



Optimization of water-urban-agricultural-ecological land use pattern: A case study of Guanzhong Basin in the southern Loess Plateau of Shaanxi Province, China

Sai Wang^{a, b}, Bin Wu^{a, *}, Hai-xue Li^{a, c, d, *}, Min-min Zhao^{a, b}, Lei Yuan^{a, b}, Xi Wu^{a, b}, Tao Ma^{a, b}, Fu-cheng Li^{a, b}, Shuang-bao Han^{a, b}

^a Center for Hydrogeology and Environmental Geology Survey, China Geological Survey, Ministry of Natural Resources, Tianjin 300304, China

^b Center for Groundwater Exploration and Development Engineering Research, China Geological Survey, Ministry of Natural Resources, Tianjin 300304, China

^c School of Environmental Studies, China University of Geosciences, Wuhan, 430078, China

^d State Environmental Protection Key Laboratory of Source Apportionment and Control of Aquatic Pollution, Hubei Key Laboratory of Yangtze Catchment Environmental Aquatic Science, China University of Geosciences, Wuhan, 430078, China

ARTICLE INFO

Article history:

Received 3 November 2021

Received in revised form 11 January 2022

Accepted 15 March 2022

Available online 18 September 2023

Keywords:

Coupled Ground-Water and Surface-Water Flow Model (GSFLOW)

Land use patterns

Water resources optimization

Ecological and economic benefits

Coupling model

Hydrological environmental engineering

Guanzhong Basin

Southern Loess Plateau

Yellow River basin

ABSTRACT

Extensive land use will cause many environmental problems. It is an urgent task to improve land use efficiency and optimize land use patterns. In recent years, due to the flow decrease, the Guanzhong Basin in Shaanxi Province is confronted with the problem of insufficient water resources reserve. Based on the Coupled Ground-Water and Surface-Water Flow Model (GSFLOW), this paper evaluates the response of water resources in the basin to changes in land use patterns, optimizes the land use pattern, improves the ecological and economic benefits, and the efficiency of various spatial development, providing a reference for ecological protection and high-quality development of the Yellow River Basin. The research shows that the land use pattern in the Guanzhong Basin should be further optimized. Under the condition of considering ecological and economic development, the percentage change of the optimum area of farmland, forest, grassland, water area, and urban area compared with the current land use area ratio is +2.3, +2.4, -6.1, +0.2, and +1.6, respectively. The economic and ecological value of land increases by 14.1% and 3.1%, respectively, and the number of water resources can increase by 2.5%.

©2024 China Geology Editorial Office.

1. Introduction

The land use pattern means the areas and distributions of different land use. The change in land use patterns will influence the regional ecological environment and social economy (Yang L et al., 2020). With China's economy stepping out of the rapid development stage and entering the high-quality development stage, land resources face a dual task of development and protection. The contradiction between the supply and demand of land resources leads to the contradiction between economic development and ecological protection (Feng BP et al., 2018). Due to historical reasons,

China's land use is generally extensive, which will cause waste of land resources, soil erosion, deterioration of the ecological environment, and other environmental problems. The optimization of land use pattern is a complex multi-objective optimization problem (Zhang HH et al., 2011; Yuan M and Liu YL, 2014). It is necessary to optimize the distribution of quality and space according to the influence of land on nature, the environment, and the social economy (Lu JH et al., 2017; Ma BY et al., 2019). The optimization of land use pattern is an urgent task to improve land use effects and promote sustainable utilization of land resources (Feng BP et al., 2018). The changes in land use pattern will change the underlying surface conditions of the basin, thus affecting the hydrology cycle. In the meantime, land use change will directly affect the land's economic benefits. Several scholars carried out a lot of research on the optimization of land use pattern. Many model methods are adopted, including gray theory (Geng H and Wang ZM, 2000; Wang J et al., 2008), genetic algorithm (Yuan M and Liu YL, 2014; Wang Q et al.,

First author: E-mail address: wangsai@mail.cgs.gov.cn (Sai Wang).

* Corresponding author: E-mail address: wbin_a@mail.cgs.gov.cn (Bin Wu); lihaixue@mail.cgs.gov.cn (Hai-xue Li).

Literary editor: Li-qiong Jia
doi:10.31035/cg2022068

2096-5192/© 2024 China Geology Editorial Office.

2018; Clark KC, 2018; Yang L et al., 2020), neural network (Carranza-García M et al., 2019; Liu S et al., 2019; Zhang WL et al., 2021), system dynamic (Tu XS et al., 2009; Tian H et al., 2017) and other mathematical methods, combined with spatial pattern predict model such as cellular automata (Li H et al., 2018; Rimal B et al., 2018; Islam K 2018; Sun YZ et al., 2020), CLUE-S (Jiang W et al., 2015; Wei W et al., 2017; Kucsicsa G et al., 2019), FLUS (Liang X et al., 2018; Wang BS et al., 2019; Zhang XR et al., 2020; Lin W et al., 2020). Most of these studies only consider the optimal allocation of social and economic benefits of land use, and rarely consider the impact of land use on the hydrological cycle process, especially for the land use scheme in areas with fragile ecological environments.

Guanzhong Basin is located in the south of the Shaanxi Loess Plateau. With superior geographical conditions, a warm climate, and rich natural resources, it is one of the important birthplaces of the Chinese nation. The Jing River and Beiluo River, which developed from the hills of the loess plateau confluence in the Guanzhong Basin, bring abundant water resources, and meanwhile, they also bring soil erosion and land desertification (Xu RR et al., 2020). The Guanzhong Basin is a fault basin formed in the Cenozoic and is a relatively independent hydrological unit. The north boundary is the north mountains of the Weihe River, the south boundary is the Qinling fold belt, and the east boundary is the Yellow River (Zhang MS et al., 2005; Song YG et al., 2021; Li HX et al., 2021). Quaternary loss deposits are widely distributed in Guanzhong Basin, and with large deposits, good water abundance constitutes a good water storage space. Aquifers are widely distributed, and there is a close hydraulic connection between aquifers. Groundwater recharge condition is good and water resources are enough. However, due to the deep exploitation of groundwater and reduction of upstream runoff in recent years, the contradiction between the supply and demand of water resources in Guanzhong Basin become intensified. Facing the problem of insufficient water resources storage and risk of water resources shortage under extreme conditions (Dong Y et al., 2019).

The policy of “Governing the Yellow River, focusing on protection and governance” was raised, which provided a direction for ecological protection and high-quality development in the Yellow River Basin in the new era (Li HX et al., 2021). To promote the complementary and coordinated development of large, medium, and small cities in Guanzhong Basin and improve the efficiency of various spatial development, it is urgent to further optimize the land use pattern. In this article, the Guanzhong Basin was selected to be an example, and a Coupled Groundwater and Surface water Flow Model was developed to evaluate the response of water resources to land use change in the basin. Optimize the water-urban-agriculture-ecological land use pattern, improve the ecological and economic benefits, and improve the efficiency of various special developments of the Guanzhong Basin to provide a reference to the ecological protection and high-quality development of the Yellow River Basin.

2. Study area

Guanzhong Basin is also known as Weihe Basin, for the Weihe River goes across the whole basin from west to east. It is located at latitude 33°N–35°20' N, longitude 106°30' E–110°30' E, skip-shaped opening from east to west. Starts from Baoji City in the west and ends in Tongguan County in the east. It is bounded by the northern mountains of the Weihe River in the north and extends to the north slope of the Qinling Mountains. It is about 320 km long from west to east, 30–120 km wide from north to south and the area is about 26600 km² (Fig. 1). With flat terrain, fertile soil, abundant water, geothermal and helium resources, Guanzhong Basin is one of the birthplaces of the Chinese civilization, the key areas of the Silk Road Economic Belt in the new era (Dong Y et al., 2019). The Guanzhong Basin has a superior geographical location, including Xi'an, Baoji, Xianyang, Weinan, Tongchuan cities, and Yangling Agricultural High-tech Industrial Demonstration Zone, with convenient transportation and is the political, economic, and cultural center of Shaanxi Province. The terrain is mainly plain and loess tableland, high in the east and low in the west. The Weihe River crosses the whole basin from west to east and flows into the Yellow River in Tongguan. The main rivers that flow into the Weihe River in the basin include the Qingjiang River, Qianhe River, Shitou River, Tangyu River, Qishui River, Heihe River, Laohe River, Fenghe River, Bahe River, Jinghe River, Shichuan River, Beiluo River, and Luofu River (Luo YL et al., 2010).

The climate in Guanzhong Basin is inland semi-arid and semi-humid with clear four seasons and rainy in the hot season which is beneficial to crop growth. Therefore, agriculture developed early, and various crops, rich in agricultural products. At the end of 2019, the cultivated land area of Guanzhong Basin was 14100 km², and the agricultural GDP was 199×10⁹ RMB, accounting for 56.2% of Shaanxi Province. The Guanzhong Basin is a key production area of grain, cotton, and oil in Shaanxi Province and even the whole of China. The annual average temperature of the Guanzhong basin is 12°C–13.6°C, and the precipitation is 530–700 mm per year. Precipitation is unevenly distributed in the basin, decreasing from west to east and from south to north, inter-annual and intra-annual distribution is uneven. Annual rainfall is mainly concentrated in July to September, accounting for about 45% of one year. Evaporation is 900–1200 mm per year, increasing from west to east (Tian H et al., 2007). The Guanzhong Basin is surrounded by mountains in the south, north, and west. The terrain is high in the north, low in the middle, high in the west, and low in the east. From the mountain to the basin center, the landform type is piedmont plain, loess tableland, and alluvial plain turn. The main river of the basin is the Weihe River, and the runoff (Huaxian Station) is about 6.5×10⁹ m³ per year (Li B et al., 2021).

Quaternary is widely distributed in the Guanzhong Basin (Fig.2) and is unconformity contact with the underlying Paleogene-Neogene. The lithology is mainly loess and gravel pebbles. The thickness of Quaternary sediments increased

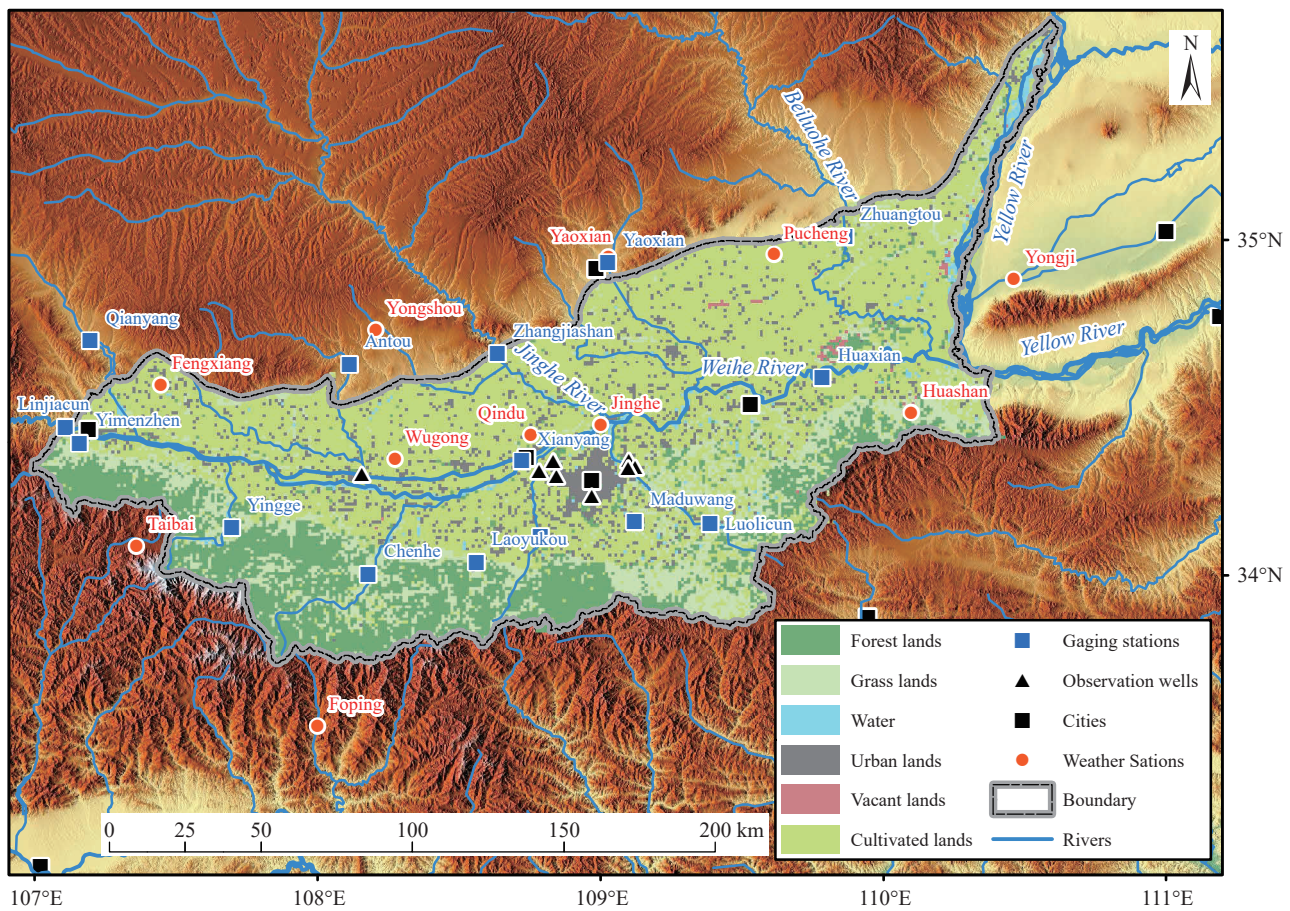


Fig. 1. General situation of Guanzhong Basin in Shaanxi Province, China.

from northwest to southeast. At the sedimentary center of the basin, the thickness of Quaternary sediments is the largest, which is generally greater than 400 m in the valley area and 100–300 m in the loess tableland area. The main distribution areas of Aeolian loess include the loess tableland area in the north and south of the Weihe River, the Qinling Mountains, the piedmont, and the platform of the northern mountains in the north Weihe River, and the thickness is 130–240 m (Dong Y et al., 2019).

3. Coupled surface water and groundwater model of the Guanzhong Basin

3.1. GSFLOW model

In this article, GSFLOW (Markstrom SL et al., 2008) was selected to construct a surface and groundwater-coupled model. GSFLOW integrated the US Geological Survey Precipitation-Modeling System (PRMS) and the US Geological Survey Modular Groundwater Flow Model (MODFLOW). PRMS is a classical distributed surface runoff model. MODFLOW is a classical groundwater model. GSFLOW simulates the hydrological processes of groundwater and surface water, such as overland runoff, stream runoff, evaporation, infiltration, soil flow, groundwater flow in the unsaturated zone and saturated zone, groundwater discharge, the interaction between stream runoff and groundwater, and so on. Lots of reaches were carried out on

surface-groundwater coupling modeling at watershed scale via using GSFLOW (Wu B et al., 2014; Zhang HJ et al., 2015; He J, 2018; Chen C et al., 2018; Wu B et al., 2019). There are also cases of GSFLOW improvements (Niswonger RG, 2020; Crystal Ng GH et al., 2018).

The computing units of surface water in GSFLOW are referred to as Hydrological Response Units (HRU), and the groundwater computing units are finite-difference cells. The unsaturated zone is under the surface soil zone and above the groundwater saturated zone, which is computed by the Unsaturated Zone Flow Package (UZP). Gravity reservoirs modular is used to transfer water between HRUs and finite-difference cells. Soil water seeps into the gravity reservoirs, and while the groundwater level is below the threshold, gravity reservoirs release water to the saturated zone, which moves down to the saturated zone. While the groundwater level is above the threshold, saturated water supplements gravity reservoirs and eventually becomes part of soil water or interflow. The Stream Routing package is used for computing stream discharge via water balance and kinematic-wave equation. Darcy's law is used to compute the exchanges between groundwater and river, according to the difference between river and groundwater levels.

3.2. Modelling

The boundary of the study area as shown in Fig. 1,

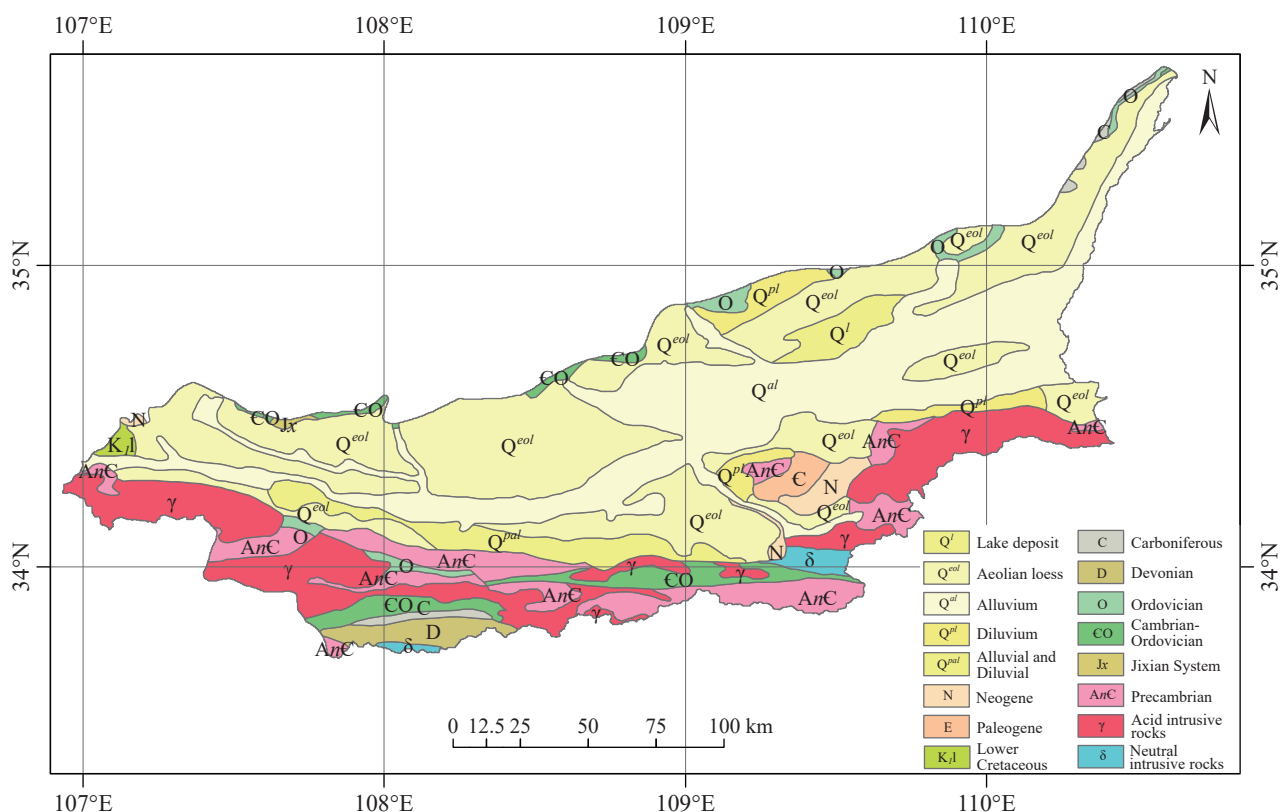


Fig. 2. Geological conditions of Guanzhong Basin in Shaanxi Province, China.

includes the whole Guanzhong Basin, west to Baoji, east to Tongguan, north to Weihe River north mountains, and south to Qinling Mountains. The area is 26600 km², including Xi'an, Baoji, Xianyang, Weinan, Tongchuan cities, and Yangling Agricultural High-tech Industrial Demonstration Zone.

Reference of geological structure modeling to section map, hydrogeological map, borehole data of previous geological reports in Guanzhong Basin and related literature (Zhang MS et al., 2005; Song YJ et al., 2021; Li HX et al., 2021). The top layer of the model is surface DEM (STRM 1 Arc-Second Global), and the bottom layer is the Quaternary bottom. According to the aquifer characteristics, the model was divided into three layers in the vertical direction: One unconfined aquifer and two confined aquifers. In the horizontal direction, the grid is divided into 213 rows and 340 columns, and the grid size is 1 km. According to the lithology and water abundance, hydrogeological parameter zoning is divided into 111 zones. Permeability coefficients of different lithologies were obtained from the literature (Gao L et al., 2012) and pumping experiments of collected boreholes. The permeability coefficient zones and aquifer thickness are shown in Fig. 3. DEM data were used for the sub-basin division. Combining soil type distribution and land use distribution, the basin was divided into 1314 HRUs. The vegetation coverage, the parameters of runoff generation and confluence, soil parameters, and other parameters of every HRU were computed. The digital river and sub-basins are shown in Fig. 4. The soil and land use data were collected from the National Tibetan Plateau Data Center (<http://data.tpdc.ac.cn>).

Meteorological data comes from the National Meteorological Information Centre (<http://data.cma.cn>), including precipitation, and daily maximum and minimum temperature. The meteorological data from 11 meteorological stations (Fig. 1) in or around the study area were selected to interpolate. Water diversion and groundwater exploitation information were collected from the water resources bulletin and relative literature (Luo YL et al., 2010). The water diversion directly reduced the corresponding water volume from the river channel (SFR module), and the water pumping directly reduced the corresponding water volume from the groundwater (WEL module). A reduced amount of water was added to the irrigation of farmland. Infiltration and evaporation wear are simulated by the model and do not need to be given. The flow observation data of fifteen hydrological stations were collected from the local water conservancy department. Huaxian and Xianyang stations were used to model calibration for those located in the mainstream of Weihe River, and the remaining 13 stations were located at the boundary of the model, as the surface boundary conditions of the model. Monthly data from eight groundwater monitoring points (Fig. 1) collected from the Shaanxi Institute of Geo-Environment Monitoring were used for model calibration. The inflow of groundwater boundary is small. The groundwater hydraulic connection between Guanzhong Basin and north-south and the western mountainous area is weak, which can be regarded as a boundary of water barrier boundary. The Yellow River is regarded as a discharge boundary in the east. The model was simulated from 2000–2019 and the time step is one day. The warm-up period

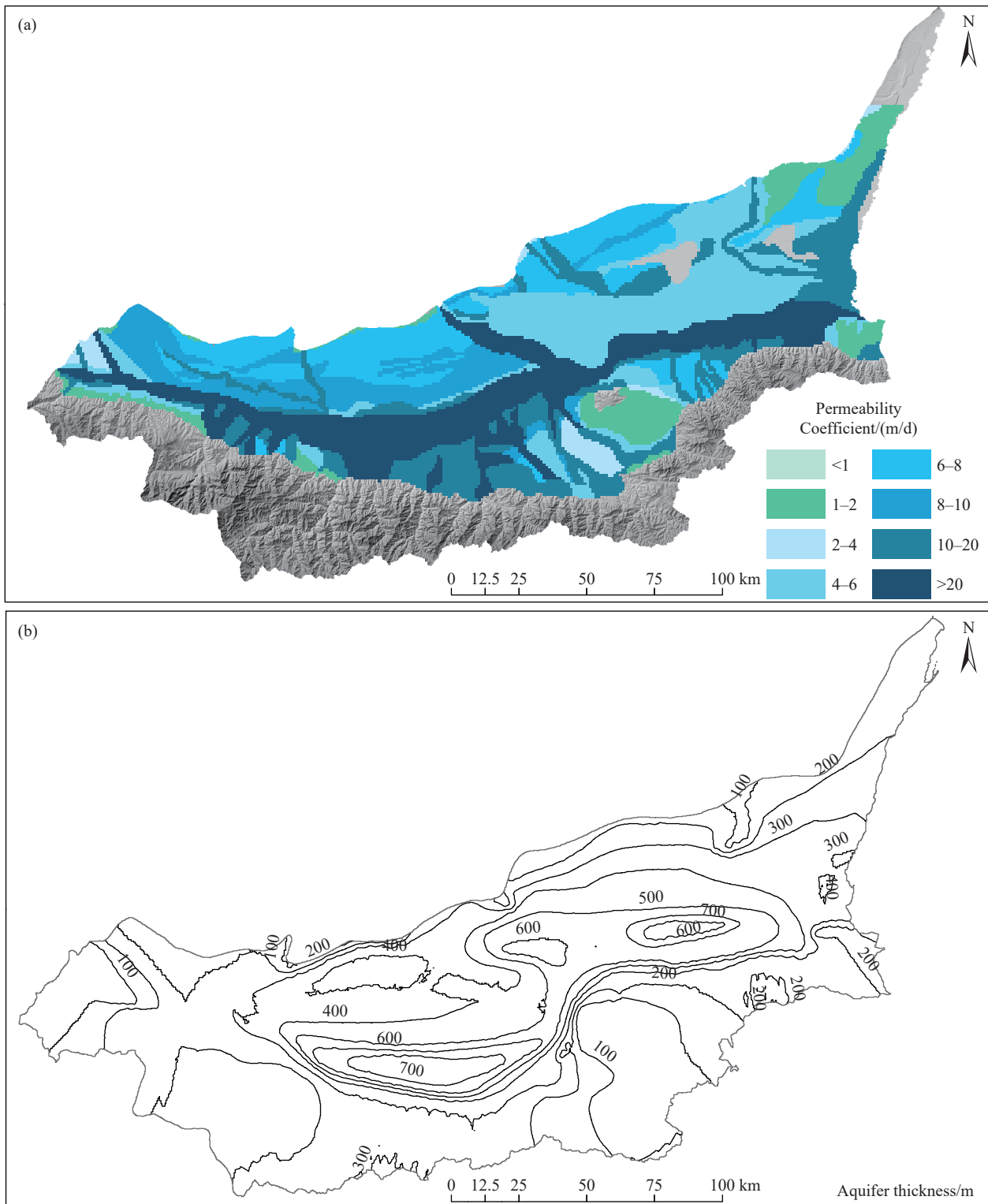


Fig. 3. Permeability coefficient and aquifer thickness. a–permeability coefficient; b–aquifer thickness.

was 2000–2011, the correction period was 2012–2015, and the forecast period was 2016–2019. Table 1 summarizes the main data used in the model, along with accuracy and sources.

3.3. Sensitive analyses and calibration

The main input and output parameters of the model were operated on uncertainty analyses. The Sobol method (Sobol

IM, 2001) was applied to analyze the output variables and the input contribution. The core of this method is to decompose the total model output covariance into the sum of the covariance of each parameter and the covariance of the parameter interaction and then classify the sensitivity of the contribution ratio of the parameters to the output covariance. According to the sensitivity analyses, it shows that for different output variables, the uncertainty resources are

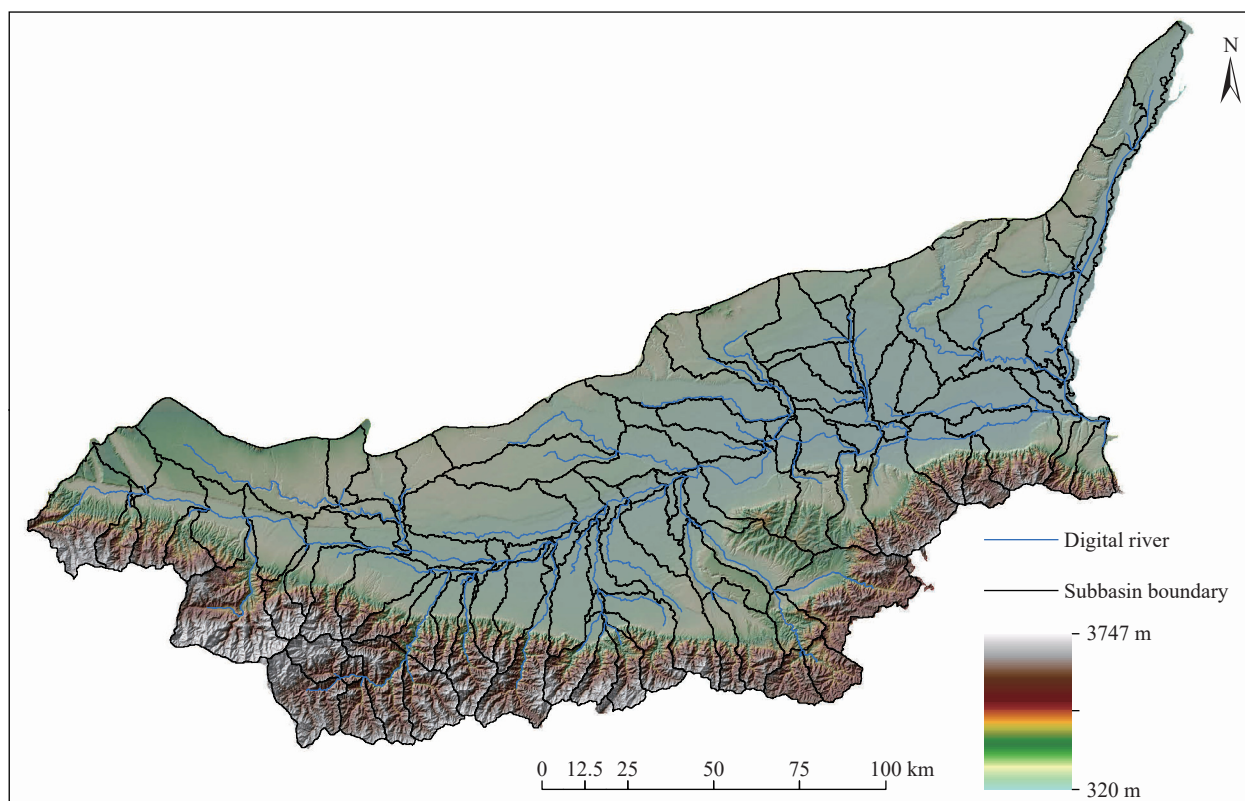


Fig. 4. Digital river and subbasins.

Table 1. Main data used for modeling.

Date	Accuracy	Source
DEM	30 m×30 m	STRM 1 Arc-Second Global
River network	1 : 100000	National Tibetan Plateau Data Center
Land use	1 : 100000	National Tibetan Plateau Data Center
Soil type	1 : 1000000	National Tibetan Plateau Data Center
Hydrogeological information	Multiple scales	China Geological Survey
Meteorological data	Daily	National Meteorological Information Centre
Diversion and Pumping information	Yearly	Local water authority
Stream flow	Monthly	Local water authority
Groundwater level	Monthly	Local water authority

different, but a small number of parameters play a leading role. The main uncertainty sources of evaporation simulation are precipitation data and irrigation data. The main uncertain source of soil moisture is the maximum evaporation depth. The main uncertainty sources of outlet stream-flow are water diversion and stream inflow, and the uncertainty of exchange between groundwater and surface water source is boundary inflow, stream inflow, and stream leakage coefficient.

The model calibration is carried out by manual parameter adjustment. The main sensitive parameters including maximum evapotranspiration depth, streambed hydraulic conductivity, manning coefficient, horizontal hydraulic conductivity, vertical hydraulic conductivity, and specific yield were selected after sensitive analysis. The outlet flow of the Huanxian station and Xianyang station and the groundwater level of the observation station around the study area were used to calibrate the model. The accuracy of stream

outflow simulation refers to Nash-Sutcliffe efficiency (NSE), and the groundwater level simulation accuracy refers to the changing trend of the groundwater level. The Nash-Sutcliffe efficiency is calculated as (Equ. 1):

$$NSE = 1 - \frac{\sum_{t=1}^T (Q_o^t - Q_m^t)^2}{\sum_{t=1}^T (Q_o^t - \bar{Q}_o)^2} \quad (1)$$

Where Q_o is the observation value, Q_m is the simulated value, and t is the time-step. If NSE is close to 1, it means that the quality of the model is good and the reliability of the model is high. If NSE is close to 0, it means that the simulation result is close to the average level of the observed value, that is, the overall result is credible, but the process simulation error is large. If NSE is far less than 0, the model is not credible.

The model calibration results are shown in Fig. 5 and Fig. 6,

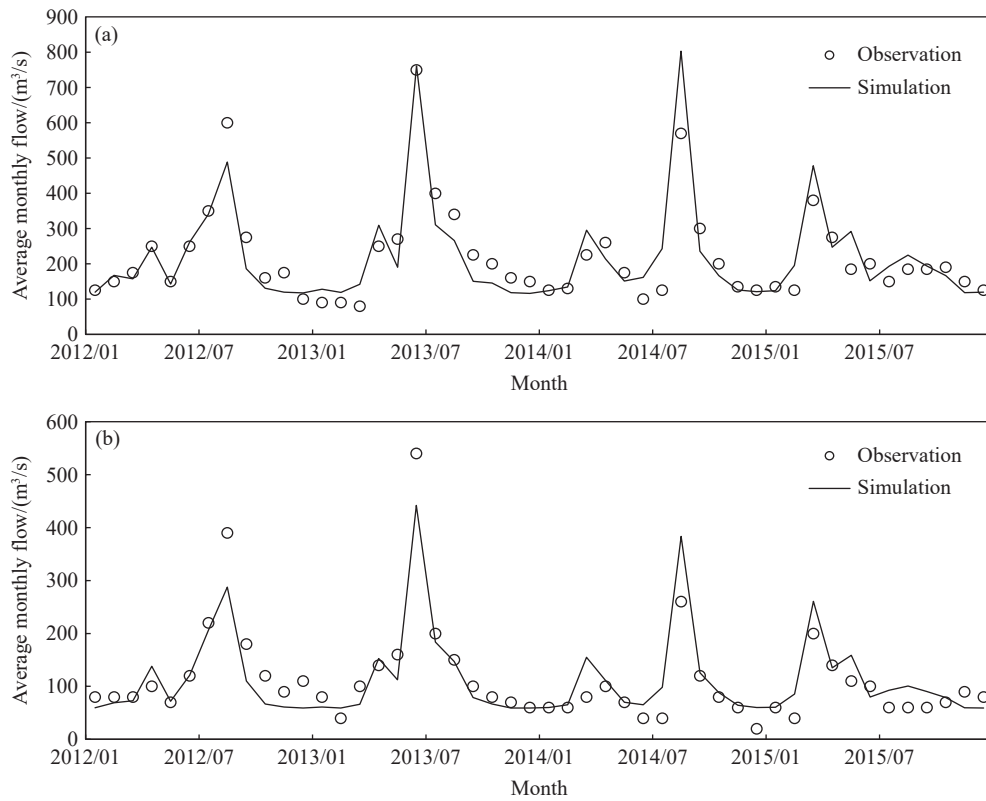


Fig. 5. Measured and simulated monthly runoff at Huaxian station and Xianyang station. a–Huaxian; b–Xianyang.

Huaxian NSE equals 0.78, and Xianyang station NSE equals 0.80. The simulation of groundwater level can basically capture the seasonal and inter-annual variation of the actual groundwater level and the simulation results are highly reliable.

4. Optimize of land use pattern model

4.1. Objective function

Based on the need for high-quality development in Guanzhong Basin, the objective function mainly considers economic and ecological benefits and constraint conditions consider the restrictions of policies on different land use modes. Land use pattern includes farmland, forest, grassland, water, urban, and unused.

(i) Economic benefit target (Equ. 2):

$$B_C = \sum_{i=1}^6 \omega_i B_{ci} + Q\omega_w B_w \quad (2)$$

where B_C is an economic benefit;

ω_i is the area of various land use type;

B_{ci} is the economic benefit per unit area of various land use types, which represents the GDP per unit area of various land use types in this article;

Q is the stream flow in the basin, which was calculated by the model as the average annual flow of 2010–2019;

B_w is the economic benefit of water resources per unit volume, which represents the surface water price per unit volume in this article;

Based on the national economic data (such as agriculture, forestry, animal husbandry, fishery, construction industry) and land use area (such as farmland, forest, grassland, water area, and town) of each city in the study area in 2019, the average GDP per unit is obtained via computed the GDP of each land use area. The average price of non-domestic water (5.5 RMB/t) was used to calculate the surface water price per unit volume. Surface runoff was calculated by using land use distribution via modeling. The results are shown in Table 2.

(ii) Ecological benefit target (Equ. 3):

$$B_E = \sum_{i=1}^6 \omega_i B_{Ei} \quad (3)$$

where B_E is an ecological benefit;

ω_i is the area of various land use type;

B_{Ei} is the ecological benefit per unit area of various land use types, which represents the ecosystem service value per unit area of various land use types in this article.

The ecological benefit per unit area is calculated based on the results of Xie GD's research (Xie GD et al., 2003). Xie GD listed an equivalent factor table of ecological value per unit area of the terrestrial ecosystem in China. The equivalent factor was defined as the potential capacity of the relative contribution of ecological services of the ecosystem. And the value is equivalent to one-seventh of the national average grain yield market in the same year. Based on the market value of the average grain yield in the study area in 2019, the grain yield in the study area was 495400 kg/km², and the unit price is 2.3 RMB/kg. The result is shown in Table 2.

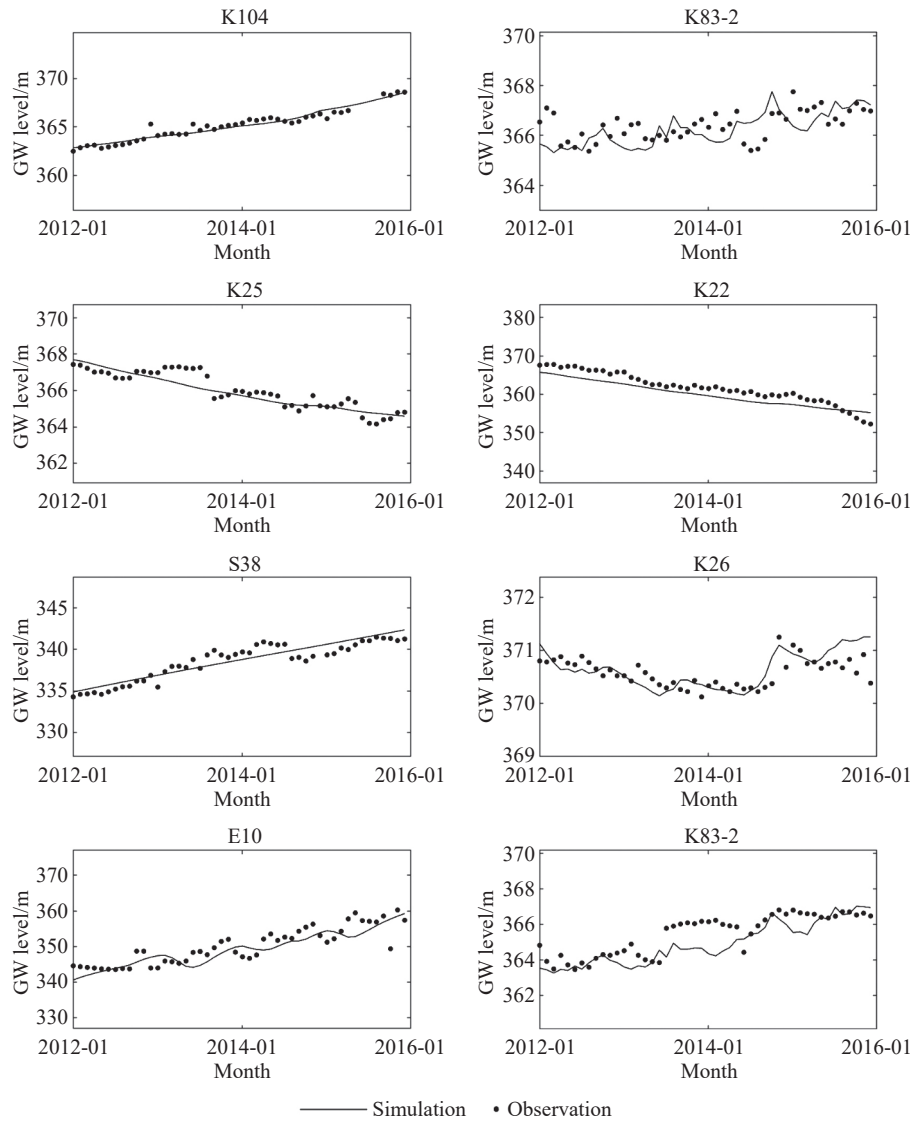


Fig. 6. Measured and simulated water level of groundwater level observation wells.

Table 2. Economic and ecological benefits of different land use types.

Unit: 10 ⁶ RMB/km ²	Agriculture land	Forest land	Grassland	Water land	Urban land	Unused land
Economic benefit	9.73	1.03	8.86	1.63	161	0
Ecological benefit	1.12	3.56	1.18	7.48	0	0.068

The main objective function is the sum of economic and ecological benefit targets (Equ. 4):

$$\max B_T = \lambda_C B_C + \lambda_E B_E \tag{4}$$

Where B_T is a weighted total benefit;
 λ_C is the weight of economic benefit;
 λ_E is weighted of ecological benefit.

The values of the two weights are decided by the different constraints.

4.2. Constraint condition

To satisfy the need for high-quality development, three development modes were set in this article: Ecological projection priority mode, economic development priority

mode, and ecology-economy equilibrium mode.

(i) Ecological protection priority mode

The ecological protection priority mode is the scenario of maximizing the ecological land use area. In this scenario, the main optimized objective is the ecological benefit growth, and the weights of economic and ecological benefits are 0.2 and 0.8. The constraint condition is that the area of forest, water, and other ecological land does not decrease, another land can be converted to ecological land, unused land can only be converted to ecological land, and the upper limit of urban area growth is 15%.

(ii) Economic development priority mode

The economic development priority mode is the scenario of maximizing the sum of the economic value of economic land and surface runoff. In this scenario, the weights of

economic and ecological benefit targets are 0.8 and 0.2. The constraint condition is that the water land area does not decrease, and another land can be converted to economic land, unused land can only be converted to economic land, and the upper limit of urban growth is 40%.

(iii) Ecology-economy equilibrium mode

The ecology-economy equilibrium mode is the scenario of maximizing the sum of ecological value, economic value, and water value. In this scenario, the weights of the economic and ecological benefit target are 0.5. The constraint condition is that the area of ecological lands such as forest land and water land does not decrease, unused land can be converted to ecological land or economic land, and the upper limit of urban growth is 20%.

4.3. Method of optimizing

Dynamic Coordinate search using Response Surface models (DYCORS) (Regis RG et al., 2013) was used to be the optimizing method in this article. DYCORS is an improved global optimization algorithm based on the random Radial Basis Function (RBF). Combined with the dynamic joint search method and random RBF alternative model, it can better balance the relationship between global search and local search. So that the search efficiency increases. The effect of this algorithm has been tested in much research (Wu B et al., 2015; Cosenza Z and Block DE, 2021).

The independent variable of the optimization process is the area of different land use types ω_i , $i=1-6$, representing agriculture land, forest land, grassland, water land, urban land, and unused land, respectively. The minimum unit of land use conversion is HRU. Set a group of ω_i values determining the reduction of initial land use distribution area, then determine the transformation HRU range according to the reduced area, and then distribute the transformation HRU range to the land use types which increased area. After distributing, the new land use distribution mode was substituted into the optimization model to compute the value of the objective function. The way to reduce or increase the area of one kind of land use type is determined by the slope. Forest and grassland are priority distributed into high slope areas. The agricultural land, urban land, and water land are priority distributed into low slope areas. In this kind of distribution mode, different land use was distributed to the suitable slope, meanwhile, the same land type is relatively concentrated, and the change of land use type is operable.

The stopping condition of the global optimization algorithm is the value of the objective function remains unchanged during the iteration progress or reaches the maximum number of iterations. Therefore, it may be that the computed optimal solution is not the optimal solution under the real condition, which depends on the efficiency of the algorithm and the number of computing resources.

5. Result and analyses

Based on the DYCORS algorithm and surface-groundwater coupling model of Guanzhong Basin, the land use pattern optimization schemes under three developing modes were obtained (Table 3 and Fig. 7). Initial values come from land use data in 2020. Under the three modes, the differences in land use pattern are obvious. The ecological benefit of forest land and water land is higher, and the economic benefit of agriculture and urban land is higher. All kinds of land use types impact runoff, so the land use pattern changes significantly.

As the results are shown in Table 3 and Fig. 7, under the ecological protection priority mode, the forest land area increased by 1417 km². The ecological value of forest land is the highest, and the ecological land in this mode increases significantly, which conforms to intuitive cognition. Although the ecological value of agriculture, for the cultivated land protection measures, the area remains approximately unchanged, the proportion increased by only 0.3%. Urban area increases by 327 km², reaching the set upper limit. This is because the economic value of the urban area is still higher than the ecological value of other land use under the weight of 0.2. Grassland area reduced by 1808 km². Both the ecological and economic value of grassland is low, while in the optimization, it can only be replaced by other high-value land use types. All unused land is converted to forest land. In general, low-value land use type such as grassland and unused land transformed into high ecological value land use type, such as forest and water land, and urban land with high economic value.

Under economic development priority mode, forest land area decreases by 493 km², grassland area decreases by 1951 km². Ecological land use type such as forest and grassland is converted into economic land use like agriculture and urban land. The agricultural land area increased by 1660 km², and the urban land area increased by 869 km², reaching the upper limit of 40%, which is set in the economic development

Table 3. Land use structures before and after optimization (km²).

Land use type	Initial		Ecological protection priority mode				Economic development priority mode				Ecology-economy equilibrium mode			
	Area	Percent	Area	Area change	Percent	Percent change	Area	Area change	Percent	Percent change	Area	Area change	Percent	Percent change
Agriculture	14800	55.6%	14870	70	55.9%	+0.3	16460	1660	61.9%	+6.2	15399	599	57.9%	+2.3
Forest	4904	18.4%	6321	1417	23.8%	+5.3	4411	-493	16.6%	-1.9	5544	640	20.8%	+2.4
Grassland	3964	14.9%	2156	-1808	8.1%	-6.8	2013	-1951	7.6%	-7.3	2330	-1634	8.8%	-6.1
Water	672	2.5%	751	79	2.8%	+0.3	672	0	2.5%	0	718	46	2.7%	+0.2
Urban	2171	8.2%	2498	327	9.4%	+1.2	3040	869	11.4%	+3.3	2605	434	9.8%	+1.6
Unused	85	0.3%	0	-85	0	-0.3	0	-85	0.0%	-0.3	0	-85	0	-0.3

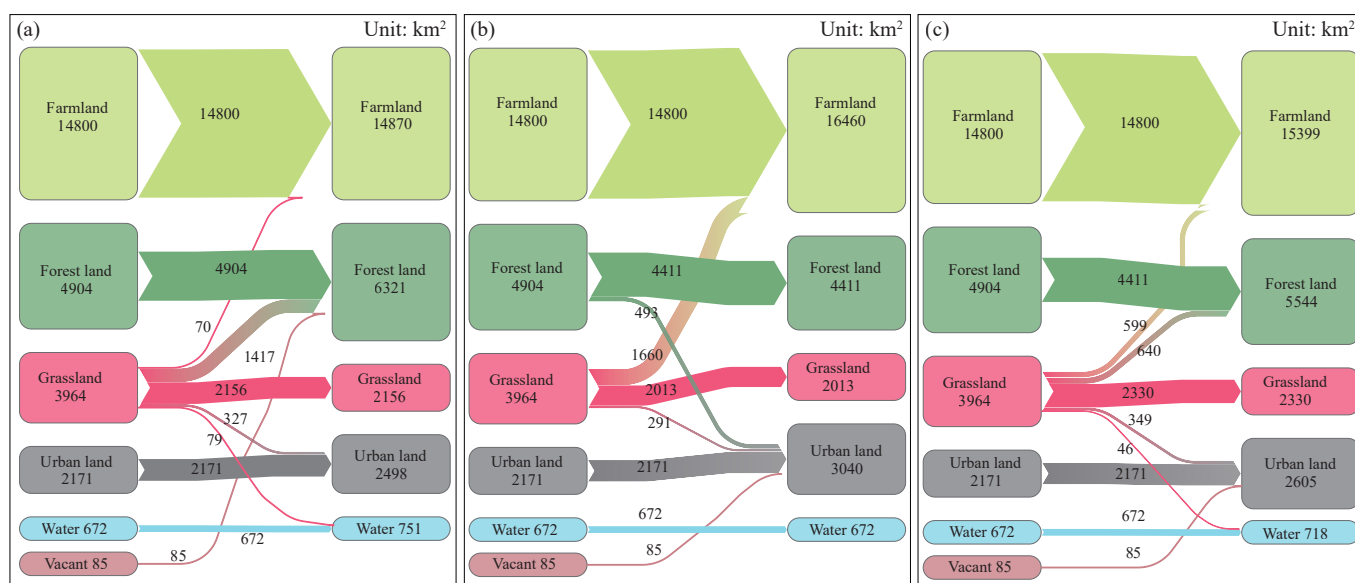


Fig. 7. Sankey diagrams of land use structures before and after optimization. a–ecological protection priority mode; b–economic development priority mode; c–ecology-economy equilibrium mode.

priority mode. All unused land is converted to urban land. Due to the control of constraints, the water land area does not change. Under this mode, the rapid expansion of urban land and the reduction of ecological land harm the high-quality development of the Guanzhong Basin.

Under the ecology-economy equilibrium mode, forest land area increases by 640 km², and ecological land use area increased significantly. Urban land area increased by 434 km², and agriculture land area increased by 599 km². Economic land with high economic value also increased. Grassland area decreased by 1634 km², and unused land all converted into urban land. This mode considers both ecological and economic values and meets the requirements of high-quality development of the Guanzhong Basin.

Table 4 shows the comparison of ecological benefit, economic benefit, and runoff of different land use patterns before and after optimization. The relationship between ecological benefits and economic benefits under three optimization modes meets the preset goal. Under ecological protection priority mode, the ecological value is the highest and the economic value is the lowest. Under the economic development priority mode, ecological value is the lowest, and economic value is the highest. The ecology-economy equilibrium mode is between the former two modes. The ecological protection priority mode is conducive to the ecological construction of the Guanzhong Basin but is not conducive to economic development. The economic development priority mode is conducive to economic development and is not conducive to ecological protection. Urban land area increased by 869 km², which is greatly conducive to the construction of the Guanzhong urban agglomeration, and the economic values increased by 28.9%. However, ecological construction is significantly inhibited, and the ecological benefit is reduced by 5%, compared with that before optimization. These two modes damage the high-quality development of the region and may lead to

development imbalance. The ecology-economy equilibrium mode takes into account both ecological and economic benefits. When the ecological benefit increases, the economic benefit increases significantly by 14%. Notably, the economic benefits of these three optimization modes are higher than the initial value, which shows that the land use pattern has a large optimization space under the current situation.

Compared with the three modes, the annual average runoff flow decreases by 3.6% in ecological protection priority mode, due to the water conservation of forest. Forest is increasing significantly, which will lead to runoff and infiltration decrease and evaporation increase, so the runoff of the study area decreased. Under the economic development priority mode, forest area decreased, and agriculture and urban land area increased significantly, runoff increased significantly. However, the forest area reduction will increase soil erosion and adversely affect farmland protection and sediment content in the runoff. Under the ecology-economy equilibrium mode, the increase of forest area is beneficial to the inhibition of soil erosion, and the total runoff is also increased. In addition to increasing economic benefits, it is also beneficial to alleviate the water shortage in the Guanzhong Basin.

In summary, the optimization scheme of the ecology-economy equilibrium mode has promoted regional economic development, increased the number of regional water resources, and maximized total benefits as much as possible while ensuring the ecological construction of the Guanzhong Basin, which meets the requirements of high-quality development of The Yellow River.

Fig. 8 shows the land use pattern distribution of the initial condition and three optimization modes. All kinds of land use type conform to land use conversion schemes determined in optimization. The growth of forest land is located in the south with high altitude and high slope region, and the growth of agricultural land is located in the area with low altitude and

Table 4. Benefit value of different land use structures before and after optimization.

	Initial	Ecological protection priority mode		Economic development priority mode		Ecology-economy equilibrium mode	
		Benefit	Percentage change	Benefit	Percentage change	Benefit	Percentage change
Ecological benefits/ 10^9 RMB	43.8	47.3	8.2%	41.6	-5.0%	45.2	3.1%
Economic benefit/ 10^9 RMB	538.9	590.9	9.6%	694.8	28.9%	614.8	14.1%
Runoff/ 10^9 m ³	6.4	6.2	-3.6%	6.8.4	6.0%	6.6	2.5%

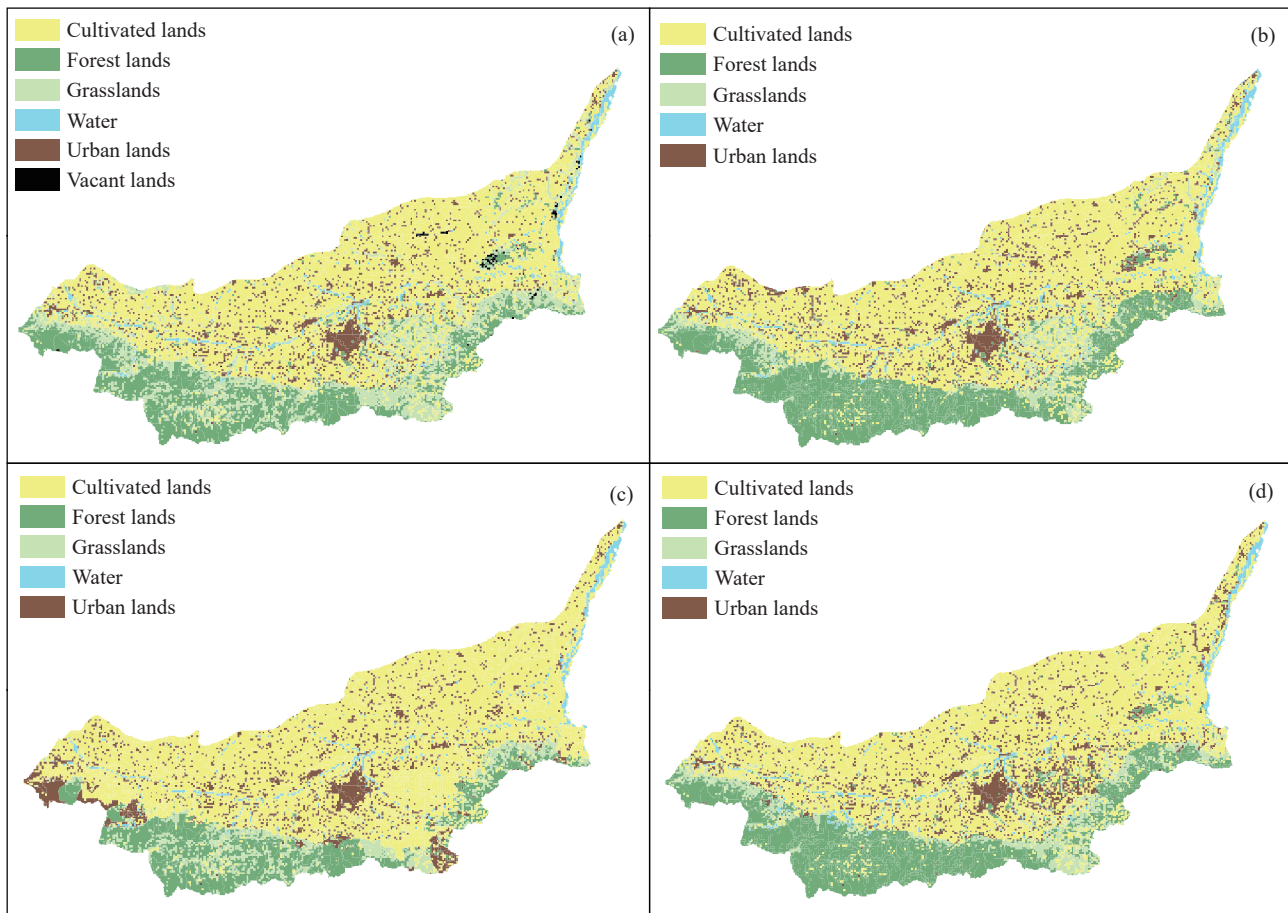


Fig. 8. Spatial distribution pattern of land use before and after optimization. a–initial condition; b–ecological protection priority mode; c–economic development priority mode; d–ecology-economy equilibrium mode.

low slope in the front of the mountain. The spatial distribution of water land is unchanged. Unused land transformed into urban land. The low economic and ecological value of grassland has regressed under the three modes. It degrades in high altitude areas and plain areas, retaining in the middle area. The newly increased area of urban land mainly appears in the plain area. However, the results of urban land distribution are uncertain for the randomness of the global optimization algorithm. The results do not have a reference for deterring the exact location of the urban land distribution.

6. Discussion

The loess plateau is a typical ecological fragile zone in China, and Guanzhong Basin is located in the southern part of the Loess Plateau. Due to the decreased runoff in Jing River and Beiluo River and other runoff in the Loess Plateau, Guanzhong Basin faces the problem of insufficient water

resources reserves, and there is a risk of water resources shortage under extreme conditions. Correct dealing with the contradiction between economic development and ecological construction, promoting the complementary and coordinated development of the large, medium, and small cities in Guanzhong Basin, and improving the efficiency of various space development, should take the further optimization of land use patterns of the basin, and make overall arrangements for all kinds of the land use type. First, it is necessary to restrict transitional development, prohibit the destruction of high ecological value regions such as forests and water, strengthen forest construction in water and soil loss areas, and strengthen the protection of water resources. At the same time, strengthen the protection of cultivated land and maintain the red line of the cultivated land area.

In this article, the land use pattern optimization scheme of ecology-economy equilibrium mode is proposed for Guanzhong Basin, which promotes regional water resources

and maximizes the total benefit as much as possible under the condition of ensuring regional ecological construction. Based on the GSFLOW model, a surface-groundwater coupling model of Guanzhong Basin was established, which was used to simulate the impact of land use change on water resources with a remarkable result. According to the model calibration of runoff and groundwater level, the simulation accuracy meets the requirement. However, there are still deficiencies in the research. First, the quantification of economic and ecological value should be further discussed. The economic value is calculated simply by the GDP output value of each category in the yearbook. Agriculture, forestry, animal husbandry, and fishery can calculate the GDP per unit. However, due to the uneven development of the construction industry, GDP per unit in different cities varies greatly, which brings errors to the calculation. There is no common recognition of the calculating method of ecological value quantification. In this article, Xie GD's method is also obtained by export scoring, which has a certain uncertainty. And the second is that the distribution of land use was based on simple judgments such as slope and altitude without considering whether soil, climate, and hydrology conditions apply to the land use mode. How to design appropriate rules for land use pattern transformation to make the land use distribution reasonable will be the focus of further research.

It should be noted that, compared with the current year (2020), the results of land use distribution in this paper changed greatly, which is not a task that can be completed in the short term, it needs more than ten years of planning. With the economic development and the change in the human environment, both the model and the benefits of economics and ecology may change, which needs to calibrate the simulation result, according to the change of society and environment, to better point out the direction for optimization of land use pattern and provide support for high-quality development of Guanzhong Basin.

7. Conclusions

In this article, Guanzhong Basin was selected to build a surface-groundwater coupling model and assess the response of water resources to land use change. Three modes were set to optimize water, urban, agriculture, and ecology land use pattern distribution in Guanzhong Basin under multiple scenarios, which improves the ecological and economic benefits of the study area, improves the development efficiency of various land use types, and provides a reference for ecological protection and high-quality development of Yellow River. The main conclusions of this paper are as follows:

(i) Combined with the surface-groundwater coupling model, the global optimization algorithm based on the surrogate model and multiple objective optimizations was used to optimize the water-urban-agriculture-ecology spatial pattern in Guanzhong Basin. Compared with the traditional land use optimization model, the influence of land use change on the hydrology circle process was considered in this

research and the economic value of water resources was added to the optimization objectives, which is original and practical. For different development modes, different optimization objectives and constraint conditions were proposed, and the model is optimized which is operable in different watersheds. And it is a general way of and use pattern optimization and has good applicability. The GSFLOW model has been verified in many studies around the world, with high simulation accuracy and universality. Especially in this study, through the good simulation of runoff and groundwater level, its applicability has been fully verified.

(ii) Based on the comparative analysis of land use pattern, ecological and economic benefits, and runoff under the three modes, it is concluded that the ecological economical equilibrium mode is the optimal mode in Guanzhong Basin. Ecology-economy equilibrium mode takes both ecological and economic benefits into account, ecological benefits increased by 3.1%, and economic benefits increased by 14.1%, with a significant increase. The increase of forest land area is beneficial to the inhibition of soil erosion, and the total runoff increased by 2.5%. In addition, to increased economic benefits, it is also conducive to alleviating the water shortage in Guanzhong Basin. The ecology-economy equilibrium mode promoted regional economic development, increased regional water resources, and maximized the total benefit as far as possible under the condition of ensuring the ecological construction, which meets the requirement of high-quality development of the Yellow River.

(iii) Under the ecology-economy equilibrium development mode, the agricultural land area increased by 599 km², the forest land area increased by 640 km², the grassland area decreased by 1634 km², the water land area increased by 46 km², the urban land area increased by 434 km², and unused land all converted into urban land. The land use types with the largest area change are agricultural land, forest land, grassland, and urban land. Basically, the reduced area of grassland is converted into agricultural land, forest land, and urban land with the transformation principle that high slope area is transformed into forest land, low slope area transformed into agriculture land, and urban land. The optimization effect of simulation results is significant, which not only helps to properly deal with the relationship between urban construction, agriculture development, and ecological protection in Guanzhong Basin but also provides a reference for the optimization of land use pattern at the watershed scale.

CRedit authorship contribution statement

Sai Wang and Bin Wu conceived the presented idea. Sai Wang established the surface water-groundwater coupling model and Bin Wu realized the optimization of land use pattern. Hai-Xue Li, Xi Wu, and Lei Yuan collected data and corrected the model. Shuang-bao Han and Fu-Cheng Li put forward the constraints and objectives of optimization. All authors discussed the results and contributed to the final

manuscript.

Declaration of competing interest

The authors declare no conflicts of interest.

Acknowledgment

This research was jointly supported by the National Natural Science Foundation of China (41702280) and the projects of the China Geology Survey (DD20221754 and DD20190333).

References

- Carranza-García M, García-Gutiérrez J, Riquelme JC. 2019. A framework for evaluating land use and land cover classification using convolutional neural networks. *Remote Sensing*, 11(3), 274. doi: [10.3390/rs11030274](https://doi.org/10.3390/rs11030274).
- Chen C, Ahmad S, Kalra A. 2018. A conceptual framework for integration development of gsfLOW model: Concerns and issues identified and addressed for model development efficiency. *Geoscientific Model Development Discussions*, 1–18. doi: [10.5194/gmd-2018-268](https://doi.org/10.5194/gmd-2018-268).
- Clarke KC. 2018. *Land Use Change Modeling with SLEUTH: Improving Calibration with a Genetic Algorithm/Geomatic Approaches for Modeling Land Change Scenarios*. Switzerland, Springer Cham Press, 139–161. doi: [10.1007/978-3-319-60801-3_8](https://doi.org/10.1007/978-3-319-60801-3_8).
- Crystal Ng GH, Wickert AD, Somers LD, Saberi L, Cronkite-Ratcliff C, Niswonger RG, McKenzie JM. 2018. GSFLOW–GRASS v1. 0: GIS-enabled hydrologic modeling of coupled groundwater-surface-water systems. *Geoscientific Model Development*, 11(12), 4755–4777. doi: [10.5194/gmd-11-4755-2018](https://doi.org/10.5194/gmd-11-4755-2018).
- Cosenza Z, Block DE. 2021. A generalizable hybrid search framework for optimizing expensive design problems using surrogate models. *Engineering Optimization*, 53(10), 1772–1785. doi: [10.1080/0305215X.2020.1826466](https://doi.org/10.1080/0305215X.2020.1826466).
- Dong Y, Song YG, Zhang MS, Lan MW, Fu XF, Liu HF, Ning QQ. 2019. Several key basic geological problems on the development of the Guanzhong urban agglomeration. *Northwestern Geology*, 52(2), 12–26 (in Chinese with English abstract). doi: [10.19751/j.cnki.61-1149/p.2019.02.002](https://doi.org/10.19751/j.cnki.61-1149/p.2019.02.002).
- Feng BP, Liang X, Zeng Z. 2018. Optimizing land usage in southern mountain areas of Jinan based on the SWAT model. *Journal of Irrigation and Drainage*, 37(5), 121–128 (in Chinese with English abstract). doi: [10.13522/j.cnki.gggs.2017.0546](https://doi.org/10.13522/j.cnki.gggs.2017.0546).
- Gao L, Shao M, Wang Y. 2012. Spatial scaling of saturated hydraulic conductivity of soils in a small watershed on the Loess Plateau, China. *Journal of Soils and Sediments*, 12(6), 863–875. doi: [10.1007/s11368-012-0511-3](https://doi.org/10.1007/s11368-012-0511-3).
- Geng H, Wang ZM. 2000. Research on optimization of land use structure based on gray linear programming. *Journal of Wuhan Technical University of Surveying and Mapping*, 25(2), 167–171, 182 (in Chinese with English abstract).
- He J. 2018. Analysis of coupling effect of surface water and groundwater in gneiss area based on GSFLOW. *Shaanxi Water Resources*, 221(6), 17–19, 22 (in Chinese with English abstract).
- Islam K, Rahman MF, Jashimuddin M. 2018. Modeling land use change using cellular automata and artificial neural network: The case of Chunati Wildlife Sanctuary, Bangladesh. *Ecological indicators*, 88, 439–453. doi: [10.1016/j.ecolind.2018.01.047](https://doi.org/10.1016/j.ecolind.2018.01.047).
- Jiang W, Chen Z, Lei X, Jia K, Wu Y. 2015. Simulating urban land use change by incorporating an autologistic regression model into a CLUE-S model. *Journal of Geographical Sciences*, 25(7), 836–850. doi: [10.1007/s11442-015-1205-8](https://doi.org/10.1007/s11442-015-1205-8).
- Kucsicsa G, Popovici EA, Bălteanu D, Grigorescu I, Dumitrașcu M, Mitrică B. 2019. Future land use/cover changes in Romania: Regional simulations based on CLUE-S model and CORINE land cover database. *Landscape and ecological engineering*, 15(1), 75–90. doi: [10.1007/s11355-018-0362-1](https://doi.org/10.1007/s11355-018-0362-1).
- Li B, Wang L, Hao XJ. 2021. Analysis of annual runoff distribution characteristics in Weihe River Basin from 1956 to 2015. *Shaanxi Water Resources*, 240(1), 34–38 (in Chinese with English abstract).
- Li H, Wang DP, Liu BY, Lin MS, Wang JY. 2018. Research on land use change based on Cellular Automata and Rough Set. *Journal of Central China Normal University (Nat. Sci.)*, 52(6), 910–915 (in Chinese with English abstract). doi: [10.19603/j.cnki.1000-1190.2018.06.021](https://doi.org/10.19603/j.cnki.1000-1190.2018.06.021).
- Li HX, Han SB, Wu X, Wang S, Liu WP, Ma T, Zhang MN, Wei YT, Yuan FQ, Yan L, Li FC, Wu B, Wang YS, Zhao MM, Yang HW, Wei SB. 2021. Distribution, characteristics and influencing factors of fresh groundwater resources in the Loess Plateau, China. *China Geology*, 4(3), 509–526. doi: [10.31035/cg2021057](https://doi.org/10.31035/cg2021057).
- Liang X, Liu X, Li X, Chen Y, Tian H, Yao Y. 2018. Delineating multi-scenario urban growth boundaries with a CA-based FLUS model and morphological method. *Landscape and Urban Planning*, 177, 47–63. doi: [10.1016/j.landurbplan.2018.04.016](https://doi.org/10.1016/j.landurbplan.2018.04.016).
- Lin W, Sun Y, Nijhuis S, Wang Z. 2020. Scenario-based flood risk assessment for urbanizing deltas using future land-use simulation (FLUS): Guangzhou Metropolitan Area as a case study. *Science of the Total Environment*, 739, 139899. doi: [10.1016/j.scitotenv.2020.139899](https://doi.org/10.1016/j.scitotenv.2020.139899).
- Liu S, Qi Z, Li X, Yeh AGO. 2019. Integration of convolutional neural networks and object-based post-classification refinement for land use and land cover mapping with optical and SAR data. *Remote Sensing*, 11(6), 690. doi: [10.3390/rs11060690](https://doi.org/10.3390/rs11060690).
- Lu J H, Mei ZX, Zhao SF, Xiao YY. 2017. Land use optimization allocation based on chaos ant colony algorithm. *Journal of Geo-information Science*, 19(8), 1026–1035 (in Chinese with English abstract). doi: [10.3724/SP.J.1047.2017.01026](https://doi.org/10.3724/SP.J.1047.2017.01026).
- Luo YL, Huang FG, Zhang HM, Bian YL. 2010. Influence of water diversion in Guanzhong irrigation area on runoff from Weihe River into the Yellow River. *Yellow River*, 32(5), 19–20, 22. doi: [10.3969/j.issn.1000-1379.2010.05.008](https://doi.org/10.3969/j.issn.1000-1379.2010.05.008).
- Ma BY, Huang J, Li SC. 2019. Optimal allocation of land use types in the Beijing-Tianjin-Hebei urban agglomeration based on ecological and economic benefits trade-offs. *Progress in Geography*, 38(1), 26–37 (in Chinese with English abstract). doi: [10.18306/dlkxjz.2019.01.003](https://doi.org/10.18306/dlkxjz.2019.01.003).
- Markstrom SL, Niswonger RG, Regan RS, Prudic DE, Barlow PM. 2008. GSFLOW–coupled Ground-water and Surface-water FLOW model based on the integration of the Precipitation-Runoff Modeling System (PRMS) and the Modular Ground-Water Flow Model (MODFLOW-2005). *US Geological Survey techniques and methods*, 6, 240. doi: [10.13140/2.1.2741.9202](https://doi.org/10.13140/2.1.2741.9202).
- Niswonger RG. 2020. An agricultural water use package for MODFLOW and GSFLOW. *Environmental Modelling & Software*, 125, 104617. doi: [10.1016/j.envsoft.2019.104617](https://doi.org/10.1016/j.envsoft.2019.104617).
- Regis RG, Shoemaker CA. 2013. Combining radial basis function surrogates and dynamic coordinate search in high-dimensional expensive black-box optimization. *Engineering Optimization*, 45(5), 529–555. doi: [10.1080/0305215X.2012.687731](https://doi.org/10.1080/0305215X.2012.687731).
- Rimal B, Zhang L, Keshtkar H, Haack BN, Rijal S, Zhang P. 2018. Land use/land cover dynamics and modeling of urban land expansion by the integration of cellular automata and markov chain. *ISPRS International Journal of Geo-Information*, 7(4), 154. doi: [10.3390/ijgi7040154](https://doi.org/10.3390/ijgi7040154).

- Sobol IM. 2001. Global sensitivity indices for nonlinear mathematical models and their Monte Carlo estimates. *Mathematics and Computers in Simulation*, 55(1–3), 271–280. doi: [10.1016/S0378-4754\(00\)00270-6](https://doi.org/10.1016/S0378-4754(00)00270-6).
- Song YG, Lan MW, Liu HF, Zhang MS, Fu XF, Ning QQ. 2021. Cenozoic stratigraphic correlation and the lower limit of Quaternary in Cuanzhong Basin. *Bulletin of Geological Science and Technology*, 40(2), 24–35 (in Chinese with English abstract). doi: [10.19509/j.cnki.dzkq.2021.0204](https://doi.org/10.19509/j.cnki.dzkq.2021.0204).
- Sun YZ, Yang J, Song SY, Zhu J, Dai JJ. 2020. Modeling of multilevel vector cellular automata and its simulation of land use change. *Acta Geographica Sinica*, 75(10), 2164–2179 (in Chinese with English abstract). doi: [10.11821/dlxb202010009](https://doi.org/10.11821/dlxb202010009).
- Tian H, Liang X, Li X, Liu XP, Ou JP, Hong Y, He ZJ. 2017. Simulating multiple land use scenarios in China during 2010–2050 based on System Dynamic Model. *Tropical Geography*, 37(4), 547–561 (in Chinese with English abstract). doi: [10.13284/j.cnki.rddl.002939](https://doi.org/10.13284/j.cnki.rddl.002939).
- Tu XS, Pu LJ, Yan X, Zhu M. 2009. Analysis of optimal allocation of land resources and soil quality regulation using system dynamics. *Research of Environmental Sciences*, 22(2), 221–226 (in Chinese with English abstract).
- Tian H, Wang WK, Cao YQ, Wang Z, Wang J. 2007. Tritium age calculation of groundwater in Guanzhong Basin. *Journal of Xi'an University of Science and Technology*, 27(3), 382–385,426 (in Chinese with English abstract).
- Wang BS, Liao JF, Zhu W, Qiu QY, Wang L, Tang LN. 2019. The weight of neighborhood setting of the FLUS model based on a historical scenario: A case study of land use simulation of urban agglomeration of the Golden Triangle of Southern Fujian in 2030. *Acta Ecologica Sinica*, 39(12), 4284–4298 (in Chinese with English abstract). doi: [10.5846/stxb201808021649](https://doi.org/10.5846/stxb201808021649).
- Wang J, Yan BJ, Li H, Wang GL. 2008. Optimized allocation for land resources and construction scales for regional highway network. *Journal of Chang'an University (Social Science Edition)*, 10(3), 34–38 (in Chinese with English abstract).
- Wang Q, Liu R, Men C, Guo L. 2018. Application of genetic algorithm to land use optimization for non-point source pollution control based on CLUE-S and SWAT. *Journal of Hydrology*, 560, 86–96. doi: [10.1016/j.jhydrol.2018.03.022](https://doi.org/10.1016/j.jhydrol.2018.03.022).
- Wei W, Xie YW, Wei XX, Xie BB, Zhang Q, Hao YY. 2017. Land use optimization based on CLUE-S model and ecological security scenario in Shiyang River Basin. *Geomatics and Information Science of Wuhan University*, 42(9), 1306–1315 (in Chinese with English abstract). doi: [10.13203/j.whugis20160051](https://doi.org/10.13203/j.whugis20160051).
- Wu B, Zheng Y, Tian Y, Wu X, Yao Y, Han F, Liu J, Zheng C. 2014. Systematic assessment of the uncertainty in integrated surface water - groundwater modeling based on the probabilistic collocation method. *Water Resources Research*, 50(7), 5848–5865. doi: [10.1002/2014WR015366](https://doi.org/10.1002/2014WR015366).
- Wu B, Zheng Y, Wu X, Tian Y, Han F, Liu J, Zheng C. 2015. Optimizing water resources management in large river basins with integrated surface water-groundwater modeling: A surrogate-based approach. *Water Resources Research*, 51(4), 2153–2173. doi: [10.1002/2014WR016653](https://doi.org/10.1002/2014WR016653).
- Wu B, Wang S, Wang WX, An YH. 2019. Impact of future climate change on water resources in the arid regions of Northwest China based on surface water-groundwater coupling model: A case study of the middle reaches of the Heihe River. *Geology in China*, 46(2), 369–380 (in Chinese with English abstract). doi: [10.12029/gc20190213](https://doi.org/10.12029/gc20190213).
- Xie GD, Lu CX, Leng YF, Zheng D, Li SC. 2003. Ecological assets valuation of the Tibetan Plateau. *Journal of Natural Resources*, 18(2), 189–196 (in Chinese with English abstract). doi: [10.11849/zrzyxb.2003.02.010](https://doi.org/10.11849/zrzyxb.2003.02.010).
- Xu RR, Gao P, Mu XM, Chai XK, Gu CJ. 2020. Dynamic of streamflow and sediment load and its response to human activities in the Weihe River Basin. *Yellow River*, 42(3), 17–24 (in Chinese with English abstract). doi: [10.3969/j.issn.1000-1379.2020.03.003](https://doi.org/10.3969/j.issn.1000-1379.2020.03.003).
- Yang L, Xie YW, Zong LL, Qiu T, Jiao JZ. 2020. Land use optimization configuration based on multi-objective genetic algorithm and FLUS model of agro-pastoral ecotone in Northwest China. *Journal of Geo-information Science*, 22(3), 568–579 (in Chinese with English abstract). doi: [10.12082/dqxkx.2020.190531](https://doi.org/10.12082/dqxkx.2020.190531).
- Yuan M, Liu YL. 2014. Land use optimization allocation based on multi-agent genetic algorithm. *Transactions of the Chinese Society of Agricultural Engineering (Transactions of the CSAE)*, 30(1), 191–199 (in Chinese with English abstract). doi: [10.3969/j.issn.1002-6819.2014.01.025](https://doi.org/10.3969/j.issn.1002-6819.2014.01.025).
- Zhang HJ, Wu JF, Lin J, Wu M, Wu JC. 2015. Comparative analysis and coupling simulation of groundwater and surface water flow based on GSFLOW. *Geotechnical Investigation and Surveying*, 43(5), 34–38 (in Chinese with English abstract).
- Zhang HH, Zeng YN, Tan R, Liu HM. 2011. A model for regional land use optimization allocation based on multi-agent system and its application. *Acta Geographica Sinica*, 66(7), 972–984 (in Chinese with English abstract). doi: [10.11821/xb201107010](https://doi.org/10.11821/xb201107010).
- Zhang MS, Zhu LF, Wang XY. 2005. Groundwater systems and sustainable development countermeasures of groundwater resources in the Guanzhong Basin. *Quaternary Sciences*, 25(1), 15–22 (in Chinese with English abstract).
- Zhang WL, Liu Q, Wu CB, Yang GD. 2021. Annual change detection of land use status based on Siamese neural network. *Bulletin of Surveying and Mapping*, (3), 91–95,104 (in Chinese with English abstract). doi: [10.13474/j.cnki.11-2246.2021.0084](https://doi.org/10.13474/j.cnki.11-2246.2021.0084).
- Zhang XR, Li AN, Nan X, Lei GB, Wang CB. 2020. Multi-scenario simulation of land use change along China-Pakistan Economic Corridor through coupling FLUS model with SD model. *Journal of Geo-information Science*, 22(12), 2393–2409 (in Chinese with English abstract). doi: [10.12082/dqxkx.2020.190618](https://doi.org/10.12082/dqxkx.2020.190618).