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Impacts of land-use change on valued ecosystem service in rapidly urbanized North China Plain

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ABSTRACT

Land-use change is a major factor driving ecosystem service change. Measuring the ecosystem service variation in response to land-use change is an effective way to assess the environmental costs and benefits of different approaches to policy-based planning. In the present study, we examined the changes in value of the ecosystem services (VES) in the North China Plain (NCP), which is an agricultural region, producing over 35% of the total grain in China, and estimated the changes of VES resulting from land-use change. A model mainly based on net primary productivity (NPP) and soil erosion amount was developed to assess the VES. The results show that the total VES of the NCP increased by $ 21.61 billion in 2000 USD during 2000–2008. However, the land-use change led to a net loss of VES by 0.08 billion USD. The expansion of built-up areas contributed to 84.61% of the loss of VES caused by land-use change. The increase of NPP mainly accounted for the increase of VES since it significantly improved the ecosystem service functions of gas regulation, nutrient cycling, and organic material provision. Overall, compared to other factors, land-use change only accounted for 0.35% of VES change during 2000–2008 in NCP.

1. Introduction

Natural ecosystems provide a great deal of resources and processes to humankind, which are collectively defined as ecosystem services (Daily, 1997). The benefits that people gain from ecosystem services make a great contribution to human well-being because their supportive functions maintain the daily living of organisms on the earth (MEA, 2003; Chen and Chen, 2006, 2007; Chen et al., 2006; Su et al., 2012c). In the past 50 years, human well-being and the economy has undergone sustainable development but at the cost of the "degradation of many ecosystem services, increased risks of nonlinear changes, and exacerbation of poverty for some groups of people" (MEA, 2005). In order to control the further degradation of ecosystems, the preservation of ecosystem services has become a central concept of local policies for water–soil conservation planning and environmental valuation assessment (Burkhard et al., 2010; Fisher and Turner, 2008).

Economic valuation is widely used for the assessment of ecosystem services (MEA, 2005; Dong et al., 2012; Logsdon and Chaubey, 2013; Rodriguez et al., 2013). Since the 1990s, numerous researches have been conducted to investigate the value of ecosystem services (VES). These assessments cover biological resources (Pearce and Moran, 1994; Zhao et al., 2004), biodiversity conversion (Mcneely, 1993), tropical forests (Peters et al., 1989; Tobias and Mendelsohn, 1991), protected areas (Munasinghe, 1994), and endangered species' management (White et al., 1997). A notable assessment of VES by Costanza et al. (1997) reported on the global biosphere, estimating 17 VES provided by 16 dominant global biomes by using a market valuation method. Since then, a large number of scholars have followed Costanza's footsteps to examine the VES of ecosystems. Nevertheless, some researchers have challenged the method and the result proposed by Costanza et al. (1997), arguing that there are the following problems with the method: too little resolution, too much variation, and limitations with the economic evaluation of land-use types (Limburg et al., 2002; Turner et al., 2003; Lu et al., 2012). Furthermore, land use types are used as a proxy for ecosystem services while the biomes used as proxies do not always perfectly match (Kreuter et al., 2001).

VES is directly or indirectly influenced by climate, land use, and other socio-economic factors. Climate affects VES by changing the

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biophysical processes of the ecosystem. Land-use change alters the production capacity of an ecosystem, modifies the physical parameters of the earth's surface, influences nutritional transport between soil and vegetation, and affects the composition and structure of ecosystems (Zang et al., 2010). Socio-economic changes influence the VES by market price (Schroter et al., 2005; Metzger et al., 2006). In addition, some other demographic, scientific and technological, cultural, and religious factors may also affect VES in different ways (Kumar, 2011).

Over the past 50 years, humankind has accelerated the change in ecosystem services more rapidly and extensively than at any other periods in human history (Daily, 1997; MEA, 2003; Scolozzi et al., 2012). One of the most important effects of human activities on VES is land-use change (Burkhard et al., 2012). Globally, the most significant land-use change is the expansion of cropland and pastoral land (Lambin and Meyfroidt, 2011; Pijanowski et al., 2014; Tayyebi et al., 2014a). However, land-use change in China is more complicated. With the accelerated economic development, the urbanization rate in China increased from 17.9% in 1978 to 49.7% in 2010, which greatly boosted the expansion of urban areas (Song and Liu, 2014; Song, 2014). The expansion of urban areas in China has simultaneously led to significant cultivated land loss (Tayyebi et al., 2014b). In many developing areas of China, poor farmers have also claimed forestry areas/grassland into cultivated land to increase their incomes. Aware of the negative ecological effects of irrational cultivated land use, the Chinese government has implemented the Grain-for-Green policy to return steeply sloping cultivated land to forests or grassland. These complicated land use-changes have had mixed effects on VES in China.

Measuring the changes in VES in response to the land-use change is an effective way to assess the environmental costs and benefits of different land-use planning decisions. There is a rapidly growing body of literature about the effects of land-use change on VES. For example, Zhao et al. (2004) investigated the changes in VES resulting from land-use change in Chongming Island, China; Kreuter et al. (2001) measured the changes in VES due to urbanization in the San Antonio area; Martinez et al. (2009) examined the effects of land-use change on the provision of ecosystem services in tropical montane cloud forests; and, Yoshida et al. (2010) assessed the changes in the valuation of ecosystem services in each land use category by using the coefficients published by Costanza et al. (1997).

When assessing the changes in VES in response to land-use change, a proxy method has been widely adopted, which views land-use type as a proxy for ecosystem services by matching the land-use types to equivalent biomes. The variation in VES is estimated by observing the changes in land-use structure. However, three problems have emerged when using this method. First, it ignores the spatial heterogeneity of VES, which may have significant influence on the process and pattern of ecosystem changes (Pickett et al., 1997). In particular, the VES can be even different within the same land-use type due to the variation in the physical parameters of the earth's surface. Second, the VES per unit area of each land-use type may change as the time goes by, which has not been considered in this method. Lastly, the VES per unit area of some land-use types is lacking, which limits the application of this method.

The visualizations of ecosystem services and the analysis of factors influencing them are useful tools for environmental managers and policy decision makers (Swetnam et al., 2011). However, before ecosystem services maps are eventually available for use in environmental risk management and related spatial planning, the methods need to be developed further (Daily and Matson, 2008; Burkhard et al., 2012; Kaiser et al., 2013). In this study, we attempt to develop a new model for mapping VES and to assess the changes in VES due to land-use change. Specifically, the purposes of this paper are to: (1) assess the dynamic changes in VES in the North China Plain (NCP); (2) quantitatively differentiate the changes in VES in response to land-use change from other factors; and (3) parameterize the VES per unit area of several land-use types that are usually lacking in previous literatures.

2. Study area and data sources

2.1. Study area

NCP is located in northern China (112°48′–122°45′E, 32°00′–40°24′N) (Fig. 1). It covers an area over 440,000 km^2, with plains accounting for 70% of this area and mountains about 30%. The mountains are mainly in the west and central region and plains mostly in the north and south of the region. The NCP lies in the warm-temperate zone and has a continental monsoon climate.

NCP is a vital agricultural region in China, characterized by the intensive use of irrigation and chemical fertilizers. The predominant cropping system of the NCP is the double-cropping of winter wheat and summer maize. NCP annually produces over 35% of the total grain and, particularly, over 60% of the wheat in China. In the past few years, the NCP has experienced intensive land-use changes due to rapid urbanization, which draws the public's attention to the need to research the consequent changes in VES.

2.2. Data sources

The data that we used for analyzing land-use changes in NCP were based on two maps of land use in 2000 and 2008 at the scale of 1:100,000. The maps were generated by Chinese Academy of Sciences (Liu et al., 2010; Deng et al., 2011; Liu et al., 2014) and the China National Environmental Monitoring Center using historical U.S. Landsat TM (Thematic Mapper) satellite images from 2000 to 2008. The remote sensing data were interpreted by the human–machine interactive approach with an average interpretative accuracy of over 95% (Liu et al., 2005). The land use was divided into six primary types (cultivated land, forestry area, grasslands, water areas, built-up area, and unused land) and 25 sub-classes (Deng et al., 2010a,b).

The net primary productivity (NPP) data in the NCP during 2000–2008, with a spatial resolution of 1 km, are the products of NASA's EOS/MODIS (i.e., MOD17A3), which contain annual NPP and QC datasets. The Normalized Difference Vegetation Index (NDVI) data in NCP were sourced from SPOT-vegetation data, with a temporal step of 10 days and spatial resolution of 1 km. The climate data, such as precipitation and temperature, were collected from the China Meteorological Data Sharing Service System (http://cdc.cma.gov.cn/home.do). The soil nutrient map of NCP was generated from the second soil survey in China. The actual evapotranspiration data utilized in this study are sourced from Data Sharing Infrastructure of Earth System Science, China, which were calculated with the IBIS model.

3. Method

3.1. Value quantification of ecosystem service

The circulation of materials and energy flows in ecosystems, which decide the diversity of the ecosystem service, are extremely complex. The MEA (2003) classifies the ecosystem services into provisioning (e.g., provision of food and fiber), regulation (e.g., regulation of climate through carbon storage), cultural (e.g., recreational values), and supporting services (e.g., nutrient cycling and soil formation). However, humankind may still not discern the ecosystem services as a whole due to the limitations of

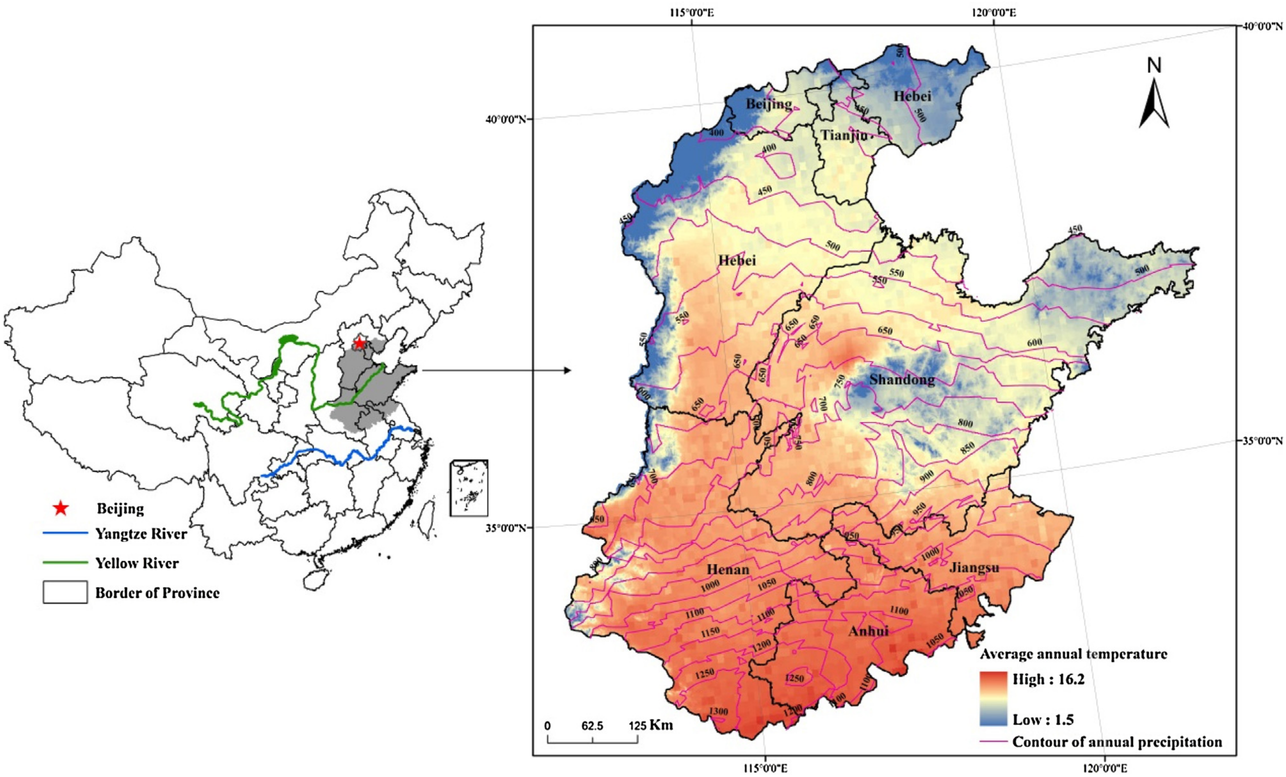

Fig. 1. Location, average annual temperature and precipitation of North China Plain.

techniques. Besides, it is difficult to quantitatively assess many of the recognized ecosystem services due to the lack of available data. Considering the data accessibility and the technique feasibility, we estimated the values of five kinds of VES for the NCP as follows: provision of organic material, nutrient cycling, soil conservation, water conservation, and gas regulation.

3.2. Assessment of the value of provision of organic material

The basic function of the ecosystem is the provision of organic material (Su et al., 2012b). We adopted the energy substitution method to assess the value of the provision of organic material. The organic material of the ecosystem was measured by NPP. The formula is as follows:

$$V_{om} = \sum \text{NPP}(x) \times P_{om} \tag{1}$$

$$P_{om} = \text{NPP}(x) \times 2.2 \times 0.67 \times P_{sc} \tag{2}$$

where V_{om} is the value of provision of organic material; NPP(x) is the organic material produced in x pixel, which expressed in g C/m^2 per year; and P_{om} is the price of organic material. The organic matter can be calculated on the basis of NPP, that is, 1 g C = 2.2 g organic material (Guo, 2012). The energy produced by 1 g organic material is equal to that of 0.67 g of standard coal; P_{sc} is the price of standard coal in 2000.

3.3. Assessment of the value of nutrient cycling

The cycle of material and energy keeps the balance of the ecosystem and drives its evolution. Through the sequestration and cycling of nutrient substances in the ecosystem, humankind can save inputs (e.g., fertilizer) in agriculture (Ouyang et al., 1999; Guo, 2012). Therefore, the value of nutrient cycling can be assessed using the saved inputs in agricultural production. The formula is as follows:

$$V_{nc} = \sum V_{nc_i}(x) = \sum \text{NPP}(x) \times R_{i1} \times R_{i2} \times P_i \tag{3}$$

where V_{nc} is the value of the nutrient cycling in the ecosystem; i is the element of N, P or K; $V_{nci}(x)$ is the value of i kind of nutrient element accumulated in x pixel; NPP(x) is the organic material produced in x pixel; R_{i1} is the distribution rate of organic material of i nutrient element in a different ecosystem; R_{i2} is the conversion coefficients from the i nutrient to the corresponding chemical fertilizer; and P_i is the price of i kind of chemical fertilizer in 2000 USD.

3.4. Assessment of the value of water conservation

The water conservation service can be divided into the water regulation service and water supply service according the difference in the underlying surface (Li et al., 2006; Kareiva, 2011). The water regulation service refers to the regulation of water in oceans, lakes and rivers. Water supply service refers to the filtration, conservation, and storage of water provided to vegetation and all kinds of organisms in soils. Since the water conservation service is similar to the function of reservoirs, we utilized the average cost of reservoir construction to assess the value of water conservationservice (Su et al., 2012b). The formula is as follows:

$$V_{wc} = \sum V(x) \times P_w \tag{4}$$

$$V(x) = \begin{cases} \sum P_{mean}(x) \times K_w \times R_w & \text{when underlying surface is soil} \\ \sum (P_{mean}(x) - \text{ET}_a(x)) & \text{when underlying surface is water areas} \end{cases} \tag{5}$$

where V_{wc} is the value of water conservation service; $V(x)$ is the water conservation volume in x pixel; P_w is the average cost of reservoir construction; $P_{mean}(x)$ is the monthly precipitation in x pixel; K_w is the ratio of runoff generated from precipitation; R_w is the coefficient for reducing runoff compared to bare land without vegetation; and $ET_a(x)$ is the monthly actual evaporation in x pixel.

3.5. Assessment of the value of soil conservation

Soil erosion has become a global environmental problem threatening the survival and development of humankind. Soil erosion usually leads to a decrease of soil fertility, river channel sedimentation and land degradation. Therefore, in this paper we defined the values of soil conservation service (V_{ac}) in three parts: the value of conserving soil fertility (V_{ef}), the value of reducing soil sedimentation in river channels (V_{en}), and value of reduced surface soil (V_{es}) (Ouyang et al., 1999; Li et al., 2006; Bai et al., 2012). The equations are as follows:

$$V_{ac} = V_{ef} + V_{en} + V_{es} \quad (6)$$

$$V_{ef} = \sum A_c(x) \times C_i \times P_i \quad (7)$$

$$V_{es} = \sum A_c(x) \times \frac{P_f}{D_{soil} \times T_{soil}} \quad (8)$$

$$V_{en} = 0.24 \times \frac{\sum A_c(x)}{D_{soil}} \times P_w \quad (9)$$

where $Ac(x)$ is the soil conservation amount, which can be calculated by Universal Soil Loss Equation (USLE). The detailed calculation process and parameters can be found in the papers by Wischmerier and Smith (1965), Wischmeier (1971), Renard and Foster (1983), Flanagan et al. (1989), Renard et al. (1997), Cai et al. (2000), Guo (2012) and Kelvin et al. (2013). C_i is the content of N, P, and K in the soil; P_i is the price of N, P, and K fertilizer in 2000; D_{soil} is the soil density; P_f is the economic benefit of forest planting; T_{soil} is the average soil thickness; D_{soil} is the soil density; and, P_w is the construction cost of reservoirs per unit.

3.6. Assessment of the value of gas regulation

The ecosystem absorbs CO_2 produced by industries and people and produce O_2 by photosynthesis (Su et al., 2012a). Assessing the values of gas regulation is thus important. The equation is as follows:

$$V_{gr} = \sum 1.62 \times \text{NPP}(x) \times P_{co_2} + \sum 1.2 \times \text{NPP}(x) \times P_{O_2} \quad (10)$$

where NPP(x) is the organic material in x pixel; according to the photosynthesis and breathing reaction equation, it can be deduced that producing 1 g dry matter absorbs 1.62 g CO_2 and releases 1.2 g O_2; P_{CO_2} is the price of carbon tax, and P_{O_2} is the price of producing O_2.

4. Results

4.1. Changes in land use

The most prominent land-use changes in the NCP during 2000–2008 are the shrinkage of cultivated land and the expansion of the built-up area (Fig. 2), as cultivated land decreased by 1.57% and the built-up area increased by 1.35%. The main cause of cultivated land loss was the expansion of the built-up area. During 2000–2008, 50.22×10^4 ha of cultivated land were converted to built-up area, contributing to 83.68% of the total loss of cultivated land. Besides, the forestry area and water area slightly increased by 0.01% and 0.07%, respectively, while grasslands and unused land decreased by 0.21% and 0.15%, respectively.

4.2. Changes in values of ecosystem services

The total VES of the NCP in 2000 was as high as $ 81.97 billion in 2000 USD. The gas regulation contributed to 44.04% of the total VES, followed by values of soil conservation (23.25%), water conservation (21.61%), nutrient cycling (5.72%), and organic material provision (5.38%), respectively. Besides, the average values per unit in 2000 were as follows: total ecosystem service, 1859.90 USD/hm^2; gas regulation, 821.26 USD/hm^2; organic material provision, 96.62 USD/hm^2; water conservation, 398.55 USD/hm^2; nutrient cycling, 108.70 USD/hm^2; and soil conservation, 434.78 USD/hm^2. The VES shows significant spatial heterogeneity, which is generally higher in western NCP, western Shandong Province and eastern NCP (Fig. 3). There is a similar spatial pattern of the values of organic material provision, gas regulation, and nutrient cycling, which gradually decreased from the southeast to the northwest. The value of water conservation gradually decreased from the south to the north, while the value of soil conservation gradually decreased from the east to the west. In particular, the value of soil conservation is particularly high in the middle and western NCP, where mountains are the dominant topography.

The total VES of the NCP in 2008 reached $ 103.58 billion in 2000 USD, increased by 26.16% compared to that in 2000. During 2000–2008, the values of gas regulation, soil conservation, nutrient cycling, and organic material provision increased by 34.11%, 32.74%, 35.22%, and 35.81%, respectively, while the value of water conservation decreased by 1.91%. The VES mainly increased in the northeast and southeast of the NCP (Fig. 4), while the decrease of VES mainly occurred in the western and central areas of the NCP. However, the regions that experienced the decrease of VES accounted for only 6.73% of the total area in NCP. In addition, there is a similar spatial pattern of the changes in the values of organic material provision, nutrient cycling, and gas regulation, which mainly increased in the central NCP and decreased in western and eastern NCP (Fig. 4). Moreover, the value of water conservation increased in the northern and eastern NCP but decreased in other regions.

4.3. Values of ecosystem services of different land-use types

Using the VES maps and land use maps, we summarized the VES for over 20 land-use types (Table 1). In 2000, the VES of the forest was as high as 4637.68 USD/hm^2 in 2000 USD, followed by woods, dense grassland, and shrub, with the VES of 4347.83 USD/hm^2, 3309.18 USD/hm^2, and 3176.33 USD/hm^2 in 2000 USD, respectively. The VES of other unused land is as low as 48.31 USD/hm^2, and the VES of other built-up area, urban built-up area and salina are also low, with values of 326.09 USD/hm^2, 374.40 USD/hm^2, and 603.86 USD/hm^2, respectively. Overall, the VES for six primary land use types ranked in order of descending values are as follows: forestry area (3937.20 USD/hm^2), grassland (3055.56 USD/hm^2), cultivated land (1775.36 USD/hm^2), water area (1545.89 USD/hm^2), unused land (978.26 USD/hm^2), and built-up area (905.80 USD/hm^2).

The VES per unit area of different land-use types increased during 2000–2008, with increasing percentages ranging from 15.33% to 100.00% (Table 1). The VES per unit area increased very significantly in other unused land (100.00%), beach and shore areas (66.67%), other built-up areas (59.26%), and salina (60.00%). Nevertheless, the changes in the VES per unit area are relatively slower in dense grassland (15.33%), dry land (22.97%), streams and rivers (23.88%), and lakes (25.44%). In 2008, the order of the VES per unit area of the six primary land-use types from higher to lower was the same as that in 2000: forestry area (5362.32 USD/hm^2 in 2000 USD), grassland (3961.35 USD/hm^2 in 2000 USD), cultivated land (2198.07 USD/hm^2 in 2000 USD), water area (2101.45 USD/hm^2

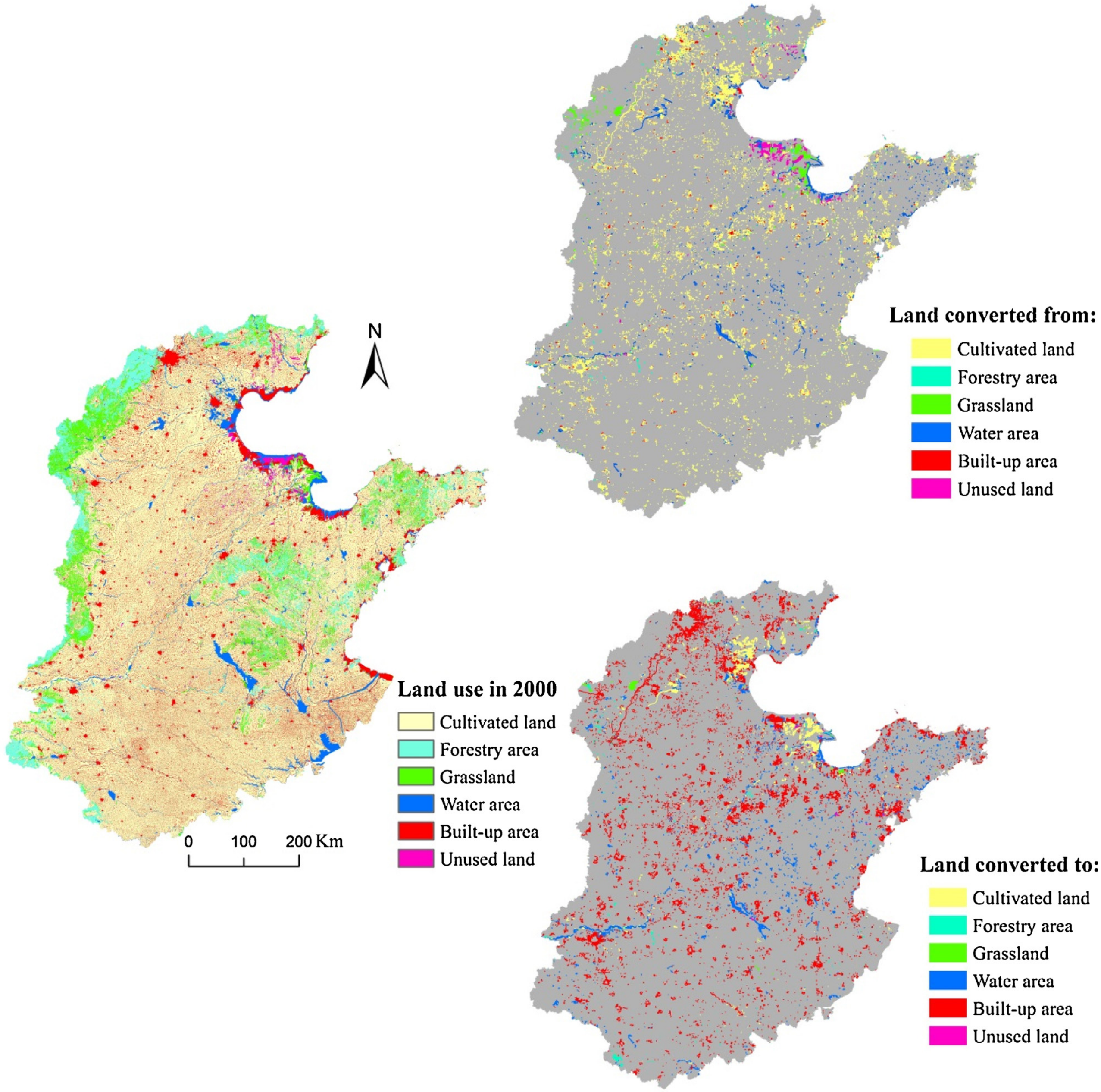

Fig. 2. Land-use changes in North China Plain during 2000–2008.

in 2000 USD), unused land (1654.59 USD/hm^2 in 2000 USD), and built-up area (1171.50 USD/hm^2 in 2000 USD).

4.4. *The effects of land-use changes on value of ecosystem services*

The VES changed from \$ 81.97 billion to \$ 103.58 billion in 2000 USD during 2000–2008 due to the influence of multiple factors. In this paper, we tried to differentiate the changes in VES in response to land-use change from other factors. One of the most important consequences of land-use change is the land-use conversion, whereby the changes in VES resulting from land-use change can be assessed by estimating the VES of converted land-use types.

During 2000–2008, a total of 126.03×10^4 ha of land in NCP experienced conversions. The total VES of these converted lands in 2000 was \$ 11907.03×10^4 in 2000 USD, while that in 2008 was only 4321.22×10^4 USD, which is a decrease of 7585.81×10^4 USD or 63.71% (Table 2). The VES decreased in 86.52% of converted land during 2000–2008, with a decrement of \$$7769.01 \times 10^4$ in 2000 USD. Among these land-use conversions, the conversion from cultivated land to built-up area led to the maximum VES loss, accounting for 66.49% (5043.49×10^4 USD) of the total decrease of VES. The decrease of VES in response to the conversion from grassland to built-up area and from forestry area to built-up area is also high, reaching 782.70×10^4 USD and 602.64×10^4 USD, respectively. In addition, several land use conversions also slightly increase the VES: the land use conversion from water area to cultivated land resulted in a VES increase of \$ 82.60×10^4 in 2000 USD, while the conversions among the secondary land use types in forestry area also resulted in an increase in VES of \$ 41.06×10^4 in 2000 USD.

The expansion of the built-up area leads to a total net decrease of VES of \$ 6582.93×10^4 in 2000 USD, resulting in 84.61% of the

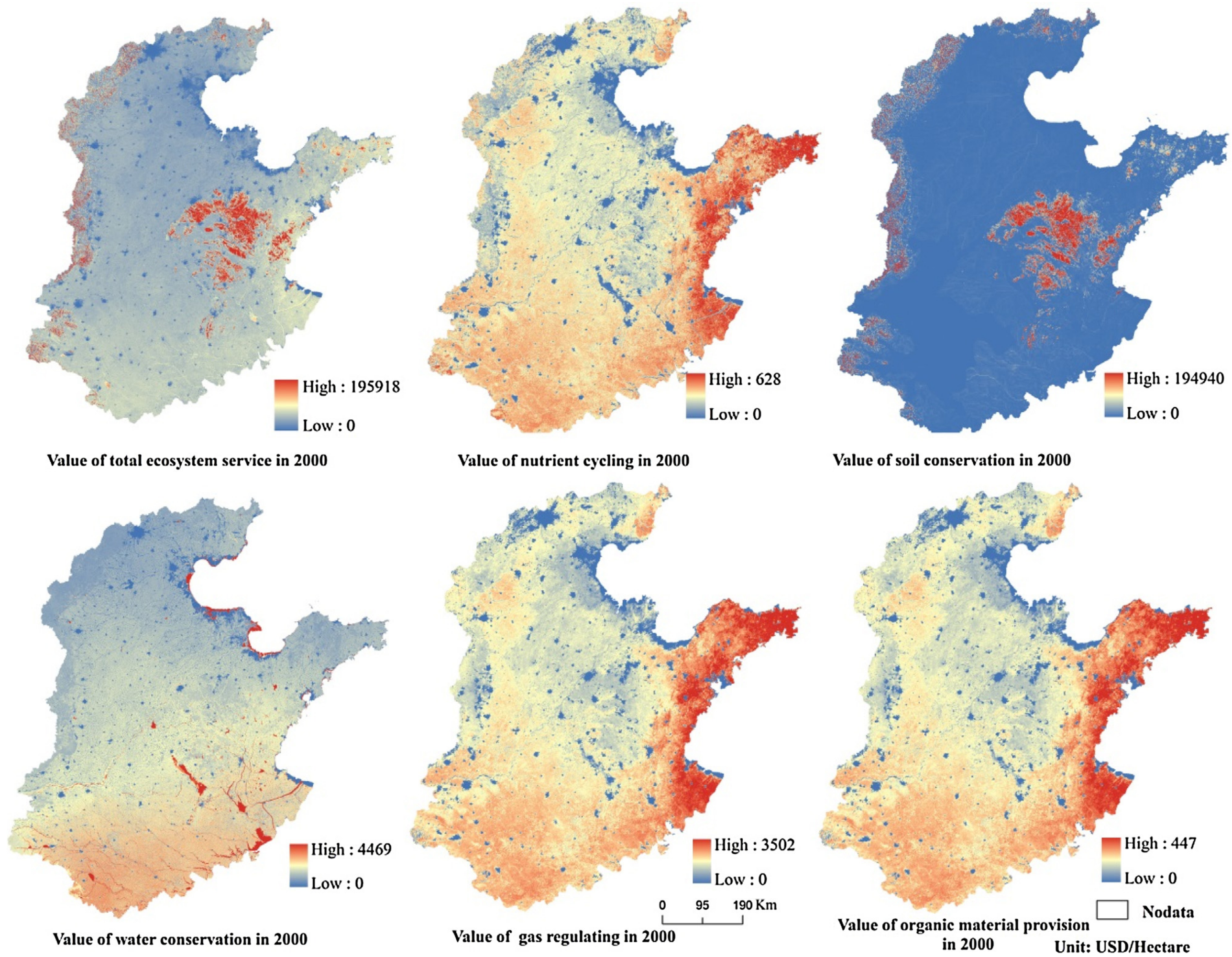

Fig. 3. Value of ecosystem services in the NCP in 2000.

Table 1
Values of ecosystem services of different land-use types.

Primary land use type	Secondary land use type	Values in (USD/hm^2)		Change percentage (%)
		2000	2008	
Cultivated land	Paddy land	1739.13	2246.38	29.17
	Dry land	1787.44	2198.07	22.97
Forestry area	Forest	4637.68	6461.35	39.32
	Shrub	3176.33	4021.74	26.62
	Woods	4347.83	6219.81	43.06
	Others	1835.75	2391.30	30.26
Grassland	Dense grass	3309.18	3816.43	15.33
	Moderate grass	2922.71	4082.13	39.67
	Sparse grass	2705.31	4057.97	50.00
Water area	Stream and rivers	1618.36	2004.83	23.88
	Lakes	2041.06	2560.39	25.44
	Reservoir and ponds	1364.73	2077.29	52.21
	Beach and shore	1413.04	2355.07	66.67
	Bottomland	1509.66	2053.14	36.00
Built-up area	Urban built-up	374.40	543.48	45.16
	Rural settlements	1062.80	1425.12	34.09
	Others	326.09	519.32	59.26
Unused land	Sandy land	1050.72	1328.50	26.44
	Salina	603.86	966.18	60.00
	Swampland	688.41	978.26	42.11
	Bare soil	1062.80	1352.66	27.27
	Others	48.31	96.62	100.00

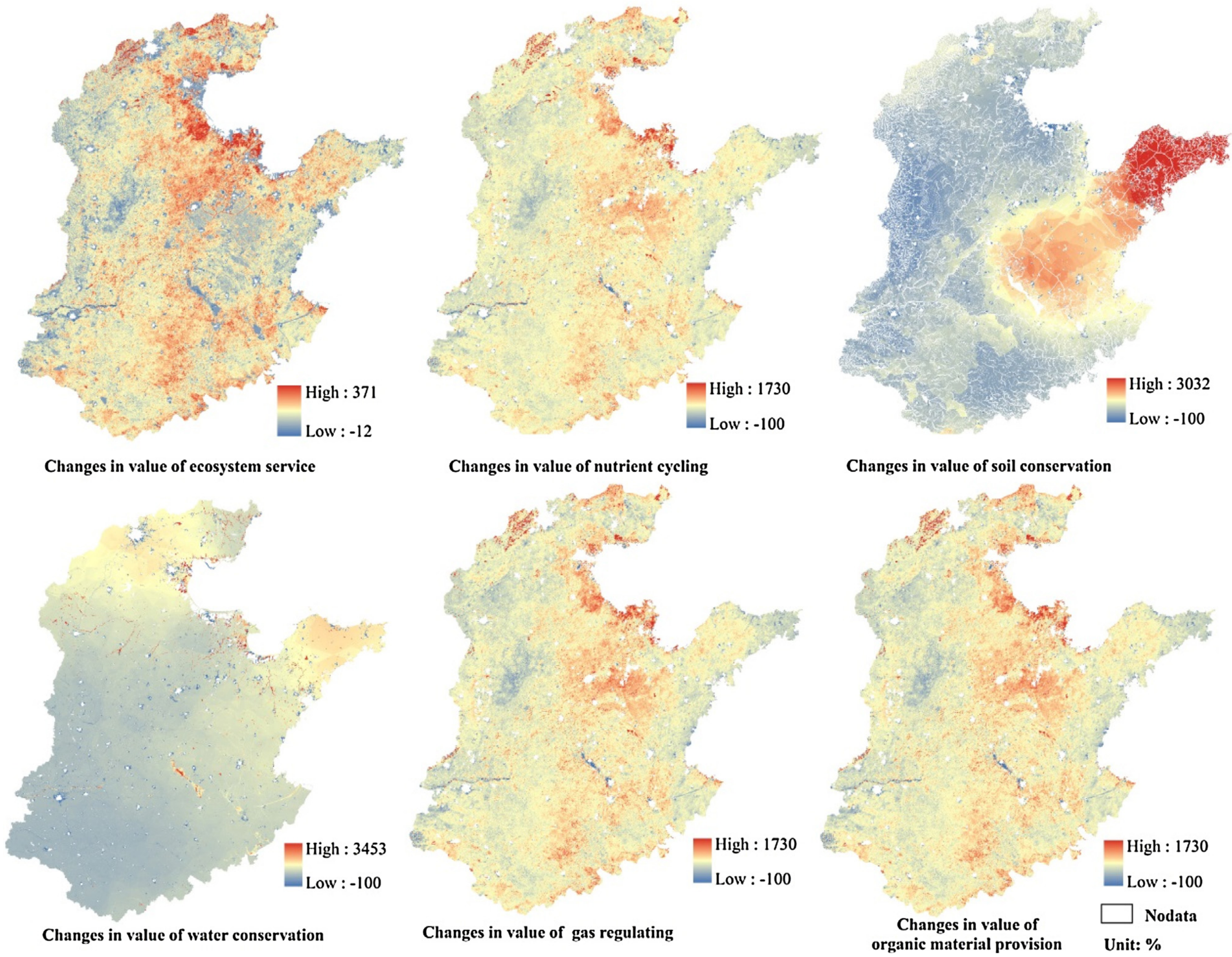

Fig. 4. Changes in values of ecosystem services in the NCP during 2000–2008.

Table 2
Changes in values of ecosystem services in response to land-use change.

Conversion	VES in ($\times 10^4$ USD)		Changes (%)	Conversion	VES in ($\times 10^4$ USD)		Changes (%)
	2000	2008			2000	2008	
1 to 1	683.20	557.47	−18.40	4 to 4	243.11	154.38	−36.50
1 to 2	414.08	344.01	−16.92	4 to 1	22.73	105.33	363.37
1 to 3	87.99	82.13	−6.66	4 to 2	12.15	14.68	20.79
1 to 4	653.87	101.89	−84.42	4 to 3	1.30	24.61	1799.44
1 to 5	5397.81	354.32	−93.44	4 to 5	22.40	1.01	−95.48
1 to 6	17.50	36.32	107.59	4 to 6	0.65	2.89	344.71
2 to 2	58.91	99.97	69.69	5 to 5	128.01	32.67	−74.48
2 to 1	28.09	26.11	−7.08	5 to 1	1.27	7.01	450.85
2 to 4	47.00	7.68	−83.66	5 to 2	0.35	1.35	288.15
2 to 5	654.00	51.36	−92.15	5 to 4	0.29	0.09	−70.04
3 to 3	1485.32	1254.93	−15.51	6 to 6	0.02	0.00	−92.31
3 to 1	91.65	94.85	3.49	6 to 1	116.93	116.99	0.05
3 to 2	766.57	741.56	−3.26	6 to 2	1.52	1.87	23.33
3 to 4	33.10	3.78	−88.58	6 to 3	2.06	3.28	58.90
3 to 5	873.04	90.34	−89.65	6 to 4	20.84	3.37	−83.82
3 to 6	3.46	4.53	30.65	6 to 5	37.81	0.44	−98.84
Total					11,907.03	4321.22	−63.71

Notes: VES is the value of ecosystem services; 1, 2, 3, 4, 5 and 6 represent cultivated land, forestry area, grassland, water area, built-up area and unused land, respectively; 1 to 2 indicates the conversion from cultivated land to forestry areas; 1 to 1 indicates the conversion between secondary land use types of cultivated land during 2000–2008.

total decrease. In addition, the expansion of the urban built-up area leads to a decrease of 3717.33×10^4 USD, rural settlement of 1196.93×10^4 USD, and other built-up areas of 1668.67×10^4 USD.

In the conversions of secondary land use types, the conversion from swampland to dry land resulted in an increased value of VES of \$ 47.88×10^4 in 2000 USD, followed by increased values for conversions from forest to other forestry areas of 31.98×10^4 USD, from reservoir and ponds to dry land of 29.66×10^4 USD, and from beach and shore to dense grass of 19.09×10^4 USD. Compared to loss of VES, the increment of VES from land-use conversions is low, with only a value of 183.20×10^4 USD (Table 2).

5. Discussion

5.1. Merits and demerits of the method

The method that we used for estimating VES has several merits. First, we directly assessed the VES on the basis of NPP and soil erosion amount, and then estimated the VES of land-use types based on the VES maps. Since the VES is estimated at the pixel level in this study, the VES of different land-use types is more detailed than ever. However, even for the same land-use type, the VES may vary due to the differences in the specific ecosystem functions. For example, the VES of forestry areas in plain areas is significantly different from that in hilly areas due to the difference in their soil conservation function, and the VES of cultivated land in a humid region is different from that in an arid region due to the difference in the water conservation function. Second, the VES estimated in this study is a dynamic result that takes account of multiple factors expect for the land-use change. Lastly, the method used in this study can contribute to the development of VES mapping. The most important parameters for estimating VES in this study are NPP and soil erosion amount, which are both spatial data, and the results of the VES estimated in this study have spatial attributes at the pixel level. These results can be useful for the policy formulation, conservation planning and environmental impact assessment.

However, there are also several flaws of the method used in this study. Costanza et al. (1997) divided ecosystem service functions into 17 categories. However, we only assessed the values of five kinds of ecosystem services due to the lack of suitable data and defensible methods. In addition, the resolution of the NPP data used to assess VES in this study is 1 km, which is a little coarse, and more accurate results can be obtained if there are available data with higher resolution.

5.2. Comparison between the VES estimated in this study and other researches

On the basis of the method of Costanza et al. (1997), Xie et al. (2008) developed a new method or per unit value to assess the VES in China. According to the research of Xie et al. (2008), the VES of forestry area, grassland, cultivated land, and rivers/lakes in China in 2007 were 1521.74 USD/hm^2, 628.02 USD/hm^2, 422.71 USD/hm^2, and 2463.77 USD/hm^2 in 2000 USD, respectively. In this paper, the VES of forestry area, grassland, cultivated land, and rivers/lakes were estimated to be 5362.32 USD/hm^2, 3961.35 USD/hm^2, 2198.07 USD/hm^2 and 2101.45 USD/hm^2 in 2000 USD in 2008, respectively. The VES of forestry area, grassland, and cultivated land in this paper are all higher than that of Xie et al. (2008), while the VES of rivers/lakes is lower than that of Xie et al. (2008). The waste treatment service of rivers/lakes is as important as the water regulation service in the research of Xie et al. (2008). But this study did not assess the VES of the waste treatment service, which may lead to underestimation of the VES of rivers/lakes.

5.3. Causes of VES change in NCP

Although the VES of NCP increased by $ 21.32 billion in 2000 USD during 2000–2008, the land-use change led to a decrease of 0.08 billion USD. The decrease of VES is mainly attributed to the conversion from cultivated land, forestry area and grassland to built-up area. The increase in VES in the NCP mainly resulted from the change of NPP, which increased by 33.88% during 2000–2008, while the provision of gas regulation, nutrient cycling, and organic material provision are all based on NPP. The increase of NPP during 2000–2008 significantly increased the provision of these three ecosystem services, the values of which increased by 34.11%, 35.22%, and 35.81%, respectively. The change percentages of the VES of these three ecosystem services are very close to that of NPP. The increase of NPP also led to an overall increase of the VES for different land-use types during 2000–2008.

In addition, the precipitation change can influence the water conservation service and soil conservation service by altering the intensity of soil erosion, and therefore changes in the spatial pattern of the values for water conservation service and soil conservation service have certain similarities with that of the precipitation change.

6. Conclusions

Our investigation provides a case study of VES assessment by using NPP and the soil erosion amount. The VES of the NCP increased by $ 21.67 billion in 2000 USD during 2000–2008. However, the VES in response to land-use change decreased by 0.08 billion USD. The result indicates that the significant increase of the VES in the NCP was mainly caused by other factors such as climate change. Furthermore, among the factors that might influence the changes of VES, the climate change plays a more important role in increasing the VES than the land-use change does.

The spatial heterogeneity of land use leads to some uncertainties about the VES of different land-use types. In general, the VES of forestry area is higher than that of grassland among the primary land-use types. However, the secondary land-use type does not necessarily abide by this rule. For example, the VES of moderate grassland is higher than that of shrub in the NCP in 2000. Therefore, it is necessary to take account of the spatial heterogeneity of the VES of specific land-use types in the process of implementation of the ecological conservation planning and formulation of ecological policies.

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