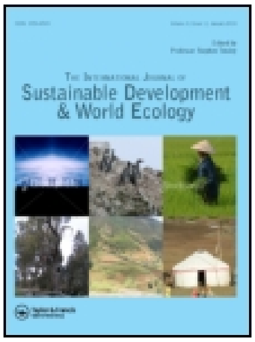

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International Journal of Sustainable Development & World Ecology

ISSN: 1350-4509 (Print) 1745-2627 (Online) Journal homepage: http://www.tandfonline.com/loi/tsdw20

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International Journal of Sustainable Development & World Ecology 13 (2006) 25–36

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Key words: Sustainable land use; landscape ecological evaluation; coastal zone; China

SUMMARY

Evaluation of sustainability is the core of research on sustainable land use. To a certain extent, traditional social, economic and ecological evaluation for sustainable land use can be regarded as an appraisal on the temporal scale without evaluation of spatial patterns. Landscape ecology can help to realize spatial evaluation for sustainable land use. In this paper, we construct landscape ecological indicators for evaluating sustainable coastal land use from the aspects of landscape productivity, threats and stability, to realize a synthetic temporal-spatial evaluation. These cover the five pillars of sustainable land use, i.e. productivity, security, protection, viability and acceptability. The results of applying landscape ecological evaluation to a case study in Wudi County in China show that land use sustainability is somewhat low and there are great regional differences between its 11 villages. We classified the 11 villages into 5 grades: strong sustainable land use, sustainable land use, weak sustainable land use, weak unsustainable land use, and strong unsustainable land use. Each grade has different land use characteristics and differs in the countermeasures required. But the core countermeasures in all the grades are to improve landscape productivity, to reduce human threats and to optimize landscape patterns.

INTRODUCTION

Sustainable land use plays important roles in sustainable development of the whole social economy. It is the foundation of regional development as well as the core of sustainable development strategy. However, there have been disputes between experts as to the essence and aim of sustainable land use since the idea was introduced in 1990. This makes it difficult for people to choose the criteria and standards for evaluating the state and degree of sustainability. Ecological integrity is one of the most effective ways to realize sustainable land use and its development. The core of landscape ecology is spatial heterogeneity and ecological integrity (Wang and Yang 1999) and there is obvious spatial heterogeneity in land use. Therefore, evaluation for sustainable land use is related to the theoretical core of landscape ecology.

There is a close relationship between landscape ecology and land evaluation. With the development of land classification and land potentiality evaluation in the 1960s, and land feasibility evaluation in the 1970s and 1980s, sustainable land use evaluation emerged in the 1990s, which paid attention to the social, economic and ecological benefits. Thus,

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evaluation for sustainable land use is regarded as extending land feasibility evaluation at the temporal scale, but lacks analysis of land use patterns and dynamic processes. Landscape ecology, however, focuses on research on recycling and exchange among matter, energy and organisms; effects of land use change on the flows of matter and energy; and the relationship in heterogeneous landscapes between patterns and processes (Turner 1989).

Based on the combination of landscape ecology and sustainable land use, landscape ecological evaluation for sustainable land use (LEESLU) will make a great contribution to synthetic evaluation at both temporal and spatial scales. LEESLU brings together evaluation of land potentiality and feasibility and social, economic and ecological functions with landscape patterns and processes and landscape heterogeneity at temporal and spatial scales. It is an important basis for land use planning and landscape management and protection.

Some research has been done on landscape ecological principles, methods and indicators for evaluating sustainable land use or land management (Bastian and Röder 1998; Grabaum and Meyer 1998; Zhang *et al.*,1998; Paoletti 1999; Rossi and Nota 2000; Qiu and Fu 2000; Fu *et al.* 2001; Gulinck *et al.* 2001; Ericksen *et al.* 2002; Piorr 2003). Based on a case study of Wudi County in Shandong Province, this paper will apply landscape ecological theories to combine multi-objectives of sustainable land use with landscape patterns, and to construct landscape ecological evaluation indexes for sustainable land use, in order to carry out synthetic analysis and evaluation for sustainable land use at spatial-temporal scales.

OBJECTIVES

Coastal land use in China

The coastal zone is a narrow strip made up of coastal land, onshore seawater, islands and the tidal zone. According to an integrated investigation of the Chinese coastal zone and shoal land resource (EGLUAICLC 1989), the total coastal line in China is 18,000 km and the land resource in the coastal zone is about 248,632 km^2. Coastal land use in China has the following characteristics:

1. Land use types. At present, 18 land use types linked to 12 industries have been developed based on four coastal types in China (Peng *et al.* 2003).
2. Land use change. Both natural factors, such as coastal siltation and erosion, and social economic and technical factors lead to dynamic coastal land use. The latter has led to national changes in coastal land use from agriculture, salt industry and mariculture, to industrial projects since the foundation of the People's Republic of China in 1949.
3. Centralization in land development. The coastal zone is suitable for large-scale synthetic exploitation and intensive management.
4. Spatial differences in land use. The coastal zone can be divided into three parts: up-tidal zone, tidal zone and sub-tidal zone, leading to a distinct spatial heterogeneity in land use. Agriculture and urban land use are mainly in the up-tidal zone, mariculture and neritic fishing in the tidal and sub-tidal zone, respectively.

Principles for choosing evaluation indexes

Evaluation indexes chosen for sustainable land use should combine the general characteristics of current coastal land use in China, represent the sustainability of coastal land use from the aspect of landscape ecology, and possess scientific validity and rationality. The construction of landscape ecological evaluation indexes for sustainable coastal land use should include the following principles:

1. Systematic generalization. LEESLU is a form of comprehensive evaluation for land use systems with the five objectives: productivity, security, protection, viability and acceptability. In order to show the general status of a land use system, it is necessary not only to evaluate landscape sustainability, and sustainability in social, economic, and ecological aspects of land use, but also to harmonize all aspects of land use.
2. Regional dominance. Evaluation for sustainable land use must be based on the dominant factors. Different combinations of resources, environment, economy and society in different regions will result in different emphases in

evaluation. Dominant and typical indexes that are consistent with local conditions must be chosen in order to improve the veracity of evaluation.

3. Dynamics. Land use is a process more than a purpose, and evaluation for sustainable land use must be dynamic. With the change of land use objects in a region, the choice of evaluation indexes will differ, therefore, choice of evaluation indexes is a process of continuous self-updating and perfecting.

4. Landscape ecology. LEESLU should use indexes that represent landscape ecological conditions.

5. Scientific validity. The construction of an evaluation index system for sustainable land use must be objective and scientific and pay attention to the validity of indexes. Standard measuring methods and normative statistical calculation of the indexes are also required.

6. Relative independence. Because factors affecting sustainable land use often correlate with each other, indexes chosen must be independent in order to avoid repetitive evaluation for the same landscape functions.

7. Operability. The key to evaluation is whether the evaluation methods are operative, the research theories are practical, the indexes are quantitative and the data are acceptable. Operative indexes can benefit quantitative evaluation in choosing statistical methods and mathematic analytic approaches.

METHODS

Landscape ecological evaluation indexes for sustainable land use

Because it took thousands of years to form land, we can conclude that it is not reproducible at the temporal scale of humans, while land can be reproduced in terms of its production function. This dual attribute determines that it is essential for sustainable land use to both keep the quantity of the land resource and to preserve its productivity. Therefore, evaluation for sustainable land use should choose factors related to land quantity and productivity to construct an index system.

Landscape is a spatial mosaic of land use. Maintenance of land productivity is closely related to the structure and function of landscape (Zhou 2000). Hence, evaluation indexes for landscape pattern, function and change are key factors in determining whether land use is sustainable. They can be directly used as landscape ecological evaluation indexes for sustainable land use (Fu *et al.* 2001). Human pressure for land is also an important restrictive factor in sustainable land use. Based on ecological effects of land use, evaluation for sustainable land use must pay more attention to human influences (Jacob 1994).

Applying landscape ecological theories, and considering the characteristics of coastal land use and landscape ecology as essential to sustainable land use, we constructed the LEESLU index system (Figure 1). The system can reflect the distance between current land use and the target of sustainable land use, and difference in ability to realize sustainable land use between different regions within a generation.

According to the Analytical Hierarchy Process (AHP), the evaluation index system can be divided into three levels: 1. the target values; 2. the rules, we chose landscape productivity, landscape threat and landscape stability; and 3. the 11 indexes chosen.

Landscape productivity (B1)

Landscape productivity reflects biological productivity, economic benefits and potential yield of land use. The essential motivation for human land use is to realize land production in order to satisfy human demand. In order to achieve harmony between humans and nature, it is necessary for sustainable land use to improve land productivity, achieve economic feasibility, and supply products to meet growing human demands. Hence, landscape productivity can be used to evaluate economic viability and productivity of sustainable land use. The higher the landscape productivity, the stronger is the ability of land to supply products and the better is the sustainability of land use.

Considering that the importance of aquaculture is equal to that of agriculture in coastal zones, we chose indexes of agricultural and aquacultural yield per unit area to measure the biological productivity. Gross output of industry and agriculture is chosen to weigh the economic benefits of land use. Because agricultural mechanical energy per

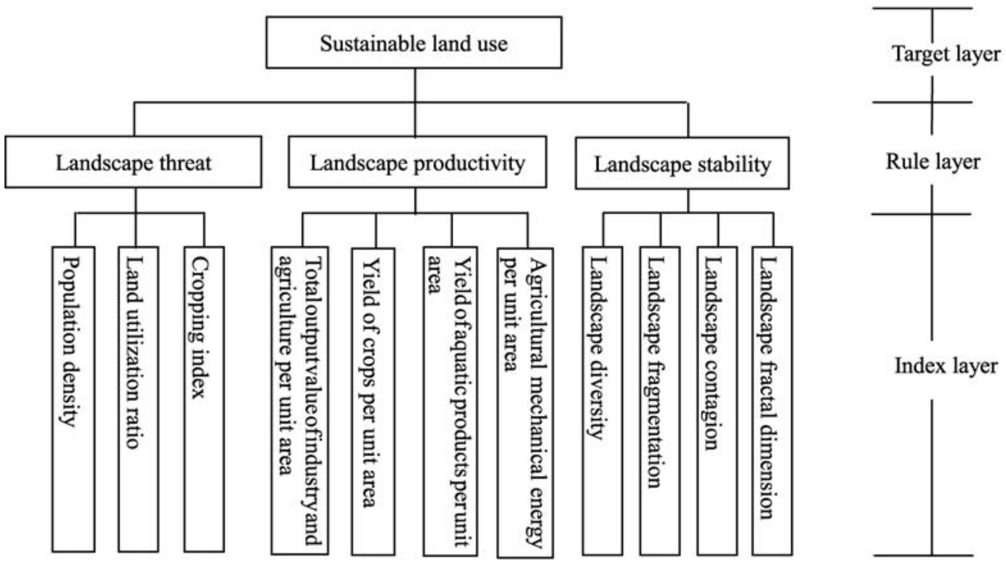

Figure 1 Indexes of landscape ecological evaluation for sustainable land use

unit area can represent the degree of mechanization and modernization of farming and is good for improving agricultural productivity, it is used to measure the potential yield.

Total output value of industry and agriculture per unit area (C1), is the quotient of total output value of industry and agriculture divided by the whole study area; Yield of crops of per unit area (C2), is the quotient of total yield of main crops divided by the whole agricultural area; Yield of aquatic products per unit area (C3), is the quotient of total yield of aquatic products divided by the whole aquatic area; and Agricultural mechanical energy per unit area (C4), is the quotient of total agricultural mechanical energy divided by the whole agricultural area.

Landscape threat (B2)

Landscape threat is the pressure imposed on landscape through human activity, which reflects human demand for land use, of which there are two aspects. First, the productive function of land, where certain products must be obtained from land use in order to supply human material demands. This aspect is reflected by indexes of landscape productivity and of landscape stability. Second, is human threat to the landscape, where human demands for materials cause pressure on sustainable land use. The more human demand from land use, the greater the pressure, the higher the aim, and the more difficulties there are in realizing sustainable land use. Therefore, we can use landscape threat to measure the sustainability of current land use and to evaluate social acceptability of sustainable land use to some extent.

Three indexes are chosen to evaluate landscape threat: population density, land utilization ratio, and cropping index. The higher the value of these indexes, the higher the extent of landscape threat, and the more difficulties there are in realizing sustainable land use. Population density (C5), is the quotient of total population in the study area divided by total area; Land utilization ratio (C6), is the proportion of utilized land in the total area; and Cropping index (C7), is the ratio of total planting area to total arable land area.

Landscape stability (B3)

Landscape stability implies that all landscape elements remain in a stable condition in the long term, or the scope and periodicity deviating from the stable condition shows statistical characteristics (Forman and Moore 1990). It consists of landscape functional stability and the stability of landscape patterns. Landscape patterns determine landscape functions. In order to realize the stability of landscape function for sustainable land use, it is necessary to maintain and optimize land use patterns of the same landscape.

Landscape stability is proportional to the resistance against external disturbance. The higher the landscape stability, the stronger is landscape resistance to external disturbance, the stronger resilience after disturbance, and the more possibilities there are to maintain landscape patterns and ensure landscape functions. Generally, in a medium developed agricultural landscape, an increase in landscape heterogeneity is good for the maintenance of landscape stability. Stability can represent the security and protection of sustainable land use to a certain extent. We use landscape diversity, landscape fragmentation, landscape contagion and landscape fractal dimension to measure landscape stability. The indexes above are divided into two types according to their influence on stability. One set of indexes has positive effects on landscape stability: landscape diversity, landscape fragmentation, and landscape fractal dimension, whose values are in direct proportion to landscape heterogeneity. The other index has negative effects on landscape stability: landscape contagion, whose value is in inverse proportion to landscape heterogeneity.

Landscape diversity (C8) is the abundance and complexity of patch type in the landscape, mainly considering the number of patch types, and the area proportion of different patch types. Landscape diversity reflects heterogeneity of patch type. The higher the landscape diversity, the more balanced is the area proportion of all patch types, the bigger landscape heterogeneity and the stronger landscape stability. On the basis of information theory and measuring of the uncertainty of an event (Shannon and Weaver 1962), more land use types and harmonious landscape proportions would lead to a higher H value:

$$H = -\sum_{k=1}^{n} P_k \ \ln(P_k)$$

where P_k is the proportion of the landscape in patch type k and n the number of patch types.

Landscape fragmentation (C9) indicates the degree of division in the landscape (Monmonier 1974), reflecting the area heterogeneity of landscape patches. In human landscapes, the index is closely related to human activities, including landscape management and human disturbance. The higher the landscape fragmentation, the smaller the patch area, the more severely the landscape is fragmented, and the higher landscape heterogeneity. Landscape fragmentation FN_1 is calculated from (Monmonier 1974):

$$FN_1 = (NP - 1)/NC$$

where Np is the total number of landscape patches in all patch types and Nc the total area in the landscape.

Landscape contagion (C10) measures the extent to which different landscape patches are aggregated or clumped, reflecting the spatial adjacency heterogeneity of landscape patches. Generally, we use index of relative contagion to substitute the index of landscape contagion. Relative contagion RC is calculated as:

$$RC = 1 - C/C_{\max}$$

$$C = -\sum_{i=1}^{n}\sum_{j=1}^{n} P_{ij} \ln(P_{ij})$$

$$C_{\max} = 2n \ln(n)$$

where P_{ij} is the probability of a grid point of patch type i being found adjacent to a grid point of patch type j, $C_{\max}$ is a maximum in which all adjacency probabilities are equal, and n is the total number of patch types in the landscape.

The value of RC ranges from 0 to 1.0. At high values of RC, the landscape is mainly made up of a few large, contiguous patches, leading to low landscape heterogeneity. At low values, the landscape is dissected into many interlaced small patches with high landscape heterogeneity, which is good for the maintenance of landscape stability.

Landscape fractal dimension (C11) is a measure of the fractal geometry of the landscape (Mandelbrot 1983; O'Neill *et al.* 1988), reflecting the shape heterogeneity of landscape patterns. It is estimated by regressing polygon area against perimeter for each patch in the landscape. The fractal dimension FD is related to the slope of the regression S, by the relationship (Lovejoy 1982; O'Neill *et al.* 1988):

$$FD = 2 \ S.$$

Landscape fractal dimension can theoretically range from 1.0 to 2.0. When the value approaches 1.0, the self-comparability of patches is stronger, and the landscape is composed of more and more simple geometric shapes like squares and rectangles. If the landscape contains many patches with complex and convoluted shapes, the fractal dimension will be large (Krummel *et al.* 1987). The bigger the value of the fractal dimension, the more complex the shapes of patches, the bigger the landscape heterogeneity, and the weaker landscape stability.

The weight of evaluation indexes

According to the hierarchy displayed in Figure 1, we construct four judgement matrixes from 1 to 9, to calculate the weight of indexes of LEESLU in the rule and index layers (Table 1). The weight passed the consistency test.

Data processing

The method of maximum difference normalization is introduced to evaluate non-dimensional quantities of original data. Two kinds of dimensionless approaches are used in data standardization according to the positive or negative polarity of the 11 indexes of LEESLU. One approach is applied to indexes with positive polarity for sustainable land use, whose values are proportional to the sustainability of land use. In LEESLU, these indexes include total output value of industry and agriculture per unit area, yield of crops of per unit area, yield of aquatic products per unit area, agricultural mechanical energy per unit area, landscape diversity, landscape fragmentation, and landscape fractal dimension. Data standardization of these indexes is as follows:

$$X'_{ij} \frac{X_{ij} - X_{j\min}}{X_{j\max} - X_{j\min}}$$

where X_{ij} is the original value of index *j* of evaluation unit *i*, X'_{ij} is the non-dimensional quantities of X_{ij}, and $X_{j\max}$ and $X_{j\min}$ are the maximum and minimum of index *j* in total evaluation units, respectively.

The second approach is applied to indexes with negative polarity for sustainable land use, whose values are in negative proportion to the sustainability of land use. In LEESLU, these indexes include population density, land utilization ratio, cropping index and landscape contagion. Data standardization of these indexes is as follows:

$$X'_{ij} \frac{X_{j\max} - X_{ij}}{X_{j\max} - X_{j\min}}$$

where the meanings of each factor are the same as those discussed above.

The sum of all the products of each index value and its corresponding weight is the value of LEESLU, which is a quantitative expression of the sustainability of current land use and the ability to realize the target of sustainable land use. The measure of this value is as follows:

$$Y_i = \sum_{j=1}^{11} W_i \times X'_{ij} \times 100$$

where Y_i is the value of LEESLU for evaluation unit *i*, W_j is the weight of index *j*, X'_{ij} is the standardized value of index *j* of evaluation unit *i*, and *n* is the number of evaluation units. In the equation, the value is multiplied by 100 so that the values of LEESLU for all the evaluation units can range from 0 to 100, which is good for comparison.

STUDY AREA AND MATERIALS

Study area

The study was carried out in Wudi County in the north of Shandong Province (Figure 2), covering an area of 1998 km^2. The geographical location is 117°57′–118°25′E, 38°10′–38°45′N. The area has a typical mesothermal continental monsoon climate, with three clearly demarcated seasons: a warm rainy summer (June–October), a cold dry winter (November–February), and a warm dry period (March–May). Average annual rainfall is 589.6 mm, and minimum and maximum temperatures are –4.5 and 26.4°C, respectively.

Wudi County is located in the coastal areas of Lubei plain, close to the Bohai Sea in the northeast, with a coastline of 102 km. It lies in the flat alluvial regions of the Yellow River with an elevation from 2 to 8 m above sea level. It has abundant land and diversified land use types, with the dominant land use ranging from fishery, aquaculture, salt industry, livestock farming, and forestry to agriculture. At the end of 2000, the population was 4.245 million with 13 nations, and the urban population was 10.2%.

Table 1 The weight of landscape ecological indexes for evaluating sustainable coastal land use

	Landscape productivity					*Landscape threat*				*Landscape stability*				
Index	*B1*	*C1*	*C2*	*C3*	*C4*	*B2*	*C5*	*C6*	*C7*	*B3*	*C8*	*C9*	*C10*	*C11*
Weight	0.4	0.15	0.1	0.1	0.05	0.35	0.125	0.125	0.1	0.25	0.1	0.075	0.0375	0.0375

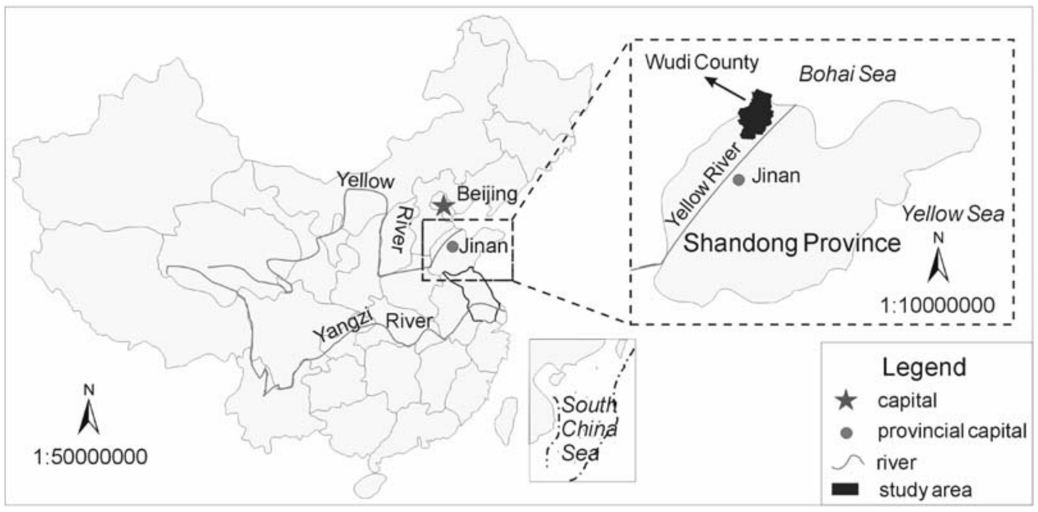

Figure 2 Location of the study area in Wudi County, Shandong Province

The whole county has 6 towns and 5 villages. The towns are Wudi, Shuiwan, Dashan, Xiaopotou, Chengkou and Mashanzi, and the villages are Xinyang, Chezhen, Liubao, Xixiaowang and Shejiaxiang.

Materials

The values of 6 of the indexes of LEESLU can be found and calculated from the *Statistical yearbook of Wudi County in 2000*. These indexes include: crop yield per unit area, yield of aquatic products per unit area, total output value of industry and agriculture per unit area, agricultural mechanical energy per unit area, population density, and a cropping index.

Based on ERDAS 8.4 software, a LANDSAT-ETM image (orbit 122/34, resolution 30 m) on June 10th, 2000, was interpreted with reference to field reconnaissance on July 7th, 2000, the land use map of Wudi County in 1998 (scale 1:50,000), and a digital elevation map of Wudi County in 1990 (scale 1:75,000). As a result, the study area was divided into 214,407 landscape patches. Nine land use types were classified: farmland, brine pan, aquacultural land, residential land, water area, tidal flat, waste grassland, saline-alkaline land and reed land (wetland covered with bulrush). The water area, waste grassland, saline-alkaline land, tidal flat and reed land were regarded as unused. On the basis of the land use classification map from the remote sensed image, the value of the other five indexes of LEESLU – land utilization ratio, landscape diversity, landscape fragmentation, landscape contagion, and landscape fractal dimension – were calculated with the aid of the landscape analysis software, FRAGSTATS.

RESULTS

The sustainability of current land use

After data collection and processing, the values of LEESLU for all 11 towns and villages in Wudi County were obtained (Table 2). All the values were comparatively low, which showed that the sustainability of land use in Wudi County is somewhat low. The rank values in descending order are: Mashanzi, Chengkou, Xinyang, Shuiwan, Xiaopotou, Dashan, Shejiaxiang, Xixiaowang, Liubao, Wudi and Chezhen.

Regional differences in the sustainability of land use

Using the statistic analysis software SPSS11.0, we did a hierarchical cluster analysis of LEESLU values for all 11 towns and villages. According to the cluster method of between-group linkage, when 1.5 is taken as the squared Euclidean distance, all 11 samples are classified into 5 types (Figure 3): (1) Wudi, Liubao, Xixiaowang and Shejiaxiang; (2) Dashan, Xiaopotou and Shuiwan; (3) Chengkou and Xinyang; and (4) Mashanzi and Chezhen. From grade 1 to grade 5, the sustainability of current land use is becoming weaker and weaker, and the ability to realize sustainable land use is reducing. LEESLU values for the whole county are grade 3, where land use can be seen as basically sustainable. The results

Table 2 Values of LEESLU for Wudi County

	Values of LEESLU			
	Landscape productivity	*Landscape threat*	*Landscape stability*	*Total value*
The whole county	7.66	18.87	11.25	37.78
Wudi	12.03	6.89	7.18	26.10
Shuiwan	13.45	15.59	7.54	36.59
Dashan	19.78	8.14	4.80	32.72
Xiaopotou	18.85	8.09	7.27	34.21
Chengkou	3.90	26.82	18.03	48.76
Mashanzi	7.50	35.00	18.20	60.70
Xinyang	31.39	5.45	9.66	46.50
Chezhen	6.36	11.50	4.19	22.05
Liubao	0.16	16.37	10.65	27.18
Xixiaowang	3.79	20.73	5.00	29.52
Shejiaxiang	17.15	9.42	4.51	31.08

of LEESLU accord with the actual situation of the county. Moreover, it can be seen from Figure 3 that in Wudi County, the sustainability of land use in the northeastern coastal area is higher than that in the southwestern inland area.

Strong sustainable land use

Only Mashanzi in the northeast of the county belongs to this grade, and has a LEESLU value of 60.7, the highest. In all 11 towns and villages, Mashanzi has the lowest landscape threat and the highest landscape stability. Total population is 29163 (6.87% of the county) and total area is 52689.87 km^2 (26.58%). Population density is 0.55 person/km2, and it has 18958.59 km^2 of unused land (32.78%): tidal flat, saline-alkaline land and waste grassland. It includes all the coastal area of the county and is the optimal area to develop inshore fisheries, aquaculture and the salt industry. Its major land use types are: seawater salt and salt chemical industry (16.15%); aquaculture, particularly prawn breeding (14.57%); and wheat and corn growing (15.52%), with dry land as the major type of farmland.

Grade two of sustainable land use

This grade consists of Chengkou and Xinyang. The LEESLU value is between 40 and 50. Total population is 55529 (13.08%) and total area is 31480.21 km^2 (15.88%).

Chenkou has low landscape threat and landscape productivity, and high landscape stability. Its population density is low, about 0.83 person/km^2. It has abundant tidal flats, saline-alkaline land and waste grassland (23.61%) of about 3194.73 km^2. It is in the northeast of the county, close to the coast and Mashanzi. It is suitable for the development of seawater fisheries and the salt industry. Major land use types are: seawater salt and salt chemical industry (8.66%); seawater breeding mainly of prawns (17.15%); and growing corn and soybean (34.81%), on a little irrigable land.

To the southwest, Xinyang has the highest landscape threat and landscape productivity of all 11 towns and villages. Its population density is high, about 6.54 person/km^2, and land reserves are poor, with 1328.85 km^2 of waste grassland (26.64%). It is in the Yellow River irrigation area, with plenty of water suitable for developing irrigable land. The major land use is wheat and corn growing (61.6%) on irrigable land.

Weak sustainable land use

This grade contains Shuiwan, Xiaopotou and Dashan. The LEESLU value varies from 32 to 40. Total population is 118400 (27.89%) and total area is 32174.6 km^2 (16.23%).

Shuiwan is in the south of the county, where landscape stability, productivity and threat are all in the middle rank. Population density is high at about 3.57 person/km^2. There are plenty of land reserves, with 3195.09 km^2 (23.36%) waste grassland. It is in the Yellow River irrigation area and its major land use is growing wheat and corn (61.17%).

Xiaopotou lies in the west of the county, with higher landscape productivity and threat and moderate landscape stability. Its population density is high with about 4.01 person/km^2, and land reserves are only 1793.43 km^2 (16.32%). It is in the Majia River irrigation area and the main crops are wheat and corn (73.18%).

Dashan lies in the west of the county, with higher landscape productivity and threat and moderate landscape stability. Population density is 3.4 person/km^2, and land reserves are poor, about 1119.15 hm^2 (14.23%). It is also in the Majia River irrigation area and its major crops are wheat and soybean (72.32%).

Weak unsustainable land use

This grade contains Shejiaxiang, Xixiaowang, Liubao and Wudi. The LEESLU value is between 26 and 32. Total population is 172286, or 40.59% of the whole county, and total area is 67291.9 km^2 (33.95%).

Shejiaxiang is in the southeast of the county, with high landscape productivity and landscape threat, and low landscape stability. Its population density is low, 2.9 person/km^2 and it has a land area of 1936.98 km^2 (14.97%). It is short of water and is more suitable to the development of agriculture and livestock farming. The major land use is growing wheat, corn, cotton and soybean (77.15%), mainly on dry land.

Xixiaowang is in the southeast of the county, with low landscape productivity, stability and threat. Population density is about 2.9 person/km^2 and, while land is plentiful at about 2865.42 km^2 (15.52%), water is scarce. This area is suitable for development of agriculture and livestock farming. Its major land use is growing wheat, corn and cotton (74.32%), mainly on dry land.

Liubao is in the middle to east of the county, with the lowest landscape productivity, and moderate landscape threat and stability. Its population density is low, about 1.27 person/km$_2$, and it has abundant land reserves of 2865.42 km$_2$ (20.69%) but is short of water. It is suitable for development of agriculture, livestock farming, fisheries and the salt industry. Its major land use is growing wheat, corn and soybean (61.63%) mainly on dry land, a small amount of brine collection (4.78%) and aquaculture (0.66%).

As the capital of the county, Wudi lies in the south, with low landscape stability, moderate productivity, and high threat. Its population density is high at 5.79 person/km^2, and land reserves are plentiful at 3080.88 km^2 (20.18%). According to its economic geographic location, Wudi is suitable for developing agriculture and urban construction. Its major land use is growing wheat, corn and some vegetables (70.69%), mainly on irrigable land.

Strong unsustainable land use

Only Chezhen in the southeast of the county belongs to this grade. It has the lowest LEESLU value at 22.05, lowest landscape stability, high threat and low productivity. The total population is 49078 (11.56%), with a density of 3.37 person/km^2 and total area of 14575.5 km^2 (7.35%). Its land reserves are only 1863.36 km^2 (12.44%). The major land use is growing wheat, corn and soybean (77.33%), mainly on dry land.

DISCUSSION

Factors influencing regional differences

Generally speaking, factors influencing sustainable land use can be divided into three groups: natural, socio-economic and human. The regional differences in Wudi County are combinations of all the three factors.

Natural resources

As the integration of climate, hydrology, soil, vegetation, geology and landform, land is the primary basis of life on Earth. Exploitation of natural resources is related to utilization of light, heat, water, soil and space. The heterogeneity of spatial distribution of natural elements determines land productivity. For example, water shortage has led some towns in Wudi County to use irrigation to improve biological productivity, while high levels of saline-alkaline soil in Chengkou and Liubao result in crop yield being just 40% of those in Xinyang.

The geographical location of industries is often close to raw materials, market, labour force or transportation routes. Especially for mining and other resource-oriented industries, these are located in areas abundant in the corresponding natural resources. In Wudi County there are plenty of natural resources suitable for development of aquaculture, excavation of shell grit and manufacture of porcelain from shells, the salt industry and salt chemical industry. These advantages are limited to coastal areas such as Mashanzi and Chengkou where the total output value of fishery and industry per unit area is far higher than that of agriculture.

Modernization of rural areas

Modernization of rural areas is important in the development of China, and includes urbanization and industrialization. Rural industrialization can enhance landscape productivity with higher production values than for rural agriculture.

With a combination of former village reformation and rural land consolidation, rural urbanization can decrease rural residential land to enhance the land utilization ratio. But rural urbanization will lead to population increase and corresponding enhancement of the quality and quantity of human demands for land production, which increase landscape threat and affect sustainable land use. For example, as the county seat, Wudi town is highly urbanised and its landscape threat is higher, which leads to low sustainability of land use.

Furthermore, landscape stability may be harmed by modernization of rural areas and mechanisation of farming may intensify patch boundaries in the agricultural landscape, increase average area of patches, and decrease landscape fractal dimensions and fragmentation.

Population quantity and quality

The sustainability of land use is determined by human demand for land production. It is the quantity and quality of land and the level of technology and management that determine the degree, direction and effects of land use.

Population quantity especially influences the sustainability of land use. Along with increasing population, the demand for land production rises, land resource per person diminishes, and population carrying capacity of land also decreases. Once population density exceeds the carrying capacity of land, current land use cannot be sustained. Therefore, the higher the population density, the higher the landscape threat, and the lower the sustainability of current land use.

Population quality determines human subjective activity and cognitive ability. That is, the higher the population quality, the more advanced the agricultural and industrial technologies practiced to enhance land productivity. However, the lower the population quality, the less educated the land users, and the more resistance there is to advanced agricultural and industrial technologies, which will decrease land productivity. For example, the LEESLU value of Chezhen is the lowest in the county because most of people in the village are from a minority group with poor education.

Evaluation of LEESLU

Often research on sustainable land uses AHP to construct an evaluation index system. However, excessive subjectivity is a great disadvantage of AHP, while the evaluation in itself depends on subjective human evaluation. In order to enhance scientific objectivity in evaluation for sustainable land use, it is necessary to make a breakthrough in methodology. Evaluation for sustainable land use deals with spatial and temporal scales and involves many disciplines, including geography, agronomy, economics, sociology, ecology and environmental sciences. There is a great need for an evaluation index that integrates all related disciplines and scales (Chen *et al.* 2001). In this study of LEESLU research, we bring a landscape ecological perspective on evaluation for sustainable land use that integrates far more disciplines to construct a synthetic evaluation index system.

In this study, we focus on regional differences in sustainability of current land use. The evaluation index system reflects the distance between current land use and the target of sustainable land use, and the differences in ability to realize sustainable land use in different regions at the scale of a human generation. It is a relative not an absolute evaluation. The critical values of the indexes are needed to construct objective standards so as to make an absolute evaluation for sustainable land use.

LEESLU focuses on landscape patterns and functions, neglecting the connections and interactions among landscape elements. Far more attention must be paid to the effects on sustainable land use of dynamics of material, energy and information flow between landscape elements. On a temporal scale, materials used in LEESLU can be divided into timed data from remote sensed images and annual averaged data from statistical yearbooks. The rationality for the integration of two such forms of data needs further verification.

Research on sustainable land use is a hotspot in land science and related disciplines, and the most satisfying evaluation index system has not yet been constructed. In this study, theories of landscape ecology are applied to construct landscape ecological indexes for evaluating sustainable coastal land use. It is a synthetic evaluation for sustainable land use at a spatial-temporal scale, combining multi-objectives of sustainable land use with landscape patterns. It is also instructive in developing research on evaluation for sustainable land use and applied research on landscape ecology.

The case study in Wudi County supports the use of LEESLU and shows land use in the study area is basically sustainable. However, sustainability in land use in the coastal area in the northeast of the county is higher, while the inland area in the southwest is lower.

ACKNOWLEDGEMENTS

The work was supported by the National Keystone Basic Research and Development Programming Project (G2000046807) and the National Natural Science Foundation of China (90102018).

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