Assessing rural land consolidation based on ecosystem service: a case study of Qingyang in Western China

W.S. Cheng[1], Z.Q. Du[2,1], C. Cao[3], X.L. Liu[1]
[1]*College of Resources and Environmental Sciences, Gansu Agricultural University, Lanzhou, P.R. of China*
[2]*Institute of Loess Plateau, Shanxi University, Taiyuan, Shanxi, P.R. of China*
[3]*College of Geography and Environmental Sciences, Northwest Normal University, Lanzhou, P.R. of China*

Abstract

Land consolidation is an important approach to increasing land use efficiency, increasing the area and quality of arable land, improved rural living standards and working conditions, enhanced integrated land use, and increased food yield. However, the efficiency of manpower, resources, and financial investments required for land consolidation depends on the economic, social, and ecological effects of the consolidation practice. We investigated 96 land consolidation projects that were carried out from 2009 to 2012 in Qingyang region in western China to estimate the ecosystem service value (ESV) before and after land consolidation projects in order to assess the effects of land consolidation. The results showed that the total ESV of the 96 projects decreased by 1,148,741 RMB from 140,988,575 RMB before the consolidation to 139,839,834 RMB after the consolidation, due to the inadequate protection and remediation of ecosystem functions. The major causes of the lowered ESV were decreased soil formation and protection functions, biodiversity, air pollution reduction, headwater conservation, and climate regulation. We proposed a new land consolidation mode that focuses on the protection of ESV, and also suggested practical strategies for natural landscape and water body construction in order to protect and improve the ecological environment. Our conclusions provide theoretical and practical guidance on future land consolidation practices.

Keywords: ecosystem service value, land consolidation, land utilization, Qingyang region.

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1 Introduction

Land consolidation increases land use efficiency and arable land area, improves arable land quality and the living and working conditions in rural areas, promotes efficient and integrated land use, and enhances land yield. China has carried out land consolidation practices since August 1999, which have been effective at protecting arable land resources, raising comprehensive agriculture productivity, optimizing land use type combinations, ensuring national food and ecological safety, and promoting social equity [1]. With the development of socioeconomics, the category, aim, content, and pattern of land consolidation have all changed significantly [2]. Rural land consolidation practices have evolved into combined efforts focused on mountains, arable lands, water bodies, roads, forests, and villages [3]. According to the *China Land and Resource Yearbook*, 181,476 land consolidation projects covering 7,696,800 ha of land have been completed from 2003 to 2011, of which 4,133,166.67 ha of lands have been rearranged, 2,195,362.26 ha of lands have been reclaimed, and 1,368,283.58 ha of lands have been developed. The annual investment increased from 14.744 billion RMB in 2004 to more than 100 billion RMB in 2011 [4]. The "National Land Consolidation Plan 2011- 2015" proposed the task for the "*Twelfth Five Year Plan*," which raised the bar to a higher standard in arable land infrastructure that would ensure yields during flood or drought events, as well as for comprehensive land consolidation practice in rural areas. This plan also stated that investment and construction scales would be increased.

However, it is not clear whether the investment of human, material, and financial resources would be efficient in large-scale land consolidation projects for rural areas. To answer this question, accurate scientific analyses on the effects of land consolidation projects from economic, social, and environmental aspects are required. Assessments of the benefits linked to land consolidation projects have been started earlier in countries other than China, and they have become even more detail oriented. For instance, with more land consolidation practice and improvements in the evaluation standard, Germany has incorporated landscape and environmental protection into land consolidation projects to coordinate the economic, social, ecological, and landscape benefits of land consolidation [5]. In the Netherlands, the evaluation of the benefits of land consolidation takes account of how changes in the shape of the area, the distance to local residents, accessibility, drainage and irrigation facility, soil physiochemical characteristics and other important factors all affect land values [6]. For the evaluation of land consolidation in rural areas, several countries and regions, including western Europe, the U.S., and Canada value agriculture operations on large pieces of consolidated land [7,8], the effects of social and cultural changes in rural areas [9], the conservation of landscape and biodiversity [10], and public participation and land redistribution issues in policy making [11]. Based on the overall profit evaluation, land consolidation is believed to be capable of efficiently increasing profits from crops and facilitating the development of rural areas [12]. It has been found that differences in resources lead to different results in land consolidation, and land use status has a significant impact on consolidation results. In China, Wang first raised the issue associated with the effects of land consolidation on national socioeconomic development and environment [13], followed by research on different aspects of land consolidation in different regions. Regarding the assessment system, it has been agreed that land consolidation effects are comprised of economic effects, social effects and ecological effects [14]. Itemized evaluation systems were established based on social impacts [15] and ecological effects [16]. More researchers used a fuzzy synthetic evaluation [17] and its derivative methods [18] in the assessment. Other methods include energy analysis [19], sequence structure [20], extensions of the model based on entropy weight [21], cloud models [22], and factor analysis [23]. In terms of the timeline of the evaluation, most researchers use benefit assessments [24], while some use prediction assessments [25]. These assessments usually focus on economic aspects [26] or environmental aspects. Methods for the assessment of environmental effects usually include the method based on the current benefits, landscape ecology method, or environmental indices method. For example, Zhao et al. evaluated ecological benefits using the direct market, substitute market and hypothetical market methods [16]. Energy analysis has also been used to assess the ecological benefits of arable land consolidation [27]. Wang et al. assessed a land consolidation project using its current benefits [28]. Applying landscape ecology theories, An et al. studied the landscape scale ecological effects of land development [29]. Li et al. quantified the effect of land consolidation on the environment by modeling indices of ecological conditions [30]. Zhang and Tian et al. estimated the change in the ecological service value (ESV) of certain land consolidation projects using the ecosystem service valuation (ESV) method [31]. However, there is no report on the effects of land consolidation using the regional scale ESV.

In land consolidation practices, several factors contribute to the damage done to the biology, ecology, and culture of a specific region. These factors include a lack of understanding in landscape ecology theories and a lack of technical support; insufficient training for management and construction personnel; a lack of understanding regarding ecosystem composition and functions, including geomorphologic, watershed, and biological characteristics of the project area; excessive transformation aimed at standardized infrastructure constructions of "square crop fields, well-developed road systems, interconnected ditches in the fields, and trees in lines," underrating ecosystem cycles and mutual benefits; and overlooking the importance of merging patches, corridors and matrixes [32]. Therefore, quantitative assessments of the ecosystem service functions before and after land consolidation projects have provided foundations for effectively protecting and improving the environment, complementing land consolidation theories in China, designing scientifically efficient land consolidation projects, regulating the management of land consolidation projects, increasing the efficiency of financial investments on land consolidation, better implementation of land consolidation, and improvements in land use efficiency. In this study, we investigated 96 land consolidation projects completed between 2009 and 2012 to estimate the ESV before and after the projects, to analyze the effect of land consolidation, to understand the reasons for the changes in ESV, to discuss land consolidation patterns that focus on protecting ESV, and to discuss construction strategies for such land consolidation patterns.

2 Materials and methods

2.1 Study sites and the basic information of the land consolidation projects

Qingyang region (106°20'-108°45' E, 35°15'-37°10' N) is located at the junction of Shangxi, Gansu, and Ningxiang Provinces along the east side of Gansu Province. Qingyang region is bordered by the Ziwuling Mountain on the east, the Liupanshan Mountain of Ningxia Province on the west, Ningxia Hui Autonomous Region on the north, and the boundary between Shanxi and Gansu Provinces on the south (it only borders Jingchuan County of Pingliang City, Gansu Province on the southwest side). It is 208 km from the east side to the west side of Qingyang, and 207 km from the north to the south, with a total area of 27,000 km^2. This area consists of one district and 7 counties, that is, Xifeng District, Huan County, Huachi County, Qingcheng County, Zhenyuan County, Ning County, Zhengning County, and Heshui County, with a population of 2.56 million. The elevation is higher in the north than in the south, ranging from 885 to 2082 m, and it is a typical loess plateau with hills and gullies. The climate of this region is semi-arid to arid. The average annual temperature is 9°C; the annual sunshine duration is 2250–2600 h, the growing season (frost free season) lasts for 140–180 days, and the average annual precipitation is 330–660 mm, with most of the precipitation occurring during mid-late July [33]. The water table is low and most of the surface water is distributed in the valleys. This indicates that the water resources are not evenly distributed spatially or temporally. Crops are the dominant agriculture in this area, and the major local crops include wheat, corn, buckwheat, millet, oat, and soybean, as well as crops for oil. In addition, Qingyang region specializes in refining petroleum and natural gas, and it is the main production area for the Changqing oil field. Qingyang region also has more than 10 mining resources, including dolomite, quartz, and limestone.

The loess in Qingyang region is about 50–80 m deep. The soil particle size is small and the soils are unconsolidated with rich nutrient content, which are beneficial in crop growth. However, only less than 10% of arable lands are on level ground, and most of the arable lands have a slope of 10–35°. The area is windy, especially in the winter and spring, and because most of the precipitation occurs in the summer in the form of thunderstorms, Qingyang is the major source of coarse sediments in the Yellow River. There has been severe soil erosion in this region due to the complex geography and lack of vegetation cover.

Agriculture production in this region has the following problems: (1) most of the cultivated fields are arid and on sloping land. The area has a low soil retention capacity, and a low and unstable yield. (2) As a result of low investments and the use of traditional agriculture practices, the current supporting infrastructure for farming is not up to date enough to meet the requirements of modern agriculture production, and the area has low resistance to natural disasters. (3) Farming on steep slopes exacerbates soil erosion and local land degradation. Soil fertility decreases each year and can scarcely maintain a stable high yield. Therefore, this region has great potential for land consolidation. The 96 land consolidation projects carried out from 2009 to 2012 (Figure 1) had a total area of 23,122.51 ha, with a total investment of 530,330,000 RMB.

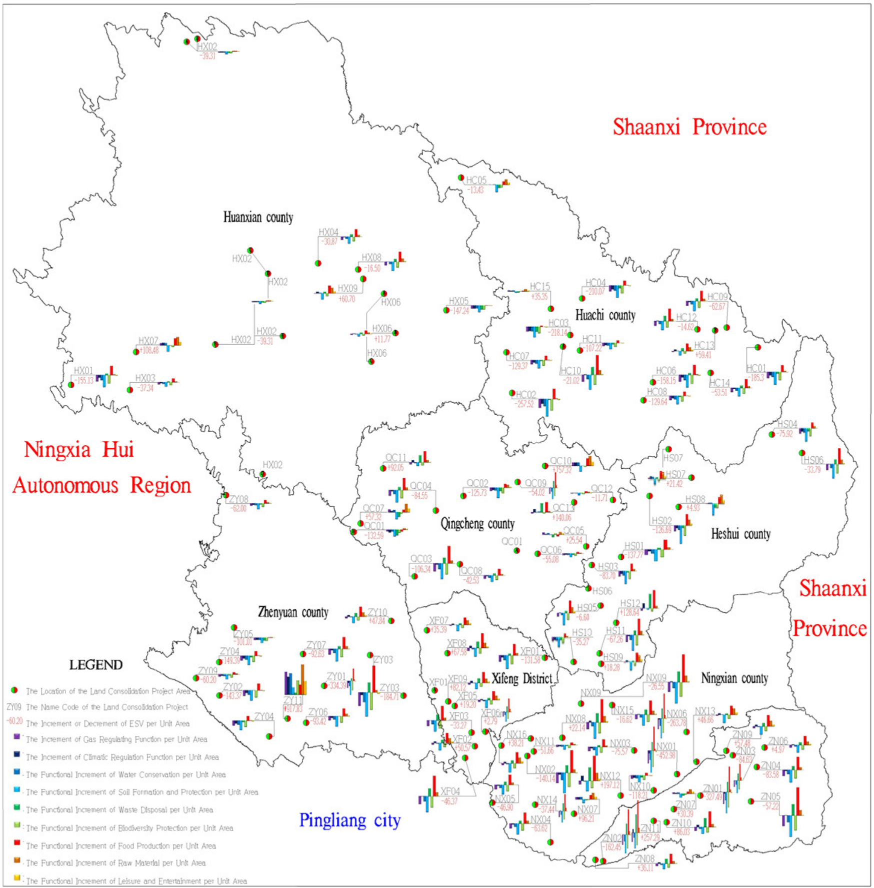

Figure 1: Schematic diagram of the total ESV per unit area and the ESV changes in single cases.

2.2 Data collection

The data collected for this study included basic information of the study areas before and after land consolidation and project designs, and the land use status before the consolidation, after the planned consolidation (ideal situation) and after the actual consolidation practice. This basic information and land use status of the project area prior to land consolidation were retrieved from field measurement-based topographic maps (scale 1:1000) and the project plan documents provided by the Ministry of Land and Resources of Qingyang City and its counties/district. The land use status after ideal consolidation practices (if everything was as planned) was obtained from the project plan documents and illustrations provided by the Ministry of Land and Resources of Qingyang City and its counties/district. The satellite images of the consolidated lands were provided by the Ministry of Land and Resources of Qingyang City and its counties/district.

To understand the basic information of the areas after land consolidation practices, we compared satellite images of early 2013 to field measurement-based topography maps by placing the satellite images over the topography maps in order to determine the changed areas. In addition, a field investigation was carried out from July 14 to August 30, 2013, which was combined with the image comparison results to reveal the current land use status after the implementation of the 96 projects (Table 1).

2.3 Data analysis

Based on the ESV theory proposed by Costanza et al. [34], Xie et al. summarized the professional opinions of Chinese researchers to establish a table of unit area service values of Chinese terrestrial ecosystems (Table 2) [35]. Our study utilized this unit area service table (Xie et al. 2003) and the ESV equation [34] to evaluate the ESV of the 96 land consolidation projects before and after the implementation of those projects, and after the ideal implementation, that is, when the project went exactly as planned. The ESV is calculated using the following equation,

$$ESV = \sum (A_k \times VC_k) \quad (1)$$

$$ESV_f = \sum (A_k \times VC_{fk}) \quad (2)$$

where, ESV refers to the ecological service value; A_k refers to the area of the kth land use type in the project area; VC_k refers to the ecological value coefficient; ESV_f refers to the value of a single service function of the ecosystem; and VC_{fk} refers to the value coefficient of a single service function.

Our calculation was based on the actual local situations. The abandoned residential area used to be cave dwellings dug into the loess, and thus showed similar characteristics to grasslands with no building structures above the ground; therefore it was counted as grasslands in our assessment. Because ridges in arable lands prior to land consolidation and 1 to 2 years after land consolidation showed similar characteristics to grasslands, they were also counted as grasslands. The ditches in the project areas were single drainage channels and had no significant contribution to ESV; therefore, they were not counted in our assessment.

3 Results

3.1 Total ESV

The sum of the total pre-consolidation ESV for the 96 projects was 140,988,575 RMB. The total ESV of the 96 project areas after ideal implementation came to a sum of 139,703,134 RMB. The total post-consolidation ESV was 139,839,834 RMB. The decrease of the total ESV from the original conditions was 1,285,441 RMB after

Table 1: Basic Statistics of the 96 Land Consolidation Projects Implemented in Qingyang City from 2009 to 2012.

		Heshui County	Huachi County	Huan County	Ning County	Qingcheng County	Xifeng District	Zhenyuan County	Zhengning County
Number of the projects		12	15	9	16	13	9	11	11
The total amount of investment (10^4 RMB)		11893	6198	5341	11096	4985	4790	4191	4539
Total scale of the construction (ha.)		4624.7	2974.01	2890.76	4529.86	2620.32	2006.91	1895.73	1579.66
Consolidation (ha.)		4319.13	2597.97	2331.99	3937.39	2347	1763.67	1450.79	1083.4
Development (ha.)		305.44	104.83	146.4	269.65	55.42	33.19	83.95	42.55
Reclamation (ha.)		0.13	271.21	412.37	323.33	223.08	210.1	360.99	453.72
Before renovation (ha.)	Dryland	3417.22	2285.39	2270.24	3137.78	2072.83	1487.02	1440.22	1009.83
	Grassland	305.44	104.83	146.4	269.65	76.36	33.19	78.56	42.55
	Abandoned Homestead	0.13	22.59	11.78	213.33	24.05	209.75	40.49	316.47
	Rural road	59.64	42.95	48.4	48.55	42.23	23.46	24.98	31.34
	Ditch	3.08	0	2.56	0	1.46	0	0	0.16
	Ridge of field	839.19	518.25	411.38	860.55	398.23	253.49	311.48	179.31
After renovation (ha.)	Newly Increased farm–land (ha.)	560.74	306.39	272.46	757.89	224.29	311.2	211.98	360.85
	Newly increased ratio (%)	12.12	10.30	9.43	16.73	8.56	15.51	11.18	22.84
	Dryland	3977.96	2591.78	2544.09	3897.56	2297.12	1798.22	1652.2	1370.67
	Forest land	31.05	11.99	8.82	28.9	16.88	19.16	15.53	14.1
	Rural road	154.31	90.26	89.83	115.2	75.34	46.62	56.38	42.93
	Ditch	4.04	0.05	0.67	4.9	4.43	1.63	0.32	0.78
	ridge of field	457.34	279.93	247.35	483.3	221.39	141.28	171.3	151.18

Actual results (ha.)	Newly Increased Farm-land (ha.)	481.49	230.00	196.43	738.59	182.52	306.30	167.81	351.24
	Newly increased ratio (%)	10.41	7.73	6.80	16.31	6.97	15.26	8.85	22.24
	Dryland	3898.71	2515.39	2466.67	3876.37	2255.35	1793.32	1608.03	1361.07
	Forest land	31.05	11.99	8.82	28.9	16.88	19.16	15.53	14.1
	Rural road	154.31	90.26	89.83	115.2	75.34	46.62	56.38	42.93
	Ditch	4.04	0.05	0.67	4.90	4.43	1.63	0.32	0.78
	ridge of field	536.59	356.32	324.77	504.49	268.32	146.18	215.47	160.78

Table 2: The ESV (Ecological Services Value) in Different Terrestrial Ecosystems of China per Unit Area (Unit: RMB/ha.).

	Forest	Grassland	Farmland	Wetland	Water Body	Desert
Gas regulation	3097.0	707.9	442.4	1592.7	0.0	0.0
Climatic regulation	2389.1	796.4	787.5	15130.9	407.0	0.0
Water conservation	2831.5	707.9	530.9	13715.2	18033.2	26.5
Soil formation and protection	3450.9	1725.5	1291.9	1513.1	8.8	17.7
Waste disposal	1159.2	1159.2	1451.2	16086.6	16086.6	8.8
Biodiversity protection	2884.6	964.5	628.2	2212.2	2203.3	300.8
Food production	88.5	265.5	884.9	265.5	88.5	8.8
Raw material	2300.6	44.2	88.5	61.9	8.8	0.0
Leisure and entertainment	1132.6	35.4	8.8	4910.9	3840.2	8.8
The total value	19334.0	6406.5	6114.3	55489.0	40676.4	371.4

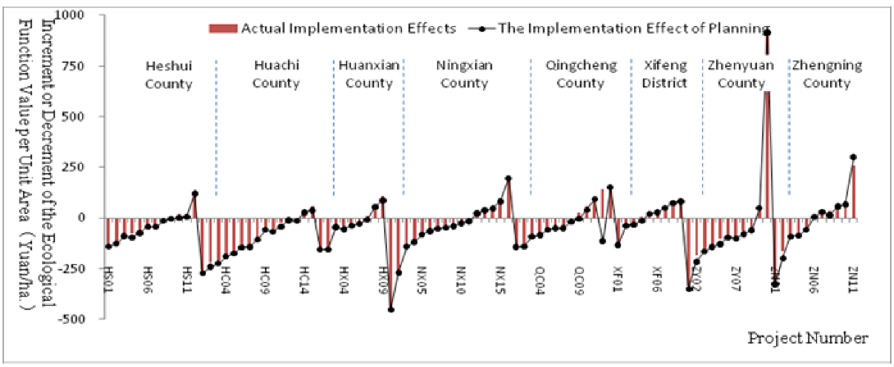

Figure 2: The comparison diagram of the increment and decrement of the total esv in 96 projects per unit area.

land consolidation and 1,148,741 RMB after the ideal implementation of land consolidation. Due to different construction scales, the unit area ESV of each project (Figures 1 and 2) was calculated for the ease of comparison. The unit area ESV showed great differences between counties and districts (Table 3).

Changes in ESV after consolidation (Figures 1 and 2, Table 3) showed that:

the protection and remediation of ecosystem functions were inadequate during land consolidation, which led to a decrease in ESV. A total of 63 of the 96 projects had decreased ESV after both the actual and the ideal consolidations. The NX01 project showed the greatest decrease in unit area ESV. The pre-consolidation ESV was 6406.50 RMB/ha, and it was lowered to 5932.52 RMB/ha after consolidation (the same for actual and ideal consolidation), a decrease of

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Table 3: Statistical Table of the ESV in Different Counties per unit Area (Unit: RMB/ha.).

	Before Renovation			After Renovation			Actual Results		
	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN
Heshui	6146.58	5861.70	6103.71	6132.24	5848.70	6022.60	6139.98	5858.40	6027.61
Huachi	6218.75	5951.07	6089.44	6177.08	5760.12	6009.43	6197.73	5780.87	6016.94
Huan	6149.92	5982.11	6064.09	6138.47	5894.32	5988.22	6160.24	5901.41	5996.04
Ning	6406.50	5943.04	6135.43	6168.11	5953.52	6067.71	6183.24	5953.52	6069.07
Qingcheng	6183.47	5835.44	6055.92	6240.12	5721.56	6025.97	6244.47	5954.52	6043.25
Xifeng	6219.16	6037.27	6115.10	6248.93	6046.41	6114.08	6241.70	6047.47	6114.79
Zhenyuan	6230.32	6008.06	6100.09	7042.79	5851.88	6066.13	7045.84	5865.88	6072.93
Zhengning	6330.31	5963.42	6091.95	6303.34	5993.81	6091.08	6260.30	5993.81	6092.85
Qingyang	6406.50	5835.44	6097.61	7042.79	5721.56	6042.01	7045.84	5780.87	6047.93

452.98 RMB/ha. The ZY11 project had the greatest increase of 914.78 RMB/ha and 917.83 RMB/ha in unit area ESV for actual post-consolidation and ideal post-consolidation, respectively. It increased from 6128.01 RMB/ha before consolidation to 7042.79 RMB/ha after ideal consolidation practices and 7045.84 RMB/ha after the actual consolidation. The unit area ESV for the 96 projects decreased from 6097.61 RMB/ha before the consolidation to 6042.01 RMB/ha after ideal consolidation and 6047.93 RMB/ha after the actual consolidation, a decrease of 55.60 RMB/ha and 49.68 RMB/ha, respectively.

The importance of protecting and remedying ecosystem functions was overlooked, which resulted in a low profit yielded from the consolidation plan. These land consolidation plans summarized opinions of different sources and professional designs, and underwent several rounds of feasibility studies and evaluations. However, in general, the ESV resulting from the ideal consolidation was even lower than the ESV after the actual consolidation practice. There were only 13 projects that had slightly higher ESV after the actual consolidation practice than after the ideal consolidation. A typical example was the QC12 project, which had a pre-consolidation ESV of 5835.44 RMB/ha. Because the consolidation plan for the QC12 project focused too much on increasing arable land coverage, which reached a 10.3% increasing rate, the ESV after ideal consolidation practice was lowered to 5721.46 RMB/ha, a decrease of 113.88 RMB/ha. On the other hand, in the actual consolidation practices, because some of the “grasslands” (i.e., field ridges) could not be removed, the arable land area only increased by 9.44% compared to the planned 10.3%; the forest coverage increased, and the ESV increased by 140.04 RMB/ha to 5975.50 RMB/ha.

3.2 Itemized ESV

Equation 2 shows that ESV is affected by 9 factors, including air pollution reduction, climate regulation, headwater protection, soil formation and erosion control, waste disposal, biodiversity protection, food production, resources, and recreation. We calculated the before and after consolidation unit area ESV for the

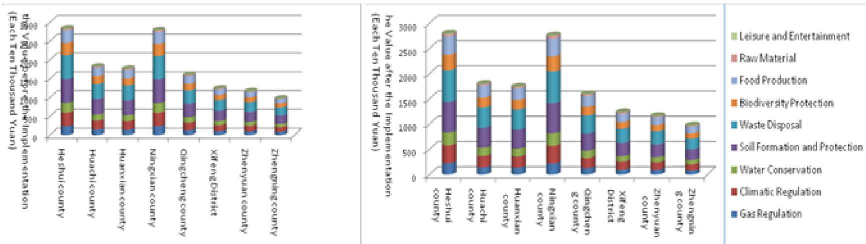

Figure 3: Comparison diagram of the single ESV change in the 96 projects before and after implementation.

96 land consolidation projects (Figure 1), and the results varied significantly between counties (Figure 3).

Land consolidation had a clear influence on the ecology. The negative influence followed the order of biodiversity protection (greatest influence), air pollution reduction, soil formation and erosion control, headwater protection, climate regulation, and waste disposal (smallest influence). After the implementation of land consolidation, only three projects had increased biodiversity protection, with increases of 0.28% on the HC14 project, 1.04% on the QC09 project, and 12.87% on the ZY11 project. All the other projects showed a decrease in biodiversity protection functions, the greatest decrease being 26.80%; the average decrease was 5.87% and the unit area ESV decreased by 41.2 RMB/ha. Two projects showed an increase in soil formation and erosion control functions, that is, the QC12 project had an increase of 0.33% and the ZY11 project had an increase of 3.27%. The other projects had decreased function in soil formation and erosion control, with the greatest decrease being 20.01%, an average decrease of 4.73%, and a unit area ESV decrease of 65.25 RMB/ha. The function of reducing air pollution increased in 11 projects, with the greatest increase being 28.51% in the ZY11 project. The other 85 projects showed a lowered ability to reduce air pollution, with the greatest decrease being 28.12% in the ZN01 project, an average decrease of 5.22%, and a unit area decrease of 26.18 RMB/ha. The headwater protection function was improved in 17 projects with the greatest improvement being 24.04% in the ZY11 project. The other 79 projects had decreased headwater protection function, with the greatest decrease being 19.58% in the NX01 project, an average decrease of 3.12% and a unit area decrease of 17.70 RMB/ha. The climate regulation function increased by 14.98% in the ZY11 project, and showed relatively small changes (-4.96% -7.16%) in the other projects. Among these projects, 45 demonstrated improved climate regulation function, 51 showed decreased climate regulation function, with an average decrease of 0.4%, and a unit area decrease of 3.12 RMB/ha. Finally, the waste disposal function increased by 15.79 RMB/ha in the unit area ESV.

Land consolidation increased the land function of providing resources and recreation. After the implementation of the 96 projects, the resource function only decreased in two projects (the HC02 project decreased by 0.44% and the HX02 project decreased by 0.80%). All other projects showed improvement in resource function with the greatest improvement being 280.40%, an average improvement of 24.49% and a unit area improvement of 18.70 RMB/ha. The recreation function decreased in 26 projects, with the greatest decrease being 50.26% in the NX01 project. It increased in the other 70 projects, with the greatest increase being 490.76% in the ZY11 project, an average increase of 22.07% and a unit area increase of 3.35 RMB/ha.

Land consolidation increased the land's food production capacity. Only three out of the 96 projects experienced decreased food production capacity, that is, the HX02 project decreased by 0.14%, and QC09 and QC 01 projects both decreased by 1.38%. All the other projects experienced increased food production capacity, with the greatest increase being 180.79%, an average increase of 9.15%, and unit area increase of 65.92 RMB/ha. However, the analysis method only counted the increased area of arable land; it did not count increases in productivity, which actually increased more than arable land area.

Increasing forest coverage is the most efficient approach in increasing ESV. The ZY11 project provided a typical example; forest coverage in the ZY11 project increased by 8.61% (10.32 ha, with the total project area of 119.88 ha) through planting trees by the side of naturally raised arable land, in the head erosion area and along country roads. Such an increase in forest coverage greatly improved the functions of recreation, providing resources, reducing air pollution, and headwater protection, with an increase of 14.98% in total ESV.

4 Discussion

4.1 Overlooking the importance of ecosystem protection and remediation was the fundamental reason for decreased ESV after land consolidation

An estimation of the total ESV showed that 63 out of the 96 projects had lowered ESV after both ideal land consolidation and actual consolidation, and only 13 projects had slightly higher ESV after the ideal land consolidation than after the actual consolidation. This indicates that the importance of protecting and remedying the ecosystem functions was overlooked. An estimation of itemized ESV showed that although land consolidation improved land functions for food production, and providing resources and recreation, it had a negative influence on ecology in the order of biodiversity protection (most affected), reducing air pollution, soil formation and erosion control, headwater protection, regulating climate and waste disposal (least affected).

We tried to determine how ESV changed with the sequence of consolidation practices. Results showed that there was no clear pattern of the changes in ESV of the projects finished between 2009 and 2011. This indicates that although China has placed more attention on protecting the environment, the local governments have not paid enough attention to the protection and remediation of ecosystem functions during land consolidation practice.

We did not find any clear pattern in the changes of ESV through differences in land use status, including geographical locations, geomorphology and water resources, in addition to differences in the administrative region, land development, consolidation, and the scale and composition of reclaimed land of the project area. This indicates that the actual conditions of each project area were not well understood during land consolidation practices, and those practices did not fully consider the protection and remediation of fragile ecosystem functions. Therefore, overlooking the importance of protecting and remedying the environment directly affected the plan and implementation of land consolidation, and was the fundamental reason for the decrease in ESV after land consolidation.

4.2 Establish land consolidation mode with a focus on protecting ESV

In order to achieve successful land consolidation, both the promotion of economic and social profits and the protection and remediation of the environment should be considered. The assessment method suggests that ESV will not decrease if the following condition is met during land consolidation,

$$19334.0 \times \Delta X_1 + 6406.5 \times \Delta X_2 + 6114.3 \times \Delta X_3 + 55489.0 \times \Delta X_4 + 40676.4 \times \Delta X_5 + 371.4 \times \Delta X_6 \geq 0 \quad (3)$$

where ΔX_1, ΔX_2, ΔX_3, ΔX_4, ΔX_5, and ΔX_6 represent increases in the coverage of forest, grasslands, arable land, wetlands, water body, and desert, respectively (negative values indicate a decrease).

We refer to land consolidation practices that meet the requirements of Eq. 3 as land consolidation with a focus on protecting ESV; the other land consolidation practices will affect or damage the environment. During the feasibility study of the land consolidation plan, the influence of land consolidation projects on the environment can be assessed using the land consolidation method that focuses on protecting ESV (Eq. 3).

4.3 Approaches that increase ESV through land consolidation

The increase in ESV during land consolidation practices depends on the location of the project, scientific planning and implementation, and increasing both the natural landscape and water bodies in fragile arid environment.

4.3.1 Strategy for constructing natural landscape

Soil erosion is very common in regions with low hills. Therefore, establishing terrace fields on slopes is necessary. Soil erosion often occurs in ditches, and it is therefore important to protect the head of the ditch from erosion. Major practices include planting trees by the head of the ditch, around the naturally raised arable fields, on slopes, and in the gullies. In regions with naturally raised arable land, planting is focused on the sides of the roads, the windward side of these regions, and on top of a wide slope. However, these plantings are limited by space, whereas ridges in arable fields are often overlooked in land consolidation practices. If we plant common local economic shrub species that are drought and cold resistant, for example, wolfberry, sea buckthorn, and caragana, on the ridges of terrace fields in the hilly region, and then plant common local economic crops that are drought and cold resistant, such as daylilies, in a single row on the ridges of arable land in regions with naturally raised land, it will control soil erosion and keep the ridges structurally stable without taking up useful space. Planting on the ridges therefore increases land use efficiency, farmers' incomes, and the aesthetic value of the landscape. Based on the above reasons, the development of "ridge economic zone" should be promoted.

4.3.2 Strategies for water body construction

For the arid loess plateau in Qingyang, the water table is low in regions with naturally raised land, while it is high in the valleys. Yet with the increased mining of oil and gas resources, the groundwater has become more severely polluted, which limits the extraction and use of groundwater resources. It is essential to build ditches, reservoirs, and water cellars to confine the water to the project area. Specifically, practices to regulate water flow during heavy rainfall or flooding include digging roadside ditches and ditches at the foot of slopes, connecting these ditches with drainage channels to introduce water into reservoirs and/or water cellars, and constructing reservoirs in the depression, at the intersections of roads as well as ditches, and in the open area in villages. These practices are combined with the head drainage ditch to regulate the rainwater in the project area into channels, confine the water in those trenches to the project area, prevent channel incision, ensure water availability for human and livestock use, and introduce water to fields at lower elevations for irrigation.

4.4 How to further improve the study

We adopted the table of unit area service values for Chinese terrestrial ecosystems developed by Xie et al. (2003) (Table 2), which presents the national average values. Because it does not reflect regional differences when assessing land consolidation projects, factors including land productivity, suitable local crops, and ground coverage of the studied region should be considered to develop a region-specific unit area ecological service value table to assess ESV.

5 Conclusions

Based on the analyses above, we concluded that the protection and remediation of ecosystem functions are an important component of land consolidation. Current land consolidation in Qingyang region has increased land use efficiency and arable land area, improved the productivity of arable land, and promoted land functions including recreation and resources. However, because of insufficient understanding of the natural conditions of the project area, a lack of focus, and inadequate protection and remediation of ecosystem functions, the ESV of the 23121.95 ha of land in the 96 projects that were completed between 2009 and 2012 decreased from 140,988,575 RMB to 139,839,834 RMB after consolidation practices, with a decrease of 1,148,741 RMB. The ESV decreased because impaired functions of soil formation and erosion control, biodiversity protection, air pollution reduction, headwater protection, and climate regulation severely affected the establishment of long-term mechanisms for land consolidation and the sustainable use of land resources. Our results showed that protecting ecosystem functions and consolidated land use can be achieved at the same time by establishing long-term land consolidation mechanisms with a focus on ESV protection, which relies on scientific strategies for constructing natural landscapes and water resources during land consolidation.

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