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Driving Force and Ecosystem Service Values Estimation in the Extreme Arid Region from 1975 to 2015: A Case Study of Alxa League, China

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Abstract: The research on ecosystem service values (ESVs) estimation in arid region is weak. We took the Alxa League of China's Inner Mongolia Autonomous Region, an extreme arid region, as an example and constructed an equivalent coefficient method to assess its ESVs from 1975 to 2015, by determining the standard unit of ESVs and the basic equivalent of the value of different ecosystem services per unit area based on the regional characteristics, literature research, expert knowledge and land use data. The results show that the ESVs first decreased from 83 170.4 million yuan (RMB) in 1975 to 82 337.8 million yuan (RMB) in 2000 and then increased to 84 033.6 million yuan (RMB) in 2015, and the ESV of sparse grassland and desert account for about 33% and 29% of the total ESVs, respectively. Among the four service types, the regulating services, support services, supply services and cultural services account for 66.5%, 22.8%, 6.0% and 4.7%, respectively. The changes of ESVs in Alxa League are determined by the socio-economic development and ecological changes. This study provides a new method to estimate the ESVs in arid region by integrating existing methods and regional characteristics, such as the cost of water for arid ecosystems.

Keywords: ecosystem service values; equivalent coefficient method; driving force; arid region; Alxa League, China

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1 Introduction

Many facets of human well-being are underpinned by nature and its subsystems such as soil, atmosphere, water and vegetation (Van Oudenhoven et al., 2018). However, in the past few centuries, especially in the last 50 yr, the development of human society and economy has undoubtedly brought great trauma to the natural ecosystems (Lu et al., 2015a; Feng et al., 2019b). Hence, there are many challenges for humanity in a rapidly changing world in protecting, managing, and restoring nature in such a way that human well-being can be sustained in balance with nature. Thus, the terms ecosystem services (ESs) and ecosystem service values (ESVs) were coined and ESVs' quantitative approaches were proposed at the end of the last century (Costanza et al., 1997; Daily, 1997), which helps us to trade-off the gains and losses in social and economic activities, especially in their impacts on nature in monetary terms. Since then, a great deal of research work has been car-

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ried out on the assessment methods of ESVs (Costanza et al., 2014; Zheng et al., 2019; Hu et al., 2020). Meanwhile, the research topics of ESVs paid considerable attention to spatial heterogeneity (Schröter et al., 2015), regional differences and socio-economic factors (Bhandari et al., 2016; Hu et al., 2019).

However, the arid regions were often neglected in ESVs' assessment because of their sparse vegetation and large areas of unused land, especially in deserts. The Gobi Desert's ecosystem, for example, was not contained in the Costanza's (1997) evaluation method, or its ESVs was given a particularly low rating (Xie et al., 2003; Xie et al., 2015b). Arid regions are an inherent part of the earth, covering 41% of the earth's surface, and supporting more than 38% of the world's population (Feng et al., 2019a; Lian et al., 2021). They also support 50% of the world's livestock, account for 44% of all cultivated land, and are major wildlife habitats. Moreover, they are considered the inventor of civilization due to the lack of floods (Liu et al., 2014; Lu et al., 2015b). The desert ecosystem is a seed bank for many desert plants and an important place for regulating carbon storage and emission, and even contains huge fresh water resources (Lu et al., 2021). Therefore, it is necessary to develop a new method to estimate the ESVs in arid region based on regional characteristics, which will greatly promote ecological protection in these regions.

At present, the estimation of ESVs can be roughly divided into two categories, namely the method based on unit service function price (hereinafter referred to as the function value method) (Wang and Lu, 2009; Zheng et al., 2019) and the method based on the equivalent coefficient of value per unit area (hereinafter referred to as equivalent coefficient method) (Costanza et al., 2014; Xie et al., 2015b; Hu et al., 2020). The function value method is to obtain the total value based on the quantity and unit price of the ecosystem service function (Zheng et al., 2019). This method simulates the ecosystem service function of a small area by establishing the production equation between the single service function and local ecological environment variables using models or tools, e.g., InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs), a major tool in ESVs research because it utilizes LULC change and related biophysical and economic data to predict the ESVs and supply of ESs (Silvestri et al., 2013; Xie et al., 2015a; Yao, 2016; Yang et al., 2018). However, this method has many input parameters and complicated calculation processes, and more importantly, it is difficult to unify the evaluation method and parameter standard of each service value (Zhang et al., 2010; Jian, 2011). The equivalent coefficient method is based on distinguishing the service functions of different types of ecosystems, constructing the value equivalent of various service functions of different types of ecosystems based on quantifiable criteria through professional questionnaire surveys of hundreds of ecologists and other relevant scholars, and then evaluating them in combination with the area of the ecosystems (Xie et al., 2015a; Yao, 2016). Compared with the function value method, the equivalent coefficient method is relatively direct and easy to use with less data demand, which is especially suitable for the assessment of ESVs on a regional, national and global scale (Costanza et al., 2014; Xie et al., 2015a; Hu et al., 2020). Therefore, the equivalent coefficient method can serve as a basis for the development of new methods of ESVs estimation in arid region.

In this paper, we took the Alxa League of China's Inner Mongolia Autonomous Region, which is a typical arid region, as the case study area. Three famous deserts including Badain Jaran Desert, Tengger Desert and Ulambu Desert traverse the whole region, accounting for 29% of the Alxa League's total area (Feng et al., 2019a). However, there are paddy fields along the Yellow River and *Euphrates poplar* forests maintained by the runoff of the Heihe River in desert areas. Because the biophysical and economic data in this region is scarce, the complex models are difficult to apply, including InVEST. The goal of the present study was to construct an equivalent coefficient method to estimate the ESVs in the Alxa League from 1975 to 2015 by integrating the existing methods and regional characteristics of cost of water for arid ecosystems, based on the statistical data and land use/land cover (LULC) data from remote sensing monitoring, and improving the value per unit area yield factor method of static evaluation. Moreover, we compared the estimated value of the cultural services with the actual tourism income in this region to validate the method's suitability. Our results can provide a more comprehensive scientific basis and decision support for regional natural asset evaluation and ecological compensation, and it also provides a new method to estimate the ESVs in arid regions.

2 Data and Methods

2.1 Study area

The Alxa League of Inner Mongolia Autonomous Region, China is located in the Inner Mongolia Plateau and lies between 97.16°E–106.87°E and 37.35°N–42.78°N with an area of 270 × 10^3 km^2 (Fig. 1). The annual precipitation decreases from an average of 200 mm in the southeast to 40 mm in the northwest, making it one of the most arid regions in China (Feng et al., 2019a). Even so, it is rich in animal and plant species with more than 300 kinds of psammophytes and desert plants, and is also home to more than 180 rare animal species (Feng et al., 2019a).

The Alxa League consists of three banners from east to west, which are the Alxa Left Banner, Alxa Right Banner and Ejin Banner. The Alxa League is the largest but least-populated prefecture-level city in Inner Mongolia with a population of 240 × 10^3 in 2015, but it has experienced severe ecological degradation because of the overgrazing of grassland, the unreasonable utilization of water and soil resources, and the decrease of upstream water inflow. In recent years, with the increase of water diversion from the Yellow River in its eastern region and discharge from the Heihe River in its western region, the LULC changed obviously and the regional ecological environment has been significantly improved (Lu et al., 2021). In addition, due to the publicity and creation of desert geoparks, desert tourism and the Euphrates poplar landscape, as well as the improvement of transportation convenience, regional tourism has developed rapidly. The Alxa League is an ideal area to study the ESVs in arid areas.

2.2 Data collecting and processing

2.2.1 Land use/land cover (LULC) data and processing

The data sources are Landsat MSS (1975), TM (1990, 2010), ETM+ data (2000) and OLI (2015), mostly obtained from the United States Geological Survey (USGS, https://glovis.usgs.gov/), and a few from China Geospatial Data Cloud (http://www.gscloud.cn/). There are five periods of LULC data (1975, 1990, 2000, 2010 and 2015) using an integrated method of remote sensing monitoring, and validation through ground investigation and the interpretation of satellite imagery with high resolution. The production of this dataset uses the object-oriented classification method based on the platform of eCognition and data processing method based on ArcGIS platform (Xie et al., 2016). The accuracy of land use data is strictly checked, and then assessed by confusion matrix. The maps are reinterpreted if the accuracy does not satisfy the mapping standards and rechecked until the accuracy reaches mapping requirements. In the processing of accuracy assessment, the data of field verification point and Google earth images are also used as ancillary materials to confirm the interpretation precision (Xie et al., 2016).

According to the land use/land cover classification system (Feng et al., 2011; Xie et al., 2016; Lu et al., 2021), there are 6 types at the first scale and 40 types at the second scale, which can meet the needs of ESVs estimation of as many as 14 types. In the estimation of the ESVs of the different ecosystems, we combine the

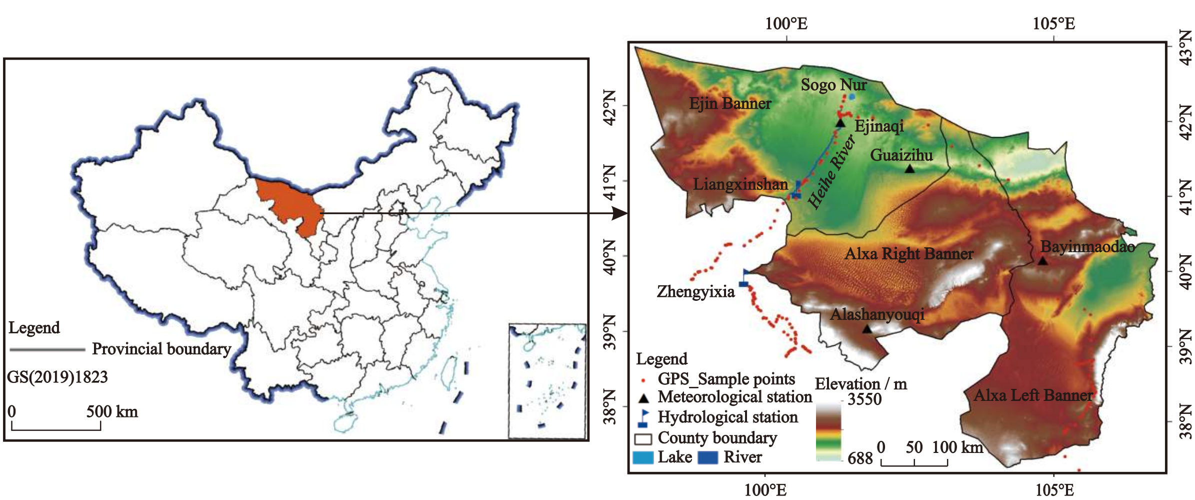

Fig. 1 Location of study area in China and meteorological and hydrological stations

LULC types at the second scale accordingly (Table 1).

2.2.2 Other auxiliary data

Precipitation and temperature are two major variables used to understand regional climatic condition, vegetation dynamics, and ESVs change. Annual precipitation and mean temperature records at the Ejinaqi, Guaizihu, Bayinmaodao and Alashanyouqi Meteorological Stations from 1975 to 2015 were collected from the China Administration of Meteorology (http://data.cma.cn/). Because the upstream runoff and water diversion from nearby rivers are the main water resource for the ecosystems in arid regions, the runoff at Zhengyixia Station and Langxinshan Station in the Heihe River and the streamflow into the terminal lakes were used to assess the impacts of water diversion on the ecosystem changes in Alxa League. The runoff data in the Heihe River between 1975 and 2015 were collected from the Environmental and Ecological Science Data Center for West China (http://westdc.westgis.ac.cn/) and the Bureau of Heihe River Water Resources Bulletin.

In addition, the roles of projects and policy factors in ecosystem changes are particularly important. In the past 40 yr, the Alxa League has carried out a large number of projects, including the 'Three-North Shelterbelt' project since 1978, 'Natural Forest Protection' Project, the 'Grain to Green' Program and 'Ecological Migrant' Project since the mid-1990s, and the Ecological Water Diversion Project (EWDP) in the Heihe River Basin since 2000. These data were obtained from the regional statistical yearbooks (Alxa League Statistics Bureau, 2001–2016), annual reports and literature (Lu et al., 2021). According to the effects of projects and policies on social economies and ecological environment, they were divided into socio-economy oriented projects and policies and ecological environment oriented projects and policies.

2.3 Ecosystem service values (ESVs) estimation

2.3.1 Types of ecosystem services (ESs)

Although the European Environment Agency (EEA) recently published the Common International Classification of Ecosystem Services (CICES, V5.1) and reclassified the ESs into three categories—provisioning, regulating and maintenance, and cultural services (Hu et al., 2019), we applied the method of the Millennium Ecosystem Assessment (MA) (2005) due to the consistency of service function classification and calculation criteria of ESVs from previous research (Costanza et al., 2014; Xie et al., 2015b; Yao, 2016; Hu et al., 2020). The ESs were divided into 4 major categories including: supply services, regulating services, support services, and cultural service, and further subdivided into 11 kinds of ESs (MA, 2005; Xie et al., 2015b) (Table 1).

2.3.2 Evaluating value of equivalent coefficient for a standard unit ecosystem service value

The equivalent coefficient for a standard unit ecosystem service value (hereinafter referred to as the standard equivalent coefficient) refers to the economic value of natural food production in 1 ha of farmland with the level of the national average yield every year (Xie et al., 2015a; 2015b), which can be used to determine the equivalent coefficient of other ESs combining expert knowledge. In this study, referring to the treatment method in the national scale provided by Xie et al. (2015b), we took the net profit of food production per unit area of farmland ecosystem in Alxa League as the ESVs of a standard equivalent coefficient. Because the statistical data is limited to the administrative district scale of the league, the grain yield value of farmland ecosystem was calculated based on the statistical data of the Inner Mongolia Autonomous Region and China from 2001 to 2015. The standard equivalent coefficient was calculated as follow.

$$D=\sum_{i=1}^{15}\frac{((P_{\mathrm{w},i}\times Y_{\mathrm{w},i}-C_{\mathrm{w},i}\times A_{\mathrm{w},i})+(P_{\mathrm{c},i}\times Y_{\mathrm{c},i}-C_{\mathrm{c},i}\times A_{\mathrm{c},i}))}{15\times(A_{\mathrm{w},i}+A_{\mathrm{c},i})} \quad (1)$$

where D is the average of the standard equivalent coefficient from 2001 to 2015 (yuan (RMB)/ha), $P_{\mathrm{w},i}$ and $P_{\mathrm{c},i}$ are the prices of the wheat and corn in year i in China (yuan (RMB)/kg), $Y_{\mathrm{w},i}$ and $Y_{\mathrm{c},i}$ are the yield of wheat and corn in year i in Inner Mongolia Autonomous Region (kg), $C_{\mathrm{w},i}$ and $C_{\mathrm{c},i}$ are the cost of wheat and corn in year i in China (yuan (RMB)/ha), and $A_{\mathrm{w},i}$ and $A_{\mathrm{c},i}$ are the area of wheat and corn in year i in Inner Mongolia Autonomous Region (ha), respectively. The data were obtained from the statistical yearbooks of Alxa League (Alxa League Statistics Bureau, 2001–2016), Inner Mongolia Autonomous Region and China, and literature (Wang, 2017).

2.3.3 Basic equivalent of value of ecosystem services per unit area

The basic equivalent of the value of ESs per unit area refers to the average annual value equivalent of each ecosystem service per unit area of different types of eco-

Table 1 The basic equivalent of ecosystem service value per unit area

LULC types (Feng et al., 2011)		Ecosystem types for ESVs estimation (Xie et al., 2015b)	Supply services			Regulating services				Support services			Cultural service	Total
			Food production	Raw material production	Water supply	Gas regulation	Climate regulation	Environmental purification	Hydrology regulation	Soil retention	Maintenance of nutrient cycling	Biodiversity	Aesthetic landscape	
Cultivated land	Paddy field	Paddy field	1.36	0.09	−2.63	1.11	0.57	0.17	2.72	0.01	0.19	0.21	0.09	3.89
	Irrigated land	Irrigated land	1.36	0.09	−1.32	1.11	0.57	0.17	2.72	0.01	0.19	0.21	0.09	5.20
Forest	Deciduous broadleaf forest	Broadleaf forest	0.29	0.66	0.34	2.17	6.50	1.93	4.74	2.65	0.20	2.41	1.06	22.95
	Evergreen needleleaf forest	Needleleaf forest	0.22	0.52	0.27	1.70	5.07	1.49	3.34	2.06	0.16	1.88	0.82	17.53
	Deciduous broadleaf shrubland	Shrubland	0.19	0.43	0.22	1.41	4.23	1.28	3.35	1.72	0.13	1.57	0.69	15.22
	Sparse forest	Sparse forest	0.16	0.36	0.14	1.18	3.52	1.00	1.76	1.43	0.11	1.30	0.57	11.53
	Sparse shrubland	Sparse shrubland	0.10	0.22	0.11	0.71	2.12	0.64	1.68	0.86	0.07	0.79	0.35	7.65
	Orchard	Orchard	1.25	0.58	−1.14	1.98	3.72	1.10	3.87	1.85	0.26	1.38	0.61	15.46
Riparian forest	Deciduous broadleaf forest	Broadleaf forest	0.29	0.66	−0.98	2.17	6.50	1.93	4.74	2.65	0.20	2.41	1.06	21.63
	Deciduous broadleaf shrubland	Shrubland	0.19	0.43	−1.06	1.41	4.23	1.28	3.35	1.72	0.13	1.57	0.69	13.94
	Sparse forest	Sparse forest	0.16	0.36	−0.49	1.18	3.52	1.00	1.76	1.43	0.11	1.30	0.57	10.90
	Sparse shrubland	Sparse shrubland	0.10	0.22	−0.53	0.71	2.12	0.64	1.68	0.86	0.07	0.79	0.35	7.01
Grassland	Temperate steppe, lawn	Grassland	0.10	0.14	0.08	0.51	1.34	0.44	0.98	0.62	0.05	0.56	0.25	5.07
	Temperate meadow	Meadow	0.22	0.33	0.18	1.14	3.02	1.00	2.21	1.39	0.11	1.27	0.56	11.43
	Sparse grassland	Sparse grassland	0.05	0.07	0.04	0.26	0.67	0.22	0.49	0.31	0.03	0.28	0.13	2.55
Water/wetland	Shrub wetland, herbaceous wetland	Wetland	0.51	0.50	2.59	1.90	3.60	3.60	24.23	2.31	0.18	7.87	4.73	52.02
	Lake, reservoir/pond, river and canal/channel	Water	0.20	0.06	2.07	0.21	0.57	1.46	25.58	0.25	0.02	0.65	0.48	31.55
Unused land	Desert	Desert	0.01	0.03	0.02	0.11	0.10	0.31	0.21	0.13	0.01	0.12	0.05	1.10
	Bare rock, Gobi, bare soil and salina	Bare land	0.00	0.00	0.02	0.02	0.00	0.10	0.03	0.02	0.00	0.02	0.01	0.22

systems (hereinafter referred to as the basic equivalent) (Xie et al, 2015b). Based on Costanza et al. (1997), Xie et al. (2008) improved the calculation method by conducting a professional questionnaire survey in China, and the equivalent coefficient was considered the value of a certain ES of a specific ecosystem (Xie et al., 2008; Hu et al., 2019). We determined the basic equivalent in Alxa League by integrating the national average provided by Xie et al (2015b) and local conditions, referring to an adjacent case of Wu'an City in Hebei Province (Yao, 2016).

In Alxa League, there is riparian forest along the Heihe River, which depends mainly on groundwater. Similarly, the irrigated land needs irrigation using river runoff or groundwater. Thus, their water supply service should be negative values as should be the paddy fields proposed by Xie et al. (2015b) and Yao. (2016). We set the values of the water supply service of the riparian forest and the irrigated land according their evapotranspiration (Li et al., 2018). In addition, the bare land in Alxa League had the ability of water supply (Li et al., 2018), and should be set the same value as desert (Xie et al., 2003; Xie et al., 2015b; Yao, 2016) (Table 1). Moreover, we used the regional tourism income to verify the value of the cultural service in this study.

3 Results

3.1 Land use/land cover changes

As Fig. 2 shows, the main LULC types in Alxa League are unused land and grassland. Unused land includes bare land and desert, which account for about 47% and 31%, respectively, while grassland accounts for 18%, but the sparse grassland predominates and is up to 15.7%. The other land cover types account for about 4%. The land cover in Alxa League changed slightly from 1975 to 2015 except for the more obvious changes to water or wet land, irrigated land, and built-up land. The area of water or wetland decreased continuously before the introduction of the EWDP in 2000, and then increased since the EWDP was implemented. The lakes in Badain Jaran desert in Alxa Right Banner changed slightly, but the terminal lakes of the Heihe River such as Swan Lake and Sogo Nur dried up in 1990 and 2000, and then recovered in 2010. The irrigated land and built-up land were in an expanding trend over the past 40 yr with the socio-economic development. Riparian forest has increased in general, which depended on the changes of sparse shrubland and deciduous broadleaf shrubland. On the contrary, the unused land decreased continuously.

3.2 Ecosystem service values changes

The total ESVs in Alxa League decreased from 1975 to 2000, and it was lowest at 82 337.8 million yuan (RMB) in 2000. From 2000 to 2015, the total value increased to 84 033.6 million yuan (RMB), which was more than it was in 1975 (Fig. 3). The ESVs of grassland was in first place in Alxa League, which amounted to 42.0%, and the sparse grassland's ESVs accounted for about 78.6%

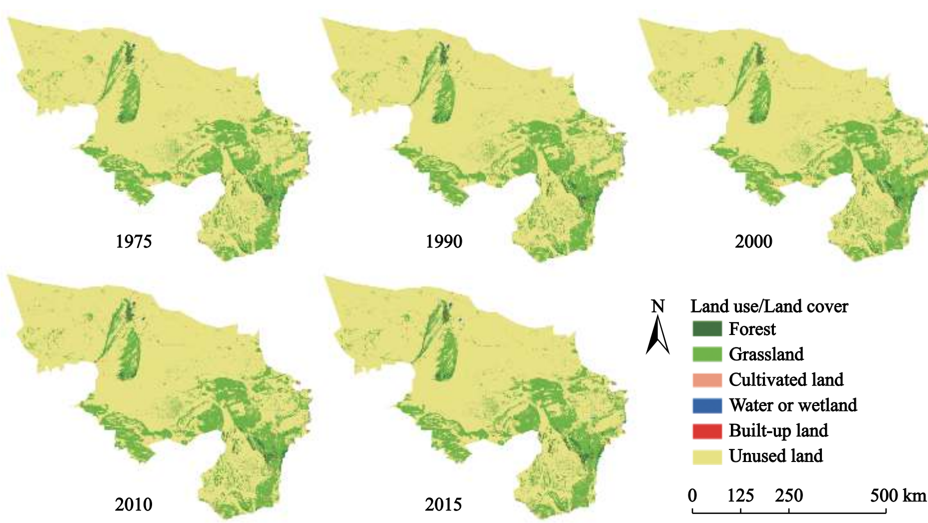

Fig. 2 The spatial changes of land use/land cover from 1975 to 2015 in Alxa League, Inner Mongolia Autonomous Region, China

of that. In second place was unused land, which accounted for 37.5%, and bare land and desert accounted for about 22.7% and 77.3% of that, respectively. The proportions of the grassland and unused land to the total value increased from 1975 to 2000 and then decreased from 2000 to 2015. In third place was forest and it accounted for about 15%, and sparse shrubland accounted for about 70% of that. The ESVs of water or wetland was fourth and accounted for 3.3%–5.0%, and it decreased from 3765.5 million yuan (RMB) in 1975 to 2717.6 million yuan (RMB) in 2000, then continually increased to 4180.2 million yuan (RMB) in 2015, which was 53.8% more than it was in 2000. This was because the terminal lakes recovered. The ESVs of cultivated land was the least and accounted for only 1%, but it increased continually from 566.3 million yuan (RMB) in 1975 to 994.8 million yuan (RMB) in 2015.

The composition of the ESVs in Alxa League was stable from 1975 to 2015 in general. In the major categories of ESs, the supply services, regulating services, support services and cultural services contributed about 6.0%, 66.5%, 22.8% and 4.7%, respectively (Fig. 4). The contributions of the supply services and regulating services first decreased from 1975 to 2000 and then increased from 2000 to 2015. On the contrary, the contributions of the support services and cultural services increased from 1975 to 2000 and then decreased from 2000 to 2015.

In the regulating services, the contribution of the hydrology regulation was the most and decreased from 21.6% in 1975 to 20.9% in 2000 and then increased to 21.9% in 2015. The climate regulation, environmental purification and gas regulation services contributed 18.5%, 17.4% and 9.4%, respectively, and the proportions of their contributions increased from 1975 to 2000 and then decreased from 2000 to 2015. In the support services, the soil retention, maintenance of nutrient cycling and biodiversity contributed 11.3%, 0.9% and 10.6%, respectively. In supply services, the food production, raw material production and water supply contributed 1.6%, 2.4% and 1.9%, respectively. The food production's value increased continually from 1249.6 million yuan (RMB) in 1975 to 1372 million yuan (RMB) in 2015, while the water supply's value decreased from 1724.4 million yuan (RMB) in 1975 to 1557.7 million yuan (RMB) in 2000 and then increased to 1619.2 million yuan (RMB) in 2015. The aesthetic landscape's least and largest values appeared in 2000 (3894.5 million yuan (RMB)) and 2015 (3939.8 million yuan (RMB)), while its proportion was about 4.7% and first increased in the period of 1975–2000 and then decreased in the period of 2000–2015.

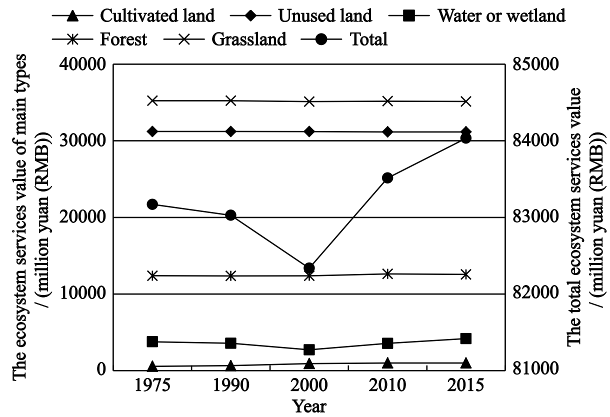

Fig. 3 The changes of ecosystem service values from 1975 to 2015 in Alxa League, Inner Mongolia Autonomous Region, China

3.3 Driving force of ecosystem service values changes

Through analyzing the climate and hydrological changes and detecting the change trend and inflection point characteristics of LULC and ESVs, we made comparison analysis between ESVs and the climatic, hydrological and socio-economic factors. The year 2000 is an important node for the changes of land use and ESVs in Alxa League. Based on the meteorological data, the mean annual precipitation ranged from 34 mm in Ejinaqi and 120 mm in Alashanyouqi in the period of 1975–2015 (Fig. 5a). The precipitation in all of four stations was in increasing trend, but did not satisfy the significance level of 10%. From 1975 to 2015, the annual temperature increased obviously with the rates of

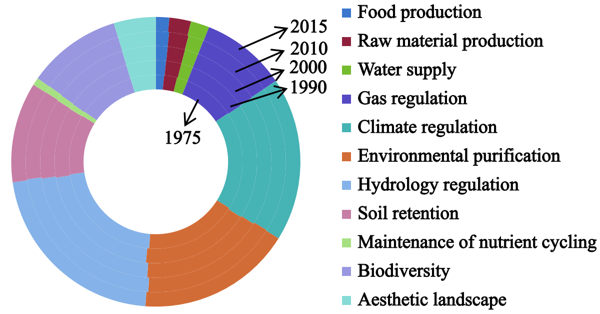

Fig. 4 The proportions of 11 ecosystem services' values to the total in Alxa League, Inner Mongolia Autonomous Region, China

0.34°C–0.52°C per 10 yr (Fig. 5b). In addition, the runoff at Zhengyixia station experienced a gradual decline until the EWDP began in 2000 and the mean runoff in the period of 1990–2000 was only 7.7 × 10^8 m^3; then it increased by 2.9 × 10^8 m^3 after the EWDP. Similarly, the runoff at Langxinshan increased from 4.5 × 10^8 m^3 in the period of 1988–1999 to 5.5 × 10^8 m^3 in the period of 2000–2015 (Fig. 5c). The discharge flowing into the Sogo Nur has remained at around 0.5 × 10^8 m^3 in recent years. Thus, under the background of a warm and wet climate, but with limited effect of the precipitation on local socio-economic development and ecological environment protection, the increase of water discharged from the Heihe River undoubtedly became the key factor to ensure the above two aspects.

In the period from 1975 to1990, the vast majority of policies were geared towards socio-economic development, including the national commodity grain construction base in 1975, reform and opening up and gross domestic product (GDP) as the main evaluation index in 1978, household contract responsibility system and grass and livestock double contract in 1983, and poverty alleviation policies in 1986, while the ecological environment oriented project only includes the 'Three-North' Shelterbelt system construction project since 1978. Entering the second period of 1991−2000, at the same time as developing of the economy (such as construction of the socialist market economy in 1992, protection of basic farmland in 1999 and great western development strategy in 2000), emphasis was also given the protection of ecological environment (establishment of the *Populus euphratica* forest nature reserve of the Inner Mongolia Autonomous Region (IMAR) in 1992, sustainable development as a national strategy in 1994, soil

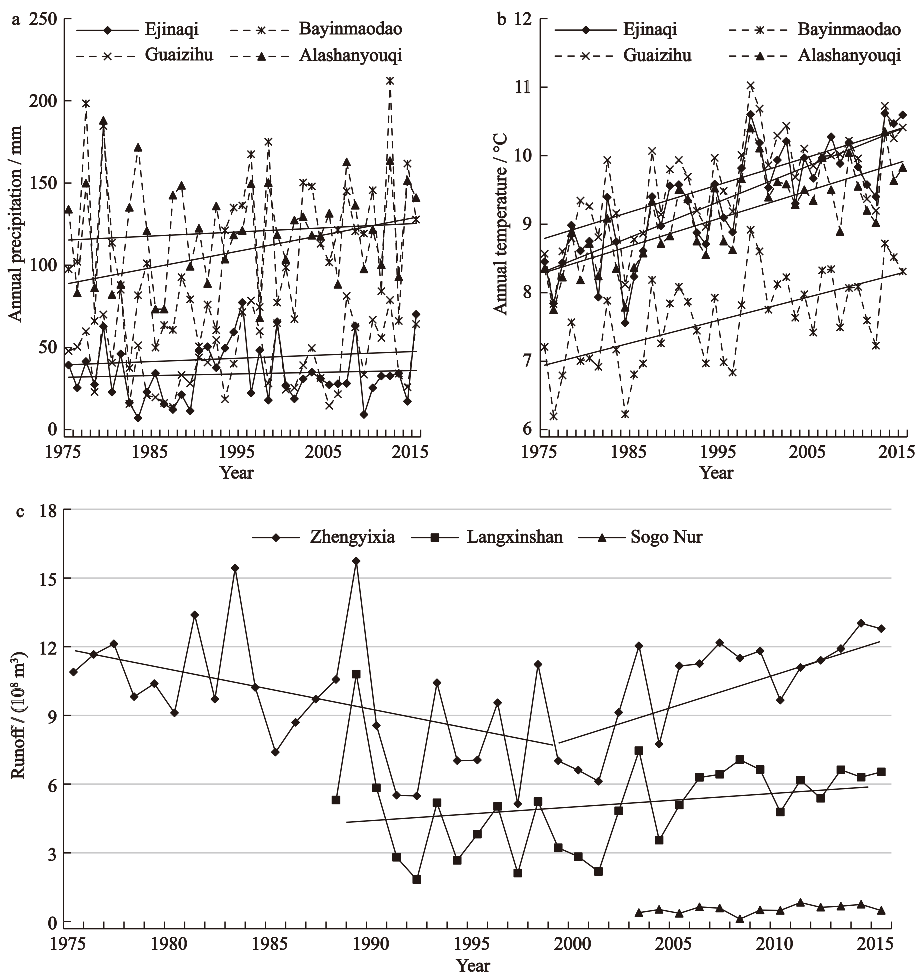

Fig. 5 The climatic and hydrological changes from 1975 to 2015 in Alxa League, Inner Mongolia Autonomous Region, China: (a) annual precipitation, (b) annual mean temperature and (c) runoff

and water conservation as a basic national policy in 1997, pilot project of natural forest protection in IMAR in 1998, 'Grain for Green' Project in 1999, and full-scale Natural Forest Protective Project and EWDP in Heihe River Basin in 2000), especially to the harnessing of the Heihe River Basin with implementation of EWDP in 2000.

Since 2000, although the economy is still booming under many policies, including joining the WTO in 2001, property sector as a pillar industry in 2003, cancelling agricultural tax in 2006, collective rights reform and land transfer in 2008 and belt and road initiative in 2015, more efforts have been made to protect and restore the country's ecology (such as eco-environment meeting of IMAR, law on desert prevention and transformation and recent management plan in Heihe River Basin 2001, eco-migration project in Ejina in 2002, establishment of *Populus euphratica* in Ejina National Nature Reserve in 2003, and new rural development strategy and Alashan Desert National Geopark in 2005), and the ecological progress became a national policy in 2011. These projects and policies dominated the changes of regional land use and also affected the distribution and composition of regional ESs and ESVs.

4 Discussion

4.1 The suitability of ESVs estimation method

In this study, we selected the Alxa League, a typical arid region dominated by desert ecosystems, as a case study, and estimated its ESVs using an equivalent coefficient method. In order to determine the standard unit ESVs of the Alxa League, we used the national price and cost of the main food crops, and the yield and the area sown in the Inner Mongolia Autonomous Region after comparison of reliability and tradeoff of data acquisition availability. The standard unit ESVs was 2857 yuan (RMB)/ha, which was appropriate compared with the national value (3406.5 yuan (RMB)/ha) estimated by Xie et al. (2015b). This was because the yield in the Alxa League was low due to an arid climate and poor land, and the benefit was lower than the national value. In the estimation of the basic equivalent of the value of ESs per unit area, we referenced the national level provided by Xie et al. (2015b), and the regional level in an adjacent case of Wu'an City in Hebei Province (Yao, 2016). Moreover, we considered the distinctive qualities of the Alxa league, such as widespread distribution of desert and bare land, and desert riparian forest, and added some ecosystems (the ordinary deciduous broadleaf forest, deciduous broadleaf shrubland, sparse forest and sparse shrubland and those belong to riparian forest) and adjusted their value based on their water consumption using the evapotranspiration data (Li et al., 2018).

There was a spectacular economic development in the Alxa League from 2002 to 2018, especially in tertiary industry, and the tourism income increased from 64.3 million yuan (RMB) to 17 420 million yuan (RMB) (Fig. 6). The estimated cultural services values were 3894.5 million yuan (RMB) in 2000 and 3935.8 million yuan (RMB) in 2010, which were much larger than the tourism income, while the cultural services value was 3939.8 million yuan (RMB) in 2015 and was considerable with the tourism income of 4700 million yuan (RMB) (Fig. 6). This indicated that the results of cultural services values had some reliability and the method has suitability, but the dynamic changes were not considered.

4.2 Importance of the arid ecosystem in the coordinated development

We successfully estimated the ESVs in Alxa League from 1975 to 2015 using the improved method. The value was up to 82 337.8–84 033.6 million yuan (RMB), while the GDP in Alxa League in 2015 was 32 258 million yuan (RMB), which was only 38% of ESVs. It should be noted that the ESVs of desert systems and bare land accounted for 37.1%–37.9% of the total ESVs. As stated by Lu et al. (2020), the native desert region is dry and rainless, with sparse vegetation and a fragile ecosystem, but it plays an irreplaceable and important role in regulating climate, material circulation and energy circulation, and contributes its own strength to the balance and stability of the earth's biosphere. In our results, although the supply services contributed about 6.0% of the total, the regulating services and support services contributed 66.5% and 22.8%, respectively. In addition, the cultural services may be reasonable and was 3894.5–3939.8 million yuan (RMB), accounting for 4.7% of the total, because the tourism revenue of Ejin Banner alone reached 1462 million yuan (RMB) in 2015, then rapidly increased to 6819 million yuan (RMB) in 2018. This also gave us a hint that dynamic

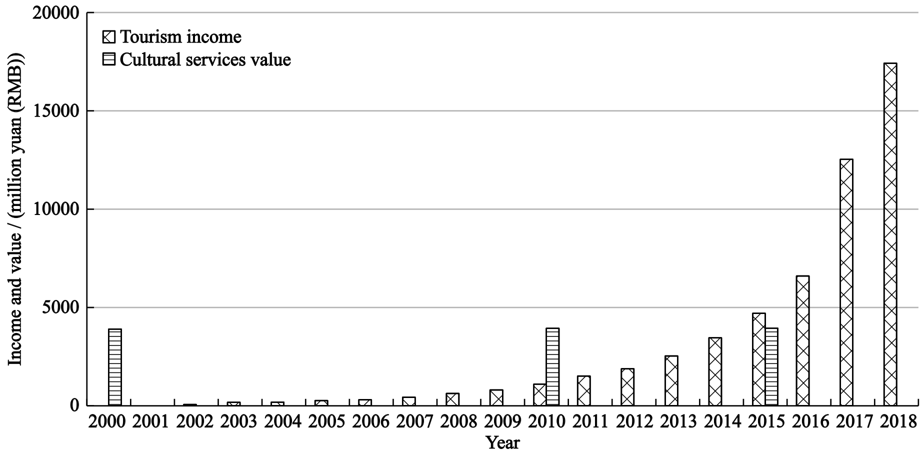

Fig. 6 The tourism income and cultural services values from 2002 to 2018 in Alxa League, Inner Mongolia Autonomous Region, China

estimation of ESVs should be considered in the future.

A slogan on the shore of Sogo Nur downstream of Heihe River reads, 'the little Sogo Nur is connected to the national high level', indicating that the state leaders are concerned about the local ecological environment, but also implies that the deterioration of the local ecological environment affects Beijing and other distant places. Many ESs are not limited to local regions, but also provide some services in distant places, such as air purification services. It is extremely necessary and important to integrate tele-services and willingness to pay into the estimation and assessment of ESVs.

5 Conclusions

This study constructed an equivalent coefficient method to account the ESVs of arid region, through determining the standard unit ESVs and the basic equivalent of the value of ESs per unit area based on the regional characteristics, literature research and expert knowledge. The ESVs in the Alxa League was estimated and its changes was analyzed duing 1975–2015 based on LULC data. The sparse grassland and desert were the two highest contributors, which accounted for about 33% and 29% of the total ESVs (82 337.8–84 033.6 million yuan (RMB)), respectively. Among the four major ESs types, the regulating services was the largest, followed by support services, supply services and cultural services, which contributed about 66.5%, 22.8%, 6.0% and 4.7%, respectively. In the secondary ESs types, the contribution of the hydrology regulation, climate regulation, environmental purification and gas regulation functions contributed about 21%. 18.5%, 17.4% and 9.4%, respectively. With the changes of the LULC, the ESVs first decreased from 1975 to 2000 and then increased from 2000 to 2015. This was mainly because the former stage mainly focused on social and economic development, while the latter stage gave consideration to social and economic development, and the ecological environment restoration and protection policies and projects represented by the EWDP in the Heihe River basin increased, and the ecological environment improved. The results can provide more comprehensive scientific basis and decision support for natural asset evaluation and ecological compensation in arid region.

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