ORIGINAL ARTICLE

Evaluation of Agricultural Ecosystem Service Value in Arid and Semiarid Regions of Northwest China Based on the Equivalent Factor Method

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Abstract

A reasonable assessment of the value of ecosystem services is an effective measure to maintain the normal operation of the ecosystem and adjust the balance between economic development and the ecological environment. With the help of the related concepts of ecosystem services, this paper establishes an evaluation framework system and adopts the widely used and comprehensive evaluation method of equivalent factors, which is a rapid accounting tool used for the evaluation of ecosystem services. The value of agricultural ecosystem services was estimated from 2008 to 2017 in a typical arid-semiarid region, and nine ecosystem service functions were analyzed. Our research showed that from 2008 to 2017 the value of agricultural ecological services in Gansu Province increased annually, and the annual growth rate in 2012 was the highest (15%). The results showed that the selection of appropriate methods could quickly and effectively evaluate the value of agricultural ecosystem services. In-depth research on the function and value of agroecological services could better promote the sustainable development of agroecosystems and maintain the balance and integrity of ecological service functions. Evaluation of the balance and integrity of agricultural ecosystem ecological service functions in arid semi-arid regions will provide recommendations for land use and sustainable development and ecological environment protection in these regions.

Highlights
• Agricultural ecosystem services have changed in an arid and semiarid region of China in recent decades.
• We reflect the results of China's ecological progress.
• This study provides advice on agricultural development of other developing countries.

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1 Introduction

Arid and semiarid regions account for approximately 40% of the world's land area. However, the improper use of natural resources has caused a series of environmental problems, such as falling water levels, land desertification and salinization, reduced vegetation and increased pollution (Zhu et al. 2016). The loss of the natural environment and agricultural land are particularly severe (Lu et al. 2015; Zhou et al. 2015), and thus, the sustainable development of the local society and economy has been greatly affected (Peng et al. 2019). Other developing countries experiencing urbanization and industrialization may face similar problems (Abd-Elaty et al. 2020; Azaiez et al. 2020; Haghighi et al. 2020; Sharafatmandrad and Mashizi 2021). With the strength of environmental protection and the consideration of human themselves, increasing attention needs to be paid to the fragility, sensitivity and security issues of the ecological environment in arid and semiarid regions.

Natural ecosystem services are the material basis for human survival and development, critical for the sustainable development of humans (Zhao et al. 2006; Wu 2013), and beneficial for policy and decision making (Cortinovis and Geneletti 2018; Posner et al. 2016). Constanza et al. (1997) subdivided the types of ecological services, proposed quantitative evaluation methods, and promoted quantitative research on ecological services. A reasonable assessment of the value of ecosystem services is an effective measure to maintain the normal operation of the ecosystem, ensure ecological safety, and adjust the balance between economic development and the ecological environment.

Agriculture represents humankind's largest engineered ecosystem, as agricultural land use accounts for one-third of the global terrestrial surface (approx. 4.9 billion ha) (FAO 2018). Livestock husbandry on grasslands (3.3 billion ha) accounts for a much larger area than crop production (1.6 billion ha) (Scheffers et al. 2016). Agricultural ecosystems provide and rely upon important ecosystem services (Zhang et al. 2007; Duguma et al. 2019). Research on agroecosystem services began in the 1990s. Researchers have shown that the evaluation and prediction of agroecological services contribute to agroecosystem protection (Longato et al. 2019; Khosravi Mashizi et al. 2019; Del Rio et al. 2020). Some researchers have focused on the regional impacts of ecosystem services (Chen et al. 2020; Yang et al. 2020; Zhong et al. 2020), especially the ecosystem service values (ESVs) of grasslands and forests (Cao et al. 2020). Sun et al. (2021) evaluated the agroecological services in North China and predicted their changes under different land-use scenarios. In addition, A good ecological environment will help control a large number of infectious disease epidemics, e.g., the current domestic and foreign rampant novel coronavirus epidemic situation caused by 2019-nCoV. Although the science of this hypothesis remains to be further studied, it shows that the role of the rural ecological environment and its ecosystem services in preventing and controlling epidemics deserves much more attention (Dietz et al. 2020; Wang and Su 2020).

Since the release of the Millennium Ecosystem Assessment (Millenium Ecosystem Assessment 2005), there have been three main methods used to evaluate the value of ecosystem services: the energy method, the InVEST model, and the economic methods. The energy method provides an ESV measurement approach by evaluating the biophysical flows used to support its generation (Odum 1996). The InVEST model maps and evaluates multiple ecological services (Kadaverugu et al. 2021). Economic methods can evaluate the economic value of an ecological system or its services to describe the interdependency of human economies and natural ecosystems (Farber et al. 2002; Zhang et al. 2010), thereby ensuring the sustainable use of those ecosystem services. There is no unified

ESV evaluation system in China, although Xie et al. (2003) improved the ESV estimation method proposed by Costanza et al. (1997).

Because the understanding of the equilibrium relationship between the natural productivity of agricultural ecosystems and economic productivity is not deep enough, the integrity of the structure and function of agroecosystems is damaged in the process of pursuing agricultural economic benefits (Swinton et al. 2007). The uneven distribution and utilization of agricultural resources may lead to poor energy flow in the agroecosystem, hindered material circulation and delayed information transmission, eventually paralyzing the agroecosystem and worsening its original sociality, high productivity and volatility. Therefore, an in-depth study of the function and value of agroecological services can provide a scientific basis for the sustainable development of agroecosystems and the maintenance of the equilibrium and integrity of ecological service functions. The long-term preservation of agricultural landscapes that provide multiple ecosystem services must be a priority. Therefore, management actions on these landscapes should consider a spatial assessment of ecosystem services, and an ecosystem services valuation could inform and support the planning process to achieve sustainability (Santos-Martín et al. 2019).

Due to the special research theme of agroecosystem services, there are few studies on agroecosystem services in arid and semiarid regions. Thus, this paper studied the agroecosystem services in Gansu Province as an example to explore the changes in agroecosystem service value in the arid and semiarid areas of Northwest China during the past two decades; the results are expected to provide a scientific basis for the accurate and efficient allocation of land resources, scientific management of ecosystems, rational regional planning and sustainable land development in China and other countries with similar situations.

2 Materials and Methods

2.1 Study Area

Gansu Province, which includes 12 prefecture-level cities and two autonomous prefectures, is located in the arid inland area of Northwest China and the upper reaches of the Yangtze and Yellow Rivers, 32°31′~42°57′ N, 92°13′~108°46′ E; the annual average temperature is 2~10 °C, and the annual average precipitation is 250~420 mm. The lowest elevation is 586 m, the highest elevation is 5696 m, and the average elevation is 5156 m; the study area covers an area of approximately 425,900 square kilometers (as of the end of 2017). Three plateaus, i.e., the Loess Plateau, the Qinghai-Tibet Plateau and the Inner Mongolia Plateau, meet here, and the terrain is undulating, crisscrossed with mountains, high elevation differences, mountains, basins, plains, deserts and Gobi, and other landform types that are rich and diverse (Fig. 1).

In addition to the Yellow River, three inland rivers, the Heihe River, the Shiyang River and the Shule River, are located in the Hexi Corridor of Gansu Province, and they provide water to oasis agroecosystems. For example, the Heihe River is the second largest inland river in Northwest China, but its ecological environment is sensitive and fragile (Li and Pan 2018). The Ejina Oasis in the lower reaches of the Heihe River provides ecological protection for the other areas in northern China. Serious desertification and fragile ecological environments are popular issues in this area. Therefore, it is an important ecological barrier of the Qinghai-Tibet Plateau and the "Northern Sand Belt" and has a very important position in Northwest China and even in the whole country.
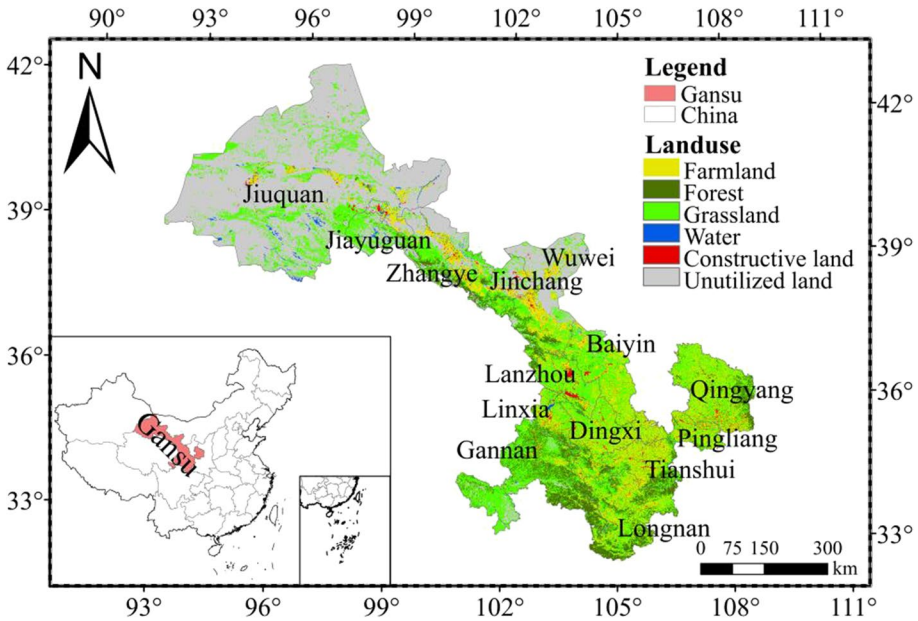
Fig. 1 Location of the study area

2.2 Data Sources

The data for different agricultural land-use types in Gansu Province from 2008 to 2017 used in this study were from the China Statistical Yearbook. The six land-use types corresponded to the six ecosystem types, i.e., forest, grassland, water body, wetland, farmland and desert, in the "Chinese Land ESV per Unit Area" table by Xie et al. (2003).

The sown area of the three main crops (wheat, corn and potato) in Gansu Province (2008–2017) came from the Gansu Provincial Statistical Yearbook and China Statistical Yearbook. The average prices of wheat, corn and potatoes were calculated based on the China Price Yearbook and the consumer price index.

2.3 Ecosystem Service Value Evaluation

Choosing an appropriate method to evaluate the service value of agricultural ecosystems is an effective measure to ensure the normal functioning of ecosystem services and is an important way to achieve regional ecological security and promote sustainable social development. This is even more important for arid and semiarid regions. Therefore, this study adopted the method developed by Xie et al. (2003) to estimate the ESV unit area of China's terrestrial ecosystem to estimate the value of agricultural ecosystem services in Gansu Province from 2008 to 2017.

The ESV per unit area of different terrestrial ecosystems shown in Table 1 was used to estimate the ESV in Gansu Province from 2008–2017. Based on the data for the three main crop areas (unit: ha) and the total output value (unit: US Dollars; All the values

Table 1 Ecosystem service value per unit area for each Chinese ecosystem

Items	Forestland	Grassland	Farmland	Wetland	Water body	Desert
GR	3.50	0.80	0.50	1.80	0.00	0.00
CR	2.70	0.90	0.89	17.10	0.46	0.00
WC	3.20	0.80	0.60	15.50	20.38	0.03
SFC	3.90	1.95	1.46	1.71	0.01	0.02
WT	1.31	1.31	1.64	18.18	18.18	0.01
BM	3.26	1.09	0.71	2.50	2.49	0.34
FP	0.10	0.30	1.00	0.30	0.10	0.01
RMP	2.60	0.05	0.10	0.07	0.01	0.00
EC	1.28	0.04	0.01	5.55	4.34	0.01

of this article are converted by the Renminbi for the US dollars, the exchange rate is $ 0.15) of food crops, the output (raw materials production; RMP) value of the three main crops per unit area (unit: Dollars /ha) was obtained for each year (Xie et al. 2003). According to Xie et al. (2003), the equivalent factor of ESV in China was defined as 1/7 of the economic value of food yield per unit area of farmland (i.e., the economic value of natural grain per unit farmland). In addition, according to the 'China Terrestrial Ecosystem Unit Area Value Equivalent Scale of Ecological Services (Xie et al. 2003), the value coefficient tables of land-use types in ecosystem service value, including gas regulation (GR), climate regulation (CR), water conservation (WC), soil formation and conservation (SFC), waste treatment (WT), biodiversity maintenance (BM), food production (FP), raw materials production (RMP), and entertainment culture (EC), were obtained.

The ecosystem service value equivalent factor 1 in Table 1 refers to the economic value of the annual natural grain output with 1 ha reaching China's average grain output, and the value demonstrates the potential of the relative contribution of ecological services produced by the ecosystem; the other ecosystem service value equivalent factors refer to the contributions of the ecological service values generated by the ecosystem to the food production service value of the farmland.

2.3.1 Calculation of the Ecosystem Service Value of Economic Crop Production per Unit Area

According to the definition of ecosystem service value equivalent factor by Xie et al. (2003) and the results of Tan and Wang (2012), the calculation formula used in this paper is as follows:

$$V_a = \frac{1}{7} \sum_{i=1}^{n} \frac{S_i P_i A_i}{M}; (i = 1, 2, 3 \ldots n) \tag{1}$$

where V_a is the value of the service function of economic crop production per unit farm area (Dollars/ha); S_i is the area of grain crop i (ha); P_i is the average price of grain crop i (Dollars/t); A_i is the output of grain crop i per unit farm area (t/ha); and M is the total area of n food crops (ha).

Table 2 shows the productive service value of economic crops per unit farm in Gansu Province from 2008 to 2017. Except for a slight decline in 2009, the productive service

Table 2 The productive service value of economic crops in unit farm for Gansu Province in 2008—2017 (Dollars /ha)

Items	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Value	142.06	141.01	152.25	169.29	197.08	201.34	206.55	214.26	220.10	225.44

value of economic crops per unit farm in Gansu Province increased each year, and there was a significant linear positive correlation between the two ($R^2 = 0.93885$; $p < 0.05$) (Fig. 2).

2.3.2 Calculation of the Unit Price of the Agricultural Ecosystem Service Value

The calculation formula of the unit price of the agricultural ecosystem service value in Gansu Province used in this paper was based on the research of Tan and Wang (2012):

$$V_{ij} = e_{ij} \, V_a, \, ; (i = 1, 2, 3 \ldots 9; j = 1, 2, 3 \ldots 6) \tag{2}$$

where V_{ij} is the unit price of the i ecological service value in land j (Dollars/ha); and E_{ij} is the i ecosystem service value equivalent factor in land j.
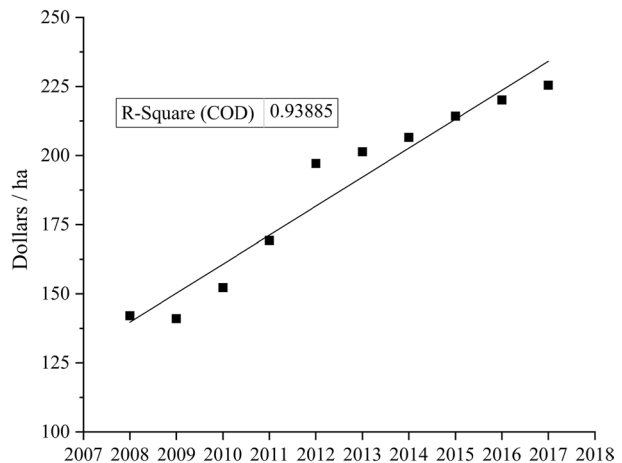
2.3.3 Calculation of the Agroecological Service Value

The calculation formula of the agroecological service value of Gansu Province was based on the research of Tan and Wang (2012):

$$V = \sum_{i=1}^{9} \sum_{j=1}^{6} S_j \, V_{ij}; \cdots \; (i = 1, 2, 3 \ldots 9; \; j = 1, 2, 3 \ldots 6) \tag{3}$$

where V is the total value of agroecological service in Gansu Province (Dollars); S_j is the area of land of category j (ha); and V_{ij} is the unit price of ecological service value i in land j (Dollars/ha).

Fig. 2 Regression graph of production service value per unit of cash crop

The experimental data were processed and analyzed in SPSS 24.0, and the charts were generated by ArcGIS 10.5 and Origin Pro 9.0.

3 Results

3.1 Value Compositions of the Agroecological Service Function

In the 10-year period 2008–2017, the total value of the agroecological service function in Gansu Province reached 3.285×10^{12} Dollars. From 2008 to 2017, the total value of the agroecological service function in Gansu Province increased each year (2.46×10^{10} Dollars, 2.46×10^{10} Dollars, 2.67×10^{10} Dollars, 2.94×10^{10} Dollars, 3.39×10^{10} Dollars, 3.47×10^{10} Dollars, 3.53×10^{10} Dollars, 3.66×10^{10} Dollars, 3.98×10^{10} Dollars and 4.28×10^{10} Dollars, respectively (Fig. 3). In Fig. 3, it is clear that the agroecosystem service function value of Gansu Province from 2009 to 2012 exhibited a rapid increasing trend. After peaking at the maximum value (15%) in 2012, the annual growth rate dramatically decreased until 2014. After 2014, the agroecosystem service function value of Gansu Province began to increase steadily.

3.2 Changes in the Values of Different Agroecosystem Services

Figure 4 shows that the values of different agroecosystem services in years 2008–2017 showed increasing trends, but their contributions to the total value of agroecological services of Gansu Province differed: SFC (18.85%) > WC (16.25%) > WT (14.47%) > BM (14.19%) > GR (13.08%) > CR (11.97%) > RMP (7.92%) > FP (4.80%) > EC (2.89%), which was similar to the results of Tan's research on the agroecosystem services value in Lanzhou city, Gansu Province, in 2008 (Tan and Wang 2012).

Fig. 3 The agroecosystem service function value and the rate of increase of Gansu Province in 2008—2017
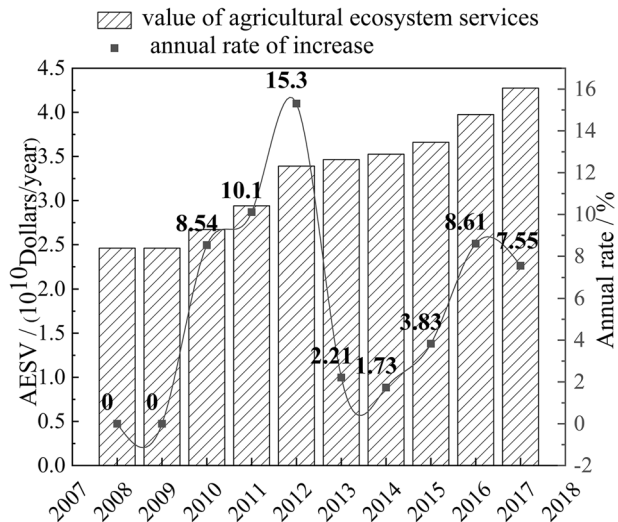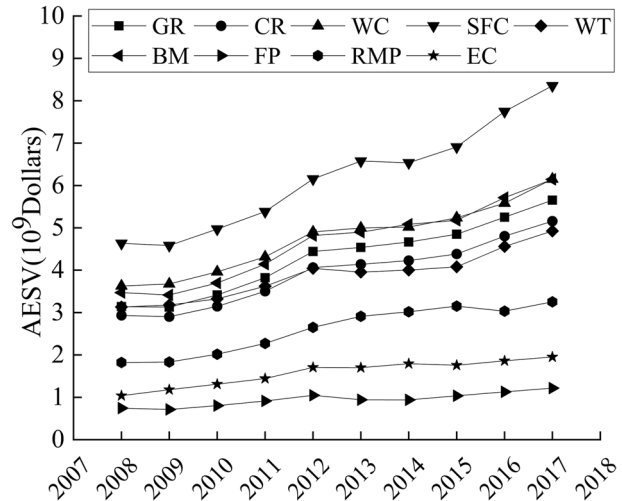
Fig. 4 The values of different agroecosystem service functions of Gansu Province in 2008—2017

The proportion of the SFC value was the largest, which was related to the high SFC value of forest land, grassland and water bodies, and the extensive adoption of soil and water conservation measures. Similar to the annual growth rate of the total value of agroecological services, the SFC value of Gansu Province reached a peak in 2012 and declined sharply from 2012 to 2014, this is mainly due to the reduction of agricultural land area, some soil pollution and some abandonment of farmland and the decline in production which were caused by the acceleration of urbanization in recent years.

The figure for the WC value had the second largest proportion. After reaching a peak in 2011, its annual growth rate (Fig. 5) exhibited a declining trend each year from 2011 to 2014, though it slowly increased after 2014. This result may be related to the high water conservation values of forest lands, water bodies and grasslands in Gansu Province. It may also be related to the accurate understanding of the current situation of water resources in Gansu Province in recent years, in which drought resistance and water saving measures were actively implemented and water resources were effectively utilized and protected (Akiyama et al. 2017).

The proportion of EC was the lowest, and its annual growth rate dramatically fluctuated and exhibited a general declining trend (Fig. 5). At the same time, Table 1 shows that the WT of farmland in had the highest unit price, followed by that of SFC and FP. The EC was the lowest. The EC of the agroecosystem was insufficient and needs further cultivation and development. At this stage, the value of large-scale sightseeing agriculture had increased greatly, such as the Rapeseed Flower Belt in Menyuan County, Qinghai Province, China. Therefore, we should vigorously develop leisure and tourism agriculture in Gansu Province (Cao et al. 2020; Lu et al. 2018) and consider the uniqueness of distinctive landscape features and cultural resources (Wang et al. 2013).

The WT value was followed by the SFC value and the WC value. In 2008–2017, the WT values in different agricultural lands showed moderate growth trends (Fig. 4). However, after 2010, the annual growth rate declined and then remained stable after 2013 (Fig. 5). This result may be due to the recycling and harmless utilization of waste from agroecosystems and other ecosystems. With the development of society, the economic
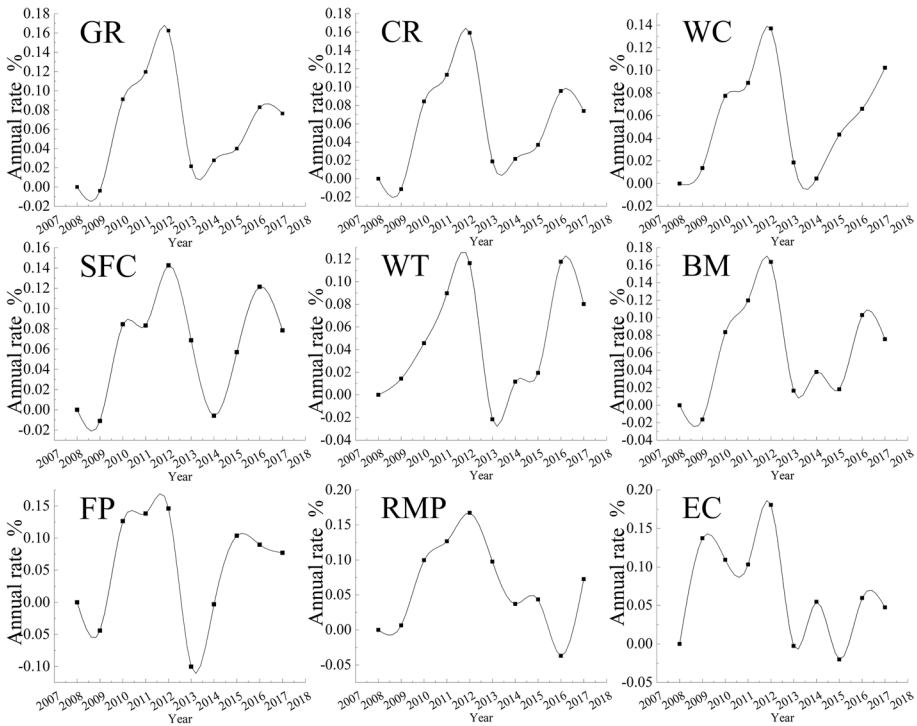
Fig. 5 The annual change in the agroecosystem service value in Gansu Province

structure has been continuously optimized and adjusted, and science and technology have been continuously developing. For this reason, the efficiency of agroecosystem waste treatment has been increasing. The proportion of WT to the agroecological service value also increased. The decline in the annual growth rate of the WT may be related to the sustainability of the WT of the corresponding agricultural lands.

From 2008 to 2017, the GR, CR, and BM of the agroecosystem accounted for the same proportions of the agroecological service value in Gansu Province, and the annual growth rates of GR, CR, and RMP were similar (Fig. 5). GR and CR had auxiliary and supporting effects on life support systems, and they can affect most biological and ecological processes on Earth spanning genetics, organismal physiology and life-history, population distributions and dynamics, community structure, and ecosystem functioning (Scheffers et al. 2016). To survive in an agroecosystem, organisms must adapt to changes in gas and climate.

Figure 4 shows that the contribution of BM to the annual average value of agroecological services in Gansu Province was 4.785×10^8 Dollars in the past ten years. Compared to the research done by Xie et al. (2008). on the Qinghai-Tibet Plateau, the contribution of BM to the value of agroecological services was 2.25×10^8 Dollars, which was 79.22% more than the result in this paper. This result indicated that the agroecosystem of Gansu Province had low biodiversity, the food chain was simple, and the contribution of organisms to the agroecosystem service value was relatively low, which encourages us to promote the development of agricultural biodiversity in Gansu Province.

4 Discussion

The ecological environment is a complex, comprehensive and fuzzy system, and the current evaluation methods are not scientific and comprehensive; thus, the evaluation of ESV has uncertainties. Hou et al. (2013) described uncertainty as an analysis of state of limited knowledge. Uncertainty is related to the classification, selection and indicators of an ecosystem service type. In addition, people's preferences for ecological service functions are still uncertain. In other words, people's subjective judgments will cause a level of uncertainty (Spangenberg and Settele 2010). Due to the availability of data and technical limitations, the assignment of some socioeconomic data and entertainment culture may be inaccurate to a certain degree. In addition, some models use certain restrictions, assumptions, simplifications, formulas and parameters to quantify these key indicators, which are the reasons for model uncertainty (Katz 2001).

It is necessary to analyze the ecological security of ecologically fragile areas in arid inland river basins to protect these important ecosystems. The degradation or loss of ecosystems affects not only human safety and health but also regional and global ecological security. To study ecological security, many researchers have proposed methods for calculating the ESV of ecological security (Liu et al. 2018; Yang et al. 2019). Uncertainty prevails in the evaluation process. Ecosystem services need to be comprehensively considered in multiple disciplines, and current assessment methods are still insufficient (Hou et al. 2013). However, with our gradual understanding of the ecosystem and progress in the synthesis and methods of evaluation disciplines, the uncertainty will gradually decrease.

Although there are still some existing defects, the discussion of ecological security issues from the perspective of the equivalent factor method can be used to understand the overall ecological status of the arid area in Northwest China from a macro perspective. This method also ignores differences within ecosystems of the same land-use type. In addition, this method does not specifically consider the differences and subordinate characteristics of different research areas. Different land-use intensities will also affect the value of ecosystem services (Gaglio et al. 2020). Therefore, in view of these shortcomings, in future research, it is still necessary to further explore a reasonable, scientific, and comprehensive evaluation index system for ecological environment quality. To address ecological problems in the arid inland river basins of Northwest China, a series of ecological conservation and restoration projects was initiated in 2000, including the Ecological Water Conveyance Project (EWCP), artificial forest planting, and the establishment of nature reserves. After assessing the ecological protection and restoration of the Heihe River and the Tarim River, Zhu et al. (2016) proposed that water resources are limited in the entire reaches of arid inland river basins, and ecological protection is more important than ecological restoration.

Based on the research results, this research proposes suggestions for ecological protection in this area. Gansu Province is an important area in the Hexi Corridor and an important part of the "One Belt and One Road" initiative. The ecological construction of Gansu Province should adhere to the principle of "adjusting the measures to the local conditions". Reasonable restoration measures should be formulated according to the land-use types, climate conditions, topography, water balance problems and other factors of the different regions. In the northern and southern regions with sparse vegetation, attention should be paid to improving the construction of shelter forests and the rational development and utilization of wasteland without damaging the environment. Oasis areas, cultivated land and basic farmland that occupy an important position in the local area should be strictly protected. A barrier in the northern region is needed to prevent the desert from moving to the

southern region. At the same time, it should be noted that although large-scale afforestation can provide protection for ecological security, it also needs to be reasonably assessed to avoid derivative ecological problems caused by construction, such as fast-diffusion damage by insects. The construction of the ecological environment should be linked with relevant ecological resources to enhance the overall stability of the region. Large-scale capital investment is very important to ecological construction. Earlier capital investment will gain benefits after a long period of time, and the dividends of ecological construction will appear. It must rely on local continuous eco-environmental recycling construction rather than blindly and continuously investing a large amount of money, and strong sustainability in ecological protection is the most rational effect.

In the static value composition of the different agroecological services, the agricultural ecosystem is dominated by farmland ecosystems, which are sources of food production and raw material production. The increase in value may be affected by many factors. For example, when calculating the equivalent factor, the selected crop products in Gansu Province are potato, corn and wheat. The prices of the three crops have risen in ten years, and there may be inflation factors. Correspondingly, the value of ecosystem services has increased in the calculation. Another study showed that the loss of value of ecosystem services is mainly due to the reduction of arable land, which is consistent with the results of this study (Chen et al. 2020). The value of SFC was highest, this result is similar to that of Tan and Wang (2012). Diversified agricultural ecosystems may enhance specific ecosystem services, and changes in agricultural ecosystems may affect the strategy of sustainable development (Duguma et al. 2019).

In today's world, maintaining land and ecological security has become a top priority for governments of all countries. Semiarid regions account for approximately 40% of the world's land area. The ecosystems in arid and semiarid regions are very sensitive to climate change and human activities. Ecosystem service value assessments can fundamentally help to solve ecological problems to maintain ecological and economic sustainability, especially in arid and semiarid areas with significant ecological problems. This article provides a reference for the evaluation of ecosystem service value on national and regional scales and has guiding significance for urban development and ecological environment layout planning in arid regions.

5 Conclusions

Through the study of the structure, time changes and different functional types of the agricultural ecological service value in Gansu Province, it was found that the social ecological balance and the agricultural ecological balance are very important for the sustainability of the development of arid and semiarid regions.

From 2008 to 2017, the value of agricultural ecosystem services in Gansu Province grew steadily. The ESV of soil formation and protection was the highest and increased the fastest. The value growth rate of entertainment and cultural services was the highest. This result may be related to the land policy of the local government. According to the proportion of each ecological function and the reason analysis, the ecological environment in this area is more complicated. The construction of the ecological environment should be linked with the relevant ecological resources to enhance the overall stability of the region, which is conducive to the rational use of the functions of the various ecosystems in these areas. The evaluation result of the service value of agricultural ecosystems is conducive to the sustainability of the development of arid and semiarid regions.

These results help emphasize the importance of protecting ecosystems and their services at the regional level. The research methods in this article are also applicable to the formulation and implementation of decisions in areas related to ecosystem services and management, such as nature and biodiversity protection, spatial planning, agriculture, forestry, water management, and the development of rural tourism. In addition, the driving force analysis shows that the significant drivers of land use and ecosystem service changes since 1750 are socioeconomic, political and technical drivers. These factors are critical to the value of agricultural ecosystem services (Baude et al. 2019). The results of this research may help us better understand the value of agroecosystems and their benefits to environmental quality and social well-being, especially in arid regions. Therefore, in the vigorous development process of the agricultural economy, attention should be paid to the role of agroecological balance and the importance of agroecological service functions to promote the construction of ecological agriculture. It will be very important to transfer the structure, improve the efficiency of production, vigorously promote the construction of ecological civilization, continuously maintain the balance of agroecosystems, and continuously improve the value of agroecosystem services.

Declarations

Conflicts of Interest The authors declare that they have no conflicts of interest.

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