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Trade-off analyses and optimization of water-related ecosystem services (WRESs) based on land use change in a typical agricultural watershed, southern China

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ABSTRACT

As the direct manifestation of human activities, land use change is the main driving factor in variations in ecological processes and ecosystem services (ESs). For better land use management in the future, it is essential to evaluate the changes of ESs affected by land use change and identify the relationships among ESs. In this study, four primary water-related ecosystem services (WRESs), including water yield, food production, water purification and soil conservation, were selected to assess the effects of past land use change (1980–2015) on WRESs in the Xiangjiang River Basin, a typical agricultural watershed in southern China. From 1980 to 2015, water yield, food production increased by 1.58% and 44.78%, respectively. And soil conservation was improved with a 13.11% decrease in sediment export. Because of the rapid expansion of agriculture and urbanization from 2000 to 2015, water purification was degraded significantly with the increase in nitrogen export (+22.56%) and phosphorus export (+25.85%). Trade-offs mainly occurred between water purification and other WRESs. Based on the existing ecological problem, four alternative land use scenarios were designed to explore the underlying effects of various land use polices. Among four scenarios, the combined scenario was selected as the optimal scenario because of the greatest improvement in water purification and small negative effect on food production. Our research provides an integrated WRESs trade-offs assessment framework. Moreover, the establishment of multiple land use scenarios based on land suitability evaluation could inform future land use decision-making and water conservation management in the agricultural watershed.

1. Introduction

Ecosystems and ecological processes continuously provide ecosystem goods and services to human, which form the foundation of human's survival. Ecosystem services (ESs), as the bridge between natural ecosystem and human society, directly and indirectly contribute to human welfare (Costanza, 1997; MA, 2005). There are complex interactions among different types of ESs, which primarily include two types: trade-offs and synergies. Trade-offs represent an increase in one ES with the decrease in another ES; Synergies occur when the changes of two ESs are in the same direction (Haase et al., 2012). However, relevant policies are often made to change land use pattern for satisfying the needs of social development, which affect the structure and function of ecosystems and then lead to the loss of balance among ESs (Burkhard et al., 2012; Fu et al., 2013). Deep understanding the relationships among various ESs is needed to improve our ability to maximize the total benefits of ESs.

Land use change, as the most direct response to human interference in the natural ecosystem, has been seen as one of the most significant driving factors of changes in ecological processes and ESs (Lawler et al., 2014; Polasky et al., 2010). Past land use management policies mainly focused on maximizing a certain type of service while ignoring the effects of these policies on other services (Bennett et al., 2009). For example, large-scale reclamation activities were carried out to improve agricultural production in

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Abbreviations

AD	Agricultural development
ADWB	Agricultural development with woodland buffer strips
ADWB_GFG	The combined scenario of ADWB and GFG
AHP	Analytical Hierarchical Process
ESs	Ecosystem services
FP	Food production
GFG	Grain for Green
InVEST	The Integrated Valuation of Ecosystem Services and Tradeoffs
MCDM	Multi-criteria decision-making
NE	Nitrogen export
PE	Phosphorus export
RMSE	Root mean squared error
SC	Soil conservation
SE	Soil export
SWAT	Soil and Water Assessment Tool
USLE	The Universal Soil Loss Equation
WP	Water purification
WP (N)	Water purification (nitrogen)
WP (P)	Water purification (phosphorus)
WRESs	Water-related ecosystem services
WY	Water yield
XJRB	Xiangjiang River Basin

response to food risk. However, these activities were conducted with the expense of forest and lakes, which resulted in serious deterioration of regulating and supporting services (MA, 2005; Molden, 2007). In the early 21st century, large ecological projects such as Grain-for-Green Program exacerbated the crisis of water scarcity despite their good performance in improving water quality and soil conservation (Wang et al., 2017). Thus, for the purpose of realizing the sustainable development of human-environment system, integrating ESs quantification and trade-offs analysis into landscapes management decision has become the current research hotspot for many scholars (Doody et al., 2016; Hou et al., 2018; Kennedy et al., 2016).

Rapid spatial pattern transformation of land use can lead to the changes of water-related ecosystem services (WRESs) values and relationships among WRESs. Due to the relative low requirements of input data and integrating multiple ESs evaluation modules, the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) model has been widely applied to identify the effects of land use change on ESs (Rimal et al., 2019; Yang et al., 2018). Former studies primarily focused on identifying the spatial and temporal distribution of ESs and their response to land use change in the past years, which did not take the direct guiding significance for future policy making into consideration. Scenario analysis, as the most commonly used method, can make up for the shortcomings in previous researches. Identifying the changes of multiple ESs and trade-offs under future or alternative land use patterns can directly inform decision-makers of the optimal ESs conservation polices (Nelson et al., 2009; Zheng et al., 2019). Scenarios are often designed by some studies to assess the uncertainties of future developments (Liang et al., 2017, 2020). However, few studies set up scenarios based on the suitability of land use conversion and local existing ecological problems. Integrating multiple factors into the establishment of scenarios will greatly improve the rationality of the evaluation results for future land use management decision-making.

As the artery of Dongting lake, the Xiangjiang River is the largest and most important tributary in the Dongting Lake Basin. The change of ecological environment in the Xiangjiang River Basin (XJRB) has a great influence on ecological security in the Dongting Lake Bain. However, with the rapid development of agriculture and urban industry in the past few years, the XJRB has become the main contributor of nutrients in Dongting lake, which lead to the deterioration of water quality (Hou et al., 2017a). The local government is facing the challenge on how to protect water environment and relevant WRESs by regulating land use pattern. In this study, the XJRB, a typical agricultural watershed, was chosen to evaluate the influence of land use change on four primary WRESs including water yield, food production, water purification and soil conservation. Specifically, the main objectives of this paper were to (a) assess the changes of four WRESs affected by land use transformation from 1980 to 2015, (b) identify the main ecological problem and trade-offs among WRESs and (c) design four alternative land use development patterns and explore the optimal scenario for future water conservation based on trade-off analyses. Our study integrates land suitability evaluation into scenarios analysis, and the integrated WRESs trade-offs assessment framework can provide a strong reference and guidance for land use optimization and WRESs conservation in the agricultural watershed.

2. Materials and methods

2.1. Study area

The Xiangjiang River Basin (XJRB), covering an area of approximately 94346 km^2, is located mainly in Hunan Province, China (24°31′-29°52′N, 110°31′-114°15′E) (Fig. 1). The average annual precipitation and annual average temperature is approximately 1400 mm and 17.6 °C, respectively. The elevation of the XJRB ranges from 33 to 2118m. The topography undulates and generally slopes northward. The basin is bounded by mountains in the southern, western, and eastern parts of the basin; the central and northern parts are relatively low and consist of basins and valley plains. The major land use types of the XJRB are cropland, woodland, grassland, built-up land, water, and bare land. Due to the rapid transformation of land use types during the past 35 years, ecosystem structure and functions have been influenced significantly, which led to changes in WRESs and relationships among WRESs.

2.2. Data sources

Five basic data that we used to analyze the WRESs: satellite image data, land use data, meteorological data, soil data, and statistic data. (1) A digital elevation model with 30 m × 30 m grid resolution was obtained from Chinese Academy of Sciences (http://www.gscloud.cn); (2) Land use data with a spatial resolution of 30m in 1980, 2000 and 2015 were acquired from GlobeLand30 (http://www.globallandcover.com) and the Resource and Environmental Science Data Center of the Chinese Academy of Sciences (http://www.resdc.cn). Six primary classes of land use types (cropland, woodland, grassland, built-up land, water, and bare land) are classified according to the actual land use settings in the XJRB. (3) Meteorological data (daily precipitation, temperature, solar radiation, etc.) covering the period 1980–2015 were collected from the national meteorological stations network of the China meteorological Data Service Center (http://data.cma.cn). Kriging

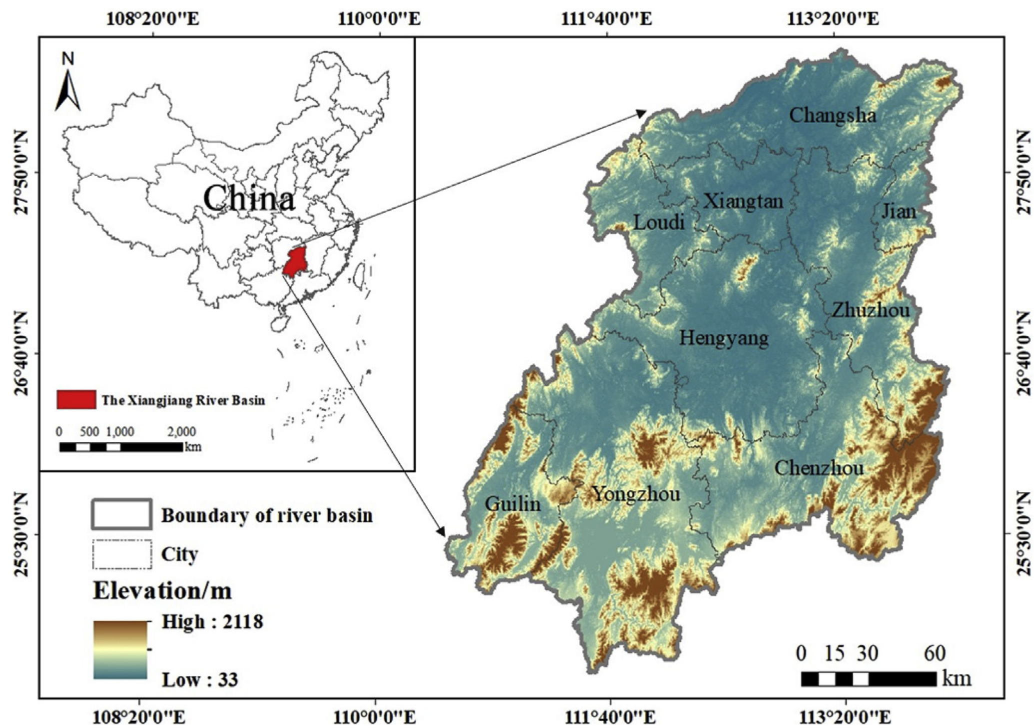


Fig. 1. Location of the xiangjiang river basin.

interpolation method in ArcGIS10.5 was used to get the spatial meteorological data. (4) The Harmonized World Soil Database (v1.1) with a resolution of 1 km was supplied by Cold and Arid Regions Sciences Data Center (http://data.casnw.net). (5) Agricultural products of the Xiangjiang River Basin were obtained from Hunan Statistical Yearbook, Jiangxi Statistical Yearbook, and Guangxi Statistical Yearbook (http://data.cnki.net).

2.3. Quantification of ecosystem services

Considering the importance in this human-water coupling system, four water-related ecosystem services (water yield, food production, water purification, soil conservation) were selected for this study. We quantified water yield, water purification, and soil conservation by using the InVEST 3.6.0 models (Sharp, 2018), and quantified food production by using yield model (Sun and Li, 2017). The average climate parameters (1980–2015) were used to generate the results under past landscape or potential land-use scenarios.

2.3.1. Water yield

Water yield in InVEST Water Yield model is defined as the amount of water runoff from the landscape, which includes surface, subsurface and baseflow. This model is based on the Budyko curve and estimates the relative contributions of water from different parts of a landscape (Sharp, 2018). The following equation was used to calculate annual water yield in each pixel:

$$Y_i = \left(1 - \frac{AET_i}{P_i}\right) \times P_i \qquad (1)$$

where AET_i and P_i represent the annual actual evapotranspiration and the annual precipitation on pixel i, respectively. Details about the input parameters are included in Table S1.

2.3.2. Food production

Food product mainly include rice, wheat, corn, beans, and tubers in the XJRB. Based on related research articles (Sun and Li, 2017; Wang et al., 2019), the yield model was applied to assess food production:

$$FP_{ij} = \frac{TFP_i}{A_i} \times a_j \qquad (2)$$

where FP_{ij} is the food production for pixel j in town i, TFP_i is the total food production in town i; A_i is the area of cropland in town i; and a_j represents the area of cropland for pixel j in town i, which equals to 900 m^2 in this study.

2.3.3. Water purification

The XJRB is one of the major contributors to the nutrients in Dongting watershed (Hou et al., 2017b). The InVEST Nutrient Delivery Ratio model can describe the movement of a mass of nutrient through space by using a simple mass balance approach (Sharp, 2018). The nitrogen (N) and phosphorus (P) export values were selected as indicators for assessing water purification. Lower nutrients export value indicates the higher capacity of water purification service. The nutrient export for each pixel is calculated as follows:

$$N\_export_i = load_i \times NDR_i \qquad (3)$$

where N_export_i is the nutrient (N, P) export on pixel i, $load_i$ is the modified nutrient load on pixel i, NDR_i is nutrient delivery ratio on pixel i. Biophysical parameters used in this model are included in Table S1.

2.3.4. Soil conservation

Based on the Universal Soil Loss Equation (USLE), the InVEST Sediment Delivery Ratio model takes the concept of hydrological connectivity into consideration (Borselli et al., 2008). The value of sediment export was selected as the indicator for assessing soil conservation. Lower sediment export value indicates the higher capacity of soil conservation service. For each pixel, the sediment export is calculated as follows (Equations (4) and (5)):

$$USLE_i = R_i \times K_i \times LS_i \times C_i \times P_i \quad (4)$$

$$S\_export_i = USLE_i \times SDR_i \quad (5)$$

where $USLE_i$ is the annual soil loss on pixel i, R_i is the rainfall erosivity factor (MJ·mm (ha·hr)$^{-1}$), K_i is the soil erodibility factor (ton·ha·hr (MJ·ha·mm)$^{-1}$), LS_i is the slope length-gradient factor, C_i and P_i are crop-management factor and support practice factor, respectively. S_export_i is the sediment export on pixel i, SDR_i is the sediment delivery ratio on pixel i. Biophysical parameters used in this model are included in Table S1.

2.4. Alternative land use scenarios

The XJRB is a basin mainly for agricultural development. The suitability for agricultural development, as a basis of the establishment of alternative scenarios, was accessed using multi-criteria decision-making (MCDM) methods (Hossain and Das, 2010). This method mainly includes two processes: the selection of evaluation criteria and the determination of criteria weights. Evaluation criteria that we selected included two topographical factors (slope, elevation), two soil condition factors (soil organic matter, soil pH), soil erosion intensity, and distance to the road. Each factor was reclassified into five levels according to suitability assignment in Table S2 (Fig. S1). The Analytical Hierarchical Process (AHP) was used to determine criteria weights (Zhang and Lu, 2010). Eventually, evaluation criteria and criteria weights were integrated to generate the suitability for agricultural development by using Weighted Overlay tool in ArcGIS. The assessment result was classified as unsuitable, generally suitable, moderately suitable, and extremely suitable (Fig. S2). Based on this evaluation, four alternative land use scenarios were established to illustrate the effects of different land use management policies on the WRESs and trade-offs among the WRESs. Land use in 2015 was served as the baseline scenario.

(1) AD (agricultural development): Areas that were extremely suitable for agricultural production were converted to cropland, except for built-up land and open water.
(2) ADWB (agricultural development with woodland buffer strips): Relevant studies indicate that riparian buffer play an important role in improving water purification service (Gleason et al., 2011; Zheng et al., 2016). Based on AD scenario, 100m-wide vegetative buffer surrounding rivers and reservoirs were set by replacing cropland with woodland.
(3) GFG (Grain for Green): Soil erosion is easier to occur in areas with steeper slopes, especially for cropland. Cropland with slope greater than 25° were returned to woodland. At the same time, unsuitable cropland with slope between 6° and 25° were transformed to grassland.
(4) ADWB_GFG (combined scenario of ADWB and GFG): Based on AD scenario, cropland with slope greater than 25° were returned to woodland; unsuitable cropland with slope between 6° and 25° were transformed to grassland. Moreover, 100m vegetative buffer strips were set.

2.5. Trade-off analysis among WRESs

The RMSE (root mean squared error) was used to quantify trade-offs among WRESs at sub-watershed scale because of the effectiveness and relative simplicity of this method (Bradford and D'Amato, 2012). In order to eliminate unit differences among WRESs, the value of each WRESs was standardized before calculating the RMSE. The RMSE is calculated as follows:

$$RMSE = \sqrt{\frac{1}{n-1} \cdot \sum_{i=1}^{n} \left(WRES_i - \overline{WRES}\right)^2} \quad (6)$$

where $WRES_i$ is the standardized value of the i-th $WRES_S$, and $\overline{WRES}$ is the expected value of the i number of $WRES_S$. The method of standardization and RMSE are detailed in Supplementary information.

3. Results

3.1. Land use change from 1980 to 2015 in the XJRB

The two primary land use types in the XJRB were cropland and woodland, which accounted for over 85% of the total area during past 35 years. Other land use types (grassland, water, built-up land and bare land) took up only a small proportion of the XJRB (Fig. 2 and Table 1). During the period from 1980 to 2015, the proportion of cropland decreased by 7.03% (1991.6 km^2) from 1980 to 2000 and then increased significantly by 19.37% (5104.4 km^2) from 2000 to 2015. Woodland kept decreasing during this period, which firstly decreased by 5.77% (3550.59 km^2) from 1980 to 2000 and then decreased by 2.86% (1605.57 km^2) from 2000 to 2015. Contrary to the change of cropland, grassland increased greatly by 135.17% (5209.93 km^2) from 1980 to 2000, then decreased sharply by 67.27% (6097.69 km^2) from 2000 to 2015. Built-up land increased rapidly by 186.98% (2486.56 km^2) while water area increased gradually by 26.66% (323.76 km^2) during the past 35 years. In summary, the XJRB experienced the land use conversion from woodland to cropland and built-up land, cropland to built-up land and grassland to woodland.

3.2. Changes in WRESs and relationships based on past land-use transformation

3.2.1. Changes in WRESs from 1980 to 2015

Changes in WRESs were drove by land use transformation in the XJRB. Fig. 3 shows that the total amount and relative changes of various WRESs from 1980 to 2015. With the decrease in evapotranspiration caused by the development of agriculture and urbanization, the total water yield increased gradually from 780.79×10^8 m^3 to 793.09×10^8 m^3 from 1980 to 2015. Although the area of cropland decreased from 1980 to 2000, food production increased by 37% as a result of the improvement of agricultural production technology. And food production increased from 1572.97×10^4 t in 2010 to 1662.37×10^4 t in 2015 as the expansion of cropland. Water purification was improved from 1980 to 2000 because of the decline in nitrogen export (−12.07%) and phosphorus export (−11.48%). However, from 2000 to 2015, the ability of water purification declined significantly because nitrogen export and phosphorus export increased by 22.56% and 25.85%, respectively. The expansion of cropland and built-up land and shrinkage of grassland and woodland were the main reasons for the decline of water purification services. With the implementation of soil protection policies, sediment export decreased obviously by 9.05% from 1980 to 2000 and 4.47% from 2000 to 2015, which indicated that soil conservation was improved gradually. Overall, over the past 35 years, WRESs have been enhanced in varying degrees except water purification.

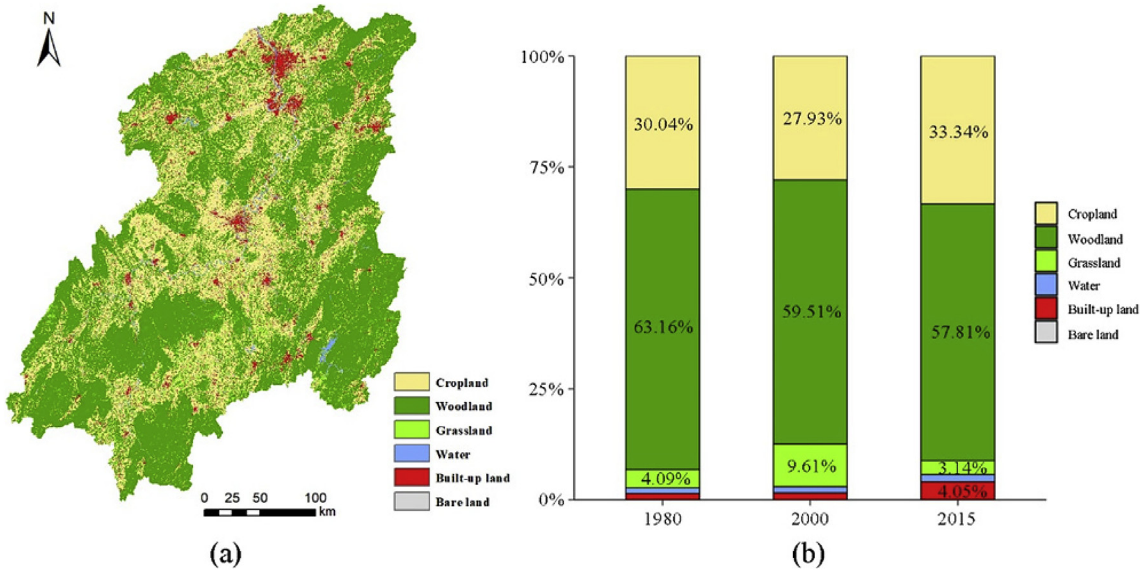


Fig. 2. Land use types of XJRB in 2015 (a) and proportions from 1980 to 2015 (b).

Table 1
Proportions of land use types and the change in area from 1980 to 2015.

Land use types	1980		2000		2015	
	km^2	%	km^2	%	km^2	%
Cropland	28342.03	30.04	26350.41	27.93	31454.78	33.34
Woodland	59584.90	63.16	56144.31	59.51	54538.74	57.81
Grassland	3854.46	4.09	9064.39	9.61	2966.70	3.14
Water	1214.61	1.29	1322.84	1.40	1538.37	1.63
Built-up land	1329.81	1.41	1463.22	1.55	3816.36	4.05
Bare land	20.02	0.02	0.65	0	30.87	0.03

3.2.2. Effects of main land use transformation on WRESs

The transformation among three major land use types (cropland, woodland and grassland) and their impacts on WRESs are analyzed (Table S3). Fig. 4 illustrates the direction of change in WRESs caused by the conversion of these three land use types. From 1980 to 2015, the total area of cropland, woodland and grassland transformed into one another accounted for approximately 30% of the study area. When cropland was converted to woodland and grassland, these changes largely decreased food production. And nitrogen, phosphorus and sediment export experienced a significant decline under the conversion, which was the sign of the enhancement of water purification and soil conservation. Although the conversion of cropland to woodland significantly decreased water yield, the change in water yield was not obvious when the transformation happened between cropland and grassland. The conversion of grassland to woodland resulted in the decline of water yield because of the higher vegetation cover and evapotranspiration in woodland. When grassland was transformed to woodland, water purification and soil conservation enhanced as a result of the substantial decline in nitrogen, phosphorus and sediment export. Compared to grassland, woodland have better capabilities in improving water quality and protecting soil.

3.2.3. Relationships between each pair of WRESs in 2015

Because the distributions of WRESs were not normal, Spearman's correlation coefficients were used to describe the relationships of pairs of WRESs at the grid level (Fig. 5). The result showed that all WRESs were significantly correlated in 2015 ($p < 0.05$). Sediment export had negative correlations with water yield ($r < 0$; $p < 0.01$) and food production ($r < 0$; $p < 0.05$), which indicated soil conservation had synergetic relationships with water yield and food production. Also, water yield exhibited a synergetic relationship with food production ($r > 0$; $p < 0.01$). However, nitrogen and phosphorus export were highly positive with food production ($r > 0.5$; $p < 0.01$), which meant an obvious trade-off relationship between water purification and food production. In addition, nitrogen and phosphorus export were positively correlated with water yield ($r > 0$; $p < 0.01$) and negatively correlated with sediment export ($r < 0$; $p < 0.05$), showing that water purification had trade-offs relationships with water yield and soil conservation.

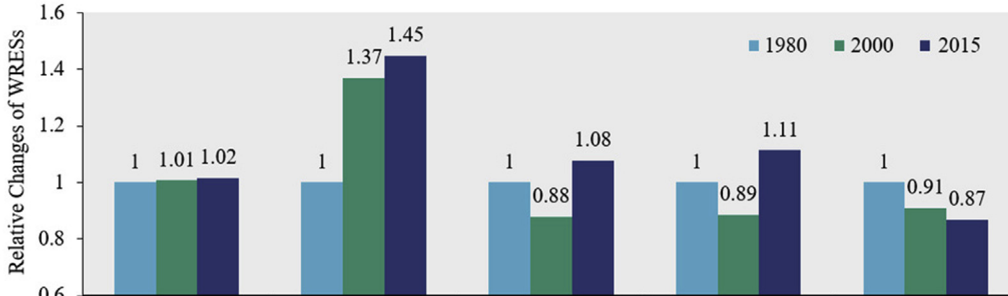
3.3. Comparison of WRESs and trade-offs based on alternative land-use scenarios

3.3.1. Changes of WRESs

In order to detect the effect of different land-use development patterns on WRESs in the XJRB, the changes of the total amount of each WRESs (relative to 2015) were assessed under alternative land-use scenarios (Table 2 and Fig. 6). Spatial changes of WRESs were also mapped to analyze the spatial differences in WRESs changes (Fig. 7).

Under AD scenario, the XJRB experienced the increase of 57.77×10^4t in food production and 1.67×10^8 m^3 in water yield compared with the baseline scenario. However, nitrogen, phosphorous and sediment export increased by 3.89% (31.76×10^4kg), 4.25% (3.73×10^4kg) and 4.97% (26.63×10^4t), respectively, which indicated the decline of water purification and soil conservation. As shown in Fig. 7, water yield and food production increased in almost the entire XJRB, while the increase in the southwest and northeast were higher than other areas. Differently, the spatial changes of water purification and soil conservation were exact opposite to those of water yield and food production, with relatively high reduction in the southwest and northeast of the XJRB.

After adding an 100m-wide woodland buffer based on AD scenario, water yield increased by 7.2×10^7 m^3 while food production increased by 28.58×10^4t compared with the baseline scenario. In addition, water purification was enhanced because nitrogen and phosphorous export decreased by 3.98% (32.45×10^4kg) and 4.41% (3.87×10^4kg) respectively, which represented the important role of the vegetative buffer surrounding rivers in reducing the influx of



	Water yield (10^8m^3/a)	Food production (10^4t/a)	Nitrogen export (10^4kg/a)	Phosphorus export (10^4kg/a)	Sedimet export (10^4t/a)
1980	780.79	1148.21	756.93	78.85	617.10
2000	786.89	1572.97	665.55	69.80	561.26
2015	793.09	1662.37	815.68	87.84	536.19

Fig. 3. Values and relative (compared with 1980) changes of WRESs from 1980 to 2015.

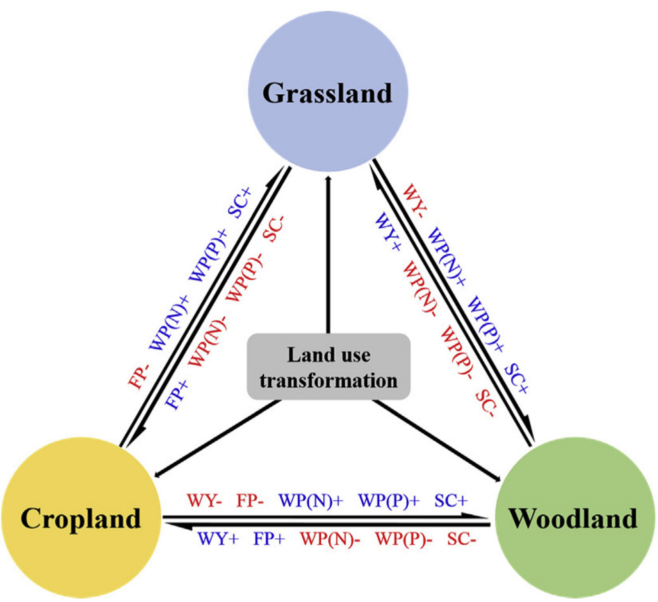


Fig. 4. The impact of transformation between three major land use types on WRESs. Blue WRESs ('+') and red WRESs ('-') represent the enhancement and reduction of the WRESs, respectively. WY: water yield; FP: food production; WP (N): water purification (nitrogen); WP (P): water purification (phosphorus); SC: soil conservation. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

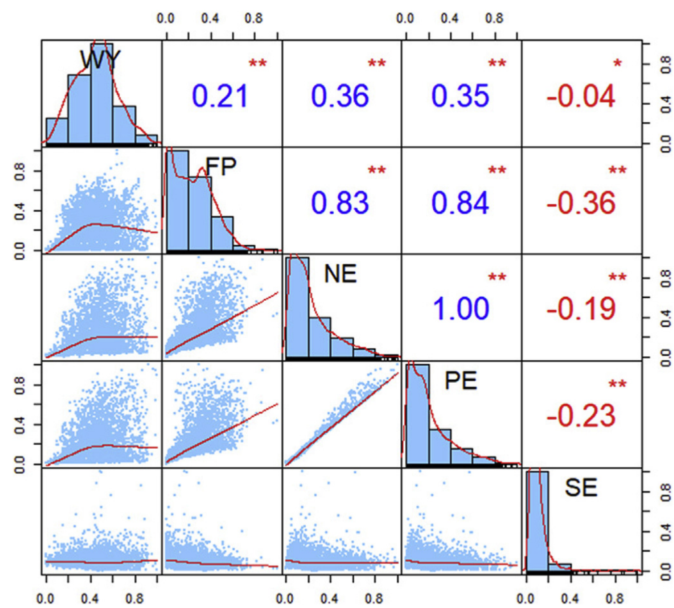


Fig. 5. Spearman's correlations among WRESs in 2015 (*p < 0.05; **p < 0.01; n = 3519). Red values and blue values represent positive and negative correlations, respectively. WY: water yield; FP: food production; NE: nitrogen export; PE: phosphorus export; SE: sediment export. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

nutrient into aquatic ecosystem. Due to the increasing risk of soil loss, soil conservation was declined because sediment export increased by 2.53% (13.57×10^4t). Under ADWB scenario, the decline of water yield and food production mainly concentrated in the north and central areas of the XJRB while the distribution of areas with increased water yield and food production were similar to the distribution under AD scenario (Fig. 7). Nitrogen and phosphorus export apparently decreased in most areas, only increased in the southwest and a small part of the southeast. The decrease of sediment export in some areas indicated that vegetative buffer not only helped improve water quality but also performed well in conserving soil.

Under GFG scenario, water yield decreased by 5×10^7 m^3 as a result of the increase of evapotranspiration. Also, food production reduced by 4.21% (69.97×10^4t) because of the loss in cropland. Due to the better nutrient retention capacities of woodland and grassland, nitrogen and phosphorous export decreased by 3.35% (27.34×10^4kg) and 3.35% (2.94×10^4kg), respectively. And soil conservation increased with the decrease of 5.89% (31.58×10^4t) in sediment export. As illustrated in Fig. 7, under GFG scenario, water yield and food production showed decreasing trends in all areas of the XJRB. In particular, the decline of water was most obvious in the south-central region while the area of largest decrease in food production mainly distributed in the northwest and north of the XJRB. On the contrary, water purification and soil conservation were improved to varying degrees in the whole XJRB. Water purification increased most in the south region, while soil conservation increased obviously in the mountainous southern, western, and eastern parts of the basin.

With the comprehensive effect of agricultural development, Grain-for-Green and woodland buffer, water yield increased by

Table 2
Values of various WRESs under 2015 (the baseline) and alternative scenarios.

Alternative scenarios	Water yield ($10^8m^3/a$)	Food production ($10^4t/a$)	Nitrogen export ($10^4kg/a$)	Phosphorous export ($10^4kg/a$)	Sediment export ($10^4t/a$)
Baseline	793.09	1662.37	815.68	87.84	536.19
AD	794.76	1720.14	847.44	91.57	562.82
ADWB	793.81	1690.95	783.23	83.97	549.76
GFG	792.59	1592.40	788.34	84.90	504.61
ADWB_GFG	793.33	1621.87	759.04	81.39	519.35

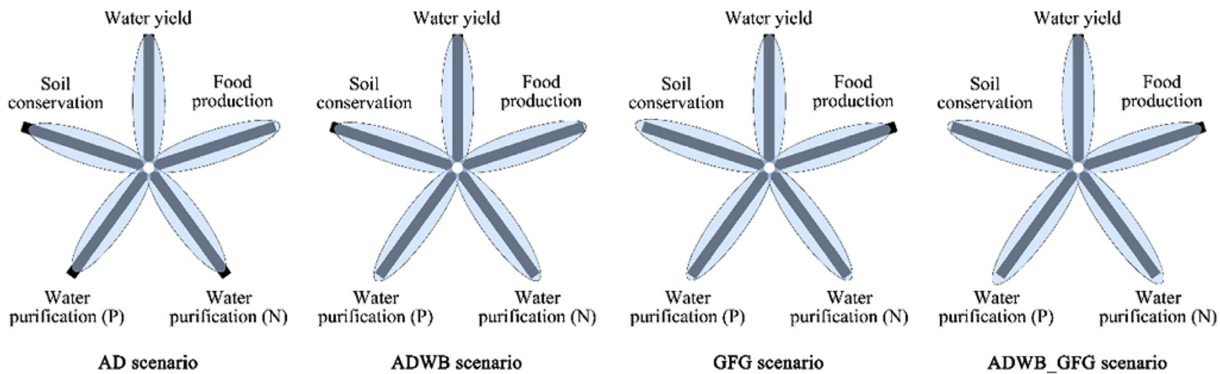


Fig. 6. Trade-offs between WRESs under alternative land-use scenarios. The lengths of the black bars represent various WRESs provision in 2015 (the baseline scenario) while the lengths of the light blue petals represent the WRESs under different scenarios. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

2.4×10^7 m^3 under ADWB_GFG scenario. Although food production decreased by 2.44% (40.2×10^4t), there was a relatively small loss compared with GFG scenario. In addition, water purification was apparently enhanced because nitrogen and phosphorous export reduced by 6.94% (56.64×10^4kg) and 7.34% (6.45×10^4kg), respectively. Moreover, sediment export decreased by 3.14% (16.84×10^4t), which indicated the improvement of soil conservation. According to Fig. 7, water yield showed an increasing trend in the southwest and northeast while the areas of decreased water yield were mainly distributed in the north, central and south of the basin. Although the distribution of food production changes was similar to that of water yield, there were more areas of decreased food production. Water purification in most areas was obviously improved and the area with the most dramatic enhancement was located in the north and the central of the XJRB. Although the increase of sediment export appeared in small areas of the southwest and southeast, sediment export declined in the most of the XJRB, especially in the south, which represented the great improvement of soil conservation.

Overall, obvious trade-off could be found among provisioning services and regulating services under AD and GFG scenario (Fig. 6). Under ADWB scenario, soil conservation declined although other three services increased. Water purification could be improved the most under ADWB_GFG scenario. Moreover, water yield and soil conservation increased with relatively small loss in food production.

3.3.2. *Changes of trade-offs*

Based on the correlation analysis, trade-offs mainly existed between water purification and other WRESs. To further analyze the changes of trade-offs under various land use scenarios, RMSE between water purification (WP) and other three WRESs (water yield (WY), food production (FP) and soil conservation (SC)) were calculated to quantify the trade-offs at sub-river basin scale (Fig. 8). Compared with 2015, RMSE values between WY and WP decreased in different degree under all scenarios; and most reduction could be found under ADWB_GFG scenarios (Fig. 8a). RMSE values between FP and WP were larger than those between other two services and WP (Fig. 8b). Except for GFG scenario, RMSE values between FP and WP decreased. Differently, RMSE values between SC and WP decreased the most under AD scenario, following by ADWB and ADWB_GFG scenarios (Fig. 8c). In summary, compared with 2015, the changes of RMSE under different scenarios were comparatively small at sub-river basin scale. Trade-offs between WY and WP and between FP and WP decreased relatively more under ADWB_GFG scenarios while trade-off between SC and WP decreased relatively more under AD scenario.

4. Discussion

4.1. *The quantifications of WRESs and trade-offs*

WRESs affected by long-term land use change in the XJRB were quantified in this study. Former studies on WRESs only focused on three ecosystem services, including water yield, soil conservation and water purification, which are related directly to hydrological processes (Gao et al., 2017; Sahle et al., 2019). Food production, linked indirectly with three ecosystem services mentioned above, was taken into account in this study. During the past 35 years, four WRESs in the XJRB were increased except water purification. In particular, the improvement of soil conservation in this study revealed the great effect of China's Grain-for-Green Program on improving regulating services and local ecology quality, which was consistent with Peng et al. (2019). With average climate parameters (1980–2015) as input data, the slight change was found in water yield. This result demonstrates that climate factors (precipitation and potential reference evapotranspiration) have the greater impact on water yield than land use change, which is similar to existing studies (Bai et al., 2019; Yang, D. et al., 2019). Although cropland decreased from 1980 to 2000, food production showed an increasing trend because the impact of cropland losses had been compensated by the innovations in agricultural production

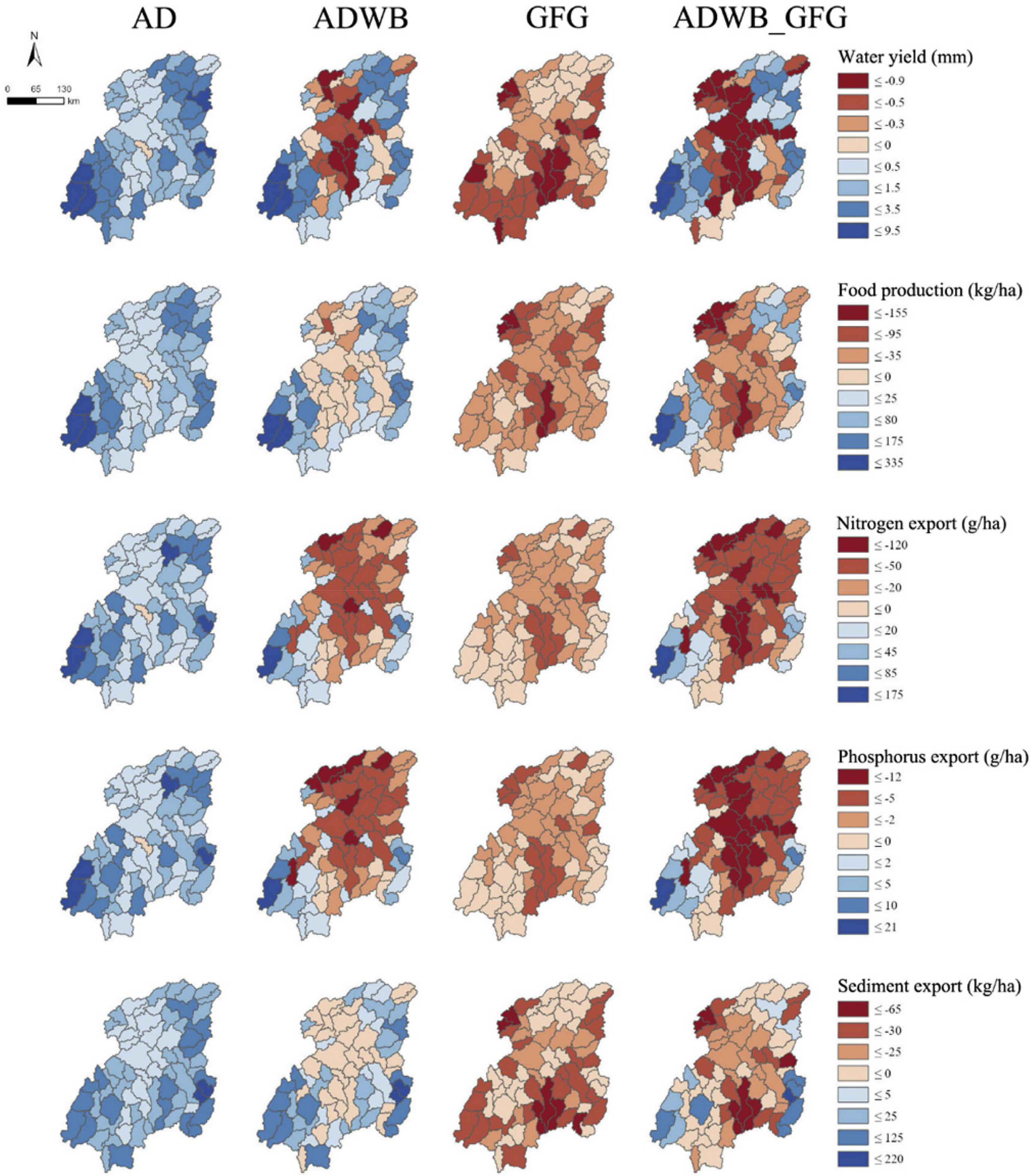


Fig. 7. WRESs changes (relative to the baseline scenario) at sub-river basin scale under alternative land-use scenarios in the XJRB.

technology. Agriculture and urban industry were two major contributors of nutrients in the XJRB, the expansion of cropland and urbanization resulted in the deterioration of water quality from 2000 to 2015. Moreover, our study revealed the conversion of different land use types would cause trade-offs among WRESs, which should be considered carefully in regional land use management. In accordance with Fu et al. (2017), the conversion of cropland to ecological land (woodland and grassland) led to the

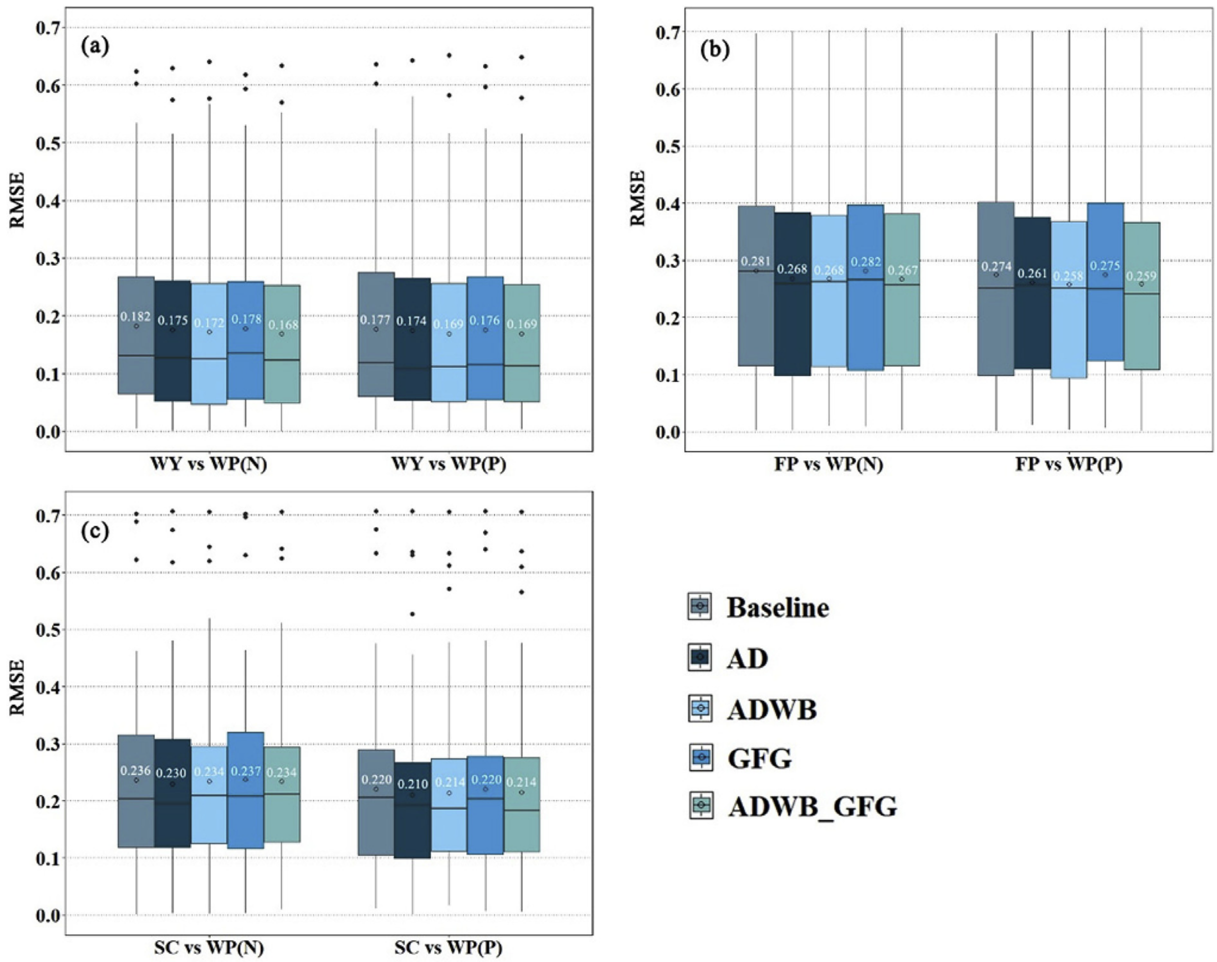


Fig. 8. The change of RMSE values of water purification and other WRESs under alternative land-use scenarios. The dark circle and the number in the box represent the mean value of RMSE under different scenarios. WY: water yield; FP: food production; SC: soil conservation; WP (N): water purification (nitrogen); WP (P): water purification (phosphorus).

improvement of soil conservation and water quality although food production decreased. Therefore, for areas with adequate food production, increasing the area of ecological land reasonably will promote the protection of regulating services.

Our study also analyzed the relationships among various WRESs based on correlation analyses. Synergy occurred between food production and water yield. Trade-off existed between soil conservation and water purification, while the same relationship was found between food production and water purification. These are consistent with the research in Erhai Lake Basin, whose water quality is also polluted by agricultural planting (Hu et al., 2018). However, our results revealed the synergetic relationship between food production and soil conservation in the XJRB, which was different from the past research in Beijing-Tianjin-Hebei Metropolitan Area (Yang, Y. et al., 2019). This was due to the fact that soil erosion in the basin mainly occurred in woodland areas with higher slope where food production was low. In addition, Hou et al. (2018) and Hu et al. (2018) found a synergetic relationship between water yield and water purification, while the relationship is trade-off in our study. The spatial distribution of precipitation and evaporation varies from region to region, which leads to different spatial pattern of water yield. Our research suggests that the relationships among ecosystem services in different regions are not exactly the same, this difference should be taken into account in future land-use management. The primary concern of policy makers should be how to reduce trade-offs between water purification and other services in the XJRB.

4.2. Implications of land use scenarios for management practices

In the past 35 years, although most WRESs showed a benign trend under land use change in the XJRB, the deterioration of water quality had intensified as a result of the rapid development of agriculture and urbanization. Local policy makers will face great challenge on water conservation management in the context of future economic development. Blindly reclaiming cropland to increase agricultural production fails to maintain the provision of other ecosystem services. The suitability evaluation of agricultural development in our study, which comprehensively considered the characteristics of local geographical factors, can be used to identify which areas are most suitable or unsuitable for agricultural production (Chen et al., 2010). Although various national ecological projects (i.e. the Grain-for-Green Program and Soil and Water Conservation) have been implemented since the 20th century, policy makers are anxious about whether the implementation of these projects have created win-wins for all ecosystem services. In order to help decision makers to deal with the uncertainties of the future, our study set four alternative future land use scenarios to analyze the effects of different regional development policies on WRESs and explore an optimal scenario that could lead to more balanced WRESs. From our scenario analysis, we showed that the implementation of various polices in the XJRB will lead to different change direction and rates of WRESs in the region. The spatial pattern changes of WRESs under various scenarios can provide an important reference for decision-makers to identify which areas are more sensitive to relevant polices. Increasing food production by agricultural land expansion was not a reasonable approach as it would lead to the degradation of soil conservation and water purification. The development of integrated soil–crop systems management and application of high-yielding crop breeds can provide more scientific and sustainable way to improve food supply (Fan et al., 2012; Jiang et al., 2016). The implementation of GFG will contribute to obvious enhancement of regulating services, especially for soil conservation. But at the same time, the increasing vegetation coverage will decrease the area of cropland and promote the regional evapotranspiration. Thus, the potential ecological-economic risks (i.e. regional food and water scarcity) under this land management scenario should not be ignored by policy makers (Jia et al., 2014). The great improvement of water quality and soil conservation under ADWB and ADWB_GFG scenario support the conclusion that the restoration of riparian vegetation plays an essential role in soil and water quality conservation (Zheng et al., 2016). The Beijing Government has invested $2.7 billion in the Yongdinghe River Ecological Corridor project to restore riparian zones (Wong et al., 2015). Our results suggest that similar ecological projects should be considered by local policy makers in the XJRB as their good performance on reducing soil loss and water pollution. Under ADWD_GFG scenario, implementing ecological projects under the situation of agricultural development can not only generate significant ecological benefits but also mitigate the negative impact of the decline of food production. According to the quantitative analysis of trade-offs, ADWD_GFG scenario shows the decreasing trends of trade-offs between water purification and other WRESs despite the smallness in extent. Therefore, ADWD_GFG scenario could be chosen as the optimal scenario because land use development pattern under this scenario can help policy-makers to achieve relative balance WRESs and a win-win situation between regional development and ecological protection.

4.3. Limitations and future research direction

There are several limitations in this study. Firstly, our study only analyzed the effects of land use change on WRESs. Climate change, as another essential factor influencing the WRESs provision and trade-off among WRESs, is not reflected in this study. In the future, it is necessary to identify which factor has a greater impact on the trade-offs among WRESs. The comprehensive consideration of climate and land use change will establish a more complete WRESs evaluation system for water conservation management. The setting of land use scenarios is based on regional development characteristics. However, the XJRB is a complex human-water system, and land use conversion is affected by multiple anthropogenic factors such as the costs of land transformation, local ecological network and the demands of different interest groups (Liang et al., 2018). Future studies should incorporate optimization algorithms such as Modern Portfolio Theory into the establishment of land use scenarios, which will greatly improve the rationality of scenarios setting (Hua et al., 2015). Secondly, the limitations of InVEST model may affect the accuracy of the quantification results. For example, water yield model may not fully consider the complex land use patterns that may lead to complex water balances; and water purification model assume that once nutrient reaches the stream it impacts water quality at the watershed outlet, which ignore the biochemical processes of nutrients in the stream (Sharp, 2018). Further studies need to integrate multiple models such as Soil and Water Assessment Tool (SWAT) model to get more accurate results. Thirdly, although four primary WRESs in the XJRB were evaluated in our study, flood mitigation is not included because of the lack of available data and the limitation of model. The XJRB, as a flood-prone area, experienced several massive floods since 1860 (Zhang et al., 2020). Flood mitigation service in the XJRB plays an essential role in ecological and socio-economic security in the Yangtze River Basin. Thus, it is necessary to quantify flood mitigation and explore the trade-offs between flood mitigation and other WRESs despite the great challenge of in-depth research of evaluation method (Cheng et al., 2019).

5. Conclusions

In this study, we analyze the changes of four primary WRESs and trade-offs among WRESs based on past land use change (1980–2015) in the XJRB. During the past 35 years, the area of cropland and built-up land increased while woodland and grassland decreased, these changes are particularly apparent from 2000 to 2015. Dramatic transformations in land-use have resulted in an overall upward trend of water yield, food production and soil conservation except water purification. Water quality deterioration was a result of the rapid expansion of agriculture and urbanization. The correlation analysis showed that trade-offs existed not only between regulating (water purification) and provisioning services (water yield and food production), but also between regulating services (water purification and soil conservation). Scenario analysis was applied to explore the uncertainties of future development. The results revealed that the pursuit of agricultural production alone or ecology alone would lead to unbalanced WRESs. Among four alternative scenarios, ADWB_GFG scenario is selected as the optimal scenario in this study because the improvement in water yield, water purification, soil conservation and relatively small negative impact on food production. Meanwhile, trade-offs between water purification and other services decreased most under ADWB_GFG scenario.

Despite the limitations in our research, we provide an integrated WRESs trade-offs assessment framework for policy makers to clarify how WRESs are impacted by land use change and optimal WRESs management based on the effects of different alternative scenarios on WRESs. Local governments will be better informed to deal with the uncertainties of future development. This assessment framework can be used to provide valuable reference information for other agricultural watersheds. Through reasonable land use management, the negative impacts of economic development will be mitigated and the achievement of Sustainable Development Goals will be promoted in the future.

CRediT authorship contribution statement

Jie Liang: Writing - review & editing, Conceptualization, Methodology. **Shuai Li:** Writing - original draft, Software, Data curation. **Xiaodong Li:** Writing - review & editing. **Xin Li:** Data curation. **Qiang Liu:** Data curation. **Qianfang Meng:** Data curation. **Anqi Lin:** Data curation. **Jinjin Li:** Data curation.

Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2020.123851.

References

Bai, Y., Ochuodho, T.O., Yang, J., 2019. Impact of land use and climate change on water-related ecosystem services in Kentucky, USA. Ecol. Indicat. 102, 51–64.
Bennett, E.M., Peterson, G.D., Gordon, L.J., 2009. Understanding relationships among multiple ecosystem services. Ecol. Lett. 12 (12), 1394–1404.
Borselli, L., Cassi, P., Torri, D., 2008. Prolegomena to sediment and flow connectivity in the landscape: a GIS and field numerical assessment. Catena 75 (3), 268–277.
Bradford, J.B., D'Amato, A.W., 2012. Recognizing trade-offs in multi-objective land management. Front. Ecol. Environ. 10 (4), 210–216.
Burkhard, B., Kroll, F., Nedkov, S., Müller, F., 2012. Mapping ecosystem service supply, demand and budgets. Ecol. Indicat. 21, 17–29.
Chen, Y., Yu, J., Khan, S., 2010. Spatial sensitivity analysis of multi-criteria weights in GIS-based land suitability evaluation. Environ. Model. Software 25 (12), 1582–1591.
Cheng, X., Van Damme, S., Li, L., Uyttenhove, P., 2019. Evaluation of cultural ecosystem services: a review of methods. Ecosyst. Serv. 37.
Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruele, J., Raskin, R.G., Sutton, P., Van den Belt, M., 1997. The value of the world's ecosystem services and natural capital. Nature 387, 253–260.
Doody, D.G., Withers, P.J.A., Dils, R.M., McDowell, R.W., Smith, V., McElarney, Y.R., Dunbar, M., Daly, D., 2016. Optimizing land use for the delivery of catchment ecosystem services. Front. Ecol. Environ. 14 (6), 325–332.
Fan, M., Shen, J., Yuan, L., Jiang, R., Chen, X., Davies, W.J., Zhang, F., 2012. Improving crop productivity and resource use efficiency to ensure food security and environmental quality in China. J. Exp. Bot. 63 (1), 13–24.
Fu, B., Forsius, M., Liu, J., 2013. Ecosystem services: climate change and policy impacts. Curr. Opin. Environ. Sustain. 5 (1), 1–3.
Fu, Q., Li, B., Hou, Y., Bi, X., Zhang, X., 2017. Effects of land use and climate change on ecosystem services in Central Asia's arid regions: a case study in Altay Prefecture, China. Sci. Total Environ. 607–608, 633–646.
Gao, J., Li, F., Gao, H., Zhou, C., Zhang, X., 2017. The impact of land-use change on water-related ecosystem services: a study of the Guishui River Basin, Beijing, China. J. Clean. Prod. 163, S148–S155.
Gleason, R.A., Euliss, N.H., Tangen, B.A., Laubhan, M.K., Browne, B.A., 2011. USDA conservation program and practice effects on wetland ecosystem services in the Prairie Pothole Region. Ecol. Appl. 21 (sp1), S65–S81.
Haase, D., Schwarz, N., Strohbach, M., Kroll, F., Seppelt, R., 2012. Synergies, trade-offs, and losses of ecosystem services in urban regions: an integrated multi-scale framework applied to the leipzig-halle region, Germany. Ecol. Soc. 17 (3).
Hossain, M.S., Das, N.G., 2010. GIS-based multi-criteria evaluation to land suitability modelling for giant prawn (Macrobrachium rosenbergii) farming in Companigonj Upazila of Noakhali, Bangladesh. Comput. Electron. Agric. 70 (1), 172–186.
Hou, Y., Chen, W., Liao, Y., Luo, Y., 2017a. Modelling of the estimated contributions of different sub-watersheds and sources to phosphorous export and loading from the Dongting Lake watershed, China. Environ. Monit. Assess. 189 (12), 602.
Hou, Y., Chen, W., Liao, Y., Luo, Y., 2017b. Scenario analysis of the impacts of socioeconomic development on phosphorous export and loading from the Dongting Lake watershed, China. Environ. Sci. Pollut. Res. Int. 24 (34), 26706–26723.
Hou, Y., Li, B., Muller, F., Fu, Q., Chen, W., 2018. A conservation decision-making framework based on ecosystem service hotspot and interaction analyses on multiple scales. Sci. Total Environ. 643, 277–291.
Hu, Y., Peng, J., Liu, Y., Tian, L., 2018. Integrating ecosystem services trade-offs with paddy land-to-dry land decisions: a scenario approach in Erhai Lake Basin, southwest China. Sci. Total Environ. 625, 849–860.
Hua, S., Liang, J., Zeng, G., Xu, M., Zhang, C., Yuan, Y., Li, X., Li, P., Liu, J., Huang, L., 2015. How to manage future groundwater resource of China under climate change and urbanization: an optimal stage investment design from modern portfolio theory. Water Res. 85, 31–37.
Jia, X., Fu, B., Feng, X., Hou, G., Liu, Y., Wang, X., 2014. The tradeoff and synergy between ecosystem services in the Grain-for-Green areas in Northern Shaanxi, China. Ecol. Indicat. 43, 103–113.
Jiang, C., Wang, F., Zhang, H., Dong, X., 2016. Quantifying changes in multiple ecosystem services during 2000–2012 on the Loess Plateau, China, as a result of climate variability and ecological restoration. Ecol. Eng. 97, 258–271.
Kennedy, C.M., Hawthorne, P.L., Miteva, D.A., Baumgarten, L., Sochi, K., Matsumoto, M., Evans, J.S., Polasky, S., Hamel, P., Vieira, E.M., Develey, P.F., Sekercioglu, C.H., Davidson, A.D., Uhlhorn, E.M., Kiesecker, J., 2016. Optimizing land use decision-making to sustain Brazilian agricultural profits, biodiversity and ecosystem services. Biol. Conserv. 204, 221–230.
Lawler, J.J., Lewis, D.J., Nelson, E., Plantinga, A.J., Polasky, S., Withey, J.C., Helmers, D.P., Martinuzzi, S., Pennington, D., Radeloff, V.C., 2014. Projected land-use change impacts on ecosystem services in the United States. Proc. Natl. Acad. Sci. U.S.A. 111 (20), 7492–7497.
Liang, J., He, X., Zeng, G., Zhong, M., Gao, X., Li, X., Li, X., Wu, H., Feng, C., Xing, W., Fang, Y., Mo, D., 2018. Integrating priority areas and ecological corridors into national network for conservation planning in China. Sci. Total Environ. 626, 22–29.
Liang, J., Liu, Q., Zhang, H., Li, X., Qian, Z., Lei, M., Li, X., Peng, Y., Li, S., Zeng, G., 2020. Interactive effects of climate variability and human activities on blue and green water scarcity in rapidly developing watershed. J. Clean. Prod. 265.
Liang, J., Zhong, M., Zeng, G., Chen, G., Hua, S., Li, X., Yuan, Y., Wu, H., Gao, X., 2017. Risk management for optimal land use planning integrating ecosystem services values: a case study in Changsha, Middle China. Sci. Total Environ. 579, 1675–1682.
Ma, 2005. Ecosystems and Human Well-Being: Synthesis. Island Press, Washington, DC.
Molden, D.J.I.B., 2007. Water for Food, Water for Life: a Comprehensive Assessment of Water Management in Agriculture. Reports.
Nelson, E., Mendoza, G., Regetz, J., Polasky, S., Tallis, H., Cameron, D., Chan, K.M.A., Daily, G.C., Goldstein, J., Kareiva, P.M., Lonsdorf, E., Naidoo, R., Ricketts, T.H., Shaw, M., 2009. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. Front. Ecol. Environ. 7 (1), 4–11.
Peng, J., Hu, X., Wang, X., Meersmans, J., Liu, Y., Qiu, S., 2019. Simulating the impact of grain-for-green programme on ecosystem services trade-offs in northwestern yunnan, China. Ecosyst. Serv. 39 (22120416).
Polasky, S., Nelson, E., Pennington, D., Johnson, K.A., 2010. The impact of land-use change on ecosystem services, biodiversity and returns to landowners: a case study in the state of Minnesota. Environ. Resour. Econ. 48 (2), 219–242.
Rimal, B., Sharma, R., Kunwar, R., Keshtkar, H., Stork, N.E., Rijal, S., Rahman, S.A., Baral, H., 2019. Effects of land use and land cover change on ecosystem services in the Koshi River Basin, Eastern Nepal. Ecosyst. Serv. 38.
Sahle, M., Saito, O., Furst, C., Yeshitela, K., 2019. Quantifying and mapping of water-related ecosystem services for enhancing the security of the food-water-energy nexus in tropical data-sparse catchment. Sci. Total Environ. 646, 573–586.
Sharp, R., Tallis, H.T., Ricketts, T., Guerry, A.D., Wood, S.A., Chaplin-Kramer, R., Nelson, E., Ennaanay, D., Wolny, S., Olwero, N., Vigerstol, K., Pennington, D., Mendoza, G., Aukema, J., Foster, J., Forrest, J., Cameron, D., Arkema, K., Lonsdorf, E., Kennedy, C., Verutes, G., Kim, C.K., Guannel, G., Papenfus, M., Toft, J., Marsik, M., Bernhardt, J., Griffin, R., Glowinski, K., Chaumont, N., Perelman, A., Lacayo, M., Mandle, L., Hamel, P., Vogl, A.L., Rogers, L., Bierbower, W., Denu, D., Douglass, J., 2018. InVEST 3.6.0 User's Guide. The Natural Capital Project. Stanford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund.
Sun, X., Li, F., 2017. Spatiotemporal assessment and trade-offs of multiple ecosystem services based on land use changes in Zengcheng, China. Sci. Total Environ. 609, 1569–1581.
Wang, J., Peng, J., Zhao, M., Liu, Y., Chen, Y., 2017. Significant trade-off for the impact of grain-for-green programme on ecosystem services in north-western yunnan, China. Sci. Total Environ. 574, 57–64.
Wang, J., Zhou, W., Pickett, S.T.A., Yu, W., Li, W., 2019. A multiscale analysis of urbanization effects on ecosystem services supply in an urban megaregion. Sci. Total Environ. 662, 824–833.
Wong, C.P., Jiang, B., Kinzig, A.P., Lee, K.N., Ouyang, Z., 2015. Linking ecosystem characteristics to final ecosystem services for public policy. Ecol. Lett. 18 (1), 108–118.
Yang, D., Liu, W., Tang, L., Chen, L., Li, X., Xu, X., 2019a. Estimation of water provision service for monsoon catchments of South China: applicability of the InVEST model. Landsc. Urban Plann. 182, 133–143.
Yang, W., Jin, Y., Sun, T., Yang, Z., Cai, Y., Yi, Y., 2018. Trade-offs among ecosystem services in coastal wetlands under the effects of reclamation activities. Ecol. Indicat. 92, 354–366.
Yang, Y., Zheng, H., Kong, L., Huang, B., Xu, W., Ouyang, Z., 2019b. Mapping ecosystem services bundles to detect high- and low-value ecosystem services areas for land use management. J. Clean. Prod. 225, 11–17.
Zhang, D., Shi, X., Xu, H., Jing, Q., Pan, X., Liu, T., Wang, H., Hou, H., 2020. A GIS-based spatial multi-index model for flood risk assessment in the Yangtze River Basin, China. Environ. Impact Assess. Rev. 83.
Zhang, X., Lu, X., 2010. Multiple criteria evaluation of ecosystem services for the Ruoergai Plateau Marshes in southwest China. Ecol. Econ. 69 (7), 1463–1470.
Zheng, H., Li, Y., Robinson, B.E., Liu, G., Ma, D., Wang, F., Lu, F., Ouyang, Z., Daily, G.C., 2016. Using ecosystem service trade-offs to inform water conservation policies and management practices. Front. Ecol. Environ. 14 (10), 527–532.
Zheng, H., Wang, L., Peng, W., Zhang, C., Li, C., Robinson, B.E., Wu, X., Kong, L., Li, R., Xiao, Y., Xu, W., Ouyang, Z., Daily, G.C., 2019. Realizing the values of natural capital for inclusive, sustainable development: informing China's new ecological development strategy. Proc. Natl. Acad. Sci. U.S.A. 116 (17), 8623–8628.