ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 5 (2011) 1192–1199

Energy Procedia

IACEED2010

The Ecological Compensation of Land Consolidation and Its Evaluation in Hilly Area of Southwest China

YIN Shuai, WEI Chao-Fu*, YANG Xin-Yue, LUO You-Jin

College of Resources and Environment, Southwest University, China 400716.

Abstract

Land consolidation is an important action to realize the reasonable disposition of land resource and enhance the land utilization efficiency in China. But as a regional reconstructive activity, there are inevitably directly or indirectly, positive or negative impacts on its regional ecological environment in land consolidation process. To minimize the negative impact of land consolidation, positive practices for ecological compensation was necessary. Taken a land consolidation project in Yujia and Qiaoting village in Wanzhou District of Chongqing as case, the ecological compensation measures and ecological effect was studied in this paper. The result show that compensation practices such as protecting the arable layer, building slope-terrace, taking stone as the raw material for channels, irrigation channel and drainage channel separately in channel design, adopting the mud-gravel road, and building culvert in the intersections of roads and channels can significantly reduce the negative ecological effect in the processes of land consolidation. So, the eco-design in land consolidation project can realize ecological compensation and also achieve the coordinated development of economy, ecology, and society.

Selection and peer-review under responsibility of RIUDS

Keywords: land consolidation; ecological compensation; hilly area; ecological environment

As a natural resource, land plays a crucial role in production and living of humanity. Additionally, the low per capita farmland and scarceness in farmland reserve is the fundamental reality in China. Under this situation, carrying out land consolidation is the inevitable choice for Chinese economy development and land using strategy [1]. Land consolidation is an important measure to achieve dynamic balance of arable land and ensure the security of food supply. And to achieve the sustainable use of land resource, we must improve the ecology construction in land consolidation projects. Only under this prerequisite can land consolidation achieve the coordination and unity of society, economy and ecology. Furthermore, carrying out ecological compensation practices will encourage developing ecological land consolidation

* Corresponding author. Tel.: 86-23-68261249; fax: +86-23-68260444.
E-mail address: weicf@swu.edu.cn.

doi:10.1016/j.egypro.2011.03.209

and internalizing the negative effects on the environment [2]. Therefore, taken the basic farmland consolidation project on Yujia and Qiaoting in Wanzhou District of Chongqing as study cases, this paper discussed the ecological compensation measures and constructed the evaluation system of ecological compensation to provide the basis for further development of land consolidation.

1. Study region

Wanzhou, the material distributions centre and transportation hub of eastern Chongqing, has unique advantages in Three Gorges Reservoir construction projection and China's Western Expansion. The study region is located in Yujia and Qiaoting in the northwest of Wanzhou district, dominated by hills with the altitude ranged from 300 to 500m. The climate is subtropical southeast monsoon with distinct seasons, abundant rainfall and sunshine. The average temperature is 18℃, ≥ 10℃ accumulated temperature is 6000 ℃ and the annual frost-free period reach up to 330 days. The total population is 3925 including 3703 of agricultural population. The income mainly base on planting, breeding and migrant working.

2. The design of ecological compensation in the process of land consolidation

2.1 The design of ecological compensation in the land levelling project

2.1.1 The design of arable layer protection

The soil of arable layer forming through long-term cultivation has abundant organic matter and nutrient [3]. So the arable layer protection was adopted in this project to maintain or improve fertility after land consolidation. The ecological compensation practices showed as follow: first, a comprehensive investigation of soil characteristics was conducted at the study region and the range of soil thickness, the soil distribution and groundwater condition were also analyzed from the investigation. Second, the barrier factors that affect land use were carried out by scientific analysis such as testing the soil chemical properties. Then the location, quantity and backfill program were determined with the computer assisted. In the project 20cm of topsoil was stripped and collected before land levelling. After that, the terrace was covered with topsoil which was previously collected.

2.1.2 The design of slope-terrace

In the hilly study area, slope-terrace was adopted in order to conserve the soil and water. The width and height between adjacent terraces was determined according to the soil quality and slope gradient. In this project, most linchs were built by soil. But in some region with thin soil layer or high gradient, the stone linchs can be built under a limited number of 30%. In the building process, the weed should be clean out first and the earth should be compact layer by layer, and then some grass can be grown when the linchs are stable. It would not only improve the ecological suitability of the terrace but also reduce the cost of the project [4].

2.2 The design of ecological compensation in the irrigation and drainage project

In order to save the cost and improve the durability, the channels of most projects tend to be straight and the raw material is concrete [5]. The negative effects of these practices are obvious. Such as, the channels with smooth surface and straight route not only accelerate the flow rate and surface water loss but cannot store water enough to foster aquatic life and exert the self-purification capacity of aquatic life

[6]. On the basis of keeping original route of the channel, the stone, more friendly to the environment, was taken as the raw material instead of concrete. And it also adopted two sets of system (irrigation channel and drainage channel) to avoid the cross-contamination between water resource and paddy. Furthermore, the channel slope was design to be gentle, and the vegetation was planted to reduce the ecological impact of water level change. After the consolidation, the channels and the ponds formed an integrated water recycling systemwhich providing a good habitat for local aquatic animals and plants.

2.3 The design of ecological compensation in the road project

As a human-made linear corridor, road can produce a space cutting phenomenon and has a significant impact on the ecology. At present, roads were hardened by concrete in most land consolidation projects which not only block the soil respiration and affect the natural temperature change but also bring an indirect effect on the ecological circulation and construction of food chain [7]. In order to reduce the negative effects, the roads were built in this project that can create a great habitat for local animals. What is more, the culvert was installed in the intersections of roads and channels which can bring lots of benefits. First, it can smooth the flow of water in the channel [8]. On the other hand, it provides a safe habitat for wildlife living on the roadsides. In conclusion, the construction of the mud-gravel road improved the landscape connectivity.

Meanwhile, the shelter belts were planted on the roadside. They can not only form a coherent network and beautify the rural landscape but also protect the biological diversity in the study region and provide an important migration corridor for local plants and animals.

3. The evaluation method of ecological compensation

3.1 The selection of evaluation factors

Land consolidation is not a simple terrace merger and increasing the quantity of arable land but rather focusing on improving the land quality and protecting the ecological environment [9]. Therefore, the local ecological condition should be considered when we choose the effective evaluation factors. So in this paper, we chose the following factors from the rationality of the ecosystem structure, the stability of ecosystemfunction and the suitability of ecological environment.

Table.1 The formula and illustration of assessment index for ecological compensation

Factor	Formula	Illustration
Water balance index (C_{11})	$C_{11}=(A_{11}/B_{11})\times100\%$	A_{11}:the supply of water; B_{11}:the demand of water
Vegetation coverage (C_{12})	$C_{12}=(A_{12}/B_{12})\times100\%$	A_{12}:the area of vegetation; B_{12}:the area of study region
Soil organic matter content (C_{13})	$C_{13}=(A_{13}/B_{13})\times100\%$	A_{13}:the weight of organic matter; B_{13}: the weight of dry soil
Soil salt content (C_{14})	$C_{14}=(A_{14}/B_{14})\times100\%$	A_{14}:the weight of salt; B_{14}: the weight of dry soil
Diversity index of land (C_{15})	$C_{15}=(A_{15}/B_{15})\times100\%$	A_{15}:the area of other agricultural land; B_{15}: :the area of agricultural land
Landscape fragmentation index (C_{16})	$C_{16}=(A_{16}/B_{16})\times100\%$	A_{16}:the number of a certain landscape patch; B_{16} :the area of the landscape
Per capita arable land (C_{17})	$C_{17}=A_{17}/B_{17}$	A_{17}:the arable land area of study region; B_{17}:the population of study region
Classification of gradient (C_{21})		Divided into 0°-6°,6°-10°,10°-15°,15°-25° and >25°

Mineralization of ground water (C_{22})		Divided into 0.5-2,2-5,5-10,10-30,30
Road accessibility rate (C_{23})	C_{23}=（A_{23}/B_{23}）×100%	A_{23}:the number of terrace that road can reach to; B_{23}: the total number of terrace
Probability of drainage (C_{24})	C_{24}=（A_{24}/B_{25}）×100%	A_{24}: drainage area; B_{24}: arable area
Land input-output ratio (C_{25})	C_{25}=（A_{25}/B_{25}）×100%	A_{25}: the input of unit area ; B_{25}: the output of unit area
Probability of irrigation (C_{26})	C_{26}=（A_{26}/B_{26}）×100%	A_{26}: irrigation area; B_{26}: arable area
Disaster bearing index (C_{27})	C_{27}=（A_{27}/B_{27}）×100%	A_{27}: the area that can ensure stable yield; B_{27}: the area of arable land
Water-soil conversation (C_{31})		Divided into excellent, preferable, general, inferior, terrible
Capacity of flood control (C_{32})		Divided into 3, 5, 10, 15 and 20 years
Soil erosion (C_{33})		Divided into no, feeblish, gentle, general and strong erosion
Coverage rate of shelter forest (C_{34})	C_{34}=（A_{34}/B_{34}）×100%	A_{34} :the area of shelter forest; B_{34}: the area suited to build shelter forest
Irrigation water quality (C_{35})		Divided into Ⅰ, Ⅱ, Ⅲ, Ⅳ and Ⅴ according national standard
Multiple crop index (C_{36})	C_{36}=（A_{36}/B_{36}）×100%	A_{36}: the area that planned the whole year; B_{36}: the area of arable land

3.2 The determination of the index weight

The index weight, as the contribution of factors to the evaluation unit, plays an important role in the process of evaluation. In this study, the AHP which is a qualitative and quantitative analysis method was applied to determined index weight. The evaluation index system was divided into 3 main levels and a hierarchical structure was created according to the disposable relationships. Then it adopted Delphi method to ascertain the weights of different factors.

Table.2 The weight and grading standards of assessment indexes

Criterion layer	Weight	Index layer	Weight	100（20）	80（40）	60（60）	40（80）	20（100）
		C_{11}	0.077	≥100	90-100	75-90	60-75	60-75
		C_{12}	0.178	≥95	85-95	75-85	60-70	<60
		C_{13}	0.193	≥3.0	2.0-3.0	1.5-2.0	1.0-1.5	<1.0
B_1	0.299	C_{14}	0.154	≥2.0	1.0-2.0	0.4-1.0	0.1-0.4	<0.1
		C_{15}	0.135	≥30	25-30	15-25	5-15	<5
		C_{16}	0.097	0.4-0.6	0.6-0.7	0.7-0.8	0.8-0.9	0.9-1.0
		C_{17}	0.166	≥0.2	0.15-0.2	0.1-0.15	0.05-0.1	<0.05
		C_{21}	0.182	≥25°	15°-25°	10°-15°	6°-10°	<6°
		C_{22}	0.128	5-30	30-100	1-5	<1	>100
		C_{23}	0.087	100	90-100	75-90	60-75	<60
B_2	0.427	C_{24}	0.172	≥85	75-85	65—75	50-65	<50
		C_{25}	0.11	≥5	3-5	2-3	1-2	<1
		C_{26}	0.172	≥90	80-90	70-80	60-70	<60
		C_{27}	0.149	≥80	70-80	60-70	40-60	<40
B_3	0.274	C_{31}	0.186	Excellent	Preferable	General	Inferior	Terrible
		C_{32}	0.101	20 years	15 years	10 years	5 years	3 years

	C_{33}	0.186	No	Feeblish	Gentle	General	Strong
	C_{34}	0.182	≥90	80-90	70-80	60-70	<60
	C_{35}	0.202	I	II	III	IV	V
	C_{36}	0.143	≥200	175-200	150-175	100-150	<100

3.3 The quantification and classification of evaluation factors

In order to standardize the evaluation and abate the work of data processing, the index is divided into 5 levels and evaluated with 100, 80, 60, 40 and 20 respectively according to the character of the factors. And the key factors should be evaluated accurately in the process of quantifying and classifying to ensure the results are rational.

3.4 The construction of evaluation model

An evaluation model was built based on the scores of different factors in each level. And then a comprehensive result was got from criterion layer to target layer.

① Calculation of criterion layer

$$B_i = \sum_{j=1}^{n_i} w_{ij}.c_{ij}\,(i = 1,2,3;\ j = 1,2,\ldots,n_i) \quad (1)$$

In this formula, B_i is the evaluation of criterion layer; W_{ij} is the weight of index-j; j is the index number of criterion layer; C_{ij} is the score of index-j.

② Calculation of target layer (the comprehensive evaluation value)

$$A = \sum_{i=1}^{3} w_i.B_i\,(i = 1,2,3) \quad (2)$$

In this formula, A is the comprehensive value of ecological compensation; w_i is the weight of index-i; i is the index number of target layer; B_i is the score of criterion layer.

Table.3 The assessment results of ecological compensation before and after land compensation

Level	Excellent	Preferable	General	Inferior	Terrible
Comprehensive index	>90	70-90	50-70	30-50	<30

4. The evaluation of ecological compensation in the study region

4.1 The rationality evaluation of ecological structure

79 reservoirs were built and 29 ponds were maintained in this project so that the water balance index increased from 92.73% to 129.9%. It suggests that the water supply of entire project area was improved greatly. In the process of building slope-terrace, the content of soil organic matter and salinity almost did not change due to the arable layer protection. Meanwhile, the project added 25.48hm^2 farmlands and per capita arable land increased from 0.097 hm^2 to 0.102 hm^2 through merging the terrace linchs and developing the waste grassland. But the diversity index of land decreased obviously due to that. Before land consolidation, the terrace was irregular and small. And then it became large and regular which was more suitable for mechanized farming and ecological balance after land consolidation. Consequently, the

landscape fragmentation index decreased from 0.87 to 0.65 and the vegetation coverage increased from 93.25% to 97.25%. In conclusion, the rationality index of ecological structure increased from 62.54 to 72.14 through ecological compensation.

Table.4 The rationality evaluation of ecological structure before and after land compensation

Index	Weight	Before land consolidation		After land consolidation	
		Value	Score	Value	Score
C_{11}	0.077	92.73	80	129.9	100
C_{12}	0.178	93.25	80	97.25	100
C_{13}	0.193	1.65	60	1.65	60
C_{14}	0.154	0.545	60	0.523	60
60	0.135	28.93	80	23.42	
80	0.097	0.87	40	0.65	
C_{17}	0.166	0.097	40	0.102	60
Rationality index of ecological structure B_1			62.54		72.14

4.2 The stability evaluation of ecological structure

As a result of building slope-terrace, the main gradient level decreased from 10°-15°to 6°-10°. That improved the capacity of soil and water conservation. Before land consolidation, the length of the rural roads was 53.31km, but most of them were very poor and did not form an effective network which significantly interfered the farming of the region. But after land consolidation, 9.75 km of road was built and 30.48km was maintained. It formed an effective network that reduced the farming distance and provided condition for the mechanized production. Finally, the road accessibility rate improved from 80% to 100%. Before land consolidation, the length of the channel was 36.82km but the distribution was uneven. Therefore, the probability of irrigation and drainage was very low, only about 75% and 70%. After this project, 27.51km of channels was built and maintained and formed a rational irrigation system. So the probability of irrigation and drainage improved to 80% and 90% respectively. Overall, through infrastructure construction, the land input-output ratio increased from 2.82 to 3.10 and disaster bearing index increased from 65% to 95%. The stability index of ecological function increased from 62.54 to 72.14 through ecological compensation.

Table.5 The stability evaluation of ecological structure before and after land compensation

Index	Weight	Before land consolidation		After land consolidation	
		Value	Score	Value	Score
C_{21}	0.182	10°-15°	60	6°-10°	80
C_{22}	0.128	0.5-2	100	0.5-2	100
C_{23}	0.087	80	60	100	100
C_{24}	0.172	70	60	80	80
C_{25}	0.11	2.82	60	3.1	80
C_{26}	0.172	75	60	90	100
C_{27}	0.149	65	60	95	100

Stability index of ecological function B_2	65.12	90.72

4.3 The suitability evaluation of ecological environment

Before land consolidation, the distribution of the channel was uneven and only stored water by the ponds in some area. Furthermore, most arable land was steep and did not take appropriate water conservation measures. By evaluation, the capacity of flood control was 5 years, the level of irrigation water quality was Ⅱ, the degree of soil erosion was moderate and water conservation level was general. After consolidation, the distribution of the channel was more reasonable and the terrace was more regular. So the level of irrigation water quality reached to Ⅰ, the capacity of flood control reached to 10 years, the degree of soil erosion was mild and water conservation level was preferable. The study region didn't have an intact shelter forest system and the coverage rate was only 55% before land consolidation. But the coverage increased to 75% after shelter forest construction. The shelter forest integrating with networks of roads and channels played a significant role in water-soil conversation and improving the field microclimate. Moreover, it provided an important migration corridor to protect the biological diversity [10]. What is more, due to the improving of cultivation condition, the multiple crop index increased from 165% to 180%. In conclusion, the suitability index of ecological environment increased from 62.54 to 72.14 through ecological compensation.

Table.6 The suitability evaluation of ecological structure before and after land compensation

Index	Weight	Before land consolidation		After land consolidation	
		Value	Score	Value	Score
C_{31}	0.186	General	60	Preferable	80
C_{32}	0.101	5 years	40	10 years	60
C_{33}	0.186	General	40	Feeblish	80
C_{34}	0.182	55	20	75	60
C_{35}	0.202	Ⅱ	80	Ⅰ	100
C_{36}	0.143	165	60	180	80
Suitability index of ecological environment B_3			51.02		78.38

4.4 The comprehensive evaluation of ecological environment

By calculation, the comprehensive index of ecological environment was 60.49 before land consolidation and 81.78 after land consolidation. The ecological environment was improved after land consolidation according to the evaluation criteria. The result demonstrates that the designs of ecological compensation practices on land consolidation project can improve the ecological environment significantly.

Table.6 The comprehensive evaluation of ecological structure before and after land compensation

Index	Weight	Before land consolidation	After land consolidation

B_1	0.299	62.54	72.14
B_2	0.427	65.12	90.72
B_3	0.274	51.02	78.38
comprehensive index of ecological environment A		60.49	81.78

5. Conclusions

Land consolidation plays an important role in increasing the arable land, developing the agricultural and promoting the social stability. However, due to the pursuit of more economic benefits and arable land quantity, land consolidation usually ignored the ecological construction, so that it has led to a series of ecological problems such as soil erosion and soil desertification. For ecological compensation, this paper proposed that the eco-design in the process of building terrace, road and channel should be carried out in land consolidation. Besides, a system of comprehensive evaluation of the ecological compensation of land consolidation from the rationality of the ecosystem structure, stability of ecosystem function and suitability of ecological environment was constructed. The result showed the eco-design in land consolidation project can realize ecological compensation and also can achieve the coordinated development of economy, ecology and society.

Acknowledgements

The project was supported by the Science and Technology Supporting Plan of China (no. 2006BAD05B01-02).

References

[1] Zheng chen-rui, Dong xu-juan.Research on the ecological compensation of land arrangement. Journal of Guizhou Commercial College [J], 2010(6):39-42.
[2] Zhong xue-bin, Yu guang-ming, He guo-song, Lu di, Carbon storage loss during land readjustment and optimization of ecological compensation[J]. Chinese Journal of Ecology, 2006, 25(3):303-308.
[3] Wang rui, Zhang xiao-cheng, Tian shui-song, Study on the land consolidation in hilly area of southwestern China. Jounal of Hebei Agricultural Sciences,2009,13(3):99-101.
[4] Yu guang-ming, Wei ya-li, Lu di, Impact of regional land consolidation on the ecosystem and its compensation, Journal of safety and environment 2006(8):46-49.
[5] Metzger M J, Rounsevell M D A, Acostar Michlik L, et al. The vulnerability of ecosystem services to land use change [J]. Agricultural ecosystems and environment, 2006, 114:69-85.
[6] REIDSMA P, TEKELENBURG T, BERG M, et al . Impacts of land-use change on biodiversity: an assessment of agricutural biodiversity in the European Union [J]. Agriculture, Ecosystem and environment, 2006, 114: 86-102.
[7] Wang jun, Luo ming, Long hua-lou, Methodology and case study of ecological evaluation for land consolidation [J]. Journal of natural resources, 2003(5): 363-367.
[8]Su shao-qing, Lin bi-shan, Zeng xiao-duo, Ecological and environmental protection problems in land consolidation and the countermeasures [J]. Ecology and environment 2006,15(4):881-884.
[9] Zhao hua, Bian zheng-fu, Leng hai-long. On enhancing ecology and environment evaluation of land rearragement [J]. China Land Science, 2003, 17(3): 34-37.
[10] Luo ming, Zhang hui-yuan. Land consolidation and its ecoligical and environmental impacts[J]. Resource Sciences, 2002, 24(2):60-63.