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Changes in the ecosystem service values of typical river basins in arid regions of Northwest China

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ABSTRACT

This study compared the 1994 and 2005 ecosystem service values of the Tarim, Manas, Shiyang and Heihe River Basins, which are four typical examples of river basins in the arid region of Northwest China. The ecosystem areas and service values were obtained from their consumer price indices, and constant prices were calculated on the basis of data from the Land Use Classification Map of 1994, TM images, CBERS images of 2005 and research results from 'the equivalent factor table of China's ecosystem service value'. The results indicated that between 1994 and 2005 in these four river basins, the land areas supporting the environment and society (i.e. forest, grassland and wetland ecosystem) generally declined, whereas areas of farmland significantly increased. The changes in these areas in smaller basins were larger and occurred more rapidly. The ecosystem service value of the Tarim River Basin was the largest and local residents would rather pay more money for its ecosystem services, which means that the ecosystem service value there had a higher scarcity. The increase in the ecosystem service value of the Heihe River Basin was the largest. The ecosystem service value of the Heihe River Basin had more important and direct influences on the population's productivity and lives than did the Tarim River Basin. In addition, the farmland area in the Tarim River Basin increased more than the other river basins; however, the people's willingness to pay for farmland ecosystem services in this basin was the lowest. Willingness to pay was not linked to resource richness, and the concepts of economic development, water utilization and soil protection need to be strengthened.

KEY WORDS Tarim River; Manas River; Shiyang River; Heihe River; willingness to pay

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INTRODUCTION

Ecosystem services are the natural environmental conditions, formed by an ecological system and during ecological processes, which are required for human survival and productivity (Daily, 1997). Changes in ecosystem services and its valuation reflect not only the influence of human activities and development on the ecosystem structure and function but also human awareness of the importance of ecosystem functioning and equilibrium in the development of the economy and natural resources. The valuation of ecosystem services has recently become a new area of study. Therefore, ecosystem services valuation has attracted the concerns of international and domestic researchers and has become a research focus in the context of international ecology and ecological economics (Chen and Zhang, 2000; Loomis *et al*., 2000; Zhang *et al*., 2001a; Li *et al*., 2010). The evaluation of arid-area ecosystems, however, was rarely concentrated as much as the humid and semi-humid area ecosystems that render services with a larger contribution capacity, such as forests and wetlands (Jukka and Olli, 2007; Tong *et al*., 2007). With regard to ecosystem rehabilitation and sustainable development, the more we know regarding the economic value of various ecosystem service functions, the more we understand the importance of these functions. It is therefore necessary to accumulate data on arid-area ecosystems. In addition, the evaluation of the value of arid-area ecosystem service functions will inform the judgement of ecosystem balance and integrity, ultimately promoting the harmonious development of the community and ecosystem.

Arid areas in Northwest China include the Xinjiang's Junggar Basin, the Tarim Basin, the Eastern Xinjiang Basin, the western Inner Mongolia Autonomous Region's Alashan Plateau, Gansu's Hexi Corridor, and Qinghai's Qaidam Basin (Pan *et al*., 2001). The development of the socio-economy and the ecological environments in the arid areas in Northwest China carries risks and typically occurs in the central areas of human activity, for example, in river basins, especially

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along the Manas, Tarim, Heihe and Shiyang Rivers. Many years of water resource development and utilization have sustained regional economic development and improved living standards. In contrast, excessive water use, including agricultural water use, has led to ecological water shortage, declines in the groundwater level, vegetation degradation, diminished river flows and lake levels, land desertification and salinization, and other environmental problems, threatening the sustainable development of river basins and the survival of local people. Comparing the different characteristics of ecosystem service values in different periods based on the development of water resources in geographical units in the northwest arid area is one way to understand changes in environmental resources. Such a comparison will provide a basis for exploring how to best develop land and water resources in arid areas, which in turn will provide a good foundation for exploring how land and water development should proceed in arid areas for land and water development in arid areas.

To understand the patterns of ecosystem changes of river basins in arid areas and the regional differences of their responses to human activities, this study analysed the changes in the ecosystem service values of the four representative ecological systems in an arid area. This analysis was based on the land uses and ecosystem service unit prices of these systems.

STUDY AREA AND METHODOLOGY

Study area

Four representative river basins in arid areas of Northwest China were studied, namely, the Tarim, Manas, Heihe and Shiyang River Basins (Figure 1). The Tarim River is the longest inland river in China. It is approximately 1321 km in length and is located at the edge of the Tarim River Basin, the most arid basin in China and a typical arid area in Northwest China. The Manas River is approximately 400 km in length (Chen *et al*., 2006). As the largest catchment centre of the Junggar Basin (Zhang, 2008), the Manas River Basin has been developed into the largest oasis farmland region in Xinjiang and the fourth largest irrigated agricultural area in China. The Shiyang River Basin is the most populated area in the Hexi Corridor. It not only is the most developed and utilized water resource but also has the most serious environmental problems among the four examined basins (Wang *et al*., 2008; Zhang *et al*., 2008a, 2008b). The Heihe River Basin is the second largest inland river basin in Northwest China and one of the three largest inland river basins in the Hexi Corridor. Changes in the structure and function of the ecosystems in these basins reflect the regional environmental quality and ecological security (Liu *et al*., 2002).

Data collection

Socio-economic and land use data for the four river basins were collected and analysed to study a period of nearly two decades. The ecosystem areas were represented using areas of different land types as determined using Landsat-5TM images, which were taken with spectral bands 4, 3 and 2 (as red, green, and blue) and with a ground resolution of 30 m. These images were taken between June and October in 1994 and 2005 according to the seasonal differences of the surface landscape. Remote sensing images from 2005 were first geometrically calibrated using a 1:100000 topographic map. These more recent images were

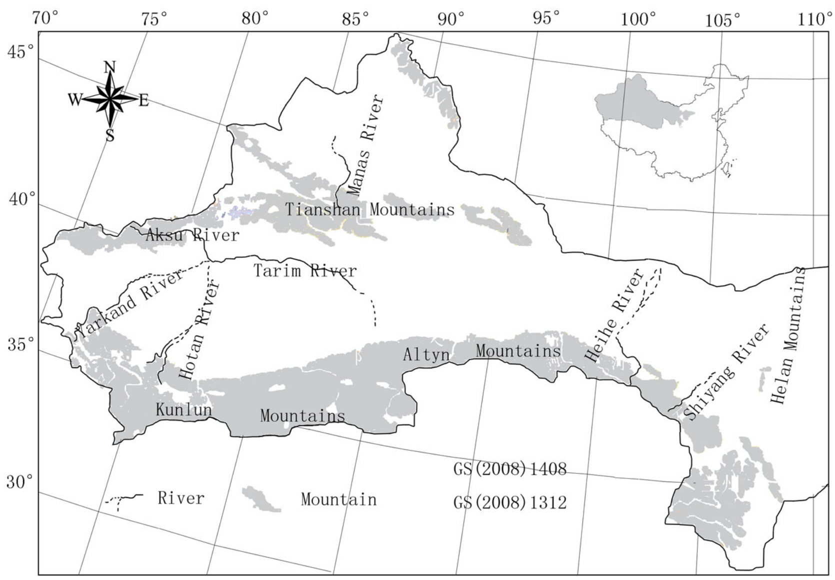

Figure 1. Distribution of typical river basins in arid desert area.

then used to calibrate the 1994 images, with RMS errors controlled within two pixels, to obtain the ecosystem area data of the different regions for the different years.

RESEARCH METHODS

Determination of equivalence of ecosystem service functions

We determined the equivalent factors of Chinese terrestrial ecosystem service values based on an equivalent factor table of ecosystem service values in China that was proposed by Xie *et al*. (2003) and the classification of regional ecosystem types (Table I). The service value of produce per 1 km^2 of farmland in China was defined as 1. The equivalent factors of other ecosystem service values were defined relative to the farmland service value per unit area.

Valuation of food production functions of farmland ecosystem

The value of the food production functions of farmland ecosystems was calculated as previously reported (Xie *et al*., 2001; Xiao *et al*., 2003).

The value of food production function per unit farmland area is determined as

$$E_a = 1/7\sum_{i=1}^{n}\frac{m_i p_i q_i}{M} \quad \mathrm{I} = 1, \ldots, \mathrm{N}. \tag{1}$$

Here, E_a is the economic value of food service per unit area provided by the farmland ecosystem ($\mathrm{Yuan}\cdot km^{-2}$); i is the crop type, including wheat, corn, sorghum, barley, beans, oil crops and sugar beet; P_i is the national average price of crop i ($\mathrm{Yuan}\cdot t^{-2}$); q_i is the yield of crop i per unit area ($t\cdot km^{-2}$); m_i is the planted area of crop i (km^2); and M is the total planted area of food crop i (km^2). The fraction one seventh is simply a parameter that relates the farmland ecosystem service value and other ecosystem service values.

Table I. The equivalent factors of terrestrial ecosystem service values in China.

Content	Forest	Grassland	Farmland	Wetlands	Others
A	3·5	0·8	0·5	0·9	0·0
B	2·7	0·9	0·9	8·8	0·0
C	3·2	0·8	0·6	17·9	0·0
D	3·9	2·0	1·5	0·9	0·0
E	1·3	1·3	1·6	18·2	0·0
F	3·23	1·1	0·7	2·5	0·3
G	0·1	0·3	1·0	0·2	0·0
H	2·6	0·1	0·1	0·0	0·0
I	1·3	0·0	0·0	5·0	0·0

A, gas regulation; B, climate regulation; C, water conservation; D, soil formation and protection; E, waste treatment; F, biodiversity protection; G, food production; H, materials; I, entertainment.

Parameter calibration

Comparable economic values.

$$E_{an} = E_{am} \times \frac{\Phi_m}{\Phi_n} \times 100\% \tag{2}$$

In this equation, both m and n are years, with m being the current year and n being the past year. E_{an} is the constant economic value calculated by the value in year n during the study period, E_{am} is the current value for year m and Φ is the yearly inflation index.

Dynamic correction method.

$$E = \frac{1}{1 + ae^{-bt}} \times E_{an} \tag{3}$$

$$t = \frac{1}{E_n} - 3 \tag{4}$$

Here, E is the value of the produce production of farmland ecosystems in year m, t is the socio-economic development indicator, a and b are constants and set to 1, e is the natural logarithm, E_n is the Engel coefficient and E_{an} is the food production value of farmland ecosystems in the current year.

The calculation of ecosystem service value per unit area in river basins

The ecosystem service value per unit area in a river basin was calculated on the basis of previous reports (Xie *et al*., 2001; Xiao *et al*., 2003). The economic value of ecosystem services per unit area of ecosystem in a river basin was determined using the equivalent factor table of ecosystem services values in China that was proposed by Xie *et al*. and the economic value of food production of farmland ecosystem services in the study area. The ecosystem services value was used to calculate the value per unit area of the other ecosystem services of other ecosystems in the region

$$E_{ij} = e_{ij}E_a \quad (\mathrm{i} = 1, 2\ldots, 9; \mathrm{j} = 1, 2, \ldots, 5) \tag{5}$$

In this equation, E_{ij} is the value per unit area of ecosystem service function i of an ecosystem j, e_{ij} is the equivalent factor of the ecosystem services i of an ecosystem *j* relative to the value of produce production per unit area of farmland ecosystem services, *i* is the type of ecosystem services and *j* is the type of land ecosystem, (i.e. forest, grassland, farmland, wetland or other).

Calculation of ecosystem service values in the river basins

$$V = \sum_{i=1}^{9}\sum_{j=1}^{5} A_j E_{ij} \quad (\mathrm{I} = 1, 2, \ldots, 9; \mathrm{j} = 1, 2, \ldots, 5) \qquad (6)$$

Here, V is the total value of ecosystem services, A_j is the area of ecosystem type *j*, E_{ij} is the value per unit area of ecosystem services *i* of ecosystem type *j*, *i* is the type of ecosystem services and *j* is the type of ecosystem.

RESULTS

Economic value per unit area of ecosystem services

The regional socio-economic development data of the Tarim, Manas, Shiyang and Heihe River Basin districts at different times were provided by the State Statistics Bureau of China. These data were used to obtain the Engel coefficients and to calculate the corresponding dynamic correction parameters for values of produce production. Parameter calibrations were made to enhance the comparability of data between 1994 and 2005. First, the national grain purchase index of the State Statistics Bureau of China was chosen to lessen the influence of inflation. Next, relatively fixed values of produce production of farmland ecosystems were calculated on the basis of the fixed values of produce production of farmland ecosystems in 1994. Last, the value per unit area of every ecosystem service was obtained after a series of corrections using the parameters listed in Table II.

The values per unit area were calculated for the different ecological systems of the four basins in 1994 and 2005. As listed in Table III, the values per unit area of the different ecological systems of the Tarim (1805 Yuan), Manas (523 Yuan) and Heihe River Basins (158 Yuan) in 1994 increased to 2832, 4200 and 3063 Yuan, respectively, in 2005. In contrast, the value per unit area of the Shiyang River Basin markedly declined from 5279 Yuan in 1994 to 3875 Yuan in 2005.

The order of values per unit area of forest ecosystem services of the four river basins was the following in 1994: Shiyang River Basin > Tarim River Basin > Manas River

Table II. The value of produce production per unit area of farmland ecosystem in different river basins (Yuan km^{-2}).

Year	Dynamic correction				Constant price in 1994				Comprehensive correction			
	a	b	c	d	a	b	c	d	a	b	c	d
1994	0·3	0·2	0·2	0·2	971·2	341·1	3581·5	113·9	261·2	75·7	764·0	22·78
2005	0·4	0·5	0·4	0·4	1112·9	1144·1	1321·4	1103·3	409·8	607·7	560·8	443·3

a, Tarim River Basin; b, Manas River Basin; c, Shiyang River Basin; d, Heihe River Basin.

Table III. The value per unit area of ecosystem services for each river basin (Yuan km^{-2}).

Time type	River basin	1994	2005
Farmland	Tarim River Basin	1804·8	2831·5
	Manas River Basin	523·0	4199·5
	Shiyang River Basin	5279·0	3875·4
	Heihe River Basin	157·5	3063·4
Forest	Tarim River Basin	5707·0	8953·5
	Manas River Basin	1653·7	13279·1
	Shiyang River Basin	16692·8	12254·4
	Heihe River Basin	497·9	9686·8
Grassland	Tarim River Basin	1891·0	2966·7
	Manas River Basin	548·0	4400·0
	Shiyang River Basin	5531·2	4060·5
	Heihe River Basin	165·0	3209·7
Wetlands	Tarim River Basin	14193·0	22267·0
	Manas River Basin	4112·7	33024·5
	Shiyang River Basin	41514·2	30476·0
	Heihe River Basin	1238·3	24090·7

Basin > Heihe River Basin. In 1994, the value per unit area of forest ecosystem services of Heihe river basin was the smallest, at 498 Yuan km^{-2}. The order of values per unit area of forest ecosystem services of the four river basins was the following in 2005: Manas River Basin > Shiyang River Basin > Heihe River Basin > Shiyang River Basin. The values per unit area of forest ecosystem services of the two largest river basins (the Tarim and Heihe River Basins) were the smallest among the four river basins. Between 1994 and 2005, the values per unit area of forest ecosystem services of the Tarim, Manas and Heihe River Basins significantly increased. Of these areas, the value per unit area of forest ecosystem services of the Heihe River Basin exhibited the largest increase, and that of the Tarim River Basin exhibited the smallest increase (56·9%). The value per unit area of forest ecosystem services of the Shiyang River Basin decreased over this time span (26·6%).

The order of values per unit area of grassland ecosystem services in 1994 was the following: Shiyang River Basin > Tarim River Basin > Manas River Basin > Heihe River Basin. Of the forest ecosystem services, the largest value was 5531 Yuan km^{-2} for the Shiyang River Basin, and the smallest one was only 498 Yuan km^{-2} for the Heihe River Basin. The order of values per unit area of grassland ecosystem services in 2005 changed to the following: Shiyang River Basin > Manas River Basin Heihe River Basin > Tarim River Basin. The values per unit area of grassland ecosystem services of the Manas River Basins (4401 Yuan km^{-2}) and Heihe River Basins (3210 Yuan km^{-2}) increased rapidly in 2005. The respective value increase for the Tarim River Basin was only 2967 Yuan km^{-2} in 2005. Between 1994 and 2005, the values per unit area of grassland ecosystem services of the Tarim, Manas and Heihe River Basins significantly increased. This value increased the most for the Heihe River Basin and the least for the Tarim River Basin (56·9%). The value per unit area of grassland ecosystem services for the Shiyang River Basin dropped by 36·2%.

In 1994, the order of values per unit area of wetland ecosystem services of the four river basins was the following: Shiyang River Basin > Tarim River Basin > Manas River Basin > Heihe River Basin. Of the four ecosystems, the largest value was 41514 Yuan km^{-2} for the Shiyang River Basin, and the smallest one was only 1238 Yuan km^{-2} for the Heihe River Basin. In 2005, the order of values per unit area of wetland ecosystem services of the four river basins changed to the following: Manas River Basin > Shiyang River Basin > Heihe River Basin > Tarim River basin. The largest value per unit area was 33 025 Yuan km^{-2}, and the smallest was only 24 091 Yuan km^{-2}. The values per unit area of ecosystem services of the Tarim, Manas and Heihe River Basins increased significantly between 1994 and 2005, with the largest increase in the Heihe River Basin and the smallest increase (56·9%) in the Tarim River Basin. The value per unit area of wetland ecosystem services of the Shiyang River Basin declined by 26·6%.

Changes in the values of ecosystem services

Changes in the area of the ecological ecosystems. Changes in farmland ecosystem areas: As shown in Figure 2A, the order of farmland areas of the four river basins in 1994 was the following: Tarim River Basin > Heihe River Basin Manas River Basin > Shiyang River Basin. This order changed in 2005 to the following: Tarim River Basin Manas River Basin > Heihe River Basin > Shiyang River Basin. The farmland areas were $1{\cdot}0 \times 10^4$ km^2, $1{\cdot}3 \times 10^4$ km^2, $4{\cdot}2 \times 10^4$ km^2 and $2{\cdot}7 \times 10^4$ km^2 for the Tarim, Heihe, Shiyang and Manas River Basins, respectively, in 2005. The largest river basin, the Tarim River Basin, had the largest farmland area, which dramatically increased by 104·4%. The farmland area of the Heihe River Basin exhibited the lowest rate of increase (3·5%), whereas this rate was (39·5%) for the smaller Manas River Basin.

Changes of forest ecosystem areas: As shown in Figure 2B, the order of forest ecosystem areas of the four river basins in 1994 was the following: Tarim River Basin > Heihe River Basin > Manas River Basin Shiyang River Basin. The Tarim River Basin had the largest forest area (49 618 km^2), and the Shiyang River Basin had the smallest (438 km^2). Although the order of the areas of the four river basins did not change in 2005, the forest ecosystem areas of the Tarim (1272 km^2) and Manas River Basins (142 km^2) decreased by 2·56 and 17·09%, respectively. The Shiyang River and Heihe River Basins were increased in forest ecosystem areas size but to a lower degree, namely, by 5 and 28 km^2, respectively.

Changes in grassland ecosystem areas: Changes in the grassland ecosystem areas of the four river basins are shown in Figure 2C. The area of grassland ecosystems in the Tarim River Basin in 1994 was 192 748 km^2, followed by the Manas River Basin. The Heihe River Basin had the smallest grassland area (1646 km^2). The order of the grassland ecosystem areas of the four river basins was the same as that in 1994: Tarim River Basin > Manas River Basin > Shiyang River Basin Heihe River Basin. The grassland ecosystem areas of the four river basins all significantly decreased between 1994 and 2005. The grassland areas of the Tarim River Basin decreased the most (9542 km^2), followed by the grassland areas of the Manas River Basin. The grassland areas of the Heihe River Basin decreased the least (259 km^2). Among the four river basins, the decrease in the grassland area of the Shiyang river basins was the largest (24·8%).

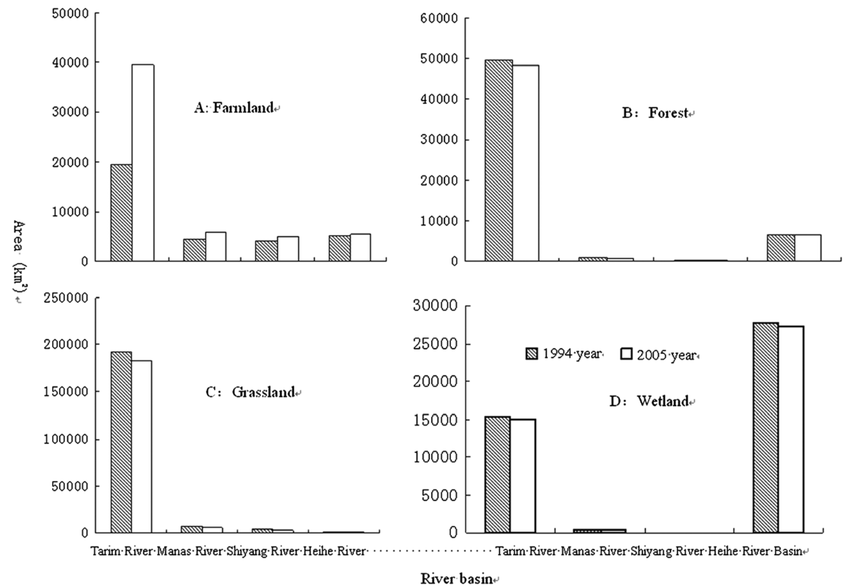

Figure 2. Area of different ecosystems of Tarim, Manas, Shiyang and Heihe River Basins in the two-time slides.

Changes in wetland ecosystem areas: Changes in the wetland ecosystem areas of the four river basins are shown in Figure 2D. The Heihe River Basin had the largest wetland ecosystem area (27 711 km^2) in 1994, followed by the Tarim (15 267 km^2), Manas, (376 km^2) and Shiyang River Basin (57 km^2). The order of the wetland ecosystem areas of the four river basins did not change in 2005. The decrease in the wetland ecosystem areas of the Heihe River Basin was the largest (501·3 km^2), followed by the Tarim River Basin (424·1 km^2), and the decrease in the Shiyang River Basin was the smallest (0·4 km^2).

Overall, between 1994 and 2005, the farmland areas of the four basins increased, whereas the grassland, forest and wetland areas decreased.

Changes in the ecosystem service value. Changing values of the farmland ecosystem service: The values of the ecosystem services of the four river basins were calculated using the value per unit area of farmland ecosystem services in 1994 and 2005. The changes in the ecosystem service values of the four river basins were then compared.

As shown in Figure 3A, the order of the values of farmland ecosystem services of the four river basins in 1994 was the following: Tarim River Basin > Shiyang River Basin > Manas River Basin > Heihe River Basin. The Tarim River Basin had the largest farmland ecosystem service values ($35{\cdot}8 \times 10^6$ Yuan), whereas the Heihe River Basin had the smallest ($8{\cdot}2 \times 10^5$ Yuan). The order of the farmland ecosystem service values of the four river basins changed to the following in 2005: Tarim River Basin > Manas River Basin > Shiyang River Basin > Heihe River Basin. This order was different from the order of their ecological system areas. The primary reason for this is that this evaluation method considered both the size of the river basin itself and the recognition of the impact of the population on ecosystem service function values. In 1994, the Shiyang River Basin had the smallest farmland ecosystem area but the second largest ecosystem service value among the four river basins, a fact that was primarily because of the farmland ecosystem services of Shiyang River Basin having a relatively high value of produce production.

Between 1994 and 2005, with the exception of the Shiyang River Basin, the farmland ecosystem service values of the river basins increased significantly. The farmland ecosystem service values of the Heihe, Manas and Tarim River Basins increased by 1913, 1020, and 221%, respectively. The degree of increase in the farmland ecosystem service values of the Tarim River Basin was the smallest (220·7%). The ecosystem service value reflects in part the willingness of people to pay to protect environmental resources (Hamid *et al.*, 2006). Thus, it can be inferred that an increase in every ecosystem service value signifies an increase in peoples' willingness to pay for the corresponding service and functions. Therefore, the increase in the farmland ecosystem service value, which was observed for the Tarim, Manas and Heihe River Basins, reflects an increase in peoples' willingness to pay for produce production. However, the decrease in the farmland ecosystem service value per unit area of the Shiyang River Basins resulted from a decrease in peoples' willingness to pay for produce production. Hence, people's willingness to pay for farmland ecosystem services increased the most in the Heihe River Basin and the least in the Tarim River Basin.

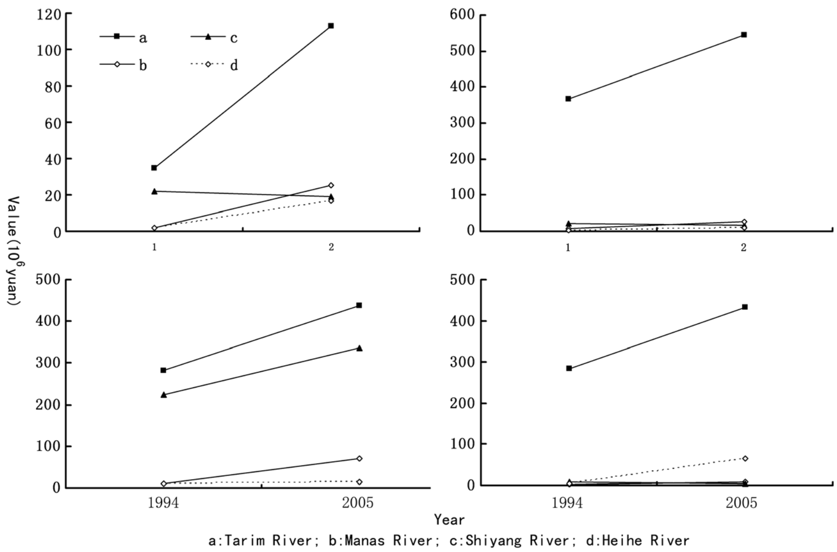

Figure 3. Ecosystem service values of the four river basins at different periods.

Changes in forest ecosystem service values: As shown in Figure 3B, the order of forest ecosystem service values of the four river basins was the following in 1994: Tarim River Basin > Shiyang River Basin > Heihe River Basin > Manas River Basin. The forest ecosystem service value of the Tarim River Basin was much larger than those of the other three basins, namely, 205 times that of the Shiyang River Basin, 88 times that of the Heihe River Basin and 38 times that of the Manas River Basin. However, this order changed greatly by 2005 to the following: Tarim River Basin > Heihe River Basin > Manas River Basin > Shiyang River Basin. The Tarim River Basin had the largest forest ecosystem service value (4×10^8 Yuan), followed by the Heihe River Basin (6×10^7 Yuan).

Between 1994 and 2005, the forest ecosystem service values increased for the Tarim, Manas and Heihe River Basins. The forest ecosystem service values of the Tarim River Basin increased the most ($1{\cdot}5 \times 10^8$ Yuan), followed by the Heihe River Basin ($5{\cdot}9 \times 10^7$ Yuan). The degree of increase in the forest ecosystem service values of the Heihe River Basin was the largest (18·5%), and that of the Tarim River Basin was the smallest. Over the same period, the degree of decrease in the forest ecosystem service values of the Shiyang River Basin was 25·8%. Although the forest ecosystem areas there increased, the degree of decline in the value per unit area of forest service ecosystems exceeded that of the increase in the ecosystem areas, leading a decreased forest ecosystem service value.

Changes in grassland ecosystem service values: Changes in the grassland ecosystem service values of the four river basins are listed in Figure 3C. In 1994, the grassland ecosystem service value of the Tarim River Basin was the largest ($3{\cdot}7 \times 10^8$ Yuan), 19 times that of the Shiyang River Basin, 101 times that of the Manas River Basin and 1342 times that of the Heihe River Basin. In 2005, the Tarim River Basin still had the largest grassland ecosystem service value ($5{\cdot}4 \times 10^8$ Yuan), and the Heihe River Basin had the smallest ($4{\cdot}5 \times 10^6$ Yuan). The grassland ecosystem service value of the Manas River Basin was $1{\cdot}2 \times 10^6$ Yuan, greater than that of the Shiyang River Basin. Between 1994 and 2005, the grassland ecosystem service values of the Tarim, Manas and Heihe River Basins increased significantly. The rate of increase in the grassland ecosystem service value of the Heihe River Basin was the largest (1538·9%), followed by the Manas River Basin. The rate of increase in the grassland ecosystem service value of the Tarim River Basin was the smallest. The rate of reduction in the grassland ecosystem service value of the Shiyang River Basin was more marked (44·8%).

Changes in wetland ecosystem service value: The observed changes in the wetland ecosystem service values of the four river basins are listed in Figure 3D. In 1994, the Tarim River Basin had the largest wetland ecosystem service value ($2{\cdot}2 \times 10^8$ Yuan), which was 140 times that of the Manas River Basin, 91 times that of the Shiyang River Basin and 6 times that of the Heihe River Basin. In 2005, the wetland ecosystem service value of the Heihe River Basin was the largest ($6{\cdot}6 \times 10^8$ Yuan), followed by that of the Tarim River Basin ($3{\cdot}3 \times 10^8$ Yuan) and that of the Shiyang River Basin ($1{\cdot}7 \times 10^8$ Yuan). Between 1994 and 2005, the wetland ecosystem service values of the Tarim, Manas and Heihe River Basins increased significantly. The degree of increase in the wetland ecosystem service value of the Heihe River Basin was the largest (1810%), followed by that of the Manas River Basin. The degree of increase in the wetland ecosystem service value of the Tarim River Basin was the smallest. Although the areas of wetland ecosystems in these basins slightly decreased, the values per unit area of their ecosystem services significantly increased, resulting in their wetland ecosystem service values increasing rapidly. This fact indicates that large increases in the ecosystem service values of these basins can compensate for the influence of decreased ecosystem areas on environmental conservancy.

DISCUSSION

There are many types of ecosystems, including forest, grassland, wetland and farmland, in arid desert regions, which are typically characterized by arid inland ecosystems. These arid river basins are rich in natural resources but have fragile environments and are intensively affected by both environmental and human-induced stresses (Wang *et al*., 1999). Studies of the ecosystem service values of farmland, forest, grassland and wetland and their changes in the land areas of these ecosystems could provide data for evaluating ecological system scarcity. Furthermore, comparing changes in the ecosystem service values of different river basins could help to provide specific regulatory strategies (Zhang *et al*., 2001b) and create a theoretical basis for ecological security and sustainable social and economic development of the arid inland basins. This study utilized the concept of ecological economics and recommends the use of the economic development level factor to value ecosystem services. Specifically, the introduction of this factor can provide novel insights for exploring the interaction mechanism between ecosystems and economic systems.

Oases in the arid region hold more than 90% of the population and produce more than 95% of the industrial and agricultural outputs (Han, 1999). Agricultural activities were still the primary human activities in the oases (assuming there is more than one type of activity) of the arid region. Therefore, oasis expansion is primarily manifested as an increase in the area of farmland ecosystems. The farmland ecological system is directly managed by humans and satisfies human needs. Therefore, increases in farmland area in oases are closely related to increases in the population. Correctly evaluating the farmland ecosystem service function and value could provide a reference and theoretical support for effective farmland ecosystem management and promote sustainable farmland ecosystem development (Zhang *et al*., 2009).

With the increase in farmland area in these four typical river basins, there was a dramatic decrease in the areas of the forest, grassland and wetland ecosystems (Fan *et al*., 2004). The structure changes of these ecosystems, especially in the conversion of forests and grasslands to farmland, are a typical feature of ecosystem degradation (Wang *et al*., 2010), indicating the coexistence of oases and desertification. Forest, grassland and wetland ecosystems within arid regions are the bases of the environment and support the farmland ecosystem (Zhang *et al*., 2008b). However, coincidental with the expansion of farmland area, these non-farmland ecosystems are generally reduced in size. This observation was more obvious in the Tarim River Basin. In short, maintaining a reasonable structure and ratio of ecosystems is very important to achieve optimal ecological and economic benefits.

The different ecosystem service values of the different river basins not only reflect the local people's willingness to pay for the ecosystem functions but also reveal the scarcity of ecosystem services in the regional society. To a certain extent, with the developing economy and the growing population, natural and social resources in arid areas might become scarcer. Therefore, the ecosystem service value might continuously increase. In fact, the human need for ecosystem services in different regions varies an effect that was clearest in the Heihe River Basin. The greater degree of increase in the ecosystem service value of the Heihe River Basin among the four river basins reflected the close relationship between ecosystem services and the lives and productivity of the population. Although the scarcity of desert ecosystem resources has long been a major issue, the willingness of local people to pay for ecosystem services is not consistent with the state of the resources. Therefore, strengthening the concepts of wetland utilization and land resource protection of desert areas is necessary.

Human activities have strong and obvious impacts on the improvement or reduction in ecosystem services. It could be sustainable that ecosystem service values can simultaneously increase with socio-economic growth if a reasonable ecosystem structure is maintained. If the integrity and balance of the ecosystem structure is broken, the ecosystem security protection system will continue to decline with the growth of the social economy. Because extensive use of wetlands and land resources will result in a continuous reduction in wetland areas, the process of regional desertification will be intensified, threatening the stability of regional production and economic development.

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