (<300mm) 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.

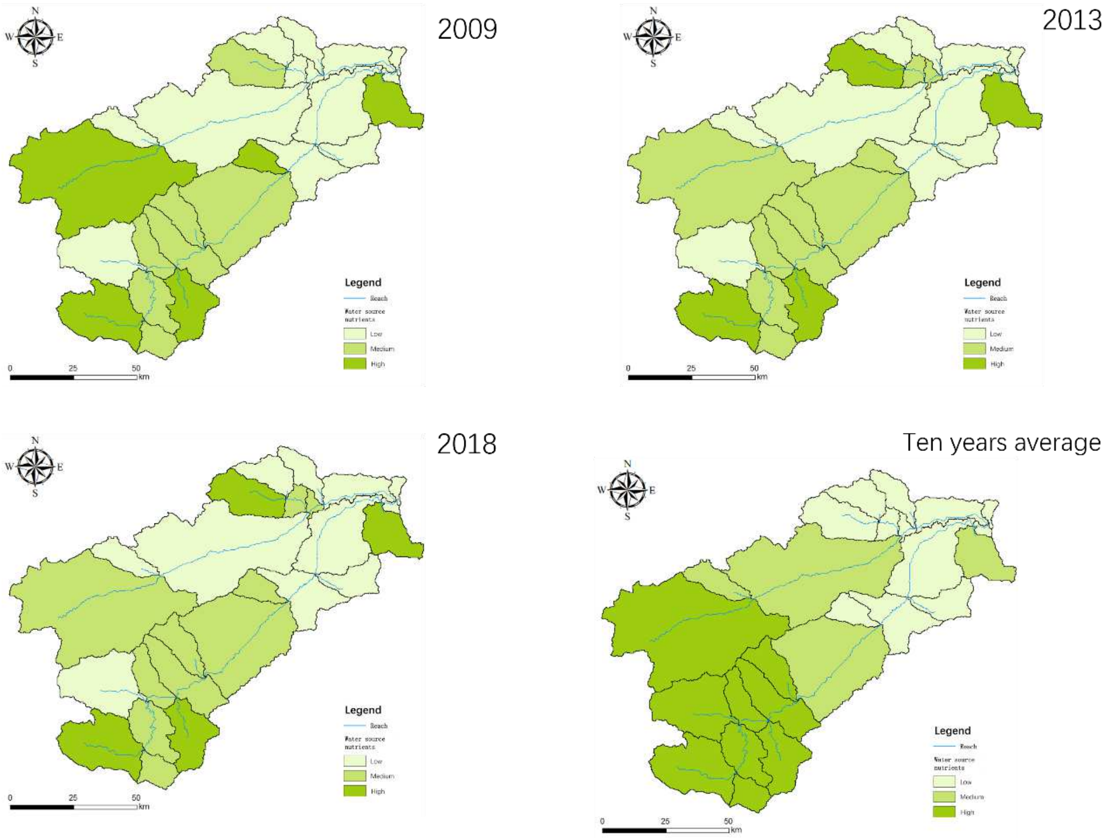

Figure 4-3 Spatial distribution of average water conservation of sub-regions in Luoyang region, 2009-2018

4.3 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 (Figure 4-4) 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 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 4-1). 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 [24,25]. 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.

Table 4-1 Value of water-supporting services of different ecosystems

Ecosystem Type	Area share (%)	Unit area water conserved($m^3 \cdot hm^{-2}$)	Value of water conservation services per unit area（$yuan \cdot hm^{-2}$）
Forests	39	4316	26370.76
Arable land	43	1969	12030.59
Urban	7	1119	6837.09
Grassland	8	2619	16002.09

4.4 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 et al[23]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[26]. 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.

In this study, it was found that the value of water connotation services per unit area of forests within the Luoyang area was much higher than that of cropland, urban and grassland, and the results of a related study by Gong Fei et al [27] also confirmed this conclusion. However, the water conservation and service value of the same ecosystem vary in different regions, for example, Liu Ju et al [28] 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; Chen Shanshan et al[29]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, respectively. and 1202.1 m^3-hm-2 respectively; in this study, the water conservation of forest and arable land in Luoyang area were 3216.3 and 1069.6 m^3-hm-2 respectively. 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[16]. 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 2009-2018, and the results are more the results are more scientific.

5 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 m3 and 74.5 million yuan respectively, and the average annual total precipitation is about 16.3 million m3. 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.

Declarations

Funding

No funding was received to assist with the preparation of this manuscript.

Competing Interests

The authors declare no conflict of interest.

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.

Authors Contributions

Zhang XQ: Methodology, Investigation, Writing-Original draft preparation.

Chen P: Conceptualization, Writing-review & editing.

Dai SN: Methodology, Formal analysis.

Han YH: Conceptualizaiton, 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.

References

[1] Anderson SJ, Ankor BL, Sutton PC. Ecosystem Service Valuations of South Africa Using a Variety of Land Cover Data Sources and Resolutions[J]. Crossref, 2017, 27: 173-178.

[2] Bagstad KJ, Semmens DJ, Waage S, et al. A Comparative Assessment of Decision-support Tools for Ecosystem Services Quantification and Valuation[J]. Crossref, 2013, 5: 27-39.

[3] Barnes P, Costanza R, Hawken P, et al. Creating an Earth Atmospheric Trust[J]. Crossref, 2008, 319(5864): 724-724.

[4] Batker, D., Swedeen, P., Costanza, R., et al. A new view of the puget sound economy: The economic value of nature's services in the puget sound basin [J].. Earth Economics, Tacoma, WA, 2008.

[5] Costanza R, Atkins PW, Bolton M, et al. Overcoming Societal Addictions: What Can We Learn From Individual Therapies?[J]. Crossref, 2017, 131: 543-550.

[6] Costanza R, Chichakly K, Dale V, et al. Simulation Games That Integrate Research, Entertainment, and Learning Around Ecosystem Services[J]. Crossref, 2014, 10: 195-201.

[7] Dou H, Li X, Li S, et al. Mapping Ecosystem Services Bundles for Analyzing Spatial Trade-offs in Inner Mongolia, China[J]. Crossref, 2020, 256: 120444.

[8] Ehrlich PR, Mooney HA. Extinction, Substitution, and Ecosystem Services[J]. Crossref, 1983, 33(4): 248-254.

[9] Farber SC, Costanza R, Wilson MA. Economic and Ecological Concepts for Valuing Ecosystem Services[J]. Crossref, 2002, 41(3): 375-392.

[10] MA. Ecosystems and Human Well-being. Washington DC, USA: Island Press, 2005

[11] Xiao Y, Xie G, Lu C, et al. The Value of Gas Exchange as a Service By Rice Paddies in Suburban Shanghai, Pr China[J]. Crossref, 2005, 109(3): 273-283.

[12] Ouyang ZYY, Wang XIAOKE, Miao H. A preliminary study of terrestrial ecosystem service functions and their ecological and economic values in China[J]. Journal of Ecology,1999(05):19-25.

[13] Ouyang Zhiyun, Zhao Tongqian, Wang Xiaoke, Miao Hong. Analysis of water ecological service function and its indirect value evaluation[J]. Journal of Ecology,2004(10):2091-2099.

[14] Xie Heights, Lu Chunxia, Cheng Shengkui. Advances in global ecosystem service valuation[J]. Resource Science,2001(06):5-9.

[15] Liu S. R., Chang J. G., Sun P. S.. Forest hydrology: Forest-water relationships in the context of global change. Journal of Plant Ecology, 2007, 31(5): 753-756 .

[16] Tang Yao, Zhu Weiping, Zhang Hui et al. Research progress on the principle of InVEST model and its application. Ecological Science, 2015, 34(3): 204-208.

[17] Bao YB, Li T, Liu F et al. Spatial and temporal variation of water conservation function in the Loess Plateau of northern Shaanxi based on InVEST model. Geography Research, 2016, 35(4): 664-676.

[18] Qiao Fei, Fu Guo, Xu Xiangqin et al. Assessment of water connotation function in Sanjiangyuan District. Environmental Science Research, 2018, 31(6): 1010-1018.

[19] Lin F, Chen XW, Yao WY, et al. Multi-timescale analysis of water conservation in watersheds with discontinuous forest distribution based on SWAT model. Journal of Geography, 2020, 75(5): 1065-1078.

[20] Wang C.G., Liu C.M., Huang Y.B. Research on the principle, structure and application of SWAT model [J]. Advances in Geographical Sciences, 2003(01):79-86.

[21] Dai JF, Cui YL. Distributed hydrological model of irrigation area based on SWAT -I. Principles and methods of model construction [J]. Journal of Water Resources, 2009, 40(02):145-152.

[22] Arabi M,Rao S,Mohamed M,et al.2006.Role of watershedsubdivision on modeling the effectiveness of best managementpractices with SWAT[J].Journal of the American Water Resources Association,(4):513-528.

[23] Gong Shihan, Xiao Yang, Zheng Hua, et al. Spatial characteristics of water conservation of Chinese ecosystems and their influencing factors. Journal of Ecology, 2017, 37(7): 2455-2462.

[24] Zhang Biao, Li Wenhua, Xie Heights, et al. Water-holding function of forest ecosystems and its measurement method. Journal of Ecology, 2009, 28(3): 529-534.

[25] Wang Yao, Xu P, Fu B, et al. Research progress of water conservation function assessment model of forest ecosystem. Ecological Economics, 2018, 34(2): 158-164.

[26] Bao YB, Li T, Liu F, et al. Spatial and temporal variation of water conservation function in the Loess Plateau of northern Shaanxi based on InVEST model. Geography Research, 2016, 35(4): 664-676.

[27] Gong Fei, Luo Yong, Tian Hsiang, et al. Assessment of the importance of the water-conserving function in the dam area of Zhangjiakou. Grassland Science, 2020, 37(7): 1337-1344.

[28] Liu J, Fu B, Zhang Chenghu, et al. Assessment of water conservation and value of the upper Minjiang River ecosystem based on the InVEST model. Yangtze River Basin Resources and Environment, 2019, 28(3): 577-585.

[29] Chen Shanshan, Liu Kang, Bao Yubin, et al. Spatial pattern of water connotation service function and influencing factors in Shangluo City. Geoscience, 2016, 36(10): 1546-1554.