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Ecological compensation for large water projects based on ecological footprint theory：a case study in China

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Abstract

Large water projects have become important ways to alleviate the water stress in China, which inevitably lead to large quantity of ecological immigrants. Reasonable policies on ecological compensation are extremely important for the realization of sustainable ecological projects. Traditional methods fail to calculate the reasonable and sustainable compensation for local residents. Taking the South-North Water Transfer Middle Route Project as an example, we suggested a new model based on the ecological footprint theory to calculate the losses of ecological immigrants and provided a more reasonable compensation amount. Results reflect that compensation quantity for the cropland, grazing land, forest land, fishing ground and built-up are recommended as 4318.53yuan/a, 223.05yuan/a, 308.41yuan/a, 904.69yuan/a and 56651.62yuan/a, respectively. This paper may be served as an example for direct the ecological compensation in developing countries.

Keywords: Ecological compensation; ecological footprint; South-North Water Transfer Middle Route Project.

1. Introduction

With the rapid industrial development and expanding population in northern China, water stress in this region is characterized with major, inefficient, irrigation water use and rapidly growing non-agricultural

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water demands, as well as limited water quantity and declining water quality[1]. The surface water has quickly been exhausted with large amounts of ground water being pumped creating serious water pollution and deterioration of the environment. The Middle Route South-to-North Water Transfer Project, one of the largest projects in China was conceived to deliver water from south China to the north to alleviate the extreme water shortage in the north and to promote the economic and social development of northern China[2].

To keep certain of the water quantity and quality, about 0.18 million people the will be impacted in the city of Shiyan. The diversion scheme has provoked many environmental concerns, principally regarding the loss of antiquities, the displacement of people and the destruction of pasture land. About 0.74 million ecological immigrants will be relocated out of the reservoir district [3].

Making reasonable compensation to these ecological immigrants plays significant role in regulating the relationships between economic developments and environmental protection. Quite a few researches have been conducted to the compensation scopes, criterion, pay methods and so on [4-6]. One of the most difficult problems is to make certain of the compensation criterion and many methods were developed to solve this problem, e.g., opportunity cost method [7], contingent valuation method [8] and so on.

However, a problem of the current methods is that it is hard to find a balance between compensation and rights. On the one hand, it is unrealistic to compensate all the losses of ecosystem services. On the other hand, the rights and interests of local immigrants tend be partly ignored. Many subjective factors will definitely impact the calculated results. There is an urgent need for a method to assess the losses of ecological immigrants and thus realize reasonable compensation.

The ecological footprint (EF) concept has been introduced in the 1990s by William Rees and Mathis Wackernagel [9, 10]. The EF measures much nature, expressed in the common unit of 'bioproductive space with world average productivity', is used exclusively for producing all the resources a given population consumes and absorbing the waste they produce, using prevailing technology. Combined the EF with ecological compensation, we developed a new method for ecological compensation in ecological immigrants. We hope our work can be served as a reference of compensation criterion of ecological immigrants in developing countries.

2. Study area

The Danjiangkou Reservoir is situated in the north-west of Shiyan City in Hubei province (109°29′-111°16′E，31°30′-33°16′N). It was constructed in the 1950s to supply drinking water to five counties, for irrigation and hydro-power and also to provide flood water storage to protect the downstream rivers including the Yangtze River. It is semi-arid zones which climate is characterized by continental monsoon with multi-year average precipitation 834mm. The mean annual air temperature is about 15.2℃.

3. Materials and methods

3.1 Ecological footprint and ecological carrying capacity

The EF is defined as "the area of productive land and water ecosystems required to produce the resources that the population consumes and assimilate the wastes that the population produces, wherever on Earth

the land and water is located" [9,10]. It is a measure of human demand on the Earth's ecosystems. An ecological footprint is a standard measurement of a unit's influence on its habitat based on consumption and pollution [11]. It compares human demand with planet Earth's ecological capacity to regenerate. It represents the amount of biologically productive land and sea area needed to regenerate the resources a human population consumes and to absorb and render harmless the corresponding waste. By measuring the footprint of a population—an individual, city, business, nation, or all of humanity—we can assess our pressure on the planet, which helps us manage our ecological assets more wisely and take personal and collective action in support of a world where humanity lives within the Earth's bounds.

There are two basic assumptions concerning the calculation of EF model: (1) Most of the consumption in energy, resources as well as the waster can be calculated in a large extent. (2) These resources and waster can be converted into biologically productive spaces, including forest land, grazing land, cropland, fishing ground, and built-up land [9, 10]. The formulation for the calculation of EF is depicted in equation (1):

$$EF = N \cdot ef = N \cdot r_j \cdot \sum(aa_i) = N \cdot r_j \cdot \sum(C_i / P_i) \quad (1)$$

N-population; *ef*-average EF; *i*-types of consumption and investment; *j*-types of productive spaces; *a*-biologically productive spaces per capital of *i*th commodity (hm^2); C_i-consumption per capital of *i*th commodity; P_i-global average productivity of *i*th commodity (t/hm^2); r_j-equilibrium factors (forest land -1.1, grazing land-0.5, cropland-2.8, fishing ground-0.2, and built-up land-2.8) (Wackernagel and Rees, 1996).

3.2 Ecological compensation criteria

Especially the study on ecological compensation standard is fewer, but it is necessary for practicing the ecological compensation. The ecological compensation criteria based on the calculations of EF can reflect the objective and direct results on local ecological condition. Through the comparison between ecological deficit and ecological surplus, the impacts to ecological immigrants can be quantitatively defined.

Generally, ecosystem services can be grouped into four functions: products supply (freshwater, water products, wood products, carbon storage, etc.), control (water adjustment, water and soil conservation, water source conservation, cleaning, etc.), biodiversity protection (provides living environment), and information (culture, entertainment, etc). Considering the current economic situation in China, we only took direct ecosystem services into the account of compensation criteria. The direct value of ecosystem services of different ecosystems were identified from different references, e.g., forest land (2512.2yuan/hm^2), grazing land (1102.8 yuan/hm^2), cropland (54327.7 yuan/hm^2), fishing ground (4011.4yuan/hm^2) and built-up land (6083200.5yuan/hm^2) [12-14].

3.3 Data sources

The data on production, consumption were collected from Hubei Statistical Yearbook, Hubei Economy Yearbook, Shiyan Statistical Yearbook and Shiyan Economy Yearbook. Results and discussion.

4. Results and discussion

4.1 The EF for the Shiyan city

The results are listed in the Table 1, Table 2 and Table 3. As we can see from the table, the EF per capital in Shiyan city was about 1.578hm^2/a in 2008. Contrarily, the ECC per capital was only about 0.438hm^2/a. The average ecological deficit per capital was 1.148hm^2/a. The above results demonstrate that the human activities have produced more pressure on natural ecosystems than ECC. The results are lower than the corresponding data for Hubei province are respectively 2.567 hm^2/a, 0.593 hm^2/a and 1.973 hm^2/a, indicating relative low economic level in the region [15].

The EF for cropland, grazing land, forest land, fishing ground and built-up land are 0.383 hm^2/a, 0.281 hm^2/a,0.026 hm^2/a, 0.190 hm^2/a, 0.669 hm^2/a and 0.025 hm^2/a, respectively. The largest EF came from fossil fuels. Overall, the ecological surplus for forest land was 0.088 hm^{2}per capita and the ecological deficit of grazing land and fishing ground were 0.279 hm^2/y and 0.184 hm^2/a, respectively.

Table 1 Biological resource consumption EF of Shiyan city in 2008.

Item	Global average productivity (kg/hm^2)	Consumption (t)	Total EF (hm^2)	Average EF (hm2/capita)	Land types
Farm production					Cropland
Paddy	2744	460247	167728	0. 0492	
Wheat	2744	231744	84454	0. 0247	
Potato	12607	48624	3856	0. 0011	
Maize	2744	135852	49508	0. 0145	
Soybean	1856	15588	8398	0. 0024	
Cotton	1000	30804	30804	0. 0091	
Oil plants	1856	171441	92371	0. 0271	
Fibre plants	1500	2858	1905	0. 0005	
Glucide	4893	15882	3245	0. 0009	
Tobacco leaf	1548	7078	4572	0. 0013	
Vegetable	18000	173438	9635	0. 0028	
Melon and fruit	18000	185133	10285	0. 0030	
Livestock production					
Pork	74	105174	1421270	0. 4172	Grazing land
beef and mutton	33	9676	293236	0. 0860	
Poultry meat	457	26305	57560	0. 0168	
Wool	15	0. 021	1.44	0. 0000004	
Goat hair	15	0. 355	23	0. 000007	
Milk	502	6361	12673	0. 0037	
Honey	50	256	5124	0. 0015	

Egg	400	49143	122859	0. 0361	
Forest products					Forest land
Tung seed oil	1600	578	361	0. 0001	
Camellia seed oil	1600	1181	738	0. 0002	
Dried bamboo shoot	3000	171	57	0. 00001	
Chinese chestnut	3000	4506	1502	0. 0004	
Tea	566	4690	8287	0. 0024	
Fruit	3500	135957	38845	0. 0114	
Cocoon	1000	450	450	0. 0001	
Log	1. 99①	63939②	32130	0. 0094	
Aquatic production					Fishing ground
	29	94017	3241965	0. 9518	

Note: ①unit:m^3/hm^2； ②Unit: m^3.

Table 2 EF of energy consumption of Shiyan city in 2008.

Item	Consumption （t）	Convert Coefficient (GJ/t)	Global average energy EF (GJ/hm^2)	Total EF (hm^2)	Average EF (hm^2/capita)	Land types
Coal	1531912	20. 934	55	1524299	0. 4505	Fossil fuels
Coke	197172	28. 47	55	197171	0. 0579	
crude oil	287404	41. 868	93	314415	0. 0845	
Gasoline	2999	43. 124	93	3138	0. 0008	
Kerosene	159	43. 124	93	157	0. 00004	
Diesel oil	8313	42. 705	93	7854	0. 0024	
Fuel oil	7913	50. 2	71	7206	0. 0023	
Liquefied petroleum gas	1434	50. 2	71	1504	0. 0004	
Eclectic power	33614	3. 36	1000	30575	0. 0090	Build-up land

Table 3 EF and ECC of Shiyan city in 2008.

Land types	Average area(hm^2/ capita)	Equilibrium factors	Average EF	Land types	Average area(hm^2/ capita)	Equilibrium factors	Yield factor	ECC/capita
Fossil fuels land	0. 609	1. 1	0. 669	CO_2 absorbed land	0	1. 1	0	0
Cropland	0. 137	2. 8	0. 383	Cropland	0. 064	2. 8	1. 66	0. 297
Grazing land	0. 562	0. 5	0. 281	Grazing land	0. 012	0. 5	0. 19	0. 001
Forest land	0. 024	1. 1	0. 026	Forest land	0. 551	1. 1	0. 19	0. 115
Built-up land	0. 009	2. 8	0. 025	Built-up land	0. 0039	2. 8	1. 66	0. 018
Fishing ground	0. 951	0. 2	0. 190	Fishing ground	0. 029	0. 2	1. 00	0. 0058
Sum			1. 576			0. 448		

4.2 Compensation criteria for ecological immigrants

The calculated compensation criteria for the ecological immigrants in case city are depicted in Table 4. For example, compensation quantity for the cropland, grazing land, forest land, fishing ground and built-up are recommended as 4318.53yuan/a, 223.05yuan/a, 308.41yuan/a, 904.69yuan/a and 56651.62yuan/a, respectively. It is worth to note that t many factors involved in the number of compensation years.

Table 4 The EF compensation criteria in Shiyan city

Item	Compensation criteria per capital (yuan/hm^2a^{-1})	Compensation (yuan/a)
Fossil fuels land	-	-
Cropland	50327	4318. 53
Grazing land	1102	308. 41
Forest land	2512	223. 05
Built-up land	6083200	56651. 62
Fishing ground	4906. 14	904. 69

5. Conclusions

This paper introduced a new method to calculate the compensation criteria for ecological immigrants. The city of Shiyan was taken an example. Some conclusion concerning the current study are as follows：

(1) The current method can provide more rapid, direct and objecting results in identifying compensation criteria.
(2) The recommended compensation criterion for ecological immigrants is about 64206.31yuan per capital.
(3) Further studies on capital sources, compensation time and compensation ways are still needed.

There is an urgent need for valid mechanism for the ecological compensation during the construction of large water projects. The principles, scope, criteria and ways for ecological compensation should be identified in a format of lows. We hope our studies can provide a meaningful reference for the ecological compensation in China.

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