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Identifying key areas of ecosystem services potential to improve ecological management in Chongqing City, southwest China

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Abstract Because natural ecosystems and ecosystem services (ES) are both critical to the well-being of humankind, it is important to understand their relationships and congruence for conservation planning. Spatial conservation planning is required to set focused preservation priorities and to assess future ecological implications. This study uses the combined measures of ES models and ES potential to estimate and analyze all four groups of ecosystem services to generate opportunities to maximize ecosystem services. Subsequently, we identify the key areas of conservation priorities as future forestation and conservation hotspot zones to improve the ecological management in Chongqing City, located in the upper reaches of the Three Gorges Reservoir Area, China. Results show that ecosystem services potential is extremely obvious. Compared to ecosystem services from 2000, we determined that soil conservation could be increased by 59.11%, carbon sequestration by 129.51%, water flow regulation by 83.42%, and water purification by 84.42%. According to our prioritization results, approximately 48% of area converted to forests exhibited high improvements in all ecosystem services (categorized as hotspot-1, hotspot-2, and hotspot-3). The hotspots identified in this study can be used as an excellent surrogate for evaluation ecological engineering benefits and can be effectively applied in improving ecological management planning.

Keywords Ecosystem services · Ecological management · Chongqing City · Potential · Hotspots

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Introduction

The link between natural ecosystems and ecosystem services is vital to the well-being of humankind. Natural ecosystems support most ecosystem services because the importance of such services lies within maintaining human livelihoods (Cao 2015; Gao et al. 2011). However, both natural ecosystems and ecosystem services are threatened by increasing human activities. Ecological problems associated with such activities significantly impact ecosystems, which has increasingly concerned ecologists and administrators (Jiang et al. 2015; Kong et al. 2017). How can we maintain natural ecosystems under sustainable development when human-natural ecosystems are facing such serious environmental problems? Anthropogenic activities are associated with modes of utilization pertaining to ecosystem services (Miao et al. 2016; Zhang et al. 2015). The crux of the problem lies with management, whose fundamental objectives are to retain or deplete ecological resource consumption on a spatiotemporal scale, the fragmentation and agglomeration of a system coupled with its structure and function, and the disorder of social behavior under economic and ecological management (Cao et al. 2017; Zhang et al. 2017). It is not yet clear to what extent ecosystem services and natural ecosystem conservation will ensure the continuance of such services. Thus, relevant investigations would be of great scientific significance (Dahal and Cao 2015; Gao et al. 2010; Jiang et al. 2015).

In the face of such problems, humankind has persisted in this serviceable relationship between its needs and the limitations of natural ecosystem resources by "remaking" nature. On the one hand, there is an ecological response (such as the heat island effect, natural disasters, and pollution effects) from regional life support systems to ecosystem services and anthropogenic activities that goes beyond the carrying capacity of natural ecosystems (Miao et al. 2016; Zhang et al. 2017). On the other hand, environmental threats and ecological degradation to ecosystems are caused by anthropogenic activities as are beneficial ecological construction initiatives (Xiao et al. 2016). According to initial engineering planning data, however, the enormous national ecological engineering investment in China may not achieve the best ecological benefits (Bai et al. 2011; Bateman et al. 2013). Based on such targets, this study proposes ways by which to identify potential regions that may benefit from the promotion of ecosystem services, which could provide scientific guidance and data in support of ecological engineering planning in the Chongqing City region and China as a whole (Chen et al. 2011; Norden et al. 2015). Accordingly, it is necessary to understand the relationships between natural ecosystem conservation priorities and ecosystem services even though it has been proven difficult to quantify levels and values of such services. Researchers are currently meticulously designing a model focused on the "production function" of a single ecosystem service within a small area (Li et al. 2011; Wang et al. 2014). Attention is being paid to the complex spatial heterogeneity of ecosystems affected by ecological-based variables, such as climate, vegetation, soil texture, topography, and anthropogenic activity, especially highly heterogeneous natural resources and geographical features in hilly areas that have hampered local governments and stakeholders working to protect their natural resources and environments under limited funds and political influence (Wang et al. 2014; Ye et al. 2012). Due to a deficiency in spatial dimensions, a rational and accurate method is important to better understand ecosystem services.

The area surrounding Chongqing City (the Chongqing region) is located in the upper reaches of the Three Gorges Reservoir Area (TGRA), a biosensitive zone largely unaffected by anthropogenic influence. The TGRA has a significant impact on the Yangtze basin, not only because the Three Gorges Dam is the world's largest hydropower project, but also because the Yangtze basin is the home to the world's largest river basin population (greater than 450 million people). However, few quantitative studies on estimates of natural ecosystems, ecosystem services, conservation planning, and management in priority areas have been conducted to date (Wu et al. 2013; Xu et al. 2011). In view of this, it is imperative as well as scientifically significant to investigate how to apply ecological principles to improve the traditional resource management structure, to develop a new management model by grouping ecological functions and management, and to understand ecological resource management mechanisms of natural ecosystems to effectively enhance industrial ecosystem services and reduce human impacts on the ecological environment.

In order to verify this premise, we tested a new combined ecosystem services method, applying the Universal Soil Loss Equation (USLE), the Carnegie-Ames-Stanford Approach (CASA) model, and the Integrated Valuation of Environmental Services and Tradeoffs (InVEST) model. The main contributions of this study are (1) to comprehensively analyze the improvement potential of the spatial distribution characteristics of ecosystem services; (2) to investigate the improvement potential of ecosystem services in relation to distribution area based on the conversion from non-forest landscapes to forest landscapes; and (3) to suggest land management strategies that would be attractive to stakeholders.

Materials and methods

Study area

The study area (Fig. 1) is located from long 105°11′ to 110°11′ E and from lat 28°10′ to 32°13′ N in the upper reaches of the TGRA where the largest water conservation project (Three Gorges Dam) in the world is situated.

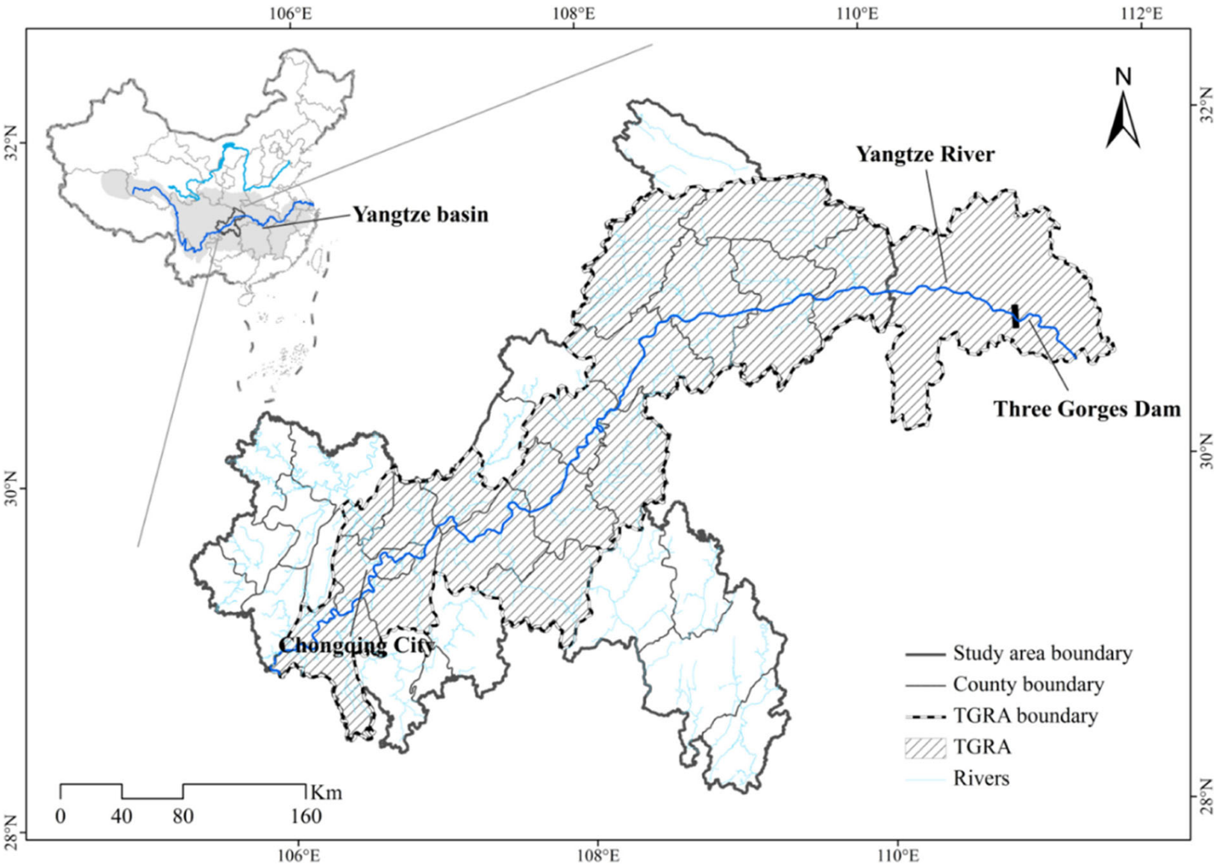

Fig. 1 Location map of the TGRA in China

Its total area is 82,400 km^2 and its population is 3.02 × 10^7. Geographical conditions in this area are complex, featuring lowlands in the west and highlands in the east. The topography of the area is dominated by mountains (accounting for 75.8% of the total area) and hills (approximately 18.2%). Approximately 6% of the area is comprised of plains (Li et al. 2009). The study area is comprised of a range of land cover types, but forests and cropland dominant. The soil types mainly comprise of purple, yellow, and paddy soils. The area is under the influence of a subtropical monsoon climate and, for most of the year, experiences humid and hot conditions (Chen et al. 2011; Huang and Yi 2010). Based on data from the Chinese National Metrological Center, the mean annual temperature range is from 17 to 19 °C, with mean minimum temperatures from 4 to 8 °C in January and mean maximum temperatures from 26 to 29 °C in July. The annual mean precipitation is approximately 1100 mm. Rainfall can vary in both amount and time of year, but approximately 85% of yearly rainfall occurs primarily during the summer (a period from 6 to 9 months).

Data sources

In this study, monthly meteorological data from 2000 to 2010 includes precipitation, temperature, and total solar radiation. We interpolated this data, collected from meteorological stations, to the entire study area, using a spatial resolution of 0.05° and applying kriging regression (Piao et al. 2001).

Information related to the distribution of land cover (from 2000, 2005, and 2010) was generated with object-oriented image classifications, using Landsat TM and ETM satellite image data. By comparing land cover to ground-based data (using 381 samples), we determined that the overall accuracy of the land cover map was 86.4 and 82.6% for 2000 and 2010, respectively. Soil data was collected from the second national soil survey. This data includes soil type, soil mineral particle composition, soil organic matter content, and soil depth (1:1000000 scale). We obtained topographical data from the Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM).

We used this DEM data to calculate slope gradients and slope lengths. Given that the normalized difference vegetation index (NDVI) is a useful indicator of vegetation, we used Moderate Resolution Imaging Spectrometer (MODIS) time series NDVI data sets (from 2000 to 2010), with a 16-day time interval. Since noise from haze and clouds, atmospheric conditions, or ice-snow could affect these products, we initially applied the asymmetric Gaussian (AG) function filter in TIMESAT 2.3 to reconstruct the NDVI time series data set to reduce noise during the preprocessing data procedure (Jonsson and Eklundh 2004). Following this, we compiled 16-day MODIS NDVI data into monthly NDVI data based on the maximum-value composite procedure (MVC) in order to further eliminate noise pollution (Holben 1986).

All the cartographic raster data were converted into the same Universal Transverse Mercator (UTM) projection with a spatial resolution of 100 m. Table 1 provides a number of details related to this data.

Methods

In the study area, we analyzed indices of four key ecosystem services, including carbon sequestration, soil conservation, water yield, and water purification (phosphorus export). The main reason why we selected these four ecosystem services was due to their significance, their high relevance to conservation planning, and the availability of this data.

Ecosystem services

Carbon sequestration

The annual amount of CO_2 sequestrated by an ecosystem can be estimated based on net ecosystem productivity (NEP) (Christie et al. 2012), defined as follows:

$$\mathrm{NEP} = \mathrm{NPP} - R_{\mathrm{h}} = \mathrm{NPP} - 0.592 \times Rs^{0.714}$$

where NEP denotes the value of carbon sequestration over time (g C m^{-2} $year^{-1}$); NPP represents the net fixation of CO_2 by an ecosystem (g C m^{-2} $year^{-1}$); R_h represents heterotrophic respiration; and Rs represents soil respiration (g C m^{-2} $year^{-1}$), which can be calculated as per the methods reported by Chen (Chen et al. 2009).

NPP flux can be calculated using CASA, which is based on light use efficiency (LUE) (Potter et al. 1993). Accordingly, we calculated NPP using the following formula:

$$\mathrm{NPP} = \mathrm{APAR} \times \varepsilon = 0.5 \times S_r \times \mathrm{FPAR} \times \varepsilon_{max} \times T_1 \times T_2 \times W$$

where APAR represents the amount of photosynthetically active radiation (PAR), calculated using solar irradiance (S_r) (MJ m^{-2}) data and PAR fractions absorbed by green vegetation (FPAR), which are determined by NDVI. The factor ε for each grid cell as a utilization rate

Table 1 Principal data sources

Data name	Data resolution	Data time	Data source
Precipitation, temperature, and total solar radiation	0.05°	2000–2010	Chinese National Meteorological Information National Meteorological Information Center and China Meteorological Administration (NMIC/CMA)
Land cover map	90 m	2000, 2005, 2010	Chinese Academy of Sciences
Soil map	1:1,000,000		Chinese Academy of Sciences
SRTM digital elevation model	90 m		International scientific data service platform
MODIS-NDVI	250 m	2000–2010	Land Processes Distributed Active Archive Center (LP DAAC)
Validation data (NPP)	Quadrats	2004	Luo's research (Luo 1996)
Validation data (SE)	Counties	2000, 2005, 2010	Soil and water conservation bulletin
Validation data (WY)	Watersheds	2000, 2005, 2010	Hydrometric station, water resources bulletin
Validation data (ALV)	Watersheds	2000, 2005, 2010	Hydrometric station

of light energy can be ascertained as the product of ε_{max} (gC MJ^{-1}), determined by means of a calibration with the field data, and scalars that represent soil moisture (*W*) availability and temperature suitability (T_1, T_2).

Soil conservation

Soil conservation can be expressed as the difference between potential and actual soil erosion (Fu et al. 2005). According to USLE, soil erosion is closely related to rainfall erosivity, soil erodibility, topography, vegetation, and conservation practices; thus, the amount of soil conservation can be defined as follows:

$$SC = R \times K \times LS \times (1 - C \times P)$$

where SC represents the soil conservation capacity (t ha^{-1} $year^{-1}$); *R* represents the annual rainfall erosivity (MJ mm ha^{-1} h^{-1} $year^{-1}$); *K* represents the soil erodibility (t ha h ha^{-1} MJ^{-1} mm^{-1}); LS represents the dimensionless topographic factor that reflects the impact of slope length and steepness on soil erosion; *C* represents the dimensionless vegetation cover factor; and *P* represents the dimensionless conservation practice. For the *R* factor, we used monthly average precipitation with an empirical equation for the calculation (Fu et al. 2011). For the *K* factor, the modified equation based on the Erosion/Productivity Impact Calculator (EPIC) model was used for calculations (Zhang et al. 2008). For the LS factor, we integrated relevant methods used for gentle slopes and steep slopes and conducted calculations using different slope segments (Hickey 2000). For the *C* factor, we made estimations based on the method using NDVI (Fu et al. 2011). For the *P* factor, the slope-based Wener method was applied for calculation (Lufafa et al. 2003).

Water yield

The water yield function, based on the water balance principle, can be calculated using the InVEST model as follows:

$$WY = \left(1 - \frac{1 + Z \times \frac{AWC}{P} \times \frac{kET_0}{P}}{1 + Z \times \frac{AWC}{P} \times \frac{kET_0}{P} + \frac{P}{kET_0}}\right) \times P$$

where WY is the annual water yield of each pixel (mm $year^{-1}$); *P* is the annual precipitation of a pixel (mm $year^{-1}$); *AWC* is the available water content of vegetation (mm $year^{-1}$), which can be estimated as the product of the differences between the field capacity and the wilting point and the minimum soil depth and the root depth (Xiao et al. 2015); *Z* is a seasonality factor that represents seasonal rainfall distribution and rainfall depth; *k* is the vegetation evapotranspiration coefficient associated with land cover types (Xiao et al. 2015); and ETo is the reference evapotranspiration calculated according to the Hargreaves equation (Hargreaves 1994). After repeated validation, it was determined that when the *Z* value is 3.0, water yield is similar to natural runoff (Xiao et al. 2015).

Water purification

Given the considerable phosphorus (P) pollution in the study area, we mainly focused on P pollution, which could be defined as a proxy for nonpoint source pollution. We applied the nutrient retention model featured in InVEST (Salles 2011).to estimate the amount of nutrients exported. Additionally, we used the relative reduction in annual discharge of dissolved P as a proxy of water purification. We calculated the quantity of pollutants exported during water purification processes based on the export coefficient approach, defined as follows:

$$LV = \log\left(\sum_U WY_u\right) / \overline{\lambda} \times pl$$

where LVx is the exported pollutant loading value of pixel *x* (kg ha^{-1} $year^{-1}$); $\sum_U WY_u$ is the water yield sum alongside the flow path over the current pixel; $\overline{\lambda}$ is the mean runoff coefficient for the relevant watershed; and pl is the pollutant export coefficient associated with the land cover types (Xiao et al. 2016). Once we calculated the amount of pollutants being exported, we could determine the quantity of pollutants in each pixel (downstream) as surface runoff transfers pollutants toward stream systems.

Identifying areas of ecosystem services potential

In this study, we defined "ecosystem services potential" as areas that could potentially and significantly improve ecosystem services. Potential areas were identified based on the amount of change in ecosystem services, under the assumption that all non-forest land cover types were converted to forest, and defined as follows:

For soil conservation potential area ($SC_{potential}$)

$$SC_{potential} = SC_{assumption} - SC = SE_a - SE_{assumption}$$
$$SC_{assumption} = R \times K \times LS \times C_{assumption} \times P$$

where $SC_{assumption}$ is the soil conservation of the assumption; $SE_{assumption}$ represents soil erosion rates under the assumption; $C_{assumption}$ is the dimensionless vegetation cover factor under the assumption, assigning a value from the statistical mean C of the forest type prior to the assumption.

For carbon sequestration potential area ($NEP_{potential}$)

$$NEP_{potential} = NEP_{assumption} - NEP = NPP_{assumption} - NPP$$

where $NEP_{assumption}$ is the net ecosystem productivity under the assumption, and $NPP_{assumption}$ is the net fixation of CO_2 by vegetation under the assumption, assigning a value from the statistical mean NPP of the forest type prior to the assumption.

For water flow regulation potential area ($WFR_{potential}$)

$$WFR_{potential} = \left| WY_{assumption} - WY \right|$$

where $WY_{assumption}$ is the water yield under the assumption, calculated using the InVEST model under the assumption.

For water purification potential area ($WP_{potential}$), we calculated the difference between the quantity of exported pollutants and those under the assumption on both sides of the banks along river networks as reported by Bai (Bai et al. 2011).

Hotspots and cold spots

In this study, hotspot analysis (Getis-Ord Gi*) was used to detect hotspots and cold spots deemed statistically significant. The Gi* statistic, which represents the amount of spatial clustering within a local sample, can be calculated as the sum of the differences between the local sample values and the mean value. The standardized Gi* statistic for each feature in the data set represents a *z*-score. *Z*-scores are measures of standard deviation, and *p* values are probabilities. Typical probabilities are 0.01, 0.05, and 0.1, and critical *z*-scores for 90, 95, and 99% confidence levels are < -1.65 or $> +1.65$, < -1.96 or $> +1.96$, and < -2.58 or $> +2.58$, respectively. Both statistical applications are associated with standard normal distribution. In this study, resultant *z*-scores and *p* values indicated where features with either high or low values (i.e., hotspots or cold spots, respectively) were spatially clustered. Values of Gi* represent each delineation of potential area clustering as a hotspot relative to ecosystem services potential point inputs within an area (such as carbon sequestration, soil conservation, water yield, and water purification). To conceptualize spatial relationships, we employed a fixed distance band. For these bands, we analyzed each feature in association with its neighboring features. We applied a weight of 1 to neighboring features within a specific critical distance, which influenced target feature calculations. Moreover, we applied a weight of 0 to neighboring features outside a critical distance, which did not influence target feature calculations. The Getis-Ord Gi* (*z*-score) was calculated as follows:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j} x_j - \overline{X} \sum_{j=1}^{n} w_{i,j}}{S \sqrt{\frac{\left| \sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j} \right)^2 \right|}{n-1}}}$$

$$\overline{X} = \frac{\sum_{j=1}^{n} x_j}{n}$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - \left(\overline{X} \right)^2}$$

where x_j is the attribute value for feature j; $w_{i,j}$ is the spatial weight between feature i and j; and n is equal to the total number of features.

Results

Model validation

To assure the model's regional applicability, we validated the results of ecosystem services using the Pearson correlation coefficients based on the observed and statistical data of the study area (Fig. 2). We found that simulated results of each ecosystem services stood in good agreement with observational-based data. Therefore, we could confirm that the ecosystem services models and their corresponding parameters used in this study were

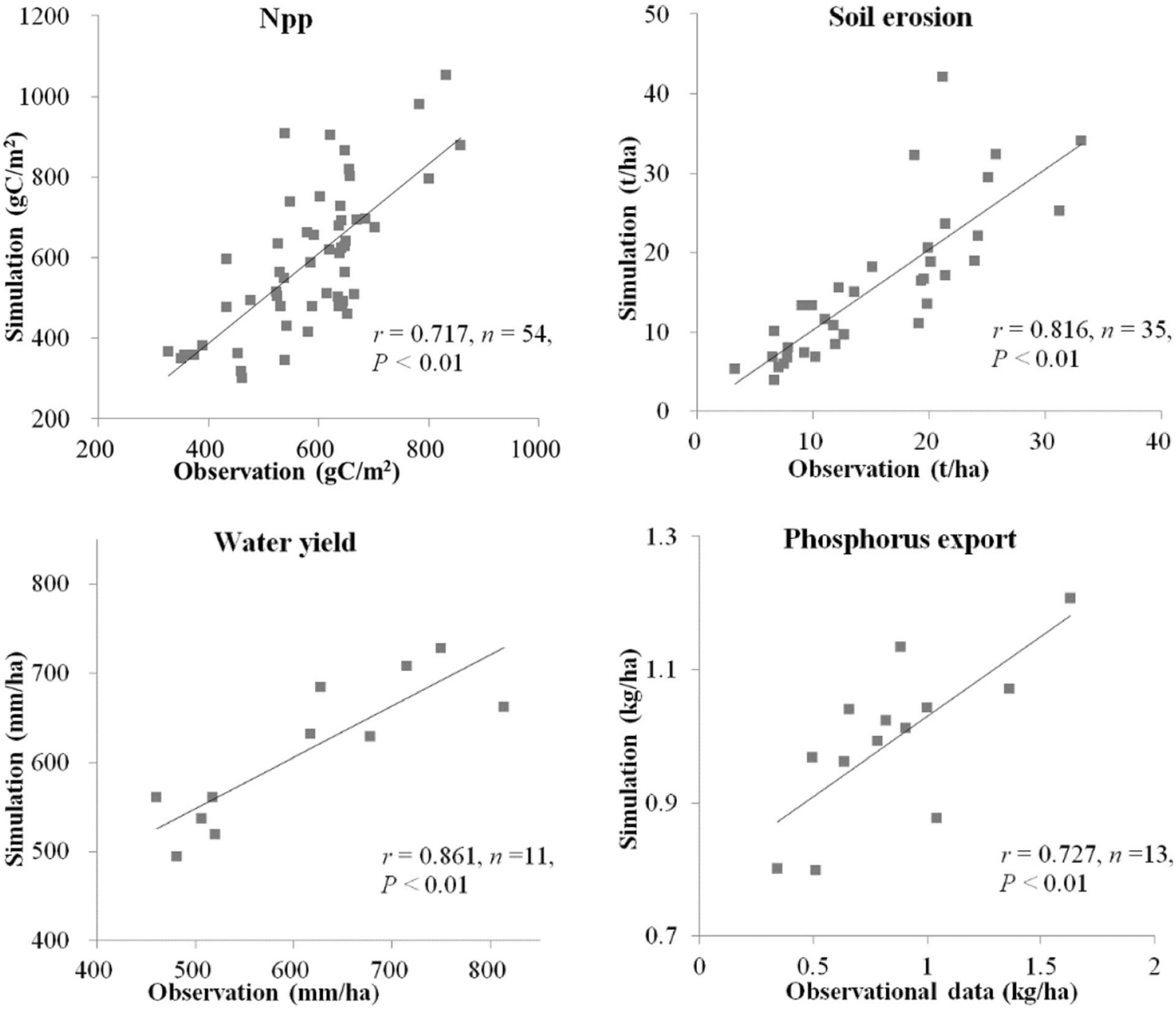

Fig. 2 Correlation validation of ecosystem services models as well as simulations (NPP, soil erosion, water yield, and phosphorus export) and observations of the mean values of specific samples

able to simulate general ecosystem services within the study area.

Spatial characteristics of areas of ecosystem services potential

In cropland, we found high values in carbon sequestration, soil retention, and water purification. In grassland, on the other hand, we found high values in water yield. However, we found no improvement in ecosystem services in urban areas (Table 2).

Ecosystem services potential for all ecosystem services investigated exhibited significant heterogeneity (Fig. 3). Forests in the central and western hilly areas that were converted from other land cover types could provide more valuable carbon sequestration services (values > 1.8 tC/ha) compared to other areas. In addition, land cover types distributed within northeastern and southeastern mountainous areas had greater potential in providing higher soil conservation (values > 200 t/ha) and water flow regulation services (values > 600 mm/ha) compared to the western agricultural plains and mountainous areas. On the other hand, improvements in water purification (values > 3 kg/ha) mainly originated from lower western elevations where agricultural and built-up land areas are the major sources of pollution.

Table 2 Mean values and percentages of each change in ecosystem services for each land use type

	Carbon sequestration		Soil erosion		Water yield		Water purification	
	Mean (tC)	Percentage (%)	Mean (t)	Percentage (%)	Mean (m^3)	Percentage (%)	Mean (kg)	Percentage (%)
Shrub	1.27	21.27	40.33	15.10	53.01	21.47	0.08	9.58
Grassland	1.79	29.83	97.48	36.49	53.68	21.75	0.12	15.10
Wetland	0.35	5.79	0.00	0.00	50.34	20.39	0.15	18.39
Cropland	1.88	31.46	107.94	40.41	49.86	20.20	0.26	32.57
Built-up	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bare land	0.70	11.66	21.38	8.00	39.96	16.19	0.20	24.37
Total	5.99	100.00	267.13	100.00	246.85	100.00	0.81	100.00

Spatial distribution characteristics for the improvement potential of ecosystem services in Chongqing

The conversion of land cover types may have a significant impact on ecosystem services provisions, especially in the conversion of non-forest landscapes to forest landscapes. Therefore, hypothetically, the ecosystem services potential was identified based on the degree of change in ecosystem services provisions. Figure 3a shows that potential areas for service function improvements in carbon sequestration and oxygen release were mainly distributed within western and central hilly farmland areas. On account of the low soil respiration in these areas, an improvement in NPP could effectively improve carbon sequestration and oxygen release. Figure 3b shows that potential areas for soil conservation service function (expressed by the amount of reduction in soil erosion) improvements were mainly in alpine farmland and grassland in the northeast and southeast. Because of strong rainfall erosivity and considerable slope and slope length factors (which are prone to soil erosion), when other land cover types were converted to forests, higher vegetation factors could reduce soil erosion more effectively compared to other regions.

Figure 3c shows that potential areas for runoff regulation service function improvements were mainly distributed in northeastern and southeastern alpine shrub and grassland. On account of the high elevation of these areas, abundant precipitation, and an increase in plant evapotranspiration, water yields in these areas could be more effectively reduced, which would regulate runoff volume and reduce the potential of floods. Figure 3d shows that potential areas for water purification service improvements were mainly distributed in central and western areas comprised of lower-lying valley farmland. Due to their low terrain, pollutants will eventually gather here and subsequently flow into river systems. Moreover, given that pollutant concentrations were highest and the capacity for purification of forest vegetation was strongest, it would be most effective to implement purification initiatives within the lower-lying valley farmland type.

After applying the assumption, we found that total improvement effects of ecosystem services were extremely obvious (Fig. 4). We also found significant reductions in soil erosion (4.63×10^8 t), water runoff (approximately 4.25×10^{10} m^3), and exported pollutants (approximately 1.25×10^3 t). Moreover, we found a significant increase in carbon sequestration (approximately 8.8×10^6 tC). In addition, we also determined that there was a lot of room for improvement for ecosystem services to reach their maximum potential. Based on ecosystem services data from 2000, we determined that soil conservation could be increased by 59.11%, carbon sequestration by 129.51%, water flow regulation by 83.42%, and water purification by 84.42%.

Identifying hotspots and cold spots in ecosystem services potential areas

We estimated areas of influence within forest ecosystems (converted from other land cover types) at an average of 18.82% for water yield potential hotspots, followed by 18.21% for carbon sequestration potential

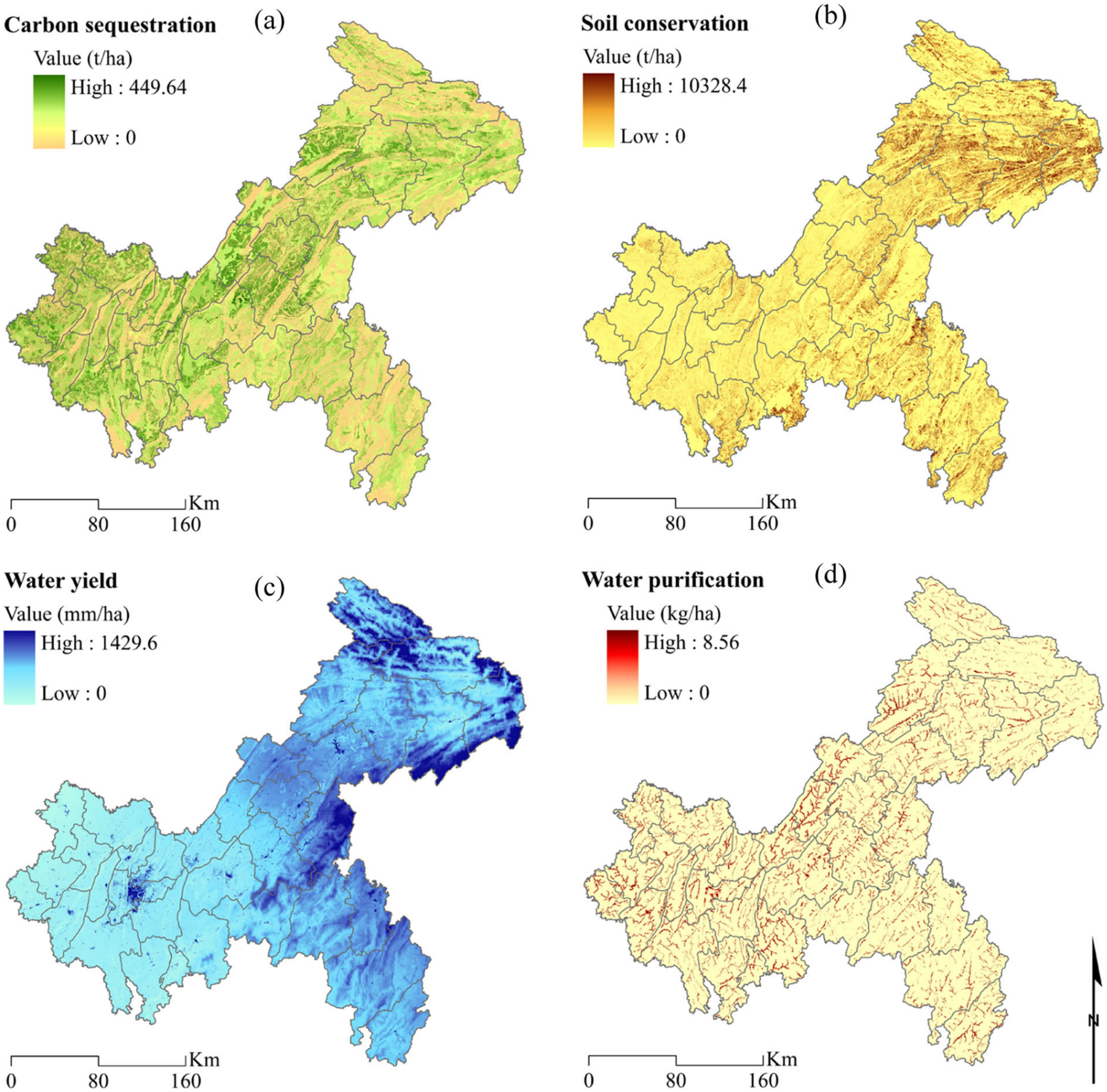

Fig. 3 The spatial distribution of ecosystem service potential for **a** carbon sequestration, **b** soil conservation, **c** water yield, and **d** water purification

hotspots, 12.94% for soil conservation potential hotspots, and 11.77% for water purification potential hotspots (Fig. 5). For the analysis of cold spots, we estimated areas of influence at an average of 23.56% for water yield potential cold spots, followed by 18.93% for carbon sequestration potential cold spots, 3.8% for soil conservation potential cold spots, and 2.74% for water purification potential cold spots. Almost all areas of hotspots had higher values than areas of cold spots, with the exception of water yield potential cold spots. This was because the spatial continuity of the rainfall factor dramatically impacted water yield results.

Carbon sequestration potential hotspots were higher for forest ecosystems mainly converted from croplands in central and western hilly areas. Soil conservation potential hotspots were distributed mostly in the northeastern mountainous area, especially in areas with steep slopes and high altitudes where there is a serious risk of soil erosion. Water yield potential hotspots were distributed mostly in northeastern and southeastern

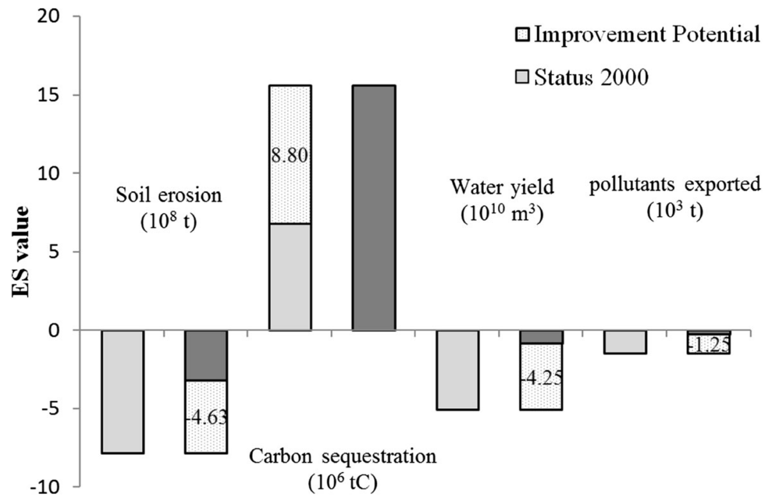

Fig. 4 The status of the value and improvement potential of ecosystem services (light gray represents values of ecosystem services in 2000; dark gray represents values of ecosystem services after improvements)

mountainous areas. Finally, we found water purification hotspots mainly at lower elevations in central and western areas where agricultural and built-up land were the major sources of pollution. It is helpful to highlight areas of ecosystem services potential, since these hotspots, exhibiting spatially continuous surfaces, clearly show areas of improvement in ecological benefits for forest ecosystem conservation planning.

We focused on grid cells exemplifying multiple improvements. Integrated spatial analysis estimated grids under the influence of carbon sequestration, soil conservation, water yield, and water purification, classified as hotspot-1, hotspot-2, and hotspot-3, based on overlay numbers (Fig. 6). Approximately 35.91% of converted forest ecosystems exhibited only slight improvements (overlay number = 1) and were included under the category hotspot-1. We estimated grid cells under medium improvements (overlay number = 2) at 10.75%, and they were included under the category hotspot-2. The percentage of grids under high improvements (overlay numbers ≥ 3) was 1.48%, and they were included under the category hotspot-3. A greater number of overlays signify improvements in a greater number of ecosystem services; subsequently, the regional significance is also greater.

Discussion

Relationships between natural ecosystems and ecosystem services

The aim of this study was to identify better hotspot planning and management as well as to explore the effectiveness of various strategies to optimize the protection of hotspots. Although forests can provide a wide range of ecosystem services, such as air purification and improvements in soil conditions, not all land areas function the same, especially in southeastern Chongqing City (as it relates to water yields) and northeastern Chongqing City (as it relates to soil conservation) (Feng and Xu 2015; Lv et al. 2016). It is especially important to improve ecosystem services in these sensitive areas. Failure to improve ecosystem services will eventually disrupt the ecological balance from which humankind and natural ecosystems survive (Cao et al. 2017; Liu et al. 2016). As for the importance of ecosystem services in the northeastern region and the TGRA, results from this study showed that the ecological restoration of these areas will significantly increase their ecological functions, thus reducing ecological risks to residents living downstream.

This study acknowledges that the overlap and spatial consistency between the four ecosystem service hotspots we investigated as well as the soil conservation and carbon sequestration results agree with those reported by Cao Shixiong (Cao 2015). On the other hand, there was only a small overlap and spatial consistency between soil conservation/water yield and water purification between the two, and this implies there was no co-occurrence between them. Regions with higher overlap and spatial consistency were mainly located in the northeastern Chongqing City region where natural forests in mountainous areas in the east have remained largely unaffected by anthropogenic influence (Liu et al. 2014; Lu et al. 2016). Moreover, it is widely accepted that carbon sequestration can help mitigate

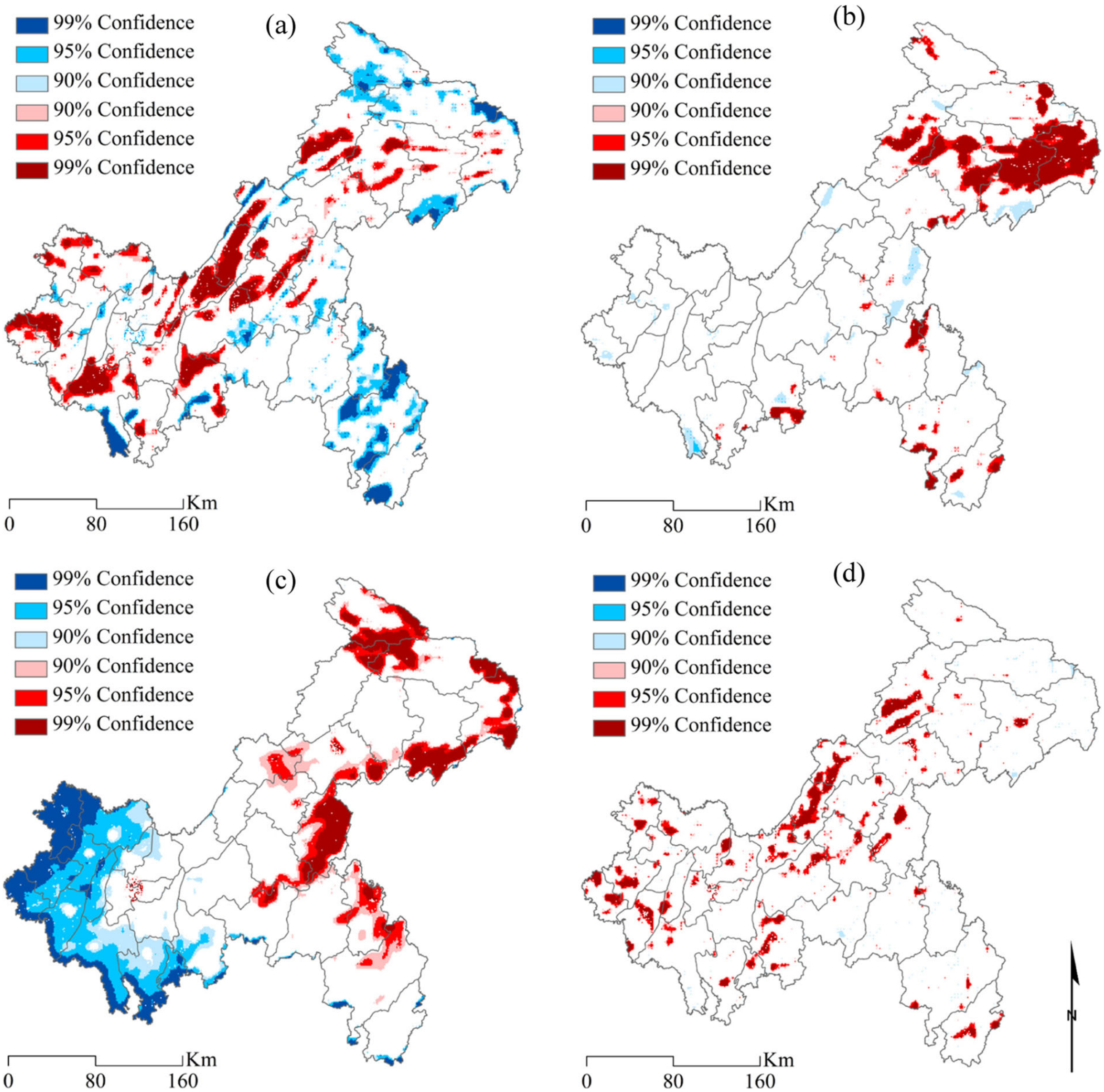

Fig. 5 Spatial distribution of ecosystem service potential hotspots and cold spots for **a** carbon sequestration, **b** soil conservation, **c** water yield, and **d** water purification

global warming. Therefore, the protection of natural ecosystems will ensure the availability of ecosystem services (Shan et al. 2014). Lastly, ecosystem services can be considered an optimized protection strategy for multiple ecosystem services.

Importance in selecting hotspot areas

Our data suggests that hotspots signify greater improvements in high value ecosystem services. Many studies have shown that before intervention is carried out in stable ecosystems, we must keep in mind that ecosystems are complex and are not fully understood (Cao et al. 2011; Schleier et al. 2014). Any attempt to restore ecological environments should be subject to strict verification to determine potential unanticipated consequences. Such caution is critical for restoration and conservation (Cao 2011; Reddy et al. 2016). In addition, the increasing number of restoration measures available for ecosystem services has not yet been systematically

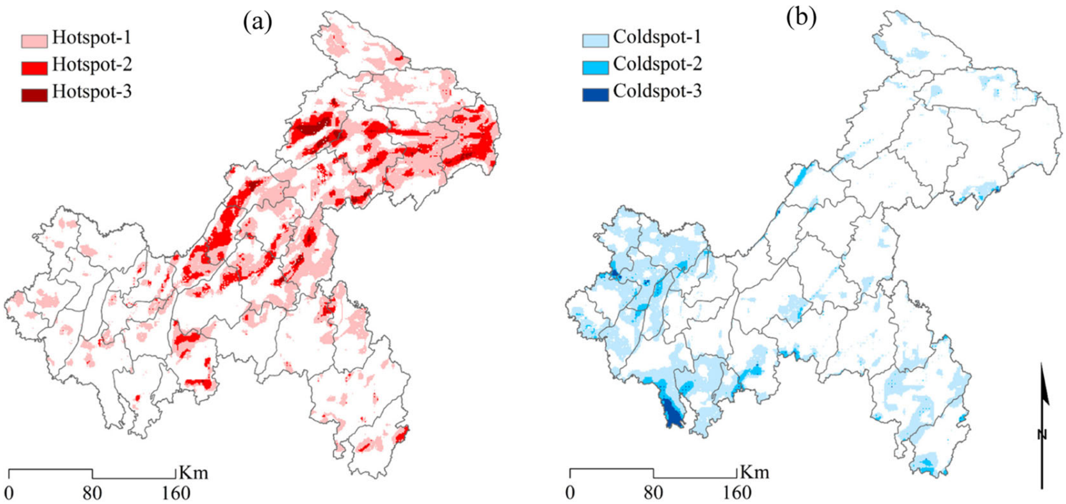

Fig. 6 Classification of ecosystem service potential **a** hotspots and **b** cold spots

evaluated. Our study showed that there is a positive correlation between restored natural ecosystems and an increase in measures related to ecosystem services (Gao et al. 2011). The spatial analysis-based method selected for the assessment of hotspots had allowed for the evaluation of ecological engineering efficacy (Bai et al. 2011; Xiao et al. 2016). Ecosystem services in hotspots are more important, which suggests that this approach is effective in counteracting any associative stress that may occur (Bagstad et al. 2013; Braat and de Groot 2012).

In general, conservation planning and management that favor ecosystem services are also beneficial for ecosystem conservation measures and vice versa. It is not surprising that there is good agreement between outcomes of the two strategies given the importance of ecosystems in maintaining ecosystem functions that support provisions of ecosystem services (Christie and Rayment 2012). However, the selection of the specific objective used does matter with regard to the specific types of conservation planning made. For ecosystem conservation directed at habitat quality, most conservation planning and management strategies have been made in the northeast and southeast sections of this direct-controlled municipality to maintain or restore higher elevations of natural vegetation, including forests, shrubs, and grass. Little management intervention and practices, however, have been conducted in the western sections of the municipality where higher elevation vegetation is better suited for provisions of ecosystem services compared to natural habitats (Corbera et al. 2009; Fu et al. 2011). Although making up only 10% of the total area, the conservation of these small areas (hotspots) would contribute greater than 20% soil retention, CO_2 fixation-O_2 production, and water flow regulation to hotspots and approximately 4% to P retention hotspots. For ecosystem services, however, planning and management have been more evenly made throughout higher elevation mountainous areas of the municipality to restore forests, shrubs, and grasslands (Hull et al. 2011).

The significance of our conservation method to mid and lower reaches of the Yangtze River

This study proposes a concept and calculation method to improve areas of ecosystem services, which has important scientific significance. Only when these potential areas that would benefit ecosystem services improvements are identified could we implement more effective scientifically planned ecological engineering initiatives based on such areas, which would provide greater services for the well-being of humankind (Krois and Schulte 2014; Maes et al. 2012). It must be noted that there are differences in opinion on the ecological consequences related to the construction of the Three Gorges Dam. By and large, however, the scientific community in China has acceded that since the dam has been built and is now a reality, they can properly control any adverse consequences that may arise. Ecological restoration can to a certain extent eliminate negative impacts of the Three Gorges Dam. Furthermore, the research methods used in this study could be used to guide ecological restoration engineering in other ecological sensitive areas, including afforested areas where the eradication of anthropogenic interference is the objective (Müller and Burkhard 2012; Prasuhn et al. 2013).

In view of the current level of scientific research, it is difficult to realize water targets and solutions pertaining to other water resource problems related to the Three Gorges Dam. Although public awareness of these water issues has been on the rise, support for the Three Gorges Dam is negligible. The best option would be to improve water productivity and protect the ecological environment of the TGRA (Swift et al. 2004). To rethink strategies would mean a reevaluation of the use of water targets of the Three Gorges Dam. The strategy previously taken surmised that using less water or the refusal of using greater amounts of water would improve ecosystem services and the well-being of humankind (Viña et al. 2013). Current ideas suggest that people want to meet their demands for food, fiber, and waste disposal services, and they may not be too concerned by their water source usage. However, the goal should not be water usage in itself but the improvement of social and personal benefits per unit of water. The identification of potential ecosystem services hotspots is a rational water conservation target of the Three Gorges Dam (Xu et al. 2011).

Implications

In this study, we identified and optimized hotspots for natural ecosystem conservation, taking ecosystem services into account. The conservation and regeneration of these small areas (hotspots of ecosystem services) will assist in the protection of 44% of hotspots, a 14% increase in ecosystem services hotspots. Moreover, results have also shown that the main services this ecosystem conservation strategy takes into account maximize provisions of ecosystem services in minimally protected areas with the least capital investment (Primmer and Furman 2012).

Furthermore, the priority area of ecosystems in the Chongqing City region could provide a variety of ecosystem services that would have significant ecological effects on downstream areas of the TGRA, but a lack of information on the relationships of these services has hindered the recognition and understanding of these ecosystems. In this study, from the standpoint of ecological processes based on remote sensing and geographic information systems (GIS), we quantified four ecosystem services using the CASA, USLE,, InVEST model, and mathematical simulations. Furthermore, we mapped the distribution of ecosystem services hotspots based on relationships between cumulative ecosystem services and cumulative area (Maes et al. 2012). Lastly, our overlay analysis was focused on specific conservation objectives.

Conclusions

According to our research, hotspots co-occur with soil retention, CO_2 fixation-O_2 production, water-flow regulation, and water quality improvements. Conservation of hotspots would maintain greater than 20% soil retention, CO_2 fixation-O_2 production, and water flow regulation hotspots and approximately 4% P retention hotspots, indicating that ecosystem conservation will also result in the protection of these services. On the other hand, conservation plans that had not previously focused on natural ecosystems did not maximize provisions of ecosystem services. By combining ecosystem services into a single conservation plan, we found that the conservation and regeneration of these small areas would contribute a level of conservation of 62% to hotspots, greater than 37% soil retention, CO_2 fixation-O_2 production, and water flow regulation hotspots, and approximately 4% P retention hotspots.

Although this study estimated four ecosystem services based on the CASA, USLE, and the InVEST model in relation to the spatial characteristics of climate, topography, vegetation, soil, and land cover, some model parameters were still defined according to results from previous studies. Furthermore, it should be noted that calculations of ecosystem services used in this study were maximum potential calculations based on mathematical models and therefore are not based on real observational values. Nevertheless, this study provides a useful initial exploration into research on ecosystem services as well as the identification and optimization of hotspots of ecosystem services.

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