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Assessing the changes in land use and ecosystem services in an oasis agricultural region of Yanqi Basin, Northwest China

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Abstract The Yanqi Basin, one of the most productive agricultural areas, has a high population density in Xinjiang, Northwest China. Land use changes, mainly driven by oasis expansion, significantly impact ecosystem services and functions, but these effects are difficult to quantify. The valuation of ecosystem services is important to clarify the ecological and environmental changes caused by agriculturalization of oasis. This study aimed to investigate variations in ecosystem services in response to land use changes during oasis agricultural expansion activities in the Yanqi Basin from 1964 to 2009. The methods used were based on formula of ecosystem service value (ESV) and ESV coefficients. Satellite data were combined with the ESV coefficients to quantify land use changes and ecosystem service changes in the study area. Sensitivity analysis determined the effect of manipulating the coefficients on the estimated values. The results show that the total ESVs in the Yanqi Basin were $1,674, $1,692, $1,471, $1,732, and $1,603 million in 1964, 1973, 1989, 1999, and 2009, respectively. The net deline in ESV was $71 million in the past 46 years, but the ESVs of each types of landscape changed significantly. The aggregated ESVs of water areas and wetlands were approximately 80 % of the total ESV. Water supply and waste treatment were the two largest service functions and contributed approximately 65 % of the total ESV. The estimated ESVs in this study were elastic with respect to the value coefficients. Therefore, the estimations were robust in spite of uncertainties on the value coefficients. These significant changes in land use occur within the entire basin over the study period. These changes cause environmental problems, such as land degradation, vegetation degeneracy, and changes in aquatic environment.

Keywords Oasis expansion · Land use change · Ecosystem services value · Remote sensing · Yanqi Basin

Introduction

In past recent years, land use change and ecosystem service valuation have become a hot topic in global change research (Assessment 2005; Barral and Oscar 2012; De Groot et al. 2010). Ecosystems on the Earth are complex, life-supporting systems, and human sustainable development must protect these supporting system and maintain the sustainability of ecosystem service function (Benayas et al. 2009; Nelson et al. 2009; Pasari et al. 2013). Humans benefit from a multitude of resources and processes that are supplied by ecosystems. These benefits are collectively known as ecosystem services, which include various products, such as clean drinking water, and processes, such as the

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decomposition of wastes (Raudsepp-Hearne et al. 2010; Yoshida et al. 2010). Ecosystem services imply natural environmental conditions, and their effectiveness is formed and sustained by the ecosystem and its ecological processes, of which the humans rely for survival (Lasslop et al. 2010; Zavaleta et al. 2010). Functions and benefits of the ecosystem are not only important components of life-supporting system but also basic elements of sustainable development of society and environment (Bennett et al. 2009; de Bello et al. 2010). Evaluating the value of an ecosystem is necessary for its introduction into the social economic system and marketization. This evaluation is also an important measure to attract social attention to environmental and ecosystem conservation (Hubacek and Kronenberg 2013).

In recent decades, the quantification of ecosystem service values (ESVs) has been identified as a key area for investigation in related academic fields (De Groot et al. 2010; Gómez-Baggethun et al. 2010; Huang and Ma 2013). Costanza et al. (1997) attempted to estimate the global biospheric value of 17 ESVs provided by 16 dominant global biomes since 1997. Domestic and foreign scholars have conducted numerous studies on ESVs (Li et al. 2010a; Xu et al. 2003). White et al. (1997) calculated the relative economic values of the otter *Lutra lutra* and the water vole *Arvicola terrestris* and suggested that public profile may be as important as rarity or degree of threat in determining a species' relative economic value. Guo et al. (2001) estimated the annual economic value of some ecosystem services of forest ecosystems using both simulation models and geographic information system (GIS), which helped in analyzing the effect of ecological factors (vegetation, soil, and slope) on ecosystem functions. Xie et al. (2003) extracted the equivalent weight factor of ecosystem services per hectare of terrestrial ecosystems in China and modified the value coefficient (VC) of Chinese ecosystem. Other studies have focused on how land use changes are coupled to ecosystem services (De Groot 2006; Kreuter et al. 2001; Wang et al. 2006; Zhao et al. 2013). Li et al. (2010b) assessed the changes in ecosystem services in response to land use changes caused mainly by climate change and human activities on the Zoige Plateau. Liu et al. (2012) also investigated changes in ecosystem services in response to land use changes caused primarily by human activities in Taiyuan City. These studies have shown that dramatic land use changes often have a significant negative impact on ecosystems and the goods and services. The combined effect of inadequate management and altered natural regimes has degraded the capacity of ecosystems to supply services. These studies were to promote the broad understanding of human dependence on nature and to raise political support for conservation.

In arid areas, an oasis is an isolated area of vegetation in a desert that typically surrounds a spring or similar water source (Jia et al. 2004). Large oases also provide habitats for animals and even humans. Although oases constitute only 4 to 5 % of the total area of the region, over 90 % of the population and over 95 % of social wealth are concentrated within these oases (He et al. 2013; Zhou and Li 2011). 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 ESVs and found that land use changes significantly affect ecosystem processes and services. Wu et al. (2007) analyzed the land use changes and ESVs, including the spatial heterogeneity based on land use data. Feng et al. (2012) assessed the impacts of land use changes on ESV during large-scale land development and provided key information for both economic development and policy makers for eco-environmental protection. Related studies (Geist et al. 2006; Huang et al. 2010; Su et al. 2006) showed that climate change and irrational human activities over the past 60 years have caused desert expansion and soil degradation, resulting in salinization of soils in the oases of the arid inland basin. Stability of oasis ecosystems is affected by both desertification in the oases–desert ecotone and salinization in the interior of the oases (Shen and Chen 2010; Feng et al. 2011). Studies on land use change in arid oasis regions and its effects on oasis ecosystem service values are important because they are theoretically and practically essential for sustainable development and stability of oases. In each of these studies, researchers have obtained insights that can provide important guidance for land managers.

The Yanqi Basin of Xinjiang, which is located in the interlocked agro-pasturing area of Northwest China, is an eco-environmental fragile area. The Yanqi Basin has become a productive agricultural area in Xinjiang Province after the inititiation of agricultural activities in the 1950s (Wang and Wang 2013). In the past 60 years, the population has increased from 5.03×10^4 in 1949 to 49.07×10^4 in 2010. Since then, rapid economic development has occurred in this region. Thus, extensive and intensive increases in land use are expected, and the consequent changes in landscape patterns and functions are expected to have significant impacts on the ecosystem services and sustainable development (Wang and Wang 2013). Many studies have focused on oasis farmland salinization, Bosten Lake salinization, water resources, and wetland resources in the Yanqi Basin (Brunner et al. 2007; Brunner et al. 2008; Wang 2013a, b). However, little attention has been given to the effect of land use change on ESV and environment in the past 60 years.

This study aims to (1) assign specific VCs for the Yanqi Basin and determine whether they can be used to evaluate changes in ecosystem services in the study area, (2) estimate variations in ESV in response to land use changes from 1964 to 2009, and (3) provide basic background data and scientific basis for the protection and restoration of the regional ecological environment and sustainable development.

Study areas

The Yanqi Basin of Xinjiang, with an altitude of 1,000 m above sea level (a.s.l.), is located in northwestern China and covers approximately 10,000 km^2, but the irrigated area is only approximately 13,000 ha (Fig. 1). The weather in this area is hot and dry during summer, but cold and snowy during winter. Maximum air temperatures and relative humidity occur in July (38.93 °C) and December (73.67 %), whereas minimum air temperatures and relative humidity occur in January (−31.93 °C) and April (36.67 %). The annual rainfall is 71.28 mm. The class A pan evaporation rate is 2,120.9 mm per year, which is 30 times more than the annual precipitation, according to the Yanqi county weather station. Summer precipitation comprises approximately 56.8 % of the total, whereas spring and fall receive almost equal amounts of precipitation at 18.5 and 18.98 %, respectively. The Yanqi Basin has three main tributaries, namely, Kaidu River, Huangshui River, and Qingshui River, all of which originate from the Tianshan Mountains. The Kaidu River originates from Shamingl Mountain of the Middle Tianshan Mountains. The Kaidu River flows through the large and small Uldus Basins, carves southeast of Elbin Mountain, enters the Yanqi Basin (1,200 m a.s.l.), and forms Bosten Lake (1,045 to 1,049 m a.s.l.), which is the largest inland freshwater lake in China. Bosten Lake is approximately 1,000 km^2 (together with adjacent small lakes), and the water volume of Bosten Lake is 8,000 million m^3. The Kongque River, the only outflow of the entire basin, connects the Yanqi Basin and the Green Corridor of the Tarim Basin. Agriculture is the dominant land use, which mainly comprises sloping farmlands, orchards, crop fields, sparse forests, and residential land. Soils are generally sandy to clayey in texture, calcareous, and mostly classified as aridisols. Predominant soil types are brown desert, meadow, swamp, irrigation farming,

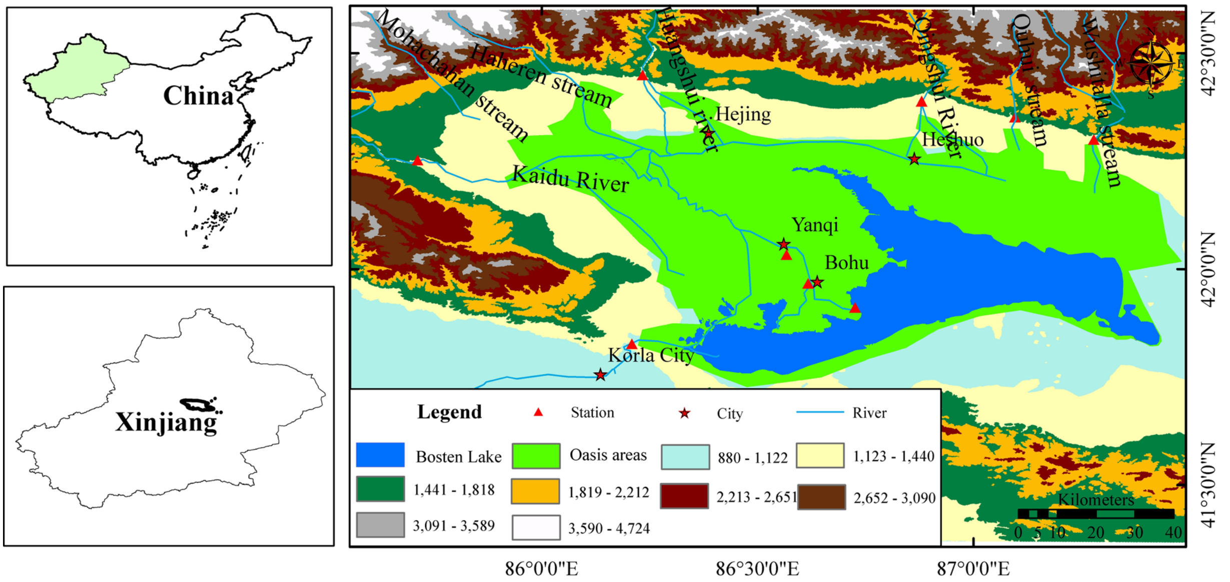

Fig. 1 Location of the study region in China

damp, saline, and weathered, which are typical for most arid and semi-arid soils (Wang 2013b). The presence of vermiculite suggests specific sites for potassium adsorption. The principal crops grown are wheat (*Triticum aestivum* L.), corn (*Zea mays* L.), beet (*Beta vulgaris*), and tomato (*Solanum lycopersicum*).

Methods and data sources

Data collection and preparation

In this study, multi-temporal and differential resolution satellite data were used to estimate land use changes. Data sources included the 1:100,000 topographic maps and data from the CORONA (1964), multi-spectral scanner (MSS) (1973), satellite thematic mapper (TM) (1989), Enhance thematic mapper (ETM) (1999), and advanced land observation satellite (ALOS) (2009) remote sensing (RS) data systems (Table 1). Although these satellite images were pre-georeferenced, they could not be compared directly because of the inconsistent coordinate reference system and resolution in each image (Hu et al. 2013; Liu et al. 2012; Zhao et al. 2004). To reduce potential position errors among the five data sets, a three-step image preparation procedure was used in the study, and the pixel size was retained at 30×30 m (Hu et al. 2013; Liu et al. 2012). Changes were identified for various land use types, including cropland, grassland, wetland, unused land (desert, alkaline land, and Gobi), water areas (lakes, rivers, drain, channels, and others), and urban land (Table 2). Land use maps were produced using a GIS data for 1964, 1973, 1989, 1999, and 2009 (Fig. 2). The compilation of landscape maps was based on a map generalization method. First, a classification system for the nine landscape patch types in the Yanqi Basin was formulated. The landscape maps of the Yanqi Basin for the five periods were then compiled by reclassifying the land use types into six patch types and combining the polygons with the same type with the support of ArcGIS10.0 software. To improve the processing precision of RS data interpretation, the land use information was investigated in 1999 and 2009, respectively (Table 3). In this study, kappa coefficients were used to assess the image classification in 1999 and 2009 (Poff and Hart 2002), with accuracy of 78.68 and 84.63 %, respectively (Table 3).

Information on water resource utilization and irrigation areas from 1950 to 2010 is based on available census data (The Institute of Water Conservancy, Bayingolin Mongol Autonomous Prefecture, 2010).

Table 1 Information on the data sources

Year	Data type	RS (path/row, collection time)
1964	CORONA (27×27 m)	KH-4A, 8/1964-9/1964
1973	MSS (79×79 m)	155/29, 1973-8-15
1989	1989 TM (30×30 m)	144/29, 1989-09-10; 143/29, 1988-01-26; 144/28, 1989-08-09; 144/30, 1989-09-10
1999	1999 ETM (30×30 m)	144/29, 1999-07-04; 144/28, 1999-07-04; 144/30, 1999-10-17
2009	ALOS (15×15 m)	143/29, 2009-08-06; 144/29, 2000-08-29; 144/30, 2009-08-29

Note Year-Month-Day

Table 2 Land use category in Yanqi Basin

Categories	Definition
Cropland	Irrigable land and vegetable field orchard
Grassland	Natural grassland, bush forest and protection, and man-made grassland
Water areas	Rivers, reservoir fishery, and lakes
Wetland	Mainly mangrove marsh
Unused land	Lands unused or difficult for using
Urban land	Land used for industrial, commercial, residential, and transportation ends

Methods

Assignment of ESVs

Costanza et al. (1997, 2002) classified the global biosphere into 16 types of ecosystems and 17 types of ecosystem functions and estimated the ESV of each type. Many Chinese scientists think that there are several shortcomings in direct adaptation of the methods; for instance, some ecosystem services have been insufficiently valuated or even ignored via using Costanza's method. To fill this gap, Xie et al. developed a new method or "unit" value for assessment of ecosystem services based on the basis of Costanza's method. Based on the parameters of Costanza et al., the equivalent weighting factor for ecosystem services per hectare was extracted by Xie et al. (2003) for terrestrial ecosystems in China, and these factors were used to correct the

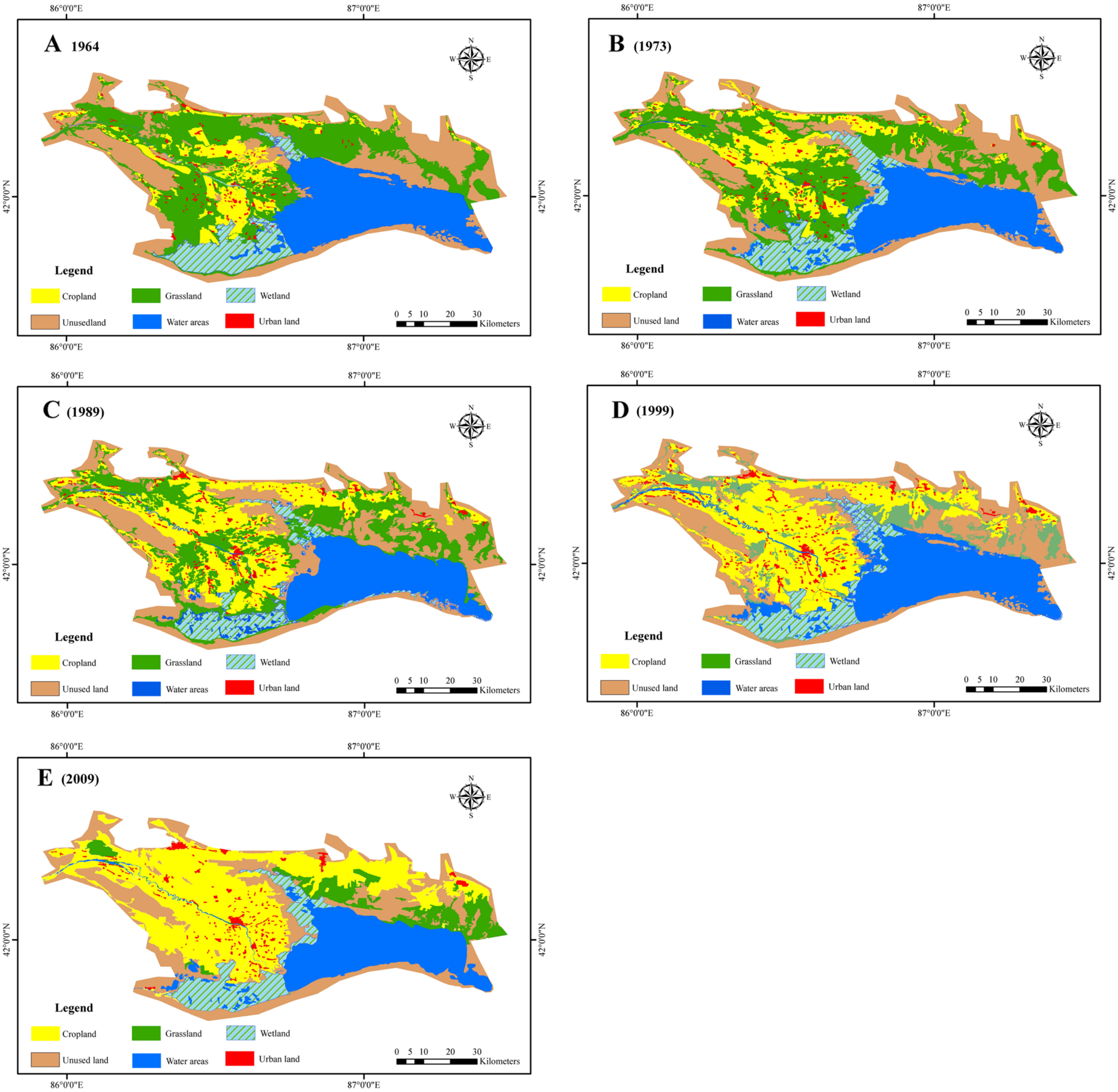

Fig. 2 Spatial pattern of land use in Yanqi basin from 1964 to 2009

VC for Chinese ecosystems. ESVs per unit area for each land use type were assigned in the Yanqi Basin based on the nearest equivalent ecosystems (e.g., woodland equates to forest), which was suggested by Xie et al. The modification method, which was suggested by Su et al. (2006), was used to modify the coefficients

Table 3 Accuracy assessment of RS image classification in 1999 and 2009

Year	Validation method	Time	Sampling method	Number of samples	Kappa coefficient (%)
1999	Field investigation	1999.9.16–21	Random sampling in different land use types	156	78.68
2009	Field investigation	2009.8.13–19	Random sampling in different land use types	238	84.63

Note Year. Month. Day

obtained by Xie et al. (Table 4). The equivalent weighting factors in Table 4 can be applied to different regions across China by localizing the average natural food production (Xie et al. 2003). The factor for the economic value of average natural food production of cropland per hectare per year was set at 1.0. All other coefficients were adjusted based on this factor. In general, the proposed natural food production is one seventh of the actual food production. The Yanqi Basin has various land use types. The main crops include grain, vegetables, fruit, and cotton. The average price of these four crops per hectare per year was used, instead of only using food production. With Yanqi Basin, the average actual food production was 4,739 kg per hectare from 1964 to 2009 in the Yanqi Basin, and the average price for crops was 1.66 Yuan per kilogram in 2009. Thus, the ESV of one equivalent weight factor in Yanqi Basin was 1,123.82 Yuan per hectare (1.0×4,739×1.66/7). The ESV of each land use type in Yanqi Basin per unit area was then assigned (Table 5) based on the nearest equivalent ecosystems suggested by Xie et al. (2003).

The methods of ESV evaluation

After obtaining the ESV of one unit area for each land use category, the ESV can be calculated as

$$ESV_k = A_k \times VC_k \tag{1}$$

$$ESV = \sum_k A_k \times VC_k \tag{2}$$

$$ESV_f = \sum_k A_k \times VC_{kf} \tag{3}$$

where ESV_k, ESV, and ESV_f refer to the ESV of land use category k, total ESV, and ESV of function f, respectively; A_k is the area (ha) for land use category k; VC_k is the VC (USD ha^{-1} year^{-1}) for land use category k; and VC_{kf} is the VC (USD ha^{-1} year^{-1}) for land use category k with ecosystem service function type f.

The methods of sensitivity analysis

Relevant studies used coefficient of sensitivity (*CS*) to determine the dependency of changes in ESV on VC (Mendoza-González et al. 2012; Li et al. 2010a). To show the sensitivity between ESV and VC, the ecosystem VCs of all land use categories are individually adjusted by 50 %. *CS* can be calculated as (Kreuter et al. 2001; Liu et al. 2012)

$$CS = \left| \frac{\left(ESV_j - ESV_i\right)/ESV_i}{\left(VC_{jk} - VC_{ik}\right)/VC_{ik}} \right| \tag{4}$$

where i and j represent the initial and adjusted values, respectively, and k is the land use category. If $CS>1$, then the estimated ecosystem value is elastic with respect to that coefficient. Thus, VC should be accurately defined. If $CS<1$, then the estimated ecosystem value is considered inelastic, and the results of the ESV calculations are reliable even if the VC value has relatively low accuracy (Kreuter et al. 2001).

Results and analysis

Land use and land cover changes

The land areas in different periods and the spatial changes were calculated using RS and GIS (Fig. 2). The statistical data of the land use changes are shown in Table 6. Grassland comprised the largest portion (>30 %) of the total area in 1964 (Table 6). This grassland was located in the northwest part of Yanqi Basin (Fig. 2). The grassland areas in Yanqi Basin dramatically decreased by 1,379.9 km^2 from 1964 to 2009. In 1964, grassland was the largest land type, but cropland became the largest land type in 2009. The changing trend in cropland was opposite to that in grassland. The cropland areas significantly increased by 1,663.5 km^2 from 1964 to 2009 in Yanqi Basin, with an average annual increase rate of 36.97 %. Wetlands and water areas are important in ecosystem services and have generally high service values (Li et al. 2010a). Water areas in Yanqi Basin were slightly reduced by 172.2 km^2 from 1964 to 2009, with an average annual decrease rate of 3.83 km^2 per year. The decrease in water areas can be attributed to the accelerated rates of cropland, whereas the increase in water areas can be attributed to the increase in wetland areas. Wetlands increased by 10 % from 1964 to 2009 at 0.9 km^2 per year. Wetlands increased by 20.2 % from 1964 to 1973 at 9.3 km^2 per year. From 1973 to 1989, wetlands decreased at 7.0 km^2 per year. From 1989 to 1999, wetlands decreased at 8.8 km^2 per year. From 1999 to 2009, wetlands increased at 15.7 km^2 per year. The area of urban land almost doubled from 1964 to 2009. From

Table 4 Equivalent weighting of ecosystem services per hectare of terrestrial ecosystems in China

ESV Function	Cropland	Forest	Grassland	Wetland	Water areas	Unused land
Gas regulation	0.5	3.5	0.8	1.8	0	0
Climate regulation	0.89	2.7	0.9	17.1	0.46	0
Water supply	0.6	3.2	0.8	15.5	20.4	0.03
Soil formation and protection	1.46	3.9	1.95	1.71	0.01	0.02
Waste treatment	1.64	1.31	1.31	18.18	18.2	0.01
Biodiversity protection	0.71	3.26	1.09	2.5	2.49	0.34
Food production	1	0.1	0.3	0.3	0.1	0.01
Raw material	0.1	2.6	0.05	0.07	0.01	0
Recreation and culture	0.01	1.28	0.04	5.55	4.34	0.01
Total	6.91	21.85	7.24	62.71	46.01	0.42

From Xie et al. (2003)

1964 to 2009, unused land decreased by 263.7 km^2, leaving 1,400 km^2 in 2009.

Thus, cropland, water areas, and unused land were the primary land use categories in terms of area and contributed to approximately 80 % of the total land use area in Yanqi Basin. Unused land was mainly concentrated in an area away from water sources, which showed less significant changes. Thus, the change in land use was strongly dependent on water distribution. Dramatic changes in land use types, such as an increase in cropland and grassland reduction, were close to water sources. The land use changes tended to diminish away from water sources, and unused land was converted to other land classes. Population growth and agricultural expansion significantly increased cropland and building land. The change in landscape pattern in Yanqi Basin reflected the effect of increasing intensity of human activity on ecological environment, thereby affecting ecosystem service and function.

Changes of ecosystem service values

The ESVs for each land use category and the total value for each study year (1964, 1973, 1989, 1999, and 2009) were calculated using the modified VCs and the area covered by each land use category (Table 7). According to Table 7, the total ESV of Yanqi Basin was approximately $1,674 million in 1964, $1,682 million in 1973, $1,471 million in 1989, $1,732 million in 1999, and $1,603 million in 2009. A net decline of $71 million in ESV was found over the 46-year period. In Yanqi Basin, the ESV of water area, which accounted for approximately 56.92 % of the total value in 1964 and 55.59 % of the total value in 1999, was the highest among the

Table 5 ESV of different land use types in the study area (USD·ha·a^{-1})

	Forest	Grassland	Cropland	Wetland	Water areas	Unused land
Gas regulation	587	134	84	302	0	0
Climate regulation	453	151	149	2,868	77	0
Water supply	537	134	101	2,600	3,422	5
Soil formation and protection	654	327	245	287	2	3
Waste treatment	220	220	275	3,049	3,053	2
Biodiversity protection	547	183	119	419	418	57
Food production	17	50	168	50	17	2
Raw material	436	8	17	12	2	0
Recreation and culture	215	7	2	931	728	2
Total	3665	1,214	1,159	10,519	7,717	70

Table 6 Areas of changes in different land use types in the Yanqi Basin from 1964 to 2009

Year	Statistic type	Land use/land cover						Total area
		Croplands	Grassland	Wetlands	Water area	Urban areas	Unused land	
1964	Area (km^2)	463.2	1,798.0	415.8	1,234.5	51.6	1,663.9	5,627
	%	8.23	31.95	7.39	21.94	0.92	29.57	100
1973	Area (km^2)	596.8	1,688.1	500.0	1,128.5	54.4	1,659.3	5,627
	%	10.61	30.00	8.88	20.05	0.97	29.50	100
1989	Area (km^2)	1,048.2	1,352.4	388.6	999.6	101.6	1,736.6	5,627
	%	18.63	24.03	6.91	17.76	1.81	30.86	100
1999	Area (km^2)	1,325.0	1,050.0	300.4	1,247.3	118.1	1,586.2	5,627
	%	23.55	18.66	5.34	22.17	2.10	28.19	100
2009	Area (km^2)	2,126.7	418.1	457.3	1,062.3	162.6	1,400.2	5,627
	%	37.79	7.43	8.13	18.88	2.89	24.88	100
1964–1973	Rate of LUCC change	14.84	−12.21	9.35	−11.78	0.31	−0.51	
1973–1989	Rate of LUCC change	28.21	−20.98	−6.96	−8.06	2.95	4.83	
1989–1999	Rate of LUCC change	27.68	−30.24	−8.82	24.77	1.65	−15.04	
1999–2009	Rate of LUCC change	80.17	−63.19	15.69	−18.50	4.45	−18.61	
1964–2009	Rate of LUCC change	36.97	−30.66	0.92	−3.83	2.47	−5.86	
	Change in area of LUCC (%)	359.14	−76.75	9.97	−13.95	215.40	−15.85	

five land use categories. The change in ESVs was mainly caused by the decrease in the total water area from 1964 to 1989 and 1999 to 2009, and the increase from 1989 to 1999. The overall net decline in ESVs was approximately \$182 million from 1964 to 1989, and the increase in ESVs was approximately \$191 million from 1989 to 1999.

By analyzing the formula for calculating the ESVs, various types of landscape changes were found, and their areas were consistent with the direction of land use change. ESV of cropland increased by approximately \$188 million from 1964 to 2009, followed by that of wetlands, which increased by approximately \$43 million. ESV of grassland decreased from \$218 million in

Table 7 ESVs in 1964, 1973, 1989, 1999, and 2009

Land use	Cropland			Grassland			Wetland			Water area			Unused land			Total
	ESV	%	C	ESV/10^6	%	C	ESV	%	C	ESV	%	C	ESV	%	C	
1964	54	3.21	0.39	218	13.04	0.41	437	26.13	3.54	953	56.92	2.59	12	0.70	0.02	1,674
1973	86	5.13	0.39	187	11.11	0.41	526	31.27	3.52	871	51.79	2.58	12	0.70	0.02	1,682
1989	150	10.18	0.44	145	9.85	0.46	393	26.72	4.03	771	52.45	2.96	12	0.80	0.03	1,471
1999	192	11.09	0.38	68	3.95	0.39	498	28.73	3.42	963	55.59	2.51	11	0.64	0.02	1,732
2009	242	15.08	0.41	51	3.17	0.43	481	29.99	3.69	819	51.11	2.71	10	0.65	0.02	1,603
1964–1973	33	1.93	–	−31	−1.93	–	88	5.14	–	−82	−5.13	–	0	−0.01	–	8
1973–1989	63	5.05	–	−42	−1.26	–	−133	−4.55	–	−99	0.67	–	0	0.11	–	−211
1989–1999	42	0.91	–	−76	−5.90	–	105	2.02	–	191	3.13	–	−1	−0.16	–	261
1999–2009	50	3.99	–	−18	−0.79	–	−17	1.26	–	−143	−4.47	–	−1	0.01	–	−129
1964–2009	188	11.87	–	−168	−9.88	–	43	3.86	–	−134	−5.80	–	−1	−0.05	–	−71

Unit for ESV is 10^6 USD/year

ESV ecosystem service value

1964 to \$51 million Yuan in 2009. The ESV of water area decreased by \$134 million from 1964 to 2009. Oasis developments resulted in the replacement of the natural grass by cropland, thereby increasing cropland area, which resulted in the decrease in amount of water into the lake area (Fig. 3) and led to the reduction in ESVs. Nonetheless, from 1989 to 1999, the water area increased rapidly, which was mainly due to water leading into the basin, but started to decrease in 2000. Thus, its ESV also decreased.

Changes of ecosystem service values function

According to Eq. 3, the ESVs provided by individual ecosystem functions (ESV_f) were also estimated (Table 7). The contributions of each ecosystem function to overall ESVs in each year were ranked based on their estimated ESV_f, whereas the overall rank of each function was based on the average value of each ESV_f throughout the study period. According to Table 8, the change of individual ESV functions showed a decreasing trend in gas regulation, water supply, soil formation and disposition, biodiversity protection, and recreation, but with insignficant variation amplitude (Table 8). The decline of water supply was the largest, and the ESV_f decreased \$51 million from 1964 to 2009. This phenomenon was mainly due to the rapid expansion of artificial oasis, which resulted in the conversion of natural vegetation into cropland, as well as perennial covered land change into season covered arable land. The latter resulted in the loss of water supply function, damage to regional biodiversity, decline in gas regulation, waste treatment, and recreation. Simultaneously, the expansion of oasis cropland resulted in increases in food production, climate regulation, and raw materials. The rate of change was 1.31, 1.30, and 0.11 % for food production, climate regulation, and raw materials, respectively (Table 9).

According to Table 8 of individual ecosystem functions, the water supply and waste treatment were highly important to ESV function, with ESVs of \$509 and \$530 million, respectively. The percentages of water conservation and waste treatment in 2009 were 31.78 and 33.08 %, respectively. These percentages were followed by those of climate regulation, recreation and culture, and biodiversity protection. Its annual average value was \$100 million or more, and the proportion of the total value was more than 5 %. The oasis of Yanqi Basin has been developed in the past 60 years. In the study area, regional natural vegetation was replaced by artificial cropland, which led to decreased water level, water salinity, and organic pollution (Li et al. 2008; Wang 2013b). The continued degradation of lakeside wetland habitats is caused by the pressures of economic development, such as recession of reed growth, reduced area, and damage to biodiversity (Brunner et al. 2008; Li et al. 2009). With regard to ESV, the oasis development of Yanqi Basin has many problems, but the ESVs showed no significant decline. Therefore, protecting the wetlands and lakes for sustainable development of the oasis is important.

Ecosystem sensitivity analysis

In this study, the sensitivity of ESV to changes in VCs must be relatively low ($CS<1$) to obtain reliable results. The CS obtained from a 50 % adjustment in VC was calculated using Eq. 4, and the result is shown in Table 10. In all cases, CS was less than unity and often near zero, which indicates that the total ESV estimated in this study was relatively inelastic with respect to changes in VCs. CS for water areas was the highest at approximately 0.52 because of the large area and high ESV VC for this land use type. CS values for wetlands, grasslands, and croplands were relatively higher in different periods. Although the areas of wetlands were small, CS

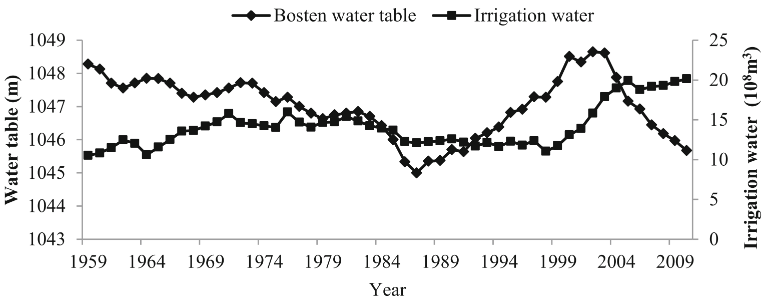

Fig. 3 Plot of Bosten Lake water table and water quantity

Table 8 ESV$_f$ for the Yanqi Basin in 1964, 1973, 1989, 1999, and 2009

Ecosystem service values function	1964			1973			1989			1999			2009			Overall rank
	ESV$_f$	%	Rank	ESV$_f$	%	Rank	ESV$_f$	%	Rank	ESV$_f$	%	Rank	ESV$_f$	%	Rank	
Gas regulation	41	2.42	7	42	2.50	7	38	2.59	7	36	2.06	7	37	2.30	7	7
Climate regulation	163	9.73	3	186	11.09	3	152	10.35	3	179	10.31	3	177	11.02	3	3
Water supply	560	33.46	1	545	32.41	2	469	31.89	2	575	33.19	2	509	31.78	2	2
Soil formation and protection	83	4.95	6	84	4.98	6	82	5.58	6	73	4.23	6	79	4.90	6	6
Waste treatment	556	33.23	2	552	32.80	1	481	32.71	1	583	33.68	1	530	33.08	1	1
Biodiversity protection	117	6.98	5	115	6.81	5	104	7.08	5	111	6.41	5	104	6.51	5	5
Food production	21	1.27	8	25	1.48	8	32	2.14	8	35	2.04	8	41	2.58	8	8
Raw material	3	0.18	9	3	0.20	9	4	0.26	9	4	0.23	9	5	0.28	9	9
Recreation and culture	130	7.77	4	130	7.74	4	109	7.40	4	136	7.84	4	121	7.53	4	4
Total	1,674	100.00	–	1,682	100.00	–	1,471	100.00	–	1,732	100.00	–	1,603	100.00	–	

Unit for ESV$_f$ is 10^6 USD/year

ESV ecosystem service value

for wetlands was relatively high because of their high VCs. CS for wetlands increased from 0.262 in 1964 to 0.313 in 1973, decreased to 0.267 in 1989, and increased to 0.288 in 1999 and 0.300 in 2009. CS for croplands increased from 0.031 in 1964 to 0.51 in 1973, 0.102 in 1989, 0.111 in 1999, and 0.151 in 2009. By contrast, CS for grasslands decreased from 0.131 in 1964 to 0.111 in 1973, 0.099 in 1989, 0.040 in 1999, and 0.032 in 2009. CS for grasslands remained relatively high because of its large area and higher ESVs. Sensitivity analysis indicated that the estimates were robust in spite of uncertainties in VCs.

Discussion

In the study, the modified coefficient method was used to assess ecosystem services of the Yanqi Basin, which was proposed by Costanza et al. (1997) and modified by Xie et al. (2003) to account for Chinese conditions, and derives ESV by multiplying the area of a given land use type by the corresponding ecosystem value coefficient. The evaluation results by the method are coarse with low resolution, deviations, and high uncertainties due to the dynamic, complex, and nonlinear ecosystems (Limburg et al. 2002; Turner et al. 2003). In addition, the accuracy of the modified value coefficients is doubtful because of ecosystem heterogeneity (Liu et al. 2012; Zhao et al. 2004). For instance, water areas and wetlands were the main land use types in Yanqi Basin, with relatively high VC. However, in the past 60 years, water quality in Bosten Lake and wetland ecological environment changed significantly, neglecting negative effects of pollution (e.g., water pollution and waste pollution) which may produce a negative value. Multiplying the area of land use type by the ecosystem value coefficient with uncertainties will therefore produce only rough estimates of ESV with a potentially high level of uncertainty. In addition, there are limitations on the economic valuation of land use types, and problems including double counting and scales.

The evaluation of ecosystem services based on land use change data has been used successfully in other case studies (Liu et al. 2012; Yoshida et al. 2010; Li et al. 2010a). In some studies, other methods were used to calculate value coefficients (Martín-López et al. 2014; McDonough et al. 2014). Although different valuation methods may lead to different estimated values, leading to criticism of the ecosystem service valuation approach,

Table 9 Changes in ESV functions in Yanqi Basin from 1964 to 2009

ESV Function	1964–1973		1973–1989		1989–1999		1999–2009		1964–2009	
	ESV	%	ESV	%	ESV	%	ESV	%	ESV	%
Gas regulation	1.43	0.07	−3.87	0.09	−2.38	−0.53	1.15	0.24	−3.68	−0.12
Climate regulation	23.61	1.36	−34.31	−0.74	26.40	−0.03	−1.87	0.71	13.82	1.30
Water supply	−15.05	−1.05	−76.11	−0.52	105.79	1.30	−65.48	−1.41	−50.85	−1.68
Soil formation and protection	0.82	0.03	−1.57	0.61	−8.79	−1.35	5.20	0.67	−4.34	−0.05
Waste treatment	−4.66	−0.43	−70.46	−0.09	102.14	0.97	−53.09	−0.60	−26.07	−0.15
Biodiversity protection	−2.31	−0.17	−10.43	0.27	6.77	−0.68	−6.52	0.11	−12.48	−0.47
Food production	3.66	0.21	6.58	0.66	3.85	−0.10	6.05	0.54	20.14	1.31
Raw material	0.34	0.02	0.46	0.06	0.24	−0.02	0.55	0.05	1.58	0.11
Recreation and culture	−0.01	−0.04	−21.29	−0.34	26.91	0.44	−15.07	−0.31	−9.46	−0.24
Total	7.83	0.00	−211.02	0.00	260.95	0.00	−129.09	0.00	−71.34	0.00

Unit for ESV_f is 10^6 USD/year

ESV ecosystem service value

it is important to remember that accurately calculating coefficients is less critical for time series analyses than for cross-sectional analyses, because these coefficients tend to affect estimates of directional change less than they affect estimates of the magnitude of ecosystem values at specific points in time (Li et al. 2010a). Since this study focused on changes in ESV over time, the results are credible, particularly in qualitative terms. In addition, the sensitivity analysis indicated that the total ESV that we estimated for the Yanqi Basin was relatively inelastic with respect to the value coefficients and that our estimates were robust despite uncertainties in the value coefficients. By calculating the ESV and analyzing changes across different time periods, these uncertainties and errors would be reduced or offset.

Economic growth often seems to conflict with ecological protection (Zhao et al. 2004). Although the ecological and economical characteristics and the techniques of evaluation varied, the estimated results in Yanqi Basin and other cities of China consistently showed that ecosystem services and functions tend to decline under current patterns of economic development. In past 60 years, the Yanqi Basin has made significant progress in economic development since the development of land and water resources. From 1964 to 2009, gross domestic product (GDP) increased from 25 million Yuan in 1964 to 8935 million Yuan in 2009, with an average growth rate of 7.77-fold per year. By contrast, ESVs decreased by 4.3 %, with an average decline rate of 0.093 % per year. The total ESVs of Yanqi Basin was approximately 446-fold of the GDP in 1964, which declined to 1.2-fold of the GDP in 2009. The global ESV was approximately 1.8-fold of the global GNP (Costanza et al. 1997). Chinese

Table 10 Change (percentage) in estimated total ESV and CS resulting from adjustment of VC

Change in VC	1964		1973		1989		1999		2009	
	Percentage	*CS*	Percentage	*CS*	Percentage	*CS*	Percentage	*CS*	Percentage	*CS*
Cropland VC ±50 %	±1.604	0.032	±2.567	0.051	±5.091	0.102	±5.545	0.111	±7.542	0.151
Grassland VC ±50 %	±6.525	0.131	±5.559	0.111	±4.928	0.099	±1.978	0.040	±1.583	0.032
Wetland VC ±50 %	±13.075	0.262	±15.646	0.313	13.368	0.267	±14.378	0.288	±15.005	0.300
Water area VC ±50 %	±28.446	0.569	±25.880	0.518	±26.213	0.524	±27.780	0.556	±25.544	0.511
Unused land VC ±50 %	±0.350	0.007	±0.347	0.007	±0.400	0.008	±0.319	0.006	±0.325	0.007

VC value coefficient, *CS* coefficient of sensitivity

ESV was approximately 1.73-fold of the Chinese GDP in 1994 (terrestrial ESV was 1.25-fold of the GDP; Hu et al. 2013). These observations imply that the level of ESVs in Yanqi Basin was below the global and national average. Sustainable development is critical in the Yanqi Basin. Therefore, a compromise between economic development and ecological protection must be addressed. A reasonable land use plan should be made with an emphasis on protecting wetlands, water areas, and grassland, which have high ESVs to maintain a balance between economic development and ecosystem health.

In arid regions, oases are concentrated areas for production and living. Oasis ecosystems are unique and directly affected by human management to satisfy human demands. Oasis ecosystems are closely related to population growth and human demands (Feng et al. 2012; Huang et al. 2010). During the 45 years since agricultural development, Yanqi Basin of Xinjiang has made great progress in economic development. Land use changes have a great effect on the ecosystem services and have also left the remaining grass fragmented and isolated. Land use changes, especially deforestation, 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. For instance, water quality in Bosten Lake and wetland ecological environment changed significantly. Bosten Lake was the largest inland freshwater lake in China. Given that agricultural activities drain water and increase salt, the salinity of the lake increased, thereby causing damage to its ecosystem. In 1958, the total dissolved solids (TDS) of Bosten Lake water was less than 1.00 g/L, and the TDSs increased to a range from 1.32 to 1.88 g/L by the 1980s (Wang 2013a). The Bosten Lake has changed from freshwater to slightly salty water (Brunner et al. 2008). In recent years, Bosten Lake decreased in salinity, but the TDS content entering the lake was approximately 100×10^4 t per year. Reducing lake water salinity requires freshwater dilution. The amount of industrial wastewater and sewage rapidly increases with industrial development and population increase in Yanqi Basin (Brunner et al. 2008). Some studies have shown that the annual amount of industrial wastewater was more than $1{,}000\times10^4$ t, and that of sewage was more than 600×10^4 t per year. With cropland drainage, the annual amount of organic materials entering the lake was more than $6{,}000\times10^4$ t (Brunner et al. 2008). The amounts of nitrogen and phosphorus nutriment were more than 300×10^4 t per year. Thus, the water quality in Bosten Lake was between groups III and IV (GB3838-2002, water quality evaluation standard of China). The eutrophication trend was very noticeable in Bosten Lake water. The combination of lake level decreased, whereas TDS increased. Moreover, organic pollution aggravation in the lake areas affected lakeside wetlands. The main indexes were the reed areas and yield. The reed wetland areas decreased from 558 km^2 in 1958 to 410 km^2 in 2007 (26.5 %). The reed yield decreased from 4×10^5 t per year in the 1960s to 2.47×10^5 t per year in the 1980s. The reed yield was 1.50×105 t per year and 1.80×10^5 t per year in 2004 and 2007, respectively. Except for bird species, which were captured, native fish species of Big-Head Schizothoracin (*Aspiorhynchus laticeps*) and Schizothoracinae (*Racoma*) disappeared. Rare waterfowls, such as great white pelican (*Pelecanus onocrotalus*), black marabou (*Ciconia nigra*), and many other land and water perched life-forms, which depend on lake area and wetland life, were seriously threatened.

Agricultural activity is a major part of human activities in oases. Oasis expansion means an increase in the area of cropland ecosystem. The increase in the extent of cultivated land results in much larger consumption of water resources. Some studies indicate that the sustainability of this irrigated land use system is due to high water quality, the elaborate terrace structure, and water management which allows adequate drainage (Luedeling et al. 2005; Tengberg 2012). However, the groundwater table in the Yanqi Basin increased with flood irrigation because of the lack of an effective farmland drainage system in the 1950s. In arid regions with high groundwater levels and phreatic evaporation, soil salinization is a major environmental problem (Brunner et al. 2004). Water resources are important to changes in land use type and spatial distribution patterns of land use in the Yanqi Basin, and they are also crucial to maintain sustainable land resources. The availability of water is the dominant factor in controlling the expansion of oases and desertification. Water availability is also crucial in the development and use of land resources.

In this study, the investigation provided a case study of land use change on ecosystem service in arid oases areas. Ecosystems in arid oases areas are much more complex and unique compared with natural ecosystems. While many previous studies focused on natural ecosystems, future studies on ecosystem service valuation should pay more attention to ecosystems in arid oasis areas where intensive interactions between human activity and ecosystems take place. This will make the techniques of valuation more useful to guide future oasis agriculture sustainable development.

Conclusion

By analyzing and discussing the changes in ecosystem service values based on land use in Yanqi Basin from 1964 to 2009, the following conclusions were reached. (1) The total ecosystem services values of the Yanqi Basin were approximately $1,674 million in 1964, $1,692 million in 1973, $1,471 million in 1989, $1,732 million in 1999, and $1,603 million in 2009. The net increases in ESVs were approximately US$8 million from 1964 to 1973 and US$261 million from 1989 to 1999. By contrast, the decreases in ecosystem service values were approximately US$211 million from 1973 to 1989 and US$129 million from 1999 to 2009, which were mainly caused by the changes in wetlands and water areas. The aggregated ESVs of water areas and wetlands were approximately 85 % of the total value, which indicate the importance of these land use categories in ecosystem services in the Yanqi Basin. (2) Waste treatment and water supply in 2009 were the top two ecological functions with high ESVs and contributed approximately 64.70 % of the total ecosystem service values. The overall rank order (from high to low) for each ecosystem function based on their contributions to the overall ESV was as follows: waste treatment, water supply, climate regulation, recreation and culture, biodiversity protection, soil formation, food production, gas regulation, and raw material. (3) Sensitivity analysis indicated that CS was far less than unity and often near zero. The total ecosystem services values estimated in this study area were relatively inelastic with respect to VCs. The estimation was robust in spite of uncertainties on VCs in this study area.

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