

Article

Variations of Ecosystem Service Value in Response to Land-Use Change in the Kashgar Region, Northwest China

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Abstract: Increasing anthropogenic activities have significantly altered ecosystems in arid oasis regions. Estimating the impact on a wide range of ecosystem services is important for decision making and the sustainable development of these regions. This study analyzed time-series Landsat data to determine the influences of oasis land-use changes on the ecosystem services in the Kashgar region in Northwest China. The following results were found. The total value of the ecosystem services in the Kashgar region were approximately \$10,845.3, \$11,218.6, \$10,291.7, and \$10,127.3 million in 1986, 1996, 2005, and 2015, respectively. The water supply, waste treatment, biodiversity protection, and recreation and cultural services were the four ecosystem services with the highest service value, contributing 77.05% of the total ecosystem services. The combined contribution rate of food production and raw material value was only about 4.02%, relatively small. The sensitivity analysis indicated that the estimated total ecosystem service value (ESV) for this study area was relatively inelastic with respect to the value coefficients. The findings of this study will be crucial for maintaining the stability and sustainable development of the oasis region, where socio-economic development and the integrity of the natural ecosystem complement each other. Furthermore, the results provide a scientific basis for decision makers in land use management, and provide a reference for researchers in the Northwest China.

Keywords: ecosystem service value (ESV); Kashgar region; land-use land cover (LULC); remote sensing (RS); geographical information system (GIS)

1. Introduction

Ecosystems are the life-support systems for the earth's environment. Human beings and other organisms benefit directly and indirectly in many ways from their ecosystems, such as through the provision of food and resources, storing carbon, air purification, biodiversity protection, pharmaceuticals, and the regulation of local climates [1,2]. As an important part of the biosphere, ecosystem services maintain the environment, and understanding the multiple benefits provided by the ecosystems is becoming increasingly important [3]. An ecosystem can be defined as the conditions and processes that contribute to human beings' and other living organisms' survival and welfare [4]. Ecosystem services are critical to maintaining life on earth and ecosystem integrity. The integration of ecological and economic concepts has contributed to the sustainable development of the natural environment [5]. The ecosystem service value (ESV) has become a focus in the fields of environmental

ecology and ecological economics. Because of human activities and climate change, ecosystem services are facing considerable pressure, which is expected to continue to increase. Among these pressures, human activities are the main contributor, by changing the ecosystem services through land-use and land-cover changes (LULCC) [6]. LULCC are the main determinant of changes in the land-use structure, the ecosystem function evaluation, and the dynamic processes of most landscapes throughout the world [7,8]. LULCC affect ecosystem services through agricultural activities, animal husbandry, human settlements, built-up areas, and mining [9,10]. Some negative impacts that the LULCC have on ecosystem services are obvious, expressed predominantly in the imbalance between the provision of ecosystem services and the demands of humans and other organisms [11]. Changes in ecosystem services are mainly caused by the anthropic alteration of land use [12].

The economic evaluation of ecosystem services has been an important aspect of ecological economics [13]. Numerous studies have estimated the various ESV around the world [14–16]. In 1997, Costanza et al. estimated the global biospheric value of 17 ecosystem services in the 16 dominant global biomes [4,17]. In 2003, Xie et al. calculated the economic value of the ecosystem services in China [18]. In 2004, Mamattursun et al. assessed variations in ESV in the Kirya Oasis in Western China [19]. These studies led to a better understanding of the complex relationship between nature and society [20].

In China, LULC have been increasing in speed, breadth, and depth. Their resulting effects have become serious, highlighting the importance of global research about LULCC [21]. The demand for resources, the increasing socio-economic development, and population growth are largely beyond the supply capacity of the natural ecosystem. As such, the human population increase and socio-economic development will face serious challenges. In arid and semi-arid regions, LULCC might have important consequences for natural resources, significantly affecting the ecosystem processes and services [22,23].

To highlight the effect of LULCC on ESV, ESV was evaluated using land-use data. The relationship between land-use changes and ESV has been explored in scientific papers. These studies have confirmed that land-use data provide an efficient basis for estimating ESV [9,24,25]. The studies have emphasized how monetization has enabled the evaluation of environmental effectiveness, thereby aiding different decision-making strategies for LULCC planning [26,27].

Kashgar is the first special economic zone in Western China. With the establishment of the “One Belt and One Road” development strategy, Kashgar has become an important hub in the new Silk Road Economic Belt, being the largest oasis conglomeration in Southern Xinjiang.

Along with the resources and energy development, the demand for natural resources has rapidly increased, and considerable changes have occurred in the land use structure, resulting in serious impacts on regional ecosystem services. However, quantitative research on LULCC in oasis areas and ESV at the regional level is limited in Western China’s Kashgar region. Therefore, evaluating the effects of LULCC on ESV in arid areas is important for the coordinated development of the regional socio-economy and the natural environment [28,29]. In this study, we chose the Kashgar region of Northwest China as the study area because it has undergone intense land-use changes during the economic growth period between 1986 and 2015, especially following the central Chinese government’s formal approval of the “Economic Development Zone” in the Kashgar region in 2010 [30]. Given these circumstances, we attempted estimate the trend in ESV change in the Kashgar region, and explore the relationship between LULCC and the ESV, from 1986 to 2015. We assessed the ESV of the Kashgar region by using multi-temporal land-use data sets from 1986, 1996, 2005, and 2015.

The objectives of this research were (1) to analyze LULCC in the study area from 1986 to 2015; (2) to examine the change in ecosystem services at the regional scale by using value coefficients and land use change data that reflect ESV, from the period of 1986 to 2015; and (3) to determine how arid LULCC affect the ecosystem services value for the Kashgar region. These quantitative analyses are urgently needed to assist with the land-use management of arid land oases and to provide a scientific basis for the environmental protection and sustainable development of the Kashgar region.

2. Materials and Methods

2.1. Study Area

The Kashgar region is located in the southwestern part of the Xinjiang Uyghur Autonomous Region, China (73°27'–79°57' E, 35°20'–40°18' N) (Figure 1).

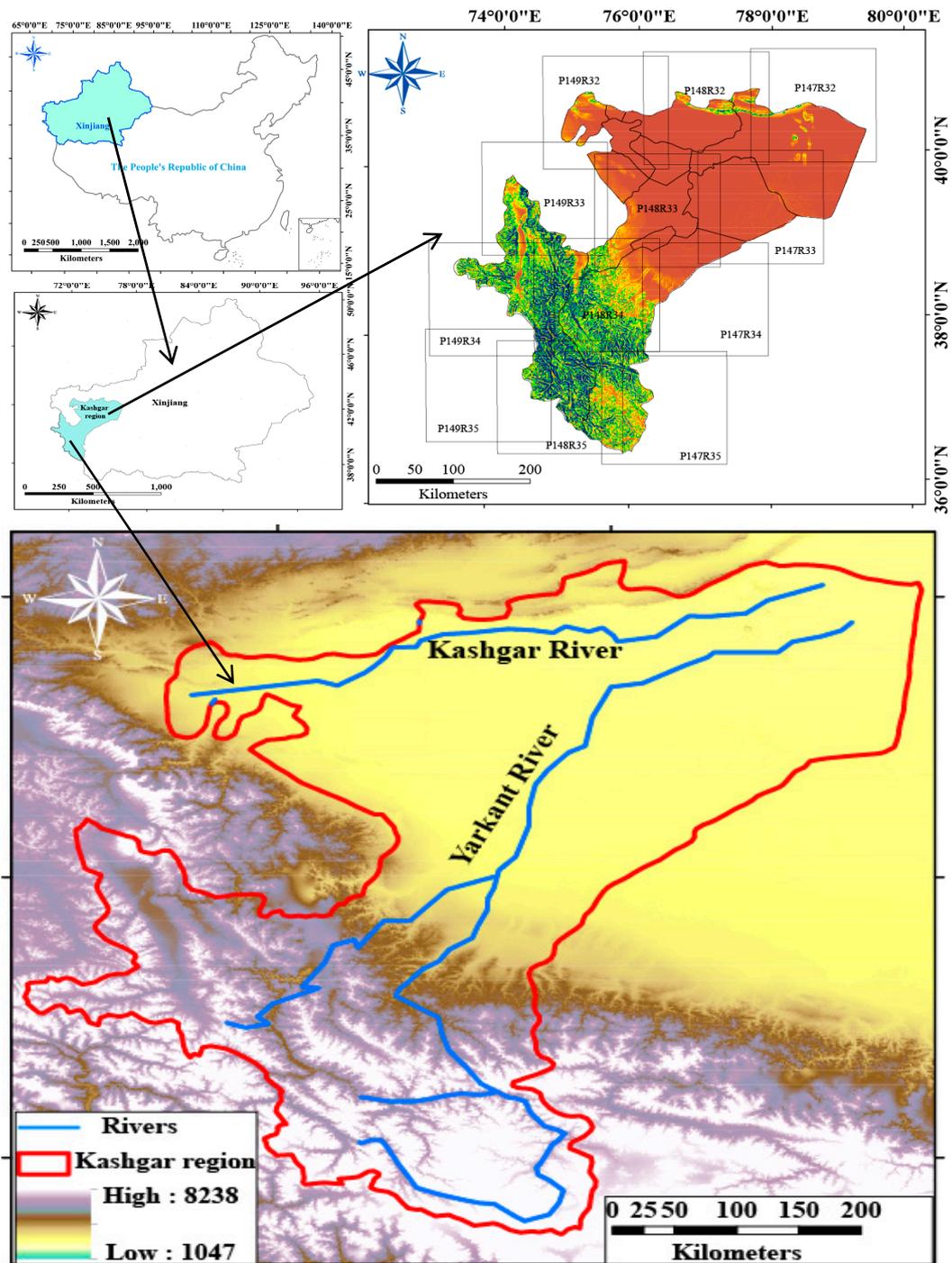


Figure 1. Map showing the location of the Kashgar region in Northwest China.

The region covers an area of 1.62×10^5 km². Administratively, it includes the cities of Kashgar, Shufu (Kona Shahr), Shule (Yingji Shahr), Yingjisha (Yengisar), Zepu (Poskam), Shache (Yarkant),

Yecheng (Kagelek), Maigaiti (Maket), Yuepuhu (Yopuga), Jiashi (Payzawat), Bachu (Maralbeshi), and Tashikuergan (Tashkorgan) counties.

The Kashgar region is adjacent to several countries, including Tajikistan, Afghanistan, and Pakistan [31]. The region has unique landforms, with the Kunlun Mountains in the south, the Tianshan Mountains in the north and west, and the Taklimakan Desert in the east. The Kashgar region ecosystem is a typical mountain–oasis–desert ecosystem [32]. The climate is a continental arid climate, characterized by low rainfall, high evaporation, sufficient sunlight, and a large temperature difference between day and night. According to the weather stations in the study area, the 50-year mean annual temperature varies from 10.5 to 11.6 °C, with a mean monthly temperature between 22 and 31.5 °C in July, and –11 and 19 °C in January [33]. The mean annual precipitation is about 116.8 mm, but the annual potential evaporation is as high as 2400–3100 mm. The annual precipitation exhibits a decreasing elevation-dependent gradient, from 220 to 500 mm in the mountainous area, 50 to 90 mm in the pediments of the mountain or alluvial fans, to 10 mm in the eastern desert part of the study area. The inter-annual distribution of precipitation is significantly heterogeneous. More than 80% of the total annual precipitation falls within the period of May to October, and less than 20% falls between November to April [30]. The topographic and climatic factors result in different land use types for the oasis, depending on being located in a temperate, tropical, or semi-arid area. Agriculture is the major industry in the region, acting as the major source of employment and income. Agricultural planting is the main land-use type, with cotton, maize, and wheat being the most common crops. The local vegetation consists of *Populus euphratica*, *Tamarix chinensis*, and *Phragmites australis*. The total water resources in this region have a volume of $78.01 \times 10^8 \text{ m}^3$, of which the surface water resource is $73.56 \times 10^8 \text{ m}^3$, with the total volume of the groundwater being $4.45 \times 10^8 \text{ m}^3$. The total population of the Kashgar region in 2015 was 449.92×10^4 . The region's gross domestic product (GDP) for 2015 was 1.204×10^{10} RMB. In 2015, the conversion between RMB and USD was $\$1 = 6.36 \text{ ¥}$ [29]. Since the 1980s, the two major oases in the Kashgar region, the Yarkant Oasis and the Kashgar Oasis, have experienced notable changes due to human activity.

2.2. Data Collection

In this study, we used land-use data, socio-economic data, an equivalent ESV coefficient, and socio-economic land-related policies to estimate the ESV of the study area since 1986. The land-use data were acquired by using multi-temporal and differential-resolution remote sensing data, which includes Landsat Thematic Mapper, Enhanced Thematic Mapper and Operational Land Imager (TM/ETM and OLI) images from 1986, 1996, 2005, and 2015, obtained from the United States Geological Survey (USGS). For each year, a total of 12 images were selected that covered the extent of the Kashgar region (Table 1). The socio-economic data were obtained from the Kashgar statistical yearbooks (1986–2015). The socio-economic land-related policies were obtained from the relevant literature.

Table 1. Landsat data acquired from 1986–2015.

Path/Row	Acquisition Data			
	1986	1996	2005	2015
147/032	24 September 1986	15 September 1996	15 September 2005	20 August 2015
147/033	24 September 1986	14 September 1996	15 September 2005	20 August 2015
147/034	13 September 1986	8 October 1996	14 September 2005	12 September 2015
147/035	2 October 1986	7 October 1996	29 August 2005	11 August 2015
148/032	22 September 1986	30 September 1996	29 August 2005	26 July 2015
148/033	19 September 1986	9 September 1996	29 August 2005	28 September 2015
148/034	18 September 1986	5 September 1996	11 July 2005	19 September 2015
148/035	10 September 1986	17 September 1996	23 August 2005	19 September 2015
149/032	30 August 1986	24 August 1996	12 August 2005	19 September 2015
149/033	9 September 1986	29 August 1996	26 July 2005	10 September 2015
149/034	25 September 1986	26 August 1996	26 July 2005	26 September 2015
149/035	30 August 1986	26 August 1996	18 July 2005	26 September 2015

Table 2. Cont.

Total accuracy of classification = 92% Kappa = 0.908									
2005 Class Types	Actual Types								
	(C)	(F)	(G)	(W)	(C)	(S)	(W)	(S)	(U)
Cultivated land (C)	92	1	4	2	2	2	1	0	1
Forestland (F)	3	89	1	0	1	1	2	0	1
Grassland (G)	2	2	91	1	2	0	1	0	0
Water body (W)	0	0	1	87	1	2	1	0	0
Construction land (C)	1	2	0	1	87	0	0	0	0
Salinized land (S)	2	2	2	2	2	90	1	1	1
Wetland (W)	0	1	1	4	2	1	94	0	4
Sandy land (S)	0	1	0	2	2	2	0	97	3
Unused land (U)	0	1	0	1	1	2	0	2	91
Total	100	100	100	100	100	100	100	100	100
Total accuracy of classification = 90.1% Kappa = 0.891									
2015 Class Types	Actual Types								
	(C)	(F)	(G)	(W)	(C)	(S)	(W)	(S)	(U)
Cultivated land (C)	91	2	2	4	5	0	2	1	1
Forestland (F)	2	88	3	2	2	1	2	1	1
Grassland (G)	2	3	90	1	2	1	1	1	1
Water body (W)	0	2	0	88	0	0	1	1	1
Construction land (C)	2	1	0	0	86	0	0	0	0
Salinized land (S)	2	1	1	1	2	92	1	0	1
Wetland (W)	1	1	4	4	1	2	91	1	1
Sandy land (S)	0	1	0	0	1	0	1	93	4
Unused land (U)	0	1	0	0	1	2	1	2	90
Total	100	100	100	100	100	100	100	100	100
Total accuracy of classification = 89% Kappa = 0.88									

Table 3. Land-use categories in the Kashgar region, together with their definitions.

Land Use Category	Definition
Cultivated land	Areas cultivated with dense annual crops and vegetables, including dry land and irrigated land.
Forestland	Areas of dense forest, open forest, orchards, and nurseries.
Grassland	Land with natural grassland cover, including steppes and grazing lands.
Water body	Rivers, lakes, and artificial water areas.
Construction land	All land used to construct human structures, including residential, commercial, and industrial buildings as well as transportation facilities, highways, rail ways, and family houses.
Salinized land	Land with salt on top soil.
Wetland	Mainly marshes along river banks, characterized by poor drainage moisture, and surface-grown long-term hygrophytes.
Sandy land	Land covered with sand, with a vegetation cover of less than 5%.
Unused land	Uncultivated areas with sparse plant cover, including barren, rocky, or abandoned sandy land in slopes, bare land.

2.4. ESV Assignment

Since the 1990s, economic valuation of ecosystem services has become a popular topic, being widely used to estimate the multiple benefits provided by ecosystems. To assess the ESV for each of the nine land-use types, each of the land-use types was compared with the different biomes identified both in the world [4] and in the Chinese ecosystem services [18]. Costanza categorized the global biosphere into 16 types of ecosystems and 17 types of service functions and then estimated their ESV [3,17]. Using Costanza's indexes as a foundation, Xie et al. modified the value coefficient for use with Chinese terrestrial ecosystems [4,19]. In this study, the ESV per unit area for each land-use

category was assigned based on the equivalent coefficient value of the ecosystem services proposed by Xie and Costanza [20] (Table 4). As such, all the monetary values for all the years were based on 2003 values.

Table 4. Ecosystem services value (ESV_f) per unit area for the different land-use categories (\$/ha/year).

ESV_f	Ecosystem Services Value (USD/ha/year)								
	Cultivated	Forest	Grass	Water	Construction	Salinized	Wet	Sandy	Unused
Gas regulation	74.7	299.4	104.	0.0	0.0	2.3	268.9	0.0	4.2
Climate regulation	133.0	282.1	108.	68.7	0.0	0.0	2554.7	0.0	9.0
Water supply	89.6	283.5	105.	3047.7	0.0	39.4	2315.6	4.1	4.8
Soil formation	218.1	278.6	155.	1.5	0.0	0.2	255.5	2.7	11.8
Waste treatment	245.0	119.2	91.5	2719.0	0.0	55.6	2716.0	1.4	18.0
Biodiversity protection	106.1	312.6	130	372.0	0.0	3.2	373.5	46.4	27.7
Food production	149.4	22.9	29.8	14.9	0.0	12.1	44.8	1.4	1.4
Raw material	14.9	206.5	25.0	1.5	0.0	1.1	10.5	0.0	2.8
Recreation and culture	1.5	144.2	60.3	648.4	12.7	15.3	829.2	1.4	16.6
Total	1032.3	1948.9	809	6873.8	12.7	129.2	9368.7	57.3	96.4

2.4.1. ESV Calculation

In this study, the ESV and ecosystem services functions for each land-use type were calculated as follows [19,20]:

$$ESV_k = \sum_f A_k \times VC_{kf} \quad (1)$$

$$ESV_f = \sum_k A_k \times VC_{kf} \quad (2)$$

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

where ESV_k , ESV_f , and ESV are the value of the ecosystem services of land-use type k , the value of ecosystem services function type f , and the total ecosystem services value, respectively. A_k is the area (ha) for land-use type k , and VC_{kf} is the value coefficient (\$/ha/year) for land-use type k and ecosystem service function type f [14,16]. The change in the value of the ecosystem services was estimated by calculating the differences between the estimated values for each land-use type in 1986, 1996, 2005, and 2015.

2.4.2. Sensitivity Analysis (CS)

As uncertainty is related to the value coefficients, in this study we used sensitivity analysis as shown in Equation (4) by adjusting the ESV coefficients for each land use type by 50%, and then calculating the corresponding change in ESV [36]. In this analysis, the coefficient sensitivity (CS) was calculated using the standard economic concept of elasticity [37,38]:

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

where ESV is the estimated ecosystem service value, VC is the value coefficient, i and j represent the initial and adjusted values (coefficient values were adjusted to the upper 50% and lower 50%), respectively, and k represents the land-use type [39]. When $CS \leq 1$, then ESV is considered inelastic with respect to the ecosystem value coefficient. The greater the value of CS , the more critical the accuracy of the ecological value coefficient when evaluating S [40].

3. Results

3.1. Land Use Dynamics

3.1.1. Land Use and Land Cover Change

The classification results of the land-use changes in the Kashgar region between 1986 and 2015 are shown in Table 5 and Figures 2 and 3. The LULCC over the past 30 years indicate that grassland, sandy land, and unused land remain the dominant cover types in the study area. Considering the LULC classification results shown in Figure 2, the most notable changes in LULC took place in the Kashgar and Yarkant oases, which are located near the Kashgar River and the Yarkant River basin. The Kashgar and Yarkant oases are characterized by intense human activity, which has converted large areas of grassland into cultivated land. Among all the land-use types, the highest change in cover occurred in grasslands, which decreased from 27% of the total area in 1986, to 16.8% in 2015.

Table 5. Land-use patterns in the Kashgar region in 1986, 1996, 2005, and 2015.

Land Use Type	1986		1996		2005		2015	
	Area (10 ³ ha)	% of Total	Area (10 ³ ha)	% of Total	Area (10 ³ ha)	% of Total	Area (10 ³ ha)	% of Total
Cultivated	883.6	7.8	963	8.5	1095.8	9.7	1454.5	12.8
Forest	221.9	2.0	278.3	2.5	321.4	2.8	338.1	3.0
Grass	3063.9	27.0	2824.1	24.9	2534.6	22.3	1901.9	16.8
Water	875.7	7.7	782.2	6.9	772.9	6.8	803.1	7.1
Construction	32.9	0.3	37.4	0.3	42.5	0.4	49.4	0.4
Salinized	377.3	3.3	370.9	3.3	326.4	2.9	298.1	2.6
Wet	52.6	0.5	109.3	1.0	70.1	0.6	40.3	0.4
Sandy	2588	22.8	2880.2	25.4	3143.3	27.7	3335.6	29.4
Unused	3254.3	28.7	3104.8	27.4	3043.2	26.8	3129.2	27.6

Sandy land showed a continual increase, from 22.8% of the total land in 1986 to 29.4% in 2015. Cultivated land expanded at an alarming rate, from 7.8% of the total land in 1986 to 12.8% in 2015. Forestland increased from 2% in 1986 to 3% in 2015. The water body experienced an initial decrease and then increasing, with a decrease from 7.7% of the total land in 1986 to 6.8% in 2005, and then an increase to 7.1% in 2015. Overall, water bodies decreased from 7.7% of the total area in 1986 to 7.1% in 2015. Construction land also increased, from 0.3% in 1986 to 0.4% in 2015. Salinized land decreased, from 3.3% in 1986 to 2.6% in 2015. Wetland increased from 0.5% in 1986 to 1% in 1996, and then decreased to 0.4% in 2015. The unused land also decreased from 28.7% in 1986 to 27.6% in 2015. During the period of 1986 to 2015, cultivated land, forest land, construction land, and sandy land all increased, whereas grassland, water, salinized land, wetland, and unused land decreased (Figure 2). Grassland displayed the greatest absolute change and water area the least. The considerable decreases in grassland and wetland, together with the simultaneous increase in cultivated land, are a result of the rapid development of commercial agriculture and inadequate regulations for the protection of wetlands and curbing irrational water use.

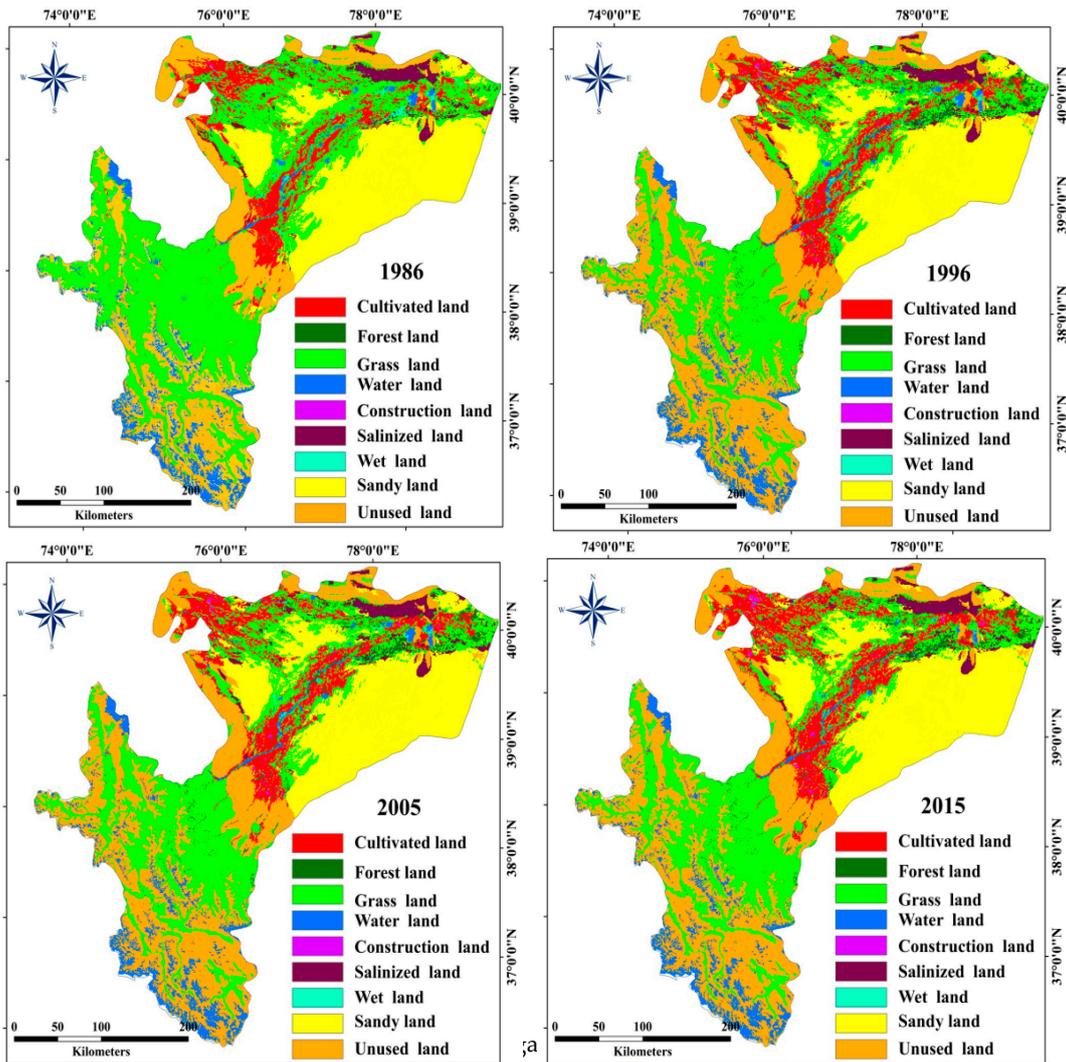


Figure 2. Land-use maps of the Kashgar region for 1986, 1996, 2005, and 2015.

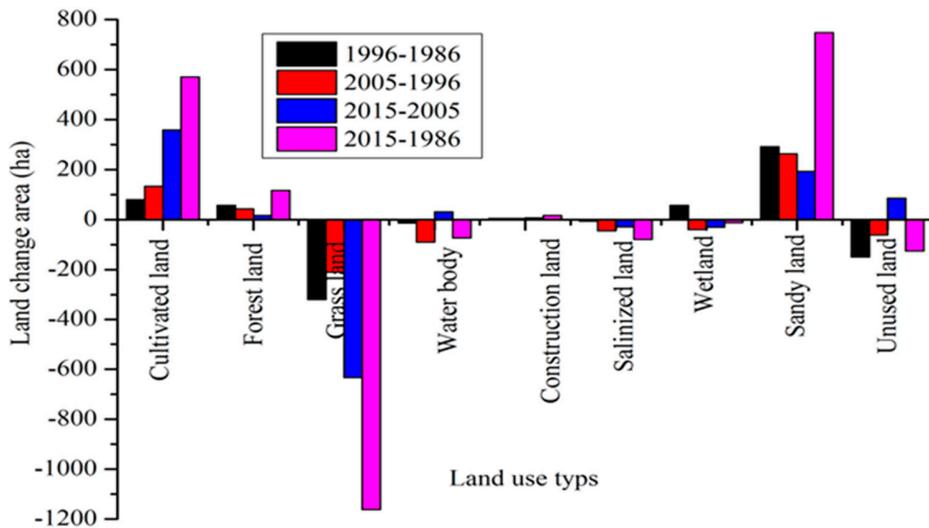


Figure 3. Land-use change chart of the Kashgar region for 1996–1986, 2005–1996, 2015–2005, and 2015–1986.

3.1.2. Land-Use Conversion

The transformation among the different LULC could reflect the direction of change, which could be best explained using a space-time change process. Our results (Table 6) revealed that, from 1986 to 2015, a complex transformation occurred among each LULC type in the Kashgar region. The main characteristics of the transference are shown below.

Table 6 shows that 883.6×10^3 ha of the cultivated land in 1986, 600.2×10^3 ha were unchanged, while 14.7×10^3 ha, 146.9×10^3 ha, 12.6×10^3 ha, 13.5×10^3 ha, 5.5×10^3 ha, 8.8×10^3 ha, 0.8×10^3 ha, and 70.0×10^3 ha were lost to forestland, grassland, water bodies, construction land, salinized land, wetland, sandy land, and unused land, respectively. The total loss of cultivated land was 272.8×10^3 ha. Of the 1454.5×10^3 ha of cultivated land in 2015, 854.2×10^3 ha were gained from forestland (29.1×10^3 ha), grassland (688.5×10^3 ha), water bodies (5.9×10^3 ha), construction land (6.9×10^3 ha), salinized land (9.7×10^3 ha), wetland (8.4×10^3 ha), sandy land (38.0×10^3 ha), and unused land (67.7×10^3 ha). Over the entire research period, all cultivated land showed an increasing trend with transference being predominantly from grassland, forest land, and unused land. Similarly, of the 3063.9×10^3 ha of grassland in 1986, 1607.3×10^3 ha remained unchanged, whereas 688.5×10^3 ha, 54×10^3 ha, 69.3×10^3 ha, 10.2×10^3 ha, 85.2×10^3 ha, 2.6×10^3 ha, 82.5×10^3 ha, and 464.3×10^3 ha changed to cultivated land, forestland, water bodies, construction land, salinized land, wetland, sandy land and unused land, respectively. Some of the 1901.9×10^3 ha of grassland in 2015 was gained from cultivated land (146.9×10^3 ha), forest land (35.9×10^3 ha), water bodies (87.0×10^3 ha), construction land (0.4×10^3 ha), salinized land (7.6×10^3 ha), wetland (4.1×10^3 ha), sandy land (33.4×10^3 ha), and unused land (109.9×10^3 ha). During the study period, 122.1×10^3 ha of forestland was unchanged, whereas 99.8×10^3 ha was converted into other land use types, and 206.0×10^3 ha of forestland was converted from other land types. A total of 535.5×10^3 ha of water was unchanged, whereas 220.2×10^3 ha was converted into other land types and another 367.6×10^3 ha was converted from other land types. For construction land, 21.0×10^3 ha was unchanged, 11.9×10^3 ha was converted into other land types, and 28.6×10^3 ha was converted from other land types. For salinized land, 172.1×10^3 ha was unchanged, and 205.2×10^3 ha was converted into other land types, and 126.0×10^3 ha was converted from other land types. For wetlands, 21.2×10^3 ha was unchanged, 21.6×10^3 ha was converted into other land types, and 24.1×10^3 ha was converted from other land use types. For sandy land, 2440.1×10^3 ha was unchanged, 147.6×10^3 ha was converted into other land types and 165.1×10^3 ha was converted from other land use types. For unused land, 2643.4×10^3 ha was unchanged, 526.3×10^3 ha was converted into other land use types, and 765.2×10^3 ha was converted from other land use types.

Table 6. Land cover conversion from 1986 to 2015 (10^3 ha).

1986–2015	(C)	(F)	(G)	(W)	(C)	(S)	(W)	(S)	(U)	Gain
Cultivated land (C)	600.2	29.1	688.5	5.9	6.9	9.7	8.4	38.0	67.7	854.2
Forest land (F)	14.7	122.1	54.0	0.2	0.0	94.2	3.1	23.1	16.7	206.0
Grass land (G)	146.9	35.9	1607.3	87.0	0.4	7.6	4.1	33.4	109.9	425.2
Water body (W)	12.6	2.0	69.3	535.5	5.0	0.1	2.6	2.8	278.2	367.6
Construction land (C)	13.5	0.4	10.2	0.1	21.0	3.1	0.0	0.8	0.5	28.6
Salinized land (S)	5.5	18.7	85.2	2.8	0.0	172.1	0.3	6.8	6.7	126.0
Wetland (W)	8.8	1.1	2.6	2.0	0.7	3.1	21.2	2.3	3.5	24.1
Sandy land (S)	0.8	11.9	82.5	0.5	0.0	23.2	3.1	2440.4	43.1	165.1
Unused land (U)	70.0	0.7	464.3	121.7	3.9	64.2	0.0	40.4	2643.4	765.2
Loss	272.8	99.8	1456.6	220.2	11.9	205.2	21.6	147.6	526.3	

3.2. Variability and Distributions of ESV through Time

3.2.1. Ecosystem Service Value Changes

In this study, by using the value coefficients (Table 4) and the areas of the land-use categories (Table 5), the ESV of each land use category and total ESV of the Kashgar region in 1986, 1996, 2005,

and 2015 were calculated using Microsoft Excel and Equations (1)–(3). The results are presented in Table 7. According to Table 7, the overall trend in ESV is characterized by volatile change processes. During the four periods, the total ESV of the Kashgar region rose from \$10,845.3 million U.S. in 1986, to \$11,218.6 million U.S. in 1996, declining to \$10,127.3 million U.S. in 2015. An overall increase in ecosystem service value, of about \$373.31 million U.S., occurred in the first 10 years (1986–1996). The net ESV benefit was \$32.9 U.S. per hectare. The ESV loss was about \$1091.3 million U.S. in the following 20 years (1996–2015), and the net ESV loss was \$96.15 U.S. per hectare.

Table 7. ESV of the Kashgar region in 1986, 1996, 2005, and 2015 (10^6 U.S.D.).

Land Use Types	1986	1996	2005	2015	1986–1996 (%)	1996–2005 (%)	2005–2015 (%)	1986–2015 (%)
Cultivated Land	912.14	994.1	1131.2	1501.5	8.99	13.79	32.7	64.6
Forest Land	432.48	542.4	626.4	659	25.42	15.49	5.2	52.4
Grass Land	2477.5	2218.9	2049	1537	-10.44	-7.66	-25.0	-38.0
Water Body	6019.3	5926.5	5312.7	5520.3	-1.54	-10.36	3.9	-8.3
ConstructionLand	0.42	0.5	0.54	0.63	13.68	8	16.2	50
Salinized Land	48.75	47.9	42.2	38.5	-1.7	-11.9	-8.7	-21.0
Wet Land	492.79	1024	656.77	377.6	107.79	-35.86	-42.5	-23.4
Sandy Land	148.55	165.3	180.4	191.5	11.29	9.13	6.1	28.9
Unused Land	313.39	299	293.1	301.3	-4.59	-1.97	2.8	-3.9
Total	10,845.3	11218.6	10,291.7	10,127.3	3.44	-8.26	-1.6	-6.6

3.2.2. Change in Ecosystem Function

To determine the effects of the change in land use on each of the ecosystem functions and its contribution rate to the total ESV within the Kashgar region in the 30-year timeframe, the ecosystem function type f was calculated using the value coefficients (Table 4) and areas of the land-use categories (Table 5). As shown in Table 8 the contribution rate of the individual ecosystem functions to the total value of the ecosystem services in each year are ranked based on their estimated average ESV_f in 1986, 1996, 2005, and 2015. The trend in the contribution rate of each ecosystem function to the overall ESV is marked with an upward arrow to denote an increasing contribution, a downward arrow to denote a decreasing contribution, and a dash to denote no change. As in showed in the Figure 4, most ecosystem functions of all land use types increased from 1986 to 1996, except for Soil formation which increased, while most ecosystem functions of all land use types declined from 1986 to 2015, except for food production that increased.

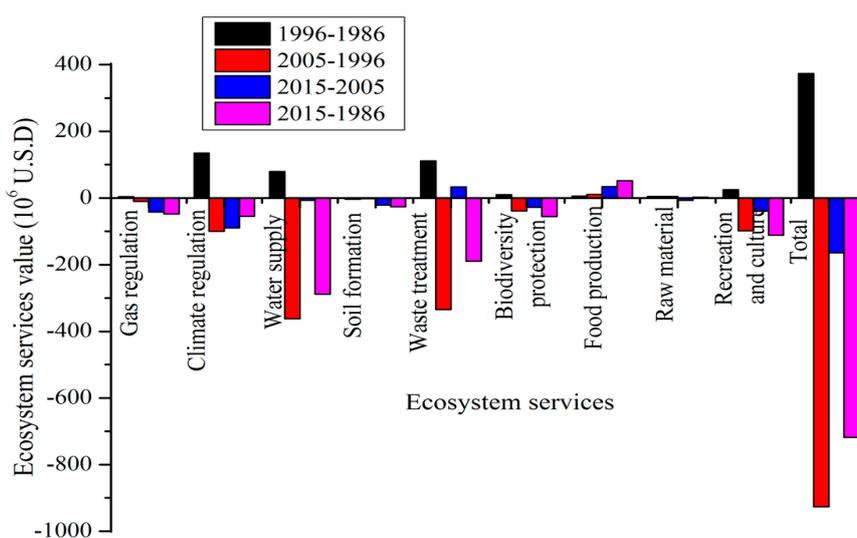


Figure 4. Ecosystem function chart of the Kashgar region for 1996–1986, 2005–1996, 2015–2005, and 2015–1986.

Table 8. ESV_f in 1986, 1996, 2005, and 2015 (10⁶ U.S.D.).

ESV _f	1986	1996	2005	2015	%	Rank	Trend
Gas regulation	479.77	483.93	474.1	432.3	4.40	7	↓
Climate regulation	734.84	869.36	769.7	680.5	7.19	6	↓
Water supply	3295.56	3375.46	3013.7	3007.2	29.88	1	↓
Soil formation	789.66	786.61	784.9	763.7	7.36	5	↓
Waste treatment	3130.35	3241.91	2907.9	2941.3	28.77	2	↓
Biodiversity protection	1118.26	1128.3	1090.1	1062.7	10.36	3	↓
Food production	256.54	262.63	273.9	308.2	2.59	8	↑
Raw material	146.98	151.96	156.8	149.8	1.43	9	↓
Recreation and culture	893.33	918.45	820.6	781.6	8.04	4	↓
Total	10,845.3	11,218.61	10,291.7	10,127.3			↓

The overall ranking for each ecosystem function, based on their contribution to the overall ESV from high to low, is water supply, waste treatment, biodiversity protection, recreation and cultural services, soil formation, climate regulation, gas regulation, food production, then raw material. Water supply, waste treatment, biodiversity protection and recreation and culture services were the top four ecological functions affecting the total ecosystem service value and their combined contribution accounts for 77.05%. The food production and raw material functions contributed the least to the ecosystem service value, with a combined contribution rate of only about 4.02%. In this study, the value of the regulating services of Kashgar region ecosystem is far greater than that of the provisioning services, indicating that regulation services are the main driver of the ecosystem services in the Kashgar region.

3.2.3. Ecosystem Services Sensitivity Analysis

To confirm the reliability in our research, the sensitivity of ESV to changes in value coefficients must be relatively low, meaning CS must be less than one in Equation (4). The change in estimated total ESV and the coefficient of sensitivity, derived from a 50% adjustment in the value of the coefficient, showed that the total ESV estimated for the study area was relatively inelastic.

The sensitivity index results showed that from 1986 to 2015 (Table 9), the ESV to CS values in the Kashgar region were all lower than one and often close to zero. In this study, a CS value less than one means that the estimated total ESV was relatively inelastic with respect to the value coefficients. In this study, the CS is ranged from 0.00 to 0.58, and changes in the total value of the ecosystem services ranged from 0 to 29.11%. Adjusting the value coefficients for construction land, sandy land, and salinized land had little impact on the estimated ESV, with a change less than 0.05% with a 50% change in value coefficient. Correspondingly, the CS is fluctuated from 0.03 to 0.58 when the coefficients for cultivated land, forest land, grass land, water body, wetland, and unused land were adjusted. Because CS was less than one, the analyses reflect that grass land, water bodies, cultivated land, and wetland play a critical role in the total ecosystem services of the study area. The sensitivity analysis indicated that the estimation was robust, regardless of scope. The value coefficients had a significant influence on the accuracy of the estimated change in ESV over the 30-year period, indicating that our results are credible and that the ESV index that was used in the research area was a good fit.

Table 9. Percentage change in estimated total ESV and coefficient of sensitivity.

Change in Value Coefficient	1986		1996		2005		2015	
	%	C _S						
Cultivated land VC ± 50%	7.41	0.15	7.90	0.16	5.49	0.11	7.41	0.15
Forest land VC ± 50%	3.48	0.07	4.34	0.09	3.04	0.06	3.25	0.07
Grass land VC ± 50%	14.45	0.30	16.50	0.33	9.94	0.20	7.59	0.15
Water body VC ± 50%	27.89	0.56	29.11	0.58	25.77	0.52	27.23	0.54
Construction land VC ± 50%	0.12	0.00	0.12	0.00	0.00	0.00	0.00	0.00
Salinized land VC ± 50%	0.09	0.00	0.10	0.00	0.20	0.00	0.19	0.00
Wetland VC ± 50%	4.32	0.09	8.91	0.18	3.18	0.06	1.86	0.04
Sandy land VC ± 50%	0.77	0.02	0.90	0.02	0.87	0.02	0.94	0.02
Unused land VC ± 50%	2.21	0.04	2.61	0.05	1.57	0.03	1.51	0.03

4. Discussion

Due to large-scale land reclamation and water resource exploitation that have occurred since 1980, the ecosystems in the Kashgar region have changed considerably [41,42] (Tables 5 and 6). Population growth, rapid economic development, and socioeconomic policies, implemented after the reform as part of the “reform and opening up policy”, have led to changes in land use and the exploitation of water resources exploitation [43].

4.1. Factors Driving LULCC

4.1.1. Population and Economic Growth

LULCC in arid areas are commonly a human-driven process that has resulted in consequences for land-related ecosystems [44]. Under certain geographical conditions and to meet increasing demands, population growth has often influenced and modified the natural landscape on different scales [45]. Kashgar is a multi-ethnic region, and most populations in Kashgar region are rural, which are the main driving forces in LULCC and economic structure change. From 1986 to 2015, the population in Kashgar region grew from 2,601,124 to 4,499,200 (Figure 5).

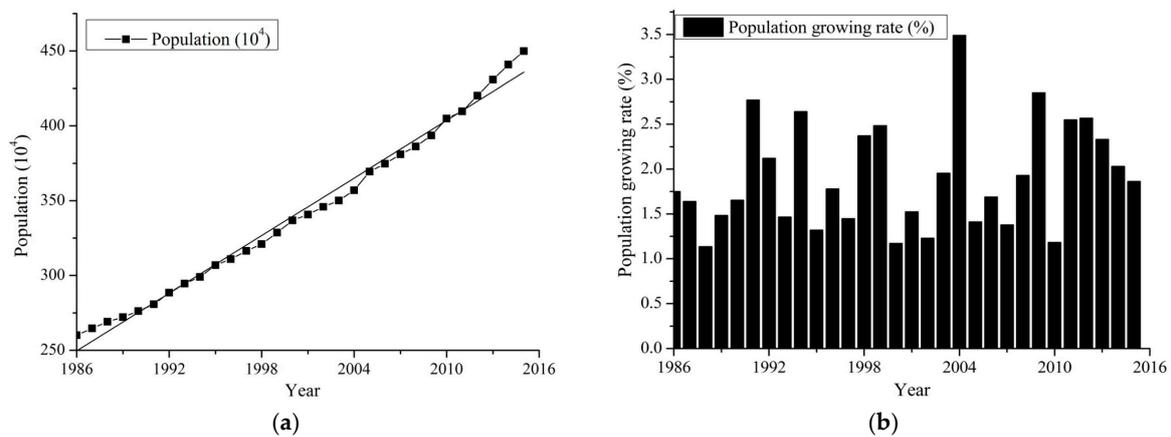


Figure 5. (a) Population increase and (b) rate of population increase.

The increased population inevitably produced an intense pressure on food and space [46]. Additionally, the Kashgar region is the main cotton producing area in Xinjiang; it has a long history of cotton production and has favorable conditions for cotton plantations [47]. From 1986 to 2015, cotton prices in the Kashgar region increased considerably, and local farmers maximized their economic profit through increased cotton production by expanding the area under cultivation, which consequently resulted in frequent land conversion. Therefore, population growth, agricultural intensification, and socio-economic development are the main driving forces of LULCC and are the critical factors influencing regional human-land relationships in the study area.

4.1.2. The Influence of Policy

Another important driving force for the LULC is closely related to the government’s land-related policies at national and local level [48].

The “reform and opening up policy”, implemented in China in 1978, generated impressive expansion of cultivated lands, significantly altering the land structure [49]. Along with the “China market economy policy” enacted in 1992, tremendous LULCC occurred in the study area, especially where natural resources were available for the expansion of cultivated lands [50]. The income of the Kashgar people largely relies on agriculture, which is the key part of the local socio-economic development [30]. At the beginning of the study period, these economic policies improved the living standard of the local people by

steadily expanding the cultivated lands in the Kashgar region. Consequently, serious desertification and degradation in the ecosystem services occurred because of irresponsible land use. In addition, two major land related laws, the “Basic Cultivated Land Protection Regulation” and the “New Land Administration Law”, implemented in 1994 and in 1999, respectively, played an important role in LULCC [51]. Established in 2010, the “Kashgar Special Economic Zone” also accelerated the land use structure change, as it attracted many entrepreneurs at home and abroad to Kashgar to build many factories and businesses [29]. Technological improvements and advances in irrigation and land resource management systems have also contributed to the rapid change in LULC. In the study area, LULCC is closely related to human-induced policy interventions and market economy.

4.2. Effect of LULCC on ESV

The population growth and rapid economic development in the study area led to the expansion of cultivated land and construction land, which accelerating deforestation and the cultivation of grassland and wetlands. The expansion of cultivated land and construction land changed the landscape pattern, causing a gradual increase in ecological degradation. During 1986 to 2015, the areas of the different land use types continually changed in the Kashgar region. Cultivated, forest, construction, and sandy lands increased, while grassland, water body, Salinized land, wetland, and unused land decreased. The changes in ESV of the land use types varied according to their changes in area. Although the ESV of cultivated, forest, construction, and sandy lands demonstrated an increasing trend, the trend in total annual ESV in the Kashgar region was variable, first increasing then decreasing, because the high value coefficient of wetlands and water bodies, and the large areas of grassland, contributed more to the overall ESV. Based on the estimated size of nine land-use types and ESV, we determined that the total annual ESV in the Kashgar region declined by 6.6% between 1986 and 2015 (Table 7). This massive decline in ESV is largely attributable to the loss of 12.3×10^3 ha wetlands and 1162×10^3 ha grasslands. In the study area, the high rate of decline of these land use would have considerably negative ecological consequences.

The total ecosystem function value also first increased then decreased. The nine single ecosystem functions decreased, except for food production. Among them, the ecosystem function values of water supply, recreation and culture, and waste treatment experienced largest decline. Recent relevant studies were performed in the Keriya Oasis and Ugan-Kuqa River Delta Oasis regions, where the ecosystems are similar to the Kashgar region. Mamattursun’s [35] study of the ecosystem services in Keriya Oasis, China, showed that the total ESV of the Keriya Oasis decreased from \$35.8 million U.S. in 1991 to \$32 million U.S. in 2008. Similar work conducted by Mamatsawut [3] in the Ugan-Kuqa River Delta Oasis, China, reported that the ecosystem service value in the Ugan-Kuqa River Delta Oasis region increased from \$1236.42 million U.S. in 2000 to \$1238.1 million U.S. in 2008. Although the two studies revealed opposite ESV trends, the changes in both areas were driven by the change in wetland area. The ESV change in the Kashgar region corresponds to the trend observed in the Keriya Oasis. The total ESV of the Kashgar region was about \$10,845.29 million U.S. in 1986, increasing to \$11,218.6 million U.S. in 1996, then decreasing to \$10,127.3 million U.S. in 2015. The net ESV benefit was about \$373.31 million from 1986 to 1996, and the net loss in ESV was about \$1091.3 million from 1996 to 2015. The increase in ESV caused by the expansion of wetland was about \$531.21 million U.S. from 1986 to 1996, whereas the loss in ESV caused by the decrease in wetland was about \$646.4 million U.S. from 1996 to 2015. Wetland conversion into cultivated land in both Kashgar and Keriya occurred over the same time period, which explains the similar response of ESV to land use change. Therefore, the uncontrolled land-use changes can negatively affect the capacity of an ecosystem to provide ecosystem services on a sustainable basis, resulting in long-term degradation of environmental quality in arid regions [52].

4.3. Possible Limitations and Future Suggestions

4.3.1. Data Selection

We extracted the LULC maps of the study area for four time frames using remote sensing and GIS tools. Due to the limitation of remote sensing interpretation, such as data classification, scale bias, and data precision [53], and the temporal and spatial dependence of LULCC on our estimation of land use pattern changes, ESV was only captured at single points in time in the study area. In addition, the Landsat data used in this study has lower resolution and mixed pixels in neighboring land use types, limiting the accurate estimation of ESV. Therefore, future ESV estimation studies should use high resolution remote sensing data for improved accuracy in land use classification. Field investigation and interviews with local leaders, experts, and residents should also be integrated [54].

4.3.2. ESV Calculation

The ESV calculation framework used in this study was proposed by Costanza and modified by Xie et al. However, as the monetarily estimated ESV is influenced by different elements including market price, exchange rate among currencies, inflation rate, land use structure optimization, social and economic development trends, and governmental policies [55], accurately evaluating ESV is difficult. In addition, the accuracy of the modified value coefficients is unreliable due to ecosystem heterogeneity [56]. These issues can considerably affect the ESV accuracy. Therefore, when we estimated the ESV change between 1986 and 2015, we assumed that the market price was the same as in 2003. One of the disadvantages of this ESV estimation is its vagueness, especially because the uncertainty of the value coefficient and the spatial, biophysical, and socio-economic heterogeneity were not considered. This limitation should be addressed in follow-up studies. This study mainly used the benefit transfer method, which just adjusted previously completed studies to this region. Including the inflation adjusted contingent valuation, that considers local people's willingness to pay, would improve the accuracy of final result.

4.3.3. Implications for Land Use Management in Future

In this study, the decrease in ESV in the Kashgar region was mainly caused by rapid changes in LULC, which can limit the capacity of an ecosystem to provide sustainable ecosystem services, possibly resulting in the long-term degradation of environmental quality. However, considering the fragile natural environment of the study area, we suggest that human activities in the Kashgar region should be pursued with caution as anthropogenic activities here will have an irreversible impact on its ecosystem services. Furthermore, coordinated socioeconomic development and ecological protection is necessary, and must be addressed properly by all stakeholders, to maintain a balance between economic development and ecosystem health in the future. Policy makers should implement a reasonable land-use policy that protects wetland and grasslands, which have high ESV. Local stakeholders should protect the ecosystem and understand the importance of ecosystem services, so as to maintain a balance between economic development and ecosystem health in the future.

5. Conclusions

This study yielded the following conclusions regarding LULCC in the Kashgar region:

- (1) The ESV decreased from approximately $\$10,845.3 \times 10^6$ U.S. in 1986 to $\$10,127.3 \times 10^6$ U.S. in 2015. This decline in ESV is attributed to a corresponding decrease in the total area of wetland, grasslands, and water bodies.
- (2) The water supply, waste treatment, biodiversity protection, and recreation and cultural services were the top four ecosystem services in terms of service value, with a combined contribution of 77.05% to the total service value. The ecosystem functions based on contributions to the total ecosystem service value were as follows, in decreasing order: water supply, waste treatment,

biodiversity protection, recreation and cultural services, soil formation, climate regulation, gas regulation food production, and raw material.

- (3) The sensitivity analysis showed a value below one and often close to zero, indicating that the estimated ESV of the study area was considerably inelastic with respect to the value coefficients. The estimated result was robust despite uncertainties in the value coefficients.

The population density changes, agricultural disturbances, and socio-economic policies were the most significant driving forces for LULCC. Results from this study suggest that anthropogenic activities in fragile and arid lands should be pursued with caution. We recommend policymakers to consider efficient measures in light of the local conditions.

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