Oasis land-use change and its effects on the eco-environment in Yanqi Basin, Xinjiang, China

Zulpiya Mamat · Hamid Yimit · Anwar Eziz · Ajigul Ablimit

Abstract Satellite data and the published coefficients about the world's and China's ecosystem were used to analyze the effects of land-use changes on the ecosystem service in the Yanqi Basin. Both economic developments and arid, fragile ecosystems have strongly affected the land use. A sensitivity analysis determined the effect of manipulating the coefficients on the estimated values. Results indicated that (1) the total value of ecosystem services in the Yanqi Basin were 9,374.66, 10,450.52, 9,964.20, and 9,8707.77 million Yuan in 1990, 2000, 2005, and 2011, respectively. The net increase in ecosystem service values were about 496.11 million Yuan within 1990–2011; (2) The aggregated ecosystem service values of water body, wetlands, grasslands, and croplands were about 99.25 % of the total value; (3) Waste treatment and soil formation were the top two ecological functions with high service values and contributing about 61.70 % of the total service values; and (4) Ecosystem service values estimated in this study were inelastic with respect to the value coefficients; therefore, the estimation was robust in spite of uncertainties on the value coefficients. A reasonable land-use plan should be based on rigorous environmental impact analyses for maintaining stability and sustainable development of the Yanqi Basin.

Keywords Ecosystem service · Land use · Variation · Yanqi Basin

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Introduction

The "ecosystem service" is a core concept of the rapidly developing interdisciplinary field of ecological economics (Daly and Farley 2004). Ecosystem service can be defined as the conditions and processes through which natural ecosystems and the species that comprise within them sustain and fulfill human life (Daily 1997), or the goods and services provided by the ecosystem which contributes to human welfare, both directly or indirectly (Costanza et al. 1997). The integration of ecological and economic concepts has made a valuable contribution to sustainability science (Justin et al. 2011). Economic valuation of ecosystem service is becoming increasingly important to understand the multiple benefits provided by ecosystems. The ecosystem service and the natural capital stocks that produced them are critical to the functioning of the earth's life-supporting system (Guo et al. 2001). They contribute to human welfare directly or indirectly and, therefore, represent part of the total economic value of the planet.

In recent decades, the quantification of ecosystem service values have therefore been identified as a key area for investigation in related academic fields (Costanza et al. 1997; Daily 1997). Numerous researches have concentrated on estimating the values of various ecosystem services. Costanza et al. (1997) attempted to estimate the global biospheric value of 17 ecosystem service values provided by 16 dominant global biomes. White et al. (1997) calculated the economic value of endangered species management. Peters et al. (1989) assessed the economic and ecological value of a tropical Amazon rainforest and proposed a strategy to use rainforests in the region. Xie et al. (2003) extracted the equivalent weight factor of ecosystem services per hectare of terrestrial ecosystems in China and modified the value coefficient of Chinese ecosystem. Li and Wang (2006)) estimated the ecological values of vegetation service in Minqin desert oases. Chang et al. (2010) assessed the ecological security of Zhangye oases based on ecosystem service values.

Changes in land use can significantly affect ecosystem processes and services. The identification and measurement of ecosystem service change as a consequence of land-use changes is shown to be an adequate way to evaluate environmental costs and benefits of different land planning decisions. Therefore, the rapidly expanding literature seeks to quantify the effects of land-use change on ecosystem services' value (Kreuter et al. 2001; Zhao et al. 2004; Li and Ren 2008; Wang et al. 2009; Yoshikawa et al. 2010; William et al. 2011). The valuation of ecosystem services ranges from studies on the value that temperate forests contribute toward fresh water supplies (Nuñez et al. 2006), to the spatial scales of ecosystem services (Hein et al. 2006), to changes in the value of ecosystem services in response to land-use changes during urbanization (Li and Ren 2008), and to the impact of land-use change on the ecosystem services of mountain–oasis–desert system (Huang et al. 2007). Other studies have focused on how land-use changes are coupled to ecosystem services (Zhang et al. 2009; Néstor et al. 2010). In each of these studies, researchers have obtained insights that can provide important guidance for land managers.

Ever since humans first began to manage their surroundings, land use has been changing. The changes over the last 50 years have been especially important and intense (J.P. Metzger et al. 2009). Society is becoming increasingly urbanized, while natural ecosystems are deteriorating.

The issue of land-use change in China is significant due to the fact that, per capita, land resources of China are far below the world average. Since China initiated its economic reforms and "Open Door Policy," rapid land-use change has taken place in most of its territories. Rational land-use and ecosystem service value changes noted in the eastern developed regions of China have received great attention. Comparatively, land use and ecosystem service value changes noted in the western regions of China have attracted less attention, especially in the arid zone oases, where there is a wide desert interspersed with many oases with the main geomorphological feature, and both economic development and arid, fragile ecosystems have strongly affected land-use and land cover (Xiuhong et al. 2008; Mamattursun et al. 2010). Therefore, research on the effects of land-use change on ecosystem service values of western arid regions of China is one of the most significant areas. But, most research results are inaccessible to the global research community because they are not reported in English (Liu and Costanza 2010).

Oases are specific landscapes that exist within deserts in arid zones. They not only are the most concentrated areas of human activities, but they also provide habitats for wild animals (Jia 1996). Oases also are the largest areas where artificial disturbances happen at the regional scale. Although oases constitute only 4–5 % of the total area of the region, over 90 % of the population and over 95 % of social wealth are concentrated within these oases. Related research showed that, over the past 50 years, irrational human activities have caused desert expansion and soil degradation, resulting in salinization of soils in the oases of the Tarim Basin (Hamid et al. 2000, 2002). The stability of oasis ecosystems are affected by both desertification in the oases–desert ecotone and salinization in the interior of the oases (Han 1999; Sawut et al. 2013). Study on land-use change in oases in arid zones and its effects on oases ecosystem service values are a significant issue that is theoretically and practically essential for sustainable development and stability of oases.

The purposes of the present research are the following:

(1) To evaluate the extent of oases land-use changes;
(2) To quantify change in ecosystem services using value coefficients from 1990 to 2011;
(3) To examine how oases' land-use changes affect the value of ecosystem service in the Yanqi Basin.

Such quantitative analyses are urgently needed. They will be useful in land-use management of oases and provide a scientific basic for eco-environmental protection and sustainable development of oases in at-risk arid zones.

Study area

Yanqi Basin, the study area, is located on the southern part of Tianshan Mountains, northwest China (86°39′–88°20′ E, 41°23′–43°31′ N). It has a total area of 723,766.86 ha (Fig. 1). The Yanqi Basin borders the Tianshan Mountains in the north and west and the Kuruktag Mountains in the south. Due to its long distance from the oceans and being surrounded by high mountains, the Yanqi Basin is characterized by a typical mid-temperate continental arid climate, with average annual rainfall of 50.7–79.9 mm, and an average annual evaporation capacity of 2,000.5–2,449.7 mm. The annual accumulative active temperature ≥10 °C is 3,414.4–3,694.1 °C, and the annual daily sun duration is 3,074.3–3,163.4 h.

Ground elevation of the Yanqi Basin is generally from 1,050 m to 1,200 m. The topographic feature is high in the west and low in the east, while high in the north and low in the south. Overall, it displays sloping landform features from the periphery to the basin. Landform types such as fluvial, aeolian, and lakes are well developed in the basin. Brown desert soil, meadow soil, swamp soil, irrigation farming soil, damp soil, saline soil, and weathered soil are the range of soil types in the basin. The vegetations in the study area are mostly desert shrubs, desertification of juicy woody salt, precarious grass bushes, and swamp reed.

Data and methods

Land-use classification

Land-use data used in this study were acquired from Landsat images of October 1990, September 2000, August 2005, and August 2011. Geometric correction and the mosaic of the images were collected using ENVI 4.5 image-processing software based on 1:100,000 topographic maps, and Gauss–Kruger Projection, which was selected for geometric correction. After geometric correction and geo-referencing, the average location errors
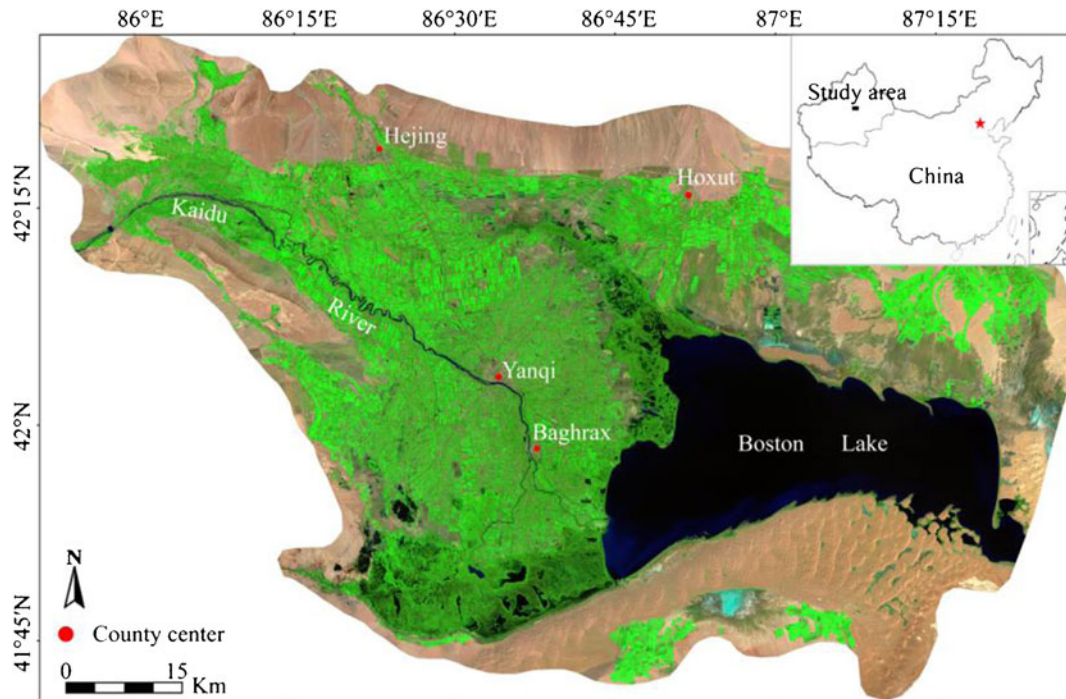
Fig. 1 Map showing the study region

in the images are less than two pixels (about 50 m). According to the research purpose and status of the study area, images were classified by using visual interpretation and supervised classification methods. Field observations clarified the presence of mainly nine land use and land cover categories in the study area. The minimum level of interpretation accuracy in the identification of land use and land cover categories from remote sensor data was at least 87 %. A brief description of the classified land-use categories used is given in Table 1. Land-use maps of the Yanqi Basin in 1990, 2000, 2005, and 2011 are given in Fig. 2.

Assignment of ecosystem service values

Environmental evaluation using ecosystem service has received much attention. It is widely used to understand the multiple benefits provided to ecosystems (Zhao et al. 2004; Daly and Farley 2004; Gopal and Golam 2006). In order to evaluate ecosystem service values for each of the nine land-use categories, each land-use category was compared with different biomes identified in both the world's ecosystem (Costanza et al. 1997) and China's ecosystem (Chen and Zhang 2000; Xie et al. 2008). To find their most representative

biome, respectively, Costanza et al. (1997) classified the global biosphere into 16 types of ecosystems and 17 types of service functions and then estimated their ecosystem service values. Based on the parameters of Costanza et al. Xie et al. (2008) extracted the equivalent weight factor of ecosystem service per hectare of terrestrial ecosystems in China and modified the value coefficient of the Chinese ecosystems. Ecosystem service values per unit area for each land-use category in the study area was assigned based on the nearest equivalent ecosystems suggested by Xie et al. (2008) and Costanza et al. (1997).

Calculation of ecosystem service values

The ecosystem service values and ecosystem service functions represented by each land-use category in the study area were obtained as follows:

$$ESV_k = \sum_f A_k \times VC_{kf} \tag{1}$$

$$ESV_f = \sum_k A_k \times VC_{kf} \tag{2}$$

Table 1 Land-use categories and their definition in the Yanqi Basin

Land-use categories	Definition	Remote sensing characteristics for every land-use categories
Water body	Rivers, lakes, artificial water areas	Had obvious geometrical shapes, showing a dark blue, blue, light blue
Wetland	Mainly mangrove marsh	Geometric feature is not obvious, showing a light red, bright red, dark gray
Sandy land	Land covered with sand, with vegetation cover <5 %	Yellow or chartreuse, has a wavy texture
Salinized land	Land with salt on top soil	Clear border, showing a gray, gray and white, white. Image texture is delicate
Farm land	Irrigated lands used for multiple cropping	Geometric features have rules, showing a light red, bright red. Image texture is relatively rough.
Grassland	Grassland with vegetation cover >5 %	Had the character of regional distribution, showing a red, pink, light red, bright red
Forest land	It is used to refer to land with a tree canopy cover more than 20 % and area of more than 0.5 ha	Linearly and patchy distributed, showing a red, bright red
Residential site	Resident areas include all areas being used for permanent settlements such as villages, towns, public gardens, etc	Geometric features more rules, showing a dark gray, gray, gray and white
Barren land	Unfertile or seriously degraded land on shallow soil and rocky areas on which neither trees nor grasses can grow	Boundary is quite distinct, showing a gray-yellow, gray, gray and white. Image texture is delicate.

Source: MAF 2005

$$ESV = \sum_k \sum_f A_k \times VC_{kf} \qquad (3)$$

where ESV_k, ESV_f, and ESV_k refer to the ecosystem service values of land-use category k, value of ecosystem service function type f, and the total ecosystem service values, respectively. A_k is the area (in hectare) for land-use category k, and VC_{kf} is the value coefficient (in Yuan per hectare per area) for land-use category k and ecosystem service function type f. The change in ecosystem service values was estimated by calculating the difference between the estimated values for each land-use category in 1990, 2000, 2005, and 2011.

Since the biomes used as proxies for the land-use categories are clearly not perfect matches as mentioned above, and there are uncertainties of the value coefficients, additional sensitivity analysis was needed in order to test the percentage change in the ecosystem service values for a given percentage change in value

coefficients. In each analysis, the coefficient of sensitivity (CS) was calculated using the standard economic concept of elasticity as follows (Kreuter et al. 2001; Li et al. 2010):

$$CS = \frac{(ESV_j - ESV_i)/ESV_i}{(VC_{jk} - VC_{ik})/VC_{ik}} \qquad (4)$$

where ESV is the estimated ecosystem service value; VC is the value coefficient; i and j represent the initial and adjusted values, respectively; and k represents the land-use category.

If CS is greater than unity, then the estimated ecosystem value is elastic with respect to that coefficient, but if CS is less than one, then the estimated ecosystem value is considered to be inelastic. The greater the proportional change in the ecosystem service value relative to the proportional change in the valuation coefficient, the more critical is the use of an accurate ecosystem value coefficient (Kreuter et al. 2001; Wang et al. 2009).
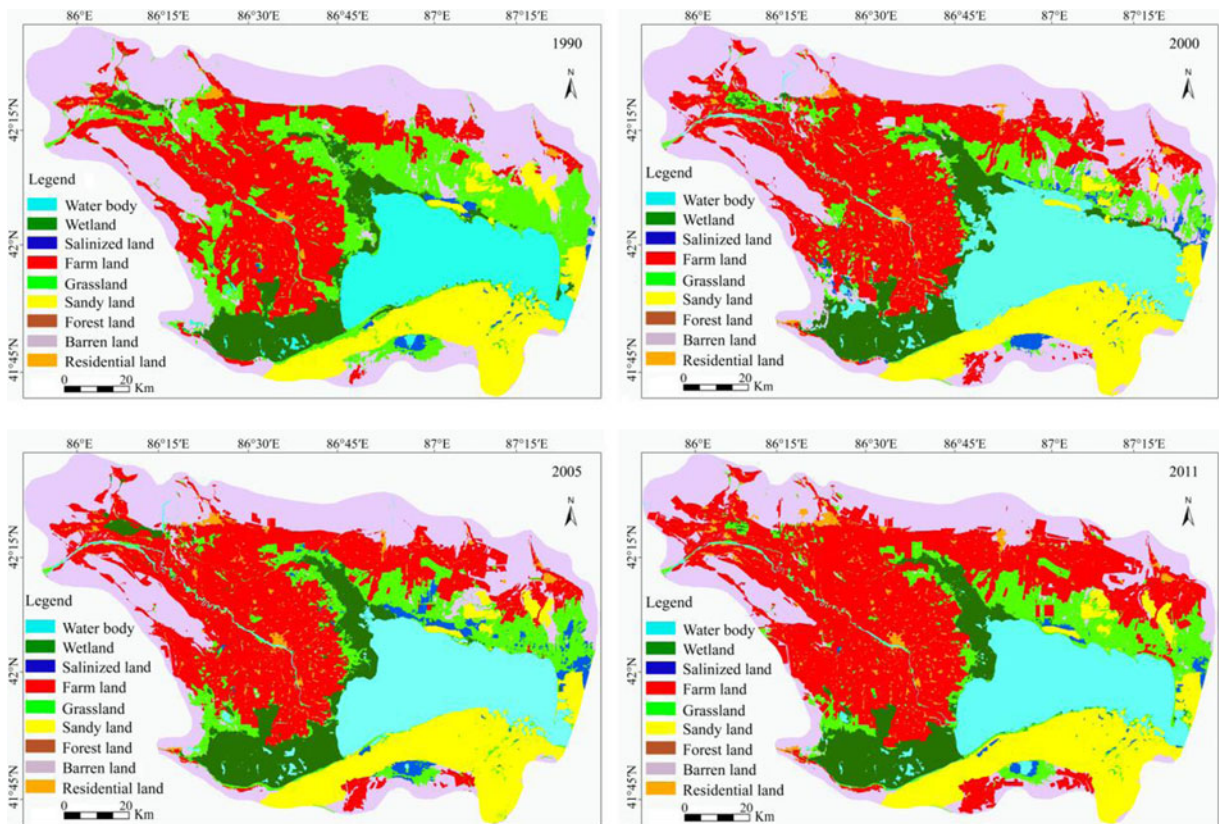

Fig. 2 Land-use cover map of Yanqi Basin oases in 1990, 2000, 2005, and 2011

Results

Changes of land-use

The statistics of the land-use changes in the Yanqi Basin within 1990–2000, 2000–2005, and 2005–2011 can be seen in Table 3.

Changes over the 21-year period indicate that the water body, wetlands, sandy lands, grasslands, farm lands, and barren lands remain the principal land cover in the study area.

The barren lands increased from 27.59 % of the total area in 1990 to 28.28 % in 2000, and decreased from 28.28 % of the total area in 2000 to 24.53 % in 2005 and to 19.96 % in 2011.

The second largest cover is farm lands. These increased from 21.50 % of the total area in 1990 to 25.64 % in 2000 and to 28.19 % in 2005 and to 34.68 % in 2011.

The water body increased from 13.25 % of the total area in 1990 to 16.29 % in 2000 and decreased from 16.29 % of the total area in 2000 to 14.34 % in 2005 and to 13.62 % in 2011.

The grasslands decreased from 17.04 % of the total area in 1990 to 8.05 % in 2000, and increased from 8.05 % of the total area in 2008 to 10.13 % in 2005, and decreased from 10.13 % of the total area in 2005 to 9.89 % in 2011.

The wetlands increased from 7.33 % of the total area in 1990 to 7.93 % in 2000, and decreased from 7.93 % of the total area in 2000 to 7.81 % in 2005 and to 7.50 % in 2011.

The sandy lands decreased from 10.80 % of the total area in 1990 to 10.33 % in 2000, and increased from 10.33 % of the total area in 2000 to 10.79 % in 2005 and to 10.94 % in 2011.

According to Fig. 2, it is obvious that the most notable change in land use happened in the interior and central parts of the basin where human activity is concentrated. The bigger patches including barren lands (changed 0.69 % within 1990–2000; 3.75 % within 2000–2005; and 4.57 % within 2005–2011), farm lands (changed 4.14 % within 1990–2000; 2.55 % within 2000–2005; and 6.49 % within 2005–2011), water body (changed 2.94 % within 1990–2000; 1.95 % within 2000–2005; and 0.72 % within 2005–2011), grasslands (changed 8.99 % within 1990–2000; 2.08 % within 2000–2005; and 0.24 % within 2005–2011), wetlands (changed 0.60 % within 1990–2000;

0.12 % within 2000–2005; and 0.31 % within 2005–2011), and sandy lands (changed 0.47 % within 1990–2000; 0.46 % within 2000–2005; and 0.15 % within 2005–2011) were relatively more stable than smaller patches such as forest lands (changed 0.35 % within 1990–2000; 0.01 % within 2000–2005; and 0.02 % within 2005–2011), salinized lands (changed 0.57 % within 1990–2000; 0.61 % within 2000–2005; and 1.23 % within 2005–2011), and residential sites (changed 0.77 % within 1990–2000; 0.1 % within 2000–2005; and 0.44 % within 2005–2011). The forest lands play an important role in ecosystem service and have generally high service values. The estimated sizes were relatively small. The considerable decrease in grasslands, wetlands, and the concomitant increase in farm lands resulted from the rapid spread of commercial agriculture and inadequate regulations for wetland protection.

Changes of ecosystem service values

By utilizing the value coefficients (Table 2) and areas of land-use categories (Table 3), the ecosystem service values of land-use category k, values of ecosystem service function type f, and the total ecosystem services values of the Yanqi Basin in 1990, 2000, 2005, and 2011 were obtained through programming in ArcView GIS software following the Eqs. (1)–(3). These results are shown in Tables 4 and 5.

According to Table 4, the total ecosystem services values of the Yanqi Basin increased from about 9,374.66 million Yuan in 1990 to about 10,450.52 million Yuan in 2000, declined from about 10,450.52 million Yuan in 2000 to 9,964.20 million Yuan in 2005 and to about 9,870.77 million Yuan in 2011. These data confirm a cumulative increase, about 496.11 million Yuan in ecosystem service over the 21-year study. The change in ecosystem service values caused mainly by the increase of the total area of wetlands, water body from 1990 to 2000, the decrease from 2000 to 2005 and to 2011, and the increase of the total area of farmlands from 1990 to 2011, which have greater ecosystem service values in the study area. Overall, the net increase in ecosystem service values was about 1,075.85 million Yuan from 1990 to 2000, and the decline in ecosystem service values was about 486.31 million Yuan from 2000 to 2005, about 93.44 million Yuan from 2005 to 2011, mainly due to the decreasing areas of water body, wetlands. The decline of ecosystem service values caused by

Table 2 Ecosystem service value of unit area of different land-use categories in the Yanqi Basin (in Yuan per hectare per area)

	Water body	Wetland	Sandy land	Salinized land	Grassland	Farm land	Forest land	Residential site	Barren land
Gas regulation	0	1,742.6	0	15.0	673.7	484.0	1,940.1	0	27.0
Climate regulation	445.3	16,554.4	0	0	700.6	861.6	1,827.8	0	58.4
Water supply	19,749.1	15,005.4	26.5	255.0	682.6	580.9	1,836.8	0	31.4
Soil formation	9.7	1,655.4	17.7	1.1	1,006.0	1,413.4	1,805.4	0	76.4
Waste treatment	17,619.3	17,599.9	8.8	360.6	592.8	1,587.7	772.5	0	116.8
Biodiversity protection	2,410.6	2,420.2	300.8	21.0	839.8	687.3	2,025.4	0	179.6
Food production	96.8	290.4	8.8	78.2	193.1	968.1	148.2	0	9.0
Raw material	9.7	67.8	0	7.0	161.7	96.8	1,338.3	0	18.0
Recreation and culture	4,201.5	5,372.9	8.8	99.0	390.7	9.7	934.1	82.6	107.8
Total	44,542.0	60,709.0	371.4	836.9	5,241.0	6,689.5	12,628.6	82.6	624.4

Source: Xie et al. 2008; Mamattursun et al. 2010

the decrease of wetlands and water body was about 120.17 million Yuan and 71.70 million Yuan, respectively.

Because of the comparatively large area and large coefficient values, the ecosystem service values produced by water body were the highest among the nine land-use categories, about 45.55 % of the total value. Because of the large coefficient value, the value of ecosystem service produced by wetlands was the secondary among the nine land-use categories, about 34.37 % of the total value. Because of the comparatively large area and large coefficient value, the value of ecosystem service produced by farmlands were also

relatively high, and about 11.10 % of the total value. Grasslands also generated higher service values (about 6.90 %) due to its large coefficient value. The aggregated ecosystem service values of water body, wetlands, grasslands, farmlands, and barren lands were about 99.25 % of the total value, indicating that these land-use categories play important roles in the ecosystem service of the study area.

The estimated 51,741.54-ha loss of grasslands, 55,258.11-ha loss of barren lands, and 2,288.88-ha loss of forest lands were converted mainly to farmlands, wetlands, residential sites, and sandy lands, and the subsequent loss in the ecosystem service seems to result

Table 3 Land-use patterns of the Yanqi Basin in 1990, 2000, 2005, and 2011

		Water body	Wetland	Sandy land	Salinized land	Grassland	Farm land	Forest land	Residential site	Barren land
1990	ha	95,862.06	53,069.76	78,188.58	5,687.01	123,349.95	155,622.78	2,864.98	9,408.97	199,713.78
	%	13.25	7.33	10.80	0.79	17.04	21.50	0.40	1.30	27.59
2000	ha	117,868.68	57,383.55	74,773.44	9,836.19	58,276.53	185,588.46	376.11	14,989.68	204,674.23
	%	16.29	7.93	10.33	1.36	8.05	25.64	0.05	2.07	28.28
2005	ha	103,786.74	56,553.21	78,130.05	14,239.89	73,337.04	204,029.55	459.54	15,688.36	177,542.55
	%	14.34	7.81	10.79	1.97	10.13	28.19	0.06	2.17	24.53
2011	ha	98,559.91	54,250.83	79,144.47	5,322.51	71,608.41	250,994.88	575.10	18,855.09	144,455.67
	%	13.62	7.50	10.94	0.74	9.89	34.68	0.08	2.61	19.96
1990–20050	ha	22,006.62	4,313.79	−3,415.14	4,149.18	−65,073.42	29,965.68	−2,487.87	5,580.71	4,960.45
2000–20055	ha	14,081.94	−830.34	3,356.61	4,403.70	15,060.51	18,441.09	83.43	698.62	−27,131.68
2005–20111	ha	−5,226.83	−2,302.38	1,014.42	−8,917.38	−1,728.63	45,965.33	115.56	3,166.79	−33,086.88
1990–20111	ha	2,697.85	1,181.07	955.89	−364.50	−51,741.54	95,372.10	−2,288.88	9,446.12	−55,258.11

Table 4 Ecosystem service value of the Yanqi Basin in 1990, 2000, 2005, and 2011

ESV$_f$/10^4 (Yuan/year)		Water body	Wetland	Sandy land	Salinized land	Grassland	Farmland	Forest land	Residential site	Barren land	Total
1990		426,988.79	322,181.21	2,903.92	475.95	64,647.71	104,103.86	3,616.81	77.72	12,470.13	937,466.08
2000		525,010.67	348,369.79	2,777.09	823.19	30,542.73	124,149.40	474.97	123.81	127,779.86	1,045,051.52
2005		462,286.90	343,328.88	2,901.75	1,191.74	38,435.94	136,485.57	574.26	129.59	11,085.76	996,420.38
2011		439,005.55	329,351.36	2,939.43	445.44	37,529.97	16,7903.03	726.27	155.74	9,019.81	987,076.60
1990–2000	10^4 Yuan	98,021.89	26,188.59	−126.84	347.25	−34,104.98	20,045.54	−3,141.83	46.10	309.73	107,585.44
	%	22.96	8.13	−4.37	72.96	−52.76	19.26	−86.87	59.31	2.48	11.48
2000–2005	10^4 Yuan	62,723.78	−5,040.91	124.67	368.55	7,893.21	12,336.17	99.29	5.77	−1,694.10	−48,631.14
	%	−11.95	−1.45	4.49	44.77	25.84	9.94	20.90	4.66	−13.26	−4.65
2005–2011	10^4 Yuan	23,281.35	13,977.54	37.68	−746.30	−906.00	31,417.46	152.01	26.16	−2,065.95	−9,343.78
	%	10.00	−4.07	1.30	62.62	−2.36	23.02	26.47	20.19	−18.64	−0.94
1990–2011	10^4 Yuan	12,016.76	7,170.16	35.50	−30.51	−27,117.74	63,799.17	−2,890.54	78.02	−3,450.32	49,610.52
	%	2.81	2.23	1.23	−6.41	−41.95	61.28	−79.92	100.39	−27.67	5.29

in a massive loss in the total ecological values of the study area per year.

Influence of land-use change on ecosystem functions

According to Eq. (2), the ecosystem service values provided by individual ecosystem functions (ESV$_f$) were also estimated (Table 5). The contributions of each ecosystem function to overall values of ecosystem service in each year were ranked based on their estimated ESV$_f$, while the overall rank of each function was based on the average value of each ESV$_f$ through the study period.

The change in the contributions of each ecosystem function to the total values of the ecosystem service is presented in Table 5 by an upwards arrow "↑" for increase in contribution, downwards arrow "↓" for decrease in contribution, and a dash "–" for no change. In general, the changes of contribution of each ecosystem function to the total service values were small, and the rank order remained nearly the same. The overall rank order for each ecosystem function based on their contributions to overall values of ecosystem service were as follows from high to low: waste treatment, water supply, climate regulation, recreation and culture, biodiversity protection, soil formation, gas regulation, food production, and raw material. Contribution of waste treatment was the highest (>31.70 %), followed by water supply (about 30 %). Contribution of raw material was the lowest (about 0.40 %).

Among the nine top-ranked ecosystem functions, the contribution of gas regulation, soil formation, biodiversity protection and food production increased during 1991–2011, while the contribution of climate regulation, water supply, waste treatment, and recreation, and culture decreased during the same period.

Ecosystem sensitivity analysis

As shown in Table 6, the percentage change in estimated total ecosystem service values and the coefficient of sensitivity resulting from a 50 % adjustment in the value of the coefficient were calculated using Eq.(4).

In all cases, CS was far less than unity and often near zero. This confirmed that the total ecosystem service values estimated in this study area were relatively inelastic with respect to the value coefficients. CS for water body, wetlands, grasslands, and farmlands were relatively bigger; CS for water body was the highest, about 0.456,

Table 5 Value of ecosystem service functions in 1990, 2000, 2005, and 2011

		Gas regulation	Climate regulation	Water supply	Soil formation	Waste treatment	Biodiversity protection	Food production	Raw material	Recreation and culture
1990	ESV$_f$	26,193.56	115,862.70	287,917.61	45,464.78	297,152.68	63,538.12	20,252.28	4,700.55	76,383.83
	%	2.79	12.36	30.71	4.85	31.70	6.78	2.16	0.50	8.15
	Rank	7	3	2	6	1	5	8	9	4
2000	ESV$_f$	23,548.57	121,580.92	344,805.57	43,472.34	344,431.49	65,972.92	22,232.03	3,667.85	85,339.53
	%	2.25	11.63	32.04	4.16	32.96	6.31	2.13	0.35	8.17
	Rank	7	3	2	6	1	5	8	4	9
2005	ESV$_f$	25,260.59	122,080.09	307,899.94	47,256.98	321,830.69	64,549.43	24,155.83	4,036.01	79,350.81
	%	2.54	12.25	30.90	4.74	32.30	6.48	2.42	0.41	7.96
	Rank	7	3	2	6	1	5	8	9	4
2011	ESV$_f$	26,935.75	121,789.21	296,425.46	53,103.85	315,225.23	65,255.94	28,460.88	4,391.67	75,488.62
	%	2.73	12.34	30.03	5.38	31.94	6.61	2.88	0.45	7.65
	Rank	8	3	2	6	1	5	7	9	4
Overall		7	3	2	6	1	5	8	9	4
Tendency		–	↑	↓	↑	↓	↑	↑	↑	↓

Unit for ESV$_f$ is 10^4 Yuan/year

because of the large areas and high service value coefficients. Although the areas of wetlands were small, CS for wetlands was relatively large because of their high value coefficients. CS for wetlands decreased from 0.344 in 1990 to 0.333 in 2000, increased to 0.345 in 2005, and decreased to 0.334 in 2011; while that for the CS for farm lands increased from 0.111 in 1990 to 0.119 in 2000, 0.137 in 2005, and 0.170 in 2011. The CS for grasslands was still relatively big, which decreased from 0.069 in 1990 to 0.029 in 2000 and increased to 0.039 in 2005, because of its large area and higher ecosystem service values.

The sensitivity analysis indicated that the estimations in this study area were robust in spite of uncertainties on the value coefficients.

Adjustment to the value coefficients for sandy lands and salinized lands had very little impact on the estimated ecosystem service values (<0.20 % change for a 50 % change in value coefficient). Correspondingly, the CS ranged from 0.001 to 0.003. Changes in the total values of ecosystem service ranged from 1.461 to 25.119 %, and the CS fluctuated from 0.029 to 0.502 when the coefficients for water body, wetlands, grasslands, and farmlands were adjusted, respectively. However, when

Table 6 The percentage change in estimated total ecosystem service value and coefficient of sensitivity resulting from adjustment of ecosystem valuation coefficients (VC)

Change of value coefficient	1990		2000		2005		2011	
	Percentage	CS	Percentage	CS	Percentage	CS	Percentage	CS
Water body VC±50 %	22.774	0.456	25.119	0.502	23.197	0.464	22.225	0.445
Wetland VC±50 %	17.184	0.344	16.668	0.333	17.228	0.345	16.691	0.334
Sandy land VC±50 %	0.155	0.003	0.133	0.003	0.146	0.003	0.149	0.003
Salinized land VC±50 %	0.025	0.001	0.039	0.001	0.060	0.001	0.023	0.001
Grassland VC±50 %	3.448	0.069	1.461	0.029	1.929	0.039	1.902	0.038
Farm land VC±50 %	5.552	0.111	5.940	0.119	6.848	0.137	8.508	0.170
Forest land VC±50 %	0.193	0.004	0.023	0.001	0.029	0.001	0.037	0.001
Residential site VC±50 %	0.004	0	0.006	0	0.007	0.001	0.008	0.001
Barren land VC±50 %	0.665	0.013	0.612	0.012	0.556	0.011	0.457	0.009

the value coefficients for water body were changed ±50 %, the total ecosystem service values changed from ±22.225 to ±25.119 % and the CS fluctuated from 0.445 to 0.502. When the value coefficients for wetlands, grasslands, and farmlands were changed ±50 %, the total ecosystem service values changed from ±16.668 to ±17.228 % for wetlands, from ±1.461 to ±3.448 % for grasslands and from ±5.551 to ±8.508 % for farmlands, and the CS fluctuated from 0.333 to 0.345 for wetlands, from 0.029 to 0.069 for grasslands, and from 0.111 to 0.170 for farmlands, respectively. Though the CS is less than one, the analyses reflect that water body, wetlands, grasslands, and farmlands play an important role in the total ecosystem service of the study area and emphasize on the significance of water body, wetlands, grasslands, and farmlands due to the huge ecological functions.

Discussions

This research showed that satellite data are useful and inexpensive for estimating changes in the value of ecosystem services at the local level. In many cases, remote sensing from satellites may be the only economically feasible way to regularly gather land-use information with high spatial and temporal resolution over large areas (Andrew and Andre 2000; Ren 2007). With the extensive field survey for land use during 2012 and the interview with local experts, farmers, and staff in the Yanqi Basin for historical land-use data, the use of satellite images are demonstrated to be an effective means for acquiring information on land-use changes. In arid zone basins, like the Yanqi Basin, extensive field-based survey methods can be difficult and expensive to implement due to restricted accessibility. In such areas, a limited amount of field sampling combined with satellite data can facilitate reasonably accurate large-scale analysis at relatively little cost (Zhao et al. 2007). Ecosystem service values by Costanza (1997) and Xie et al. (2008) which represented the most comprehensive set of valuation coefficients available to us for absolutely accurate coefficients are often less critical for land-use change analyses than time-specific analyses of the value of ecosystem service because coefficients tend to affect estimates of directional change less than estimates of the magnitude of ecosystem value at a specific point in time (Kreuter et al. 2001). Nevertheless, in order for the kind of ecosystem service analysis that we conducted to become more

meaningful for policy formulation affecting land use, it is imperative to obtain value coefficients for ecosystem service that more accurately reflect local conditions. One approach to implement this in a pragmatic way would be to identify benchmark ecosystem service values for dominant ecosystem types within a region and then to evaluate the ecosystem services provided at specific locations relative to the representative benchmark (Kreuter et al. 2001). Because ecosystem service is generally not traded directly, indirect valuation techniques will be needed to obtain location-specific values for ecosystem service. Once such coefficients are determined, the values of ecosystem service can be calculated at larger regional scales though the use of remotely sensed data and GIS tools to classify land into representative ecosystems for which benchmark service values has been determined. In using such an approach, it is important to realize that absolutely accurate coefficients are often less critical for land-use change analyses than time-specific analyses of the value of ecosystem services because coefficients tend to affect estimates of directional change less than estimates of the magnitude of ecosystem values at a specific point in time (Yoshikawa et al. 2010; Li et al. 2007, 2010).

During the recent 20 years, rapid land-use changes have taken place in the Yanqi Basin. Land-use change is commonly defined as a human-induced process that has great consequences for land and related ecosystems. Man has always affected and modified the natural landscape at different scales and to different extents (Peng et al. 2005; Otto et al. 2007). Changes in population density and agricultural intensification are the most important driving forces of land-use change and the leading factors of regional man–land relationships (Tanrivermis 2003). The increase of population most likely resulted in the other land-use patterns being converted to agricultural land, and also induced agricultural restructuring (Shao et al. 2005). In the Yanqi Basin, farmers cultivated lands by destroying wetlands and grasslands, resulting in wetlands and water body being converted to farmland. As a result, the total annual ecosystem service values in the Yanqi Basin have declined because of high ecosystem service values of wetlands and water body (Mamattursun et al. 2010).

As shown in Fig. 3, from 1985 to 2010, the population in the Yanqi Basin grew rapidly. In order to solve the food problem for the increased population, wetlands, water body, grasslands, and forest lands were converted to farmlands over the study period. An

expansion of the artificial oases was urgently needed in the Yanqi Basin to satisfy people's livelihood demands. This has increased with the increasing population. People's livelihood demands have changed the original land use (Mamattursun et al. 2010).

Economic reforms implemented in China since the end of the 1970s have caused impressive growth of agricultural production (Nico et al. 2007). Economic developments of the Yanqi Basin, mainly based on agriculture and crop production, play the most important role in the local livelihoods and economic development of the area. Crop production of the Yanqi Basin increased from 942.3×10⁴ t in 1971 to 3,000,425×10⁴ t in 2010 (Fig. 3). Wetlands, water body, forests, and grasslands were converted to farmlands for growing crops. This resulted in the wetland degradation which has most important ecosystem service functions. Future agricultural growth is also threatened by improper expansion of farmland.

Another driving force behind the land-use change is closely related to shifts in government policies (Gopal et al. 2006; Cocklin et al. 2007; Clementa and Amezaga 2008). Local governments are emerging as major players in translating the land policy established by the Chinese Central Government into local patterns of land use (Skinner et al. 2001). Since China initiated economic reforms and an Open Door Policy in 1978, tremendous land-use change has occurred in many regions of China. The conversion of farmland to nonagricultural land is considered one of the major features of land-use change. In 1992, China began to adopt a market economy, causing major change in land use in the study area, especially where crop plantation is intense. To gain high economic returns, farmers often adjusted or switched their products and, therefore land-use, to meet changing markets, leading to frequent conversions between land types. Furthermore, two principal laws govern farmland preservation

efforts in China: the Basic Farmland Protection Regulation, passed in 1994, and the New Land Administration Law, enacted in 1999.

In 1999, the Chinese government introduced the Slope Land Conversion Program at the national level, which was later named Cropland Conversion Program at the provincial level, to minimize cultivation of crops by encouraging farmers to plant trees and grass instead, hence, decreasing farmland. This program provided compensation in terms of money and food grain for up to 8 years (Ostwalda and Chen 2006). The existing institutional and policy structure created incentives for both insufficient farmland retention and excessive farmland conversion, resulting in significant inefficiencies in land use (Lichtenberg and Ding 2008). In addition, technological innovations and advances in irrigation and management systems have also contributed to the rapid change in land use (Luo et al. 2005). Evidently, land-use change in the study area is closely related to human-induced policy shifts. Given the rapidity of land-use changes, it is critical that additional studies should be undertaken to evaluate these alternative policies, focusing on what their effects might be and how these might be implemented (Mamattursun et al. 2010).

In this study area, land-use changes have a great effect on the ecosystem services. Based on the estimated size of eight land-use categories and ecosystem services values, we determined that the total annual ecosystem service values in the Yanqi Basin have increased by 5.293 % between 1990 and 2011. This increase in ecosystem services is largely attributable to the 2.81 % growth of water body, 2.23 % growth of wetlands, and 61.28 % growth of farmlands. The high rate of growth of such services will undoubtedly have serious negative ecological consequences in the long term.
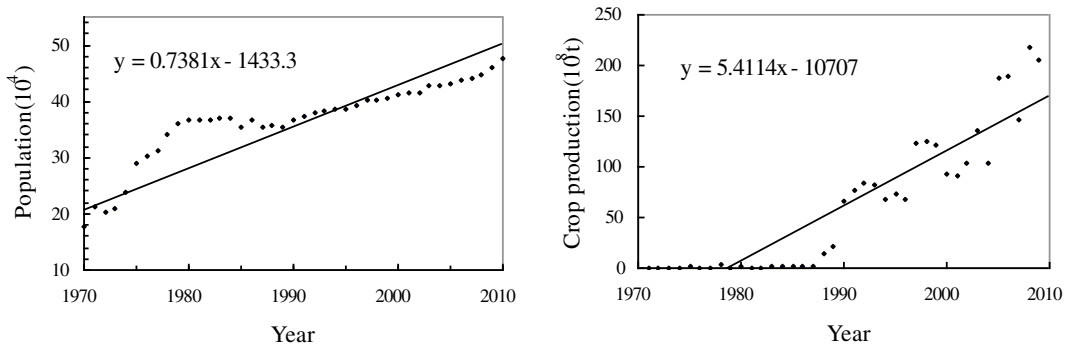

Fig. 3 Population and cropland production change in the Yanqi Basin 1950–2005

The argument highlighted is that, in the future land-use policy formulation, the conservation of wetlands should take precedence over the single-minded, uncontrolled reclamations for economic purposes. Rigorous environmental impact analyses must be conducted, and great importance has to be attached to wetland protection in the Yanqi Basin. A compromise between economic development and ecological protection must therefore be addressed. Land-use changes can limit the capacity of an ecosystem to provide more ecosystem services on a sustained basis and can result in long-term degradation of environmental quality (Laurance 1999; Portela and Rademacher 2001). From the standpoint of economic policy, local people should be helped to escape from poverty as soon as possible. Local people cannot be expected to bear poverty in the name of environmental protection. Environmental protection should be based on the economic profits of local people. With the guarantee of the income of local people, they could possibly attend to environmental protection. A reasonable land-use plan should be made with emphasis on protecting wetlands, water body, and grasslands which have high ecosystem service values, so as to maintain a balance between economic development and ecosystem health in the future.

Conclusions

By analyzing and discussing the changes of ecosystem service values based on land use in the Yanqi Basin from 1990 to 2011, the conclusions are as follows:

(1) The total ecosystem service values of the Yanqi Basin were about 9374.66 million Yuan in 1990, 104,505.52 million Yuan in 2000, 9,964.20 million Yuan in 2005, and 9,870.77 million Yuan in 2011. The net increase in ecosystem service values were about 1,075.85 million Yuan from 1990 to 2000, and the decline in ecosystem service values were about 486.31 million Yuan from 2000 to 2005, and 93.44 million Yuan from 2005 to 2011, which was mainly caused by the decreasing areas of wetlands and water body. The decline of ecosystem service values caused by the decrease of wetlands and water body was about 71.70 million Yuan and 120.17 million Yuan, respectively. The aggregated ecosystem service values of water body, wetlands, grasslands, and farmlands were about 99.25 % of the total value, indicating that these land-use categories play important roles in ecosystem services of the study area.

(2) Waste treatment and soil formation were the top two ecological functions with high service value, contributing about 61.70 % of the total service values. The overall rank order for each ecosystem function based on their contributions to overall value of ecosystem service was as follows, from high to low: waste treatment, water supply, climate regulation, recreation and culture, biodiversity protection, soil formation, gas regulation, food production, and raw material.

(3) The sensitivity analysis indicated that CS was far less than unity and often near zero, indicating that the total ecosystem service values estimated in this study area was relatively inelastic with respect to the value coefficients. The estimation in this study area was robust in spite of uncertainties on the value coefficients.

Changes in population densities, agricultural intensifications, and economic policies were the most important driving forces of land-use changes and the leading factors of regional man–land relationships. Considering this fragile and arid environment, the suggestion is that human activities in the Yanqi Basin should be pursued with caution because environmentally positive human activities in the study area could be changed into environmentally negative human activities. This trend would be significant not only to economic activities but also to eco-environmental protection and sustainable development of this area.

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