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An Analysis of the Spatial Heterogeneity of the Functioning of Ecosystem Services Related to Land-and-Water Resources

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ABSTRACT

The types and quality of services are provided to humans by ecosystems vary widely across the earth's landscapes. As human population increases, people are placing increasing importance on ecosystem services and the topic has moved to the forefront of human concerns. This paper analyses regional differences in the functioning of ecosystem services related to land-and-water resources based on panel data collected in 2011 and establishes an index system that can be used to evaluate the functioning of ecosystem services. Furthermore, 31 regions were clustered and compared using an evaluation matrix that considers the current level and pace of economic development in those regions. First, results show that a certain level of spatial heterogeneity exists among the ecosystem services provided by land-and-water resources in different regions of China; this heterogeneity is closely connected with the current conditions and speed of economic development. Second, the services provided by ecosystems appear to function and perform better in north, east and northeast China, in areas with stronger economic development, but a limited history of past development. Finally, ecosystem services perform poorly in north China, south China, Tibet, and northwest and southwest China in areas that exhibit different speeds of economic development.

INTRODUCTION

Water and land resources strongly support basic human needs for the production and provisioning of various products, and additionally provide precious assets that may ensure the sustainable development of human society. The natural sustainability of various ecological services provides a solid foundation and important driving force for the sustainable and healthy development of the human society. Essentially, humans need to coordinate the development of human populations, natural resources and the environment if they expect to be able to depend on the sustainability of ecosystems and their service functions (Satoru Okubo et al. 2003). Therefore, protecting and improving the functioning of sustainable ecosystem services such as important land-and-water resources is worth our attention because those services are critical for the survival and advancement of human society. By employing reasonable production activities and appropriate scientific technology, humans are able to influence the proper functioning of various ecosystem services and may find ways to enhance the performance of those services. Currently, an abundance of studies have been produced in academic circles related to improving the service functions of land-and-water resources. Specifically, research has mainly concentrated on three aspects of ecosystem services. First, quantitative empirical research has combined the analysis of individual ecosystem service functions of water and land resources with actual study areas (Weiyao Wei et al. 2011, El Nahry et al. 2011). Second, qualitative and quantitative assessment and development of ecological compensation mechanisms have been developed from the perspectives of ecological security, risks and benefits in land-and-water resources use (Ines Winz et al. 2009, Pytrik Reidsmaa et al. 2011). Third, empirical research has been conducted related to the improvement of the value of the service functions of land-and-water resources; the goal of this research has been the optimal allocation of land-and-water resources based on 3S technology with the incorporation of professional engineering viewpoints and review of actual areas to be analysed on the ground (Xisheng Hu et al. 2013, Verburg et al. 2011). These studies will assist land managers and government agencies in making remarkable achievements in reducing the current threats which society faces related to the use of land-and-water resources and the improvement of land management from the traditional macro and micro-scales. However, little systematic research is cur-

rently available related to the management of entire ecosystems and the related integration of land-and-water resources use or to comparative analysis of the spatial heterogeneity of ecological service functions of land-and-water resources in different areas. Research is sorely needed related to the construction of an evaluation index system that is based on the value of ecosystem services (VES) that will make a more systematic and profound analysis of the variations and spatial heterogeneity in the ecological benefits of land-and-water resource use. Next, double-layer contrasts and cluster analyses should be carried out based on the comprehensive evaluation of a VES index system in all regions, combined with the an analysis of the measurement of the current level and rate of economic benefits. Finally, guided by the analysis results, effective empirical suggestions should be proposed from the perspective of the VES for the enhancement of ecological benefits of regional land-and-water resources at the present stage and the macroscopic management of soil and water erosion.

DATA SOURCES AND RESEARCH METHODS

Data sources and normalization: The initial data used in this study came from statistics for 2011 harvested from the 2012 China Statistical Yearbook, 2012 China Rural Statistical Yearbook and 2012 China Statistical Yearbook of Land and Resources. To eliminate the effects of differences in data units and values on the results, all the selected data were normalized by adopting the following formula:

$$z_i = \frac{x_i - \bar{x}}{s} \quad ...(1)$$

Where, z_i refers to the standardized value of the original data of the selected index in various samples; x_i is the original data of the selected index in various samples, $\bar{x}$ is the mean value of the same index in the selected samples, and s is the standard deviation of the same index in the selected samples.

Evaluation index system of the functioning of ecosystem services related to land-and-water resources: The construction of an evaluation index system related to the efficiency of the use of land-and-water resources can generally be resolved by coupling both water and land resource data as well as Press-State-Response. However, from an ecosystem perspective, the efficiency of the use of land-and-water resources is not merely expressed using individual elements, but should be analysed from a more comprehensive scale to look at the effects on the entire ecosystem that is centred on land-and-water resources. For this reason, the present study attempted to develop an index system based on a new perspective we defined as the value of ecosystem service functioning (VES). Currently, an increasing number of related studies are being conducted that mainly focus on analysing and testing the VES using quantitative evaluation methods, as well as corresponding research that integrates specific sites or projects with the VES function response (Badr et al. 2010, De Langea et al. 2010, Baojie Li et al. 2010). However, this method still involves the study and development of an index system and comprehensive evaluation of ecosystem services by considering land-and-water resources use as a multilevel ecosystem and uniting this with the VES Table. Therefore, constructing an evaluation index system based on the ecological benefits humans receive from land-and-water resources by using the development of a domestic value for ecosystem services functioning is very important. First, this method can account for the entire value of the functions of an ecosystem. Furthermore, it can effectively reflect the overlapping parts of ecological benefits humans receive in the form of economic and social benefits, allowing the creation of a more scientifically sound and integrated index system. Table 1 shows the specific index system of ecological benefits of land-and-water utilization. The dimension is conversed from the components of the unit area VES table of China's terrestrial ecosystem and the correlation refers to the positive or negative correlation between index and value of the ecosystem service function.

Research methods: The spatial heterogeneity of the functions of ecosystem services provided by land-and-water resources can be demonstrated as a comprehensive measurement corresponding to the various subsystem service function discrepancies in the different regional spatial locations. This study employed SPSS software and principal component analysis to extract the common factors of an evaluation index system related to the functions of ecosystem services of land-and-water resources and to calculate the scores of common factors in each sample area. Then, the variance of the contribution rate of each factor is taken as the weight to calculate the comprehensive evaluation scores of the service function in each sample area by a weighted average. Using comprehensive scores to determine the service functions of ecosystems can help researchers to determine the spatial variations in the functioning of ecosystem services related to land-and-water resources. Simultaneously, to further weigh the effects of economic growth on the value of ecosystem services, evaluation scores should be compared and comprehensively clustered based on the level and speed of regional economic development from the two aspects of cross section and variations in the relative link ratio. The clustering matrix used to conduct this comprehensive evaluation is mainly constructed by combining the speed of regional economic development in two different periods; in the present study, this is calculated at the ratio of the regional GDP in 2011 compared to that in 2010. According to

the ranks of the speed of regional economic development, the districts can be classified into three grades, rapid, moderate, and slow development regions. When combined with the good, moderate and poor economic service functions, a comprehensive evaluation matrix can be structured (Table 2).

RESULTS AND ANALYSIS

Comparative analysis of the function of ecosystem services related to land-and-water resources in 31 provinces sensu lato: Based on the evaluation of the function of ecosystem services related to land-and-water resources in various regions of China in 2011 (Table 3 and Fig. 1), Shandong Province ranks the first by a large margin among the 31 provinces sensu lato analysed here. Guangdong, Henan, Heilongjiang and Liaoning provinces are listed from second to fifth, respectively although an especially significant gap exists among the first three. Jiangsu, Sichuan, Shaanxi, Zhejiang and Hebei provinces rank from sixth to ten, and the gap between them is fairly small. Guizhou, Hainan, Tianjin, Ningxia and Qinghai rank as the last five, and the difference between Guizhou, Hainan and Tianjin provinces is relatively small but is a certain amount larger than the last two. Concerning the service function scores, both north China and northeast China have two municipalities listed among the top five where the service function value of land-and-water resources is relatively high. With combination of the level and rate of local economic development, such districts are not the ones that develop at the most rapid pace. Generally, past economic development has a negative relationship to available ecological services. That is, economic development tends to result in a degradation of ecological services, making such service less readily available. Thus one can see that a certain amount of mutual inhibition exists between the speed of economic development and availability of the functions of the ecological services provided by land-and-water resources. In comparison, the value of the ecosystem services of land-and-water resources still creates a disadvantage in most provinces sensu lato such as those of the Qinghai-Tibet region, southwest China and northwest China. Moreover, economic development in these regions lags behind that of others. Hence, one can conclude that different stages of economic development will have different effects on functioning of ecosystem service. When economic development remains at a low level, despite the small-scale loss of some of the land-and-water resources provided by the ecosystem, the effects of development and land use are also less. In such a way, the functions of ecosystem service are not fully used. On the contrary, as economic development progresses to a certain degree, the excessive use of the economic service functions of land-and-water resources will result in an impairment of ecosystem services (Espinha Marques et al. 2011, Guangjin Tian et al. 2012). For example, the current centers of economic development such as Tianjin and Beijing are obviously in an inferior position as it relates to the availability of ecological services in those areas when compared to conditions nationwide.

Comprehensive evaluation on the spatial heterogeneity of ecosystem service functions in land-and-water resources: The functioning of ecosystem services provided by land-and-water resources should be evaluated by combining that analysis with an analysis of the rate of regional economic development (Tables 4 and 5). Based on these tables, one can see that only Shaanxi province possesses a combination of well-functioning ecological services related to land-and-water resources combined with rapid economic development. The current rate of economic development in this region falls in the mid-range compared to development rates nationwide, but there is a considerable room for improvement because of the current rapid rate of development. In the meantime, Shaanxi province also exhibits an outstanding performance in the service functions of gas regulation, climate control and water conservation, which contributes greatly to its ranking as having good-functioning ecological services with rapid development. While Shaanxi province does not have superior resources, it is located in the arid area without a conspicuous advantage in the area of land-and-water resources. But while benefiting from accelerating economic development, Shaanxi province also reasonably affects and exploits the service functions of land-and-water resources provided by the ecosystem to coordinate the relationship between land-and-water resources and economic progress. This should be seen as an example for emulation by other regions with similar conditions. Heilongjiang and Sichuan provinces have very good land-and-water resources service functions, but development is occurring at rather moderate speed. These two provinces can be classified as having good ecosystem services functioning and moderate development mainly because they have been developing relatively evenly in the service function area despite having an obvious advantage in the field of the production of raw materials. Furthermore, several provinces sensu lato, including Liaoning, Shandong, Henan, Hebei, Jiangsu, Zhejiang, and Guangdong, are ranked at the top in the quality of ecosystem services provided by land-and-water resources. They mutually share the common asset of performing well in the production of foods. Apart from this, Liaoning and Henan provinces have good water conservation and gas regulation. Jiangsu, Zhejiang and Guangdong provinces have outstanding in sewage treatment facilities and landscape services. In addition, Shandong province stands first among the provinces sensu lato with

Table 1: Evaluation index system of the functioning of ecosystem services related to land-and-water resources.

Dimension	Index	Unit	Correlation
Food production	gain output per unit area	kg/hm^2	+
	Total output of aquatic products	10^7 kg	+
	Gross output value of farming, forestry, animal husbandry and fishery	10,000 USD	+
Raw material production	Industrial added value of oil and gas exploitation and utilization	10,000 USD	+
	Oil yield	10^7 kg	+
	Gas production rate	10^8 m^3	+
	Annual extracted ore tonnage of non-oil-gas mineral resources	10^7 kg	+
Gas regulation	Fertilizer input	10^7 kg	-
	Pesticide use	10^3 kg	-
	Agricultural use of plastic film	10^3 kg	-
Climate control	Total afforested area	hm^2	+
	Total afforested area by Grain-to-Green Project	hm^2	+
Water and soil conservation	Area of water and soil erosion management	hm^2	+
	Total volume of reservoir	10^8 m^3	+
	Effective irrigation area	hm^2	+
	Waterlogging control area	hm^2	+
	Land consolidation	hm^2	+
	Actual urban sewage treatment	10^7 kg	+
Waste treatment	Urban sludge disposal and land utilization	10^7 kg	+
	Investment in urban environment and infrastructure construction	10,000 USD	+
	Investment in industrial pollution sources management	10,000 USD	+
	Proportion of wet land in the total area	%	+
Biodiversity conservation and landscape	Forest coverage rate	%	+
	Urban greenbelt area	hm^2	+
	City park area	hm^2	+

Table 2: Evaluation matrix of the functioning of ecosystem services related to land-and-water resources

Ranking of ecosystem service functions provided by land-and-water resources	Economic development speed in different regions		
	1-10	11-20	21-31
1-10	Good function-rapid development	Good function-moderate development	Good function-slow development
11-20	Moderate function-rapid development	Moderate function-moderate development	Moderate function-slow development
21-31	Poor function-rapid development	Poor function-moderate development	Poor function-slow development

its well-planned water conservation, gas regulation and sewage treatment facilities. However, the regions mentioned above are always among the list of having a high level of economic development, so their upside potentials are relatively small and the rate of future development will also be slower. This is the reason why they are not graded as regions with "good function-rapid development." Lastly, these regions should accelerate economic development while maintaining the functions of land-and-water related ecosystem services. Overall, regions with poor ecosystem functioning can be divided into the following three types. First are those provinces sensu lato that are leading in the realm of economic development, such as the cities of Tianjin, Beijing, and Shanghai, where excessive effects of the exploitation of land-and-water resources provided by the ecosystem are leading to a decline in the functioning of ecosystem services (Timilsina & Beghin 2012). Therefore, these regions should concentrate their efforts on mitigating and restoring the functions of these ecosystem services. The second type includes those regions and provinces sensu lato with insufficient exploration of resources and knowledge of the functions of ecosystem services, such as Qinghai, Ningxia, Guizhou and Tibet. Therefore, the provinces sensu lato of Qinghai, Ningxia and Guizhou are among the lowest ranked locations in the sense of economic development and currently lack a significant rate of development. Thus, these regions are able to continue to accelerate their advancing rate of economic development while using local ecosystem services appropriately and maintaining their functions. Thirdly, other regions, such as Guangxi, Hainan and Gansu

Table 3: Evaluation of the function of ecosystem services related to land-and-water resources in different regions during 2011.

Region	Service function value	Rank of scores	Rank of economic development level	Rank of economic development speed	Type
Shandong	0.849222	1	10	28	Good function-slow development
Guangdong	0.571797	2	8	29	Good function-slow development
Henan	0.464285	3	23	26	Good function-slow development
Heilongjiang	0.326089	4	17	20	Good function-moderate development
Liaoning	0.295059	5	7	21	Good function-slow development
Jiangsu	0.282698	6	4	25	Good function-slow development
Sichuan	0.274491	7	24	14	Good function-moderate development
Shaanxi	0.249753	8	15	7	Good function-rapid development
Zhejiang	0.218783	9	5d	27	Good function-slow development
Hebei	0.208073	10	14	22	Good function-slow development
Hunan	0.187765	11	30	8	Moderate function-rapid development
Hubei	0.156669	12	13	10	Moderate function-rapid development
Hunan	0.13318	13	20	11	Moderate function-moderate development
Inner Mongolia	0.125783	14	6	9	Moderate function-rapid development
Fujian	-0.01514	15	9	24	Moderate function-slow development
Xinjiang	-0.02226	16	19	19	Moderate function-slow development
Shanghai	-0.02714	17	2	31	Moderate function-slow development
Jiangxi	-0.02723	18	25	4	Moderate function-rapid development
Anhui	-0.03177	19	26	5	Moderate function-rapid development
Jilin	-0.07441	20	11	17	Moderate function-moderate development
Guangxi	-0.15403	21	27	13	Poor function-moderate development
Beijing	-0.19421	22	3	30	Poor function-slow development
Shanxi	-0.21416	23	18	16	Poor function-moderate development
Chongqing	-0.25394	24	12	1	Poor function-rapid development
Gansu	-0.34994	25	29	18	Poor function-moderate development
Guizhou	-0.41296	26	31	3	Poor function-rapid development
Hainan	-0.42062	27	22	15	Poor function-moderate development
Tianjin	-0.42098	28	1	12	Poor function-moderate development
Ningxia	-0.55627	29	16	2	Poor function-rapid development
Qinghai	-0.56351	30	21	6	Poor function-rapid development

provinces sensu lato, need to continue to find a way to harmonize economic development with appropriate resource conservation in the sense of wise resource use (Newbold 2007). As for the regional distribution of ecosystem services and economic development, more regions in north China, east China and northeast China exhibit good functioning of ecosystem services related to land-and-water resources. In addition, a few regions in northwest China, south China, and southwest China have mostly shown rapid economic development and now have limited potential for expansion. Regions with poorly functioning ecological services are widespread geographically, and are scattered across north, south, northwest and southwest China, as well as the Qinghai-Tibet region but their rates of economic development vary.

DISCUSSION AND CONCLUSIONS

The present study developed an evaluation index system designed to rank the performance and functioning of ecosystem services related to land-and-water resources based on the perspective of placing a value on ecological services. The results provide a comprehensive assessment of the spatial heterogeneity of regional ecological services in combination with an analysis of the current level and pace of ongoing economic development. The land-and-water resources analysed in this study include the ecosystem and environment, human population, land-and-water resources, and the relationships between them. The research methods used here effectively integrate and contrast these characteristics of the landscape in both time and space. The conclusions drawn here systematically and directly reveal the deficiencies and upside potential for the continued functioning of ecosystem services related to land-and-water resources. This study provides data that will provide land management planners with an empirical reference designed to assist them in improving current imbalances in the functioning of regional land-and-water resources ecosystem services with the goal of assisting land managers in having an effective influence on and regulation of ecosystem service functions. Based on the above empirical research, one can

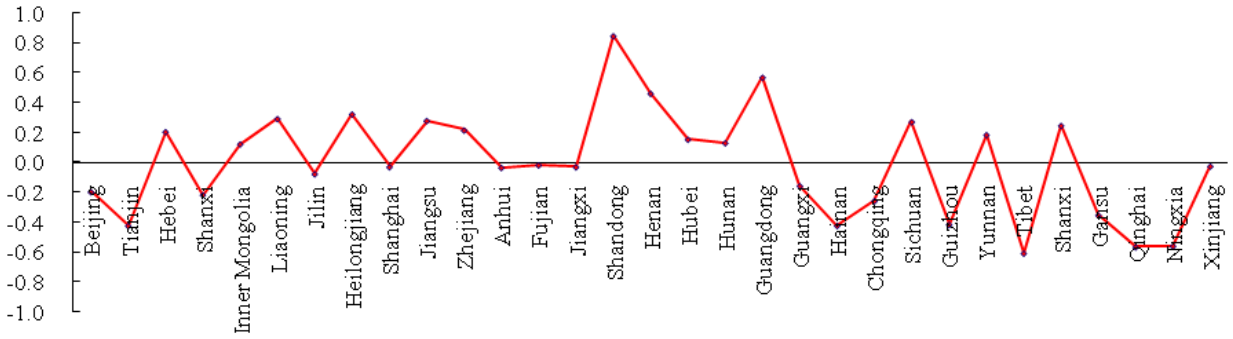

Fig. 1: Evaluation of the functions of ecosystem services related to land-and-water resources in different regions during 2011.

conclude that the function of ecosystem services related to land-and-water resources in China exhibits a certain degree of spatial heterogeneity and is closely related to the current level and pace of regional economic development. Land managers in regions that are in different stages of economic development should clearly recognize how the actions of people positively or negatively influence the land-and-water resources and ecosystems in their areas and implement appropriate regulations and policies (Requier-Desjardins et al. 2011). Following conclusions can be drawn from the study.

1. The following 31 provinces sensu lato are ranked based on the above analysis and the evaluation of the current functioning of ecosystem services related to land-and-water resources in 2011: Shandong, Guangdong, Henan, Heilongjiang, Liaoning, Jiangsu, Sichuan, Shaanxi, Zhejiang, Hebei, Yunnan, Hubei, Hunan, Inner Mongolia, Fujian, Xinjiang, Shanghai, Jiangxi, Anhui, Jilin, Guangxi, Beijing, Shanxi, Chongqing, Gansu, Guizhou, Hainan, Tianjin, Ningxia, Qinghai and Tibet.
2. Factor analysis shows that the principal factors influencing the functioning of ecosystem services provided by land-and-water resources are fertilizer input, followed by effective irrigation area. These factors are followed by the level of influence from the combined gross output value of farming, forestry, animal husbandry and fisheries, followed by pesticide use, waterlogging control area, agricultural use of plastic film, city park area, urban greenbelt area, current urban sewage treatment, total output of aquatic products, total afforested area, area of water and soil erosion management, and lastly, annual extracted ore tonnage of non-oil/gas mineral resources.
3. As displayed in the clustering results of the comprehensive evaluation matrix, Shaanxi province received the best classification, while Heilongjiang and Sichuan provinces are listed high. Seven provinces were classified as "good function-slow development," two as "moderate function-moderate development," and Beijing and Tibet were classified at the low end of the spectrum. More regions in north, east, and northeast China have well-functioning ecosystem services, while a few regions in northwest, south and southwest China mostly exhibit rapid development but limited potential for growth. In addition, regions with poor ecological services are widespread in north, south, northwest and southwest China and in Qinghai-Tibet, but their economic development speeds vary from one location to another. Naturally, because an abundance of data is not readily available and because of the limited proficiency of author himself, the VES-based index evaluation system still requires some improvement and refinement. For example, index components still require some further integration to a certain degree, which is related to the complexities of the functions of various ecosystem services and relationships and interactions occurring between all ecosystem elements. More importantly, the current database requires further subdivision and perfection. On this point, the author plans to conduct in-depth research in a later study and analysis.

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Table 4: Comprehensive evaluation of the functions of ecosystem services related to land-and-water resources in different districts.

Regions	Good function-rapid develop ment	Good function-moderate develop ment	Good function-slow develop ment	Moderate function-rapid develop ment	Moderate function-moderate develop ment	Moderate function-slow develop ment	Poor function-rapid develop ment	Poor function-moderate develop ment	Poor function slow develop ment
Northeast China	-	Heilongjiang	Liaoning	-	Jilin	-	-	-	-
North China	-	-	Shandong, Henan, Hebei	Inner Mongolia	-	-	-	Shanxi, Tianjin	Beijing
East China	-	-	Jiangsu, Zhejiang	Anhui	-	Shanghai	-	-	-
South China	-	-	Guangdong	-	-	Fujian	-	Guangxi, Hainan	-
Central China	-	-	-	Hubei, Jiangxi	Hunan	-	-	-	-
Qinghai-Tibet	-	-	-	-	-	-	Qinghai	-	Tibet
Northwest China	Shaanxi	-	-	-	Xinjiang	-	Ningxia	Gansu	-
Southwest China	-	Sichuan	-	Yunnan	-	-	Chongqing, Guizhou	-	-
Total	1	2	7	5	3	2	4	5	2

Table 5: Factor loading of indices related to the functioning of ecosystem services provided by land-and-water resources.

Extraction dimensions	Index loading	Factor values	Eigen	Proportion
Gas regulation and food production	Fertilizer input	0.884	5.242	20.967
	Effective irrigation area	0.856		
	Gross output value of farming, forestry, animal husbandry and fishery	0.852		
	Pesticide use	0.838		
	Water logging control area	0.798		
	Agricultural use of plastic film	0.699		
Landscape and sewage treatment	City park area	0.921	4.769	19.074
	Urban greenbelt area	0.881		
	Actual urban sewage treatment	0.832		
	Total output of aquatic products	0.809		
Climate control and raw material production	Total afforested area	0.891	3.132	12.528
	Area of water and soil erosion management	0.815		
	Annual extracted ore tonnage of non-oil-gas mineral resources	0.766		

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