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Method for Evaluating the Degrees of Land Use Sustainability of Mountainous County and its Application in Yunnan Province, China

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Abstract: The evaluation of sustainable land use is the key issue in the field of studying the sustainable land utilization. In general analysis, the sustainable land use is evaluated respectively from its ecological sustainability, economic sustainability and social sustainability in China and other countries in recent years. Although this evaluation is an important work, it seems insufficient and hard to comprehensively reflect the whole degree of land use sustainability. Thus, to make up this deficiency, this paper brings forward the evaluation indexes, which make it possible to quantitatively reflect the whole degree of land use sustainability, namely, the concept of "degrees of overall land use sustainability" (D_{OS}), and research and development of the method of measurement and calculation in D_{OS}. Taking the evaluation of the degree of land use sustainability in county regions of Yunnan Province as the actual example for analysis, results are basically as follows:

1) The degree of land use sustainability (D_{OS}) is the ration index to organically and systematically integrate the degree of ecological friendliness (D_{EF}), the degree of economic viability (D_{EV}) and the degree of social acceptability (D_{SA}), able to comprehensively reflect the whole sustainability degree of regional land use.

2) Based on the value of D_{OS}, the grading system and standard for the sustainability of land use may be established and totally divided into five grades, namely, the high-degree sustainability, middle-degree sustainability, low-degree sustainability, conditional sustainability and non-sustainability. Meanwhile, the standard for distinguishing sustainability grades has also been confirmed so as to determine the nature of sustainability degrees in different grades. This makes the possibility for the combination of nature determination with ration in research result and provides with the scientific guideline and decision-making gist for better implementation of sustainable land use strategy.

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3) The practice in evaluation of sustainability degree in county regional land use in Yunnan shows that the value of the degree of land use sustainability (D_{OS}) of whole Yunnan Province is only 58.39, belonging to the grade of low-degree sustainability. Two thirds of counties in the whole province represent the grade of "conditional sustainability" and "non-sustainability" in the sustainability of land use. Among these counties, 11.11 % shows "non-sustainability". The lowest degree of land use sustainability appears especially in the middle plateau mountain region of Northeast Yunnan, where the value of D_{OS} in most counties (districts) is below 40 %, belonging to the grade of "non-sustainability". The sustainability degree in the karst mountainous region in lower-middle plateau mountain region in Southeast Yunnan is generally low and the value of sustainability degree (D_{OS}) in most of the counties (cities and districts) is below 55. The value of sustainability degree (D_{OS}) in most of the counties (cities and districts) in the north, west, northwest and southwest parts of Yunnan is below 55. This article also analyzes the reasons of low degree of sustainability in land use in Yunnan and puts forward the countermeasures to increase the degree of sustainability in land use in the whole province.

Keywords: Land use; degrees of overall sustainability; evaluation method; county level; degrees of ecological friendliness; degrees of economic viability; degrees of social acceptability

Introduction

Since 1990 when the concept of sustainable land use was officially established, experts and scholars both at home and aboard have devoted themselves to studying sustainable land use evaluation index system and methods based on the connotation and goal of sustainable land use. In 1993, FAO officially promulgated *An International Framework for Evaluating Sustainable Land Management*, a programmatic document setting up five standards for sustainable land use evaluation, namely, productivity, security, protection, viability and acceptability. Based on the *Framework*, many experts and scholars have made a great deal of researches (Berroteran et al. 1997, Gameda et al. 1997, Hurni 2000, Lefroy et al. 2000, Tanrivermis 2003, Banai 2005, Peng et al. 2007). In recent years, the system decomposition method has been used in the sustainable land use evaluation index system studies in China and other countries. This method mainly decomposes the complex system of land use into several subsystems and carries out quantitative evaluation of those subsystems by adopting the optimum evaluation index. Finally, it piles up the sustainability of all subsystems (mainly by step analysis) to get the sustainability of the entire system (Peng et al. 2003). In recent years, the international community has been giving attention to the study of the ecological benefit evaluation related to land productivity and land use. Such study is also known as the study of land quality indicators (Kim 1999). However, relatively fewer studies have been made on evaluation of social and economic benefits of sustainable land use. Generally speaking, respective evaluation of ecological sustainability, economic sustainability and social sustainability of land use is very important. Its shortcomings and defects include its inability to comprehensively reflect the overall land use sustainability. Mountainous area is a special area with an "inborn" weak ecological environment. For the past several decades, China's mountainous ecological environment has been badly damaged, and it is an urgent need to carry out in-depth eco-friendly-based land use sustainability evaluation, planning, and management study so as to guarantee the environmental-friendly community construction in mountainous areas and the smooth implementation of sustainable land use strategy. To do so, this paper aims to put forward an evaluation index that can reflect the degrees of overall land use sustainability in a quantitative manner. In other words, it studies and establishes the estimation and evaluation methods by using "the degrees of land use sustainability" concept and makes concrete case study on the degrees of land use sustainability at county level in Yunnan, a typical mountainous province in China.

1 Principles and Methods

1.1 Concept of regional land use sustainability degrees and its estimation method

Now, the five aspects put forward by FAO (1993), productivity, security, protection, viability and acceptability, have become the universally recognized standards in sustainable land use. Actually, these five aspects can be summed up into three, ecological sustainability, economic viability (or sustainability), and social acceptability (or sustainability) (Yang and Liang 2004). The present world emphasizes "environmental friendly" (or "ecological friendly") and thus we can substitute the aforesaid "ecological sustainability" with "ecological friendliness" with a view to highlighting and demanding human beings' friendliness toward ecological environment in their land use. Nowadays, ecological problems loom large in land use and ecological deterioration and degradation has been so serious that it gravely endangers the sustainable use of land resources and sustainable social and economic development. "Ecological friendly" should be given special attention in current and future land use, and efforts should be made to perform well in land ecological environment construction and realize ecological sustainability in land use (Yang and Liu 2007). This paper thus classifies the standard of sustainable land use into three fundamental aspects, namely, ecological friendliness, economic viability, and social acceptability. During sustainable land use evaluation, in order to assess the degrees of land use sustainability, we put forward a quantitative comprehensive evaluation index: Degrees of Overall Land Use Sustainability (or D_{OS} for short). It refers to the organic synthesis and system integration of the degrees of ecological friendliness (D_{EF} for short), degrees of economic viability (D_{EV} for short) and degrees of social acceptability (D_{SA} for short) of the aforesaid land use. This concept can be used in both regional evaluation and plot evaluation. In constructing evaluation index and estimation method, we mainly consider regional evaluation, especially that on mountainous county scale.

The degrees of regional land use sustainability are systematic indexes for comprehensively reflecting the aforesaid D_{EF}, D_{EV}, and D_{SA}. The value of D_{OS} can be estimated in the following way:

$$D_{OS} = w_1 \cdot D_{EF} + w_2 \cdot D_{EV} + w_3 \cdot D_{SA} \quad \text{...... (1)}$$

In formula (1), D_{EF}, D_{EV} and D_{SA} represent the Degrees of Ecological Friendliness, Degrees of Economic Viability and Degrees of Social Acceptability in land use, respectively, and w_1, w_2 and w_3 stand for the weights of D_{EF}, D_{EV} and D_{SA}, respectively.

The higher the D_{OS} value, the greater the degrees of overall sustainability in land use.

1.2 Basic target system of evaluation and calculation method

In formula (1), D_{EF}, D_{EV} and D_{SA} are normally decided by many concrete factors or targets. In order to estimate the value of D_{OS}, therefore, we have to establish a basic target system that can better reflect D_{EF}, D_{EV} and D_{SA} in land use. This paper uses *China's sustainable land use evaluation target system* constructed by Zhang Fengrong and others (2003) as a reference to construct a concrete target system. In the process, our understanding and experience in land use study have also been used.

1.2.1 Basic target system of D_{EF} and its calculation method

D_{EF} target is a basic target in the entire sustainable land use system. It directly decides whether or not the land use system can constantly sustain the land's inherent role and function in ecological terms. Therefore, we should choose, from such angles as development, utilization, transformation (or improvement) and protection, the factors and attributes as the evaluation targets that can reflect D_{EF}. These include the index of land overexploitation, index of land transformation standard, index of land protection standard, and index of soil and water conservation degree (or standard), which can, in a quantitative manner, reveal D_{EF} status of land use in mountainous areas. It is noteworthy that the degree (or standard) of soil and water conservation is also one of the important aspects in reflecting land protection standard. At present, most mountainous areas suffer from serious loss of soil and water due to unreasonable development and use of land. In fact, the loss of soil and water has become the No.1 ecological crisis in mountainous areas. Therefore, it is quite necessary to put aside the degree of soil and water conservation as a key target and increase its weight during D_{EF} evaluation of land use. Each index depends on several basic targets (Table 1). In addition, as these targets have different features, their valuing range widely differs from each other and cannot be directly compared. In particular, they cannot be directly put together during comprehensive evaluation. Because of this, it is necessary to find a method that can convert all targets into the values for unified evaluation (Chen 2002). This paper sets the range for all evaluation targets as [0 ~ 100] and then, by using system conversion index, converts the calculation values of all indexes into values within the range, with 100 as the highest D_{EF} and 0 as the lowest D_{EF}. Based on this, the weight sum is gotten as the comprehensive index for overall evaluation. During the conversion, several mathematic methods, including power conversion method, satisfaction degree conversion method, grading mark-giving method and reciprocal method, can be adopted to meet the actual needs.

Table 1 The system of indicators and their calculating methods of eco-friendliness evaluation of land use at county level in mountainous areas

Indicators of evaluation	Basic targets	Calculating methods
Index of land over-exploitation	Over-reclaimed rate	Index of over-reclamation = 100 - [(Present reclaimed rate - Rate suitable to reclamation) ÷ Rate suitable to reclamation] × 100
Index of land transformation	Degree of terraced slope lands	Index of terraced slope lands = (Areas of terraced field or land ÷ Areas of sloping cultivated land) × 100
	Rate of effective irrigation of cultivated land	Index of effective irrigation of cultivated land = (Areas of irrigated paddy + Areas of irrigated field) ÷ Total areas of cultivated land) × 100
	Proportion of medium and low-yield land areas	Index of medium and low-yield land areas = 100 - (Areas of medium and low-yield lands ÷ Areas of used lands) × 100
Index of land protection	Forest cover rate	Index of forest cover = (Forest cover rate of a county ÷ Forest cover rate of the highest county) × 100
	Wetland area proportion	Index of wetland area = (Wetland area proportion of a county ÷ Wetland area proportion of the highest county) × 100
	Bare ground (naked soil and naked rock) area proportion	Index of bare ground area = (Bare ground area proportion of a county ÷ Bare ground area proportion of the highest county) × 100
	Flood-drought disaster area proportion	Index of flood-drought disaster area = 100 - [Proportion of flood-drought disaster area ÷ (Standard of ultra-high-level flood disaster (15%) + Standard of acute drought disaster (20%))]× 100
Index of soil and water conservation	Proportion of soil and water loss area	Index of soil loss area = 100 - (Soil loss area ÷ Total land areas) × 100
	Ratio of soil and water loss intensity	Index of soil loss intensity = [4.00 - (Average soil erosion modulus ÷ Soil loss tolerance)] ÷ (4.00 - 1.00) × 100

1) Index of over-exploitation (I_{OE}). Land over-exploitation is the source of land ecological problems in mountainous areas. Usually, the higher the over-rexploitation degrees, the greater the ecological deterioration or degradation in mountainous areas becomes. The actual status of land use in mountainous areas can be represented by several concrete targets, like the over-reclaimed rate, forest over-cutting rate (forest growth - decline ratio), over-grazing rate and over-fishing rate. Taking Yunnan’s condition into consideration, this paper chooses to use the “over-reclaimed rate” target and discards other targets due to the incomplete basic materials of the counties involved. During the calculation of the over-cultivating rate for the chosen counties of Yunnan, we adopt the 2004 land investigation data as their present cultivated land areas. The land areas suitable to reclamation used in this paper are based on the land suitability evaluation results (Yang 2001) and the relevant study results (Yang *et al.* 2006) we got in the recent years and through the complementary analysis and data revision based on the 2004 land investigation results.

2) Index of land transformation (I_{LT}). In mountainous areas, the land condition can be indicated by three targets, degree of terraced slope lands, rate of effective irrigation of cultivated land, and area proportion of medium and low-yield lands. During calculation, the adopted area of present cultivated land, areas of terraced field and terraced land, and areas of paddy field and irrigated field of the counties are the land investigation data in 2004. The areas of the medium and low-yield lands in the counties are obtained based on the results from the area investigation (OARPCY 1995) of the "four-low" lands (medium and low-yield field, low-yield garden plot, low-yield woodland, and low-yield waters) carried out in 1995 by the Office of Agriculture Regional Planning Commission of Yunnan Province, the results from our relevant investigation and study on grade evaluation of cultivated land suitability (Yang 2001) in recent years, the results from 2004 land investigation, and the results from our relevant investigation in different places of Yunnan. I_{LT} can be calculated in the following way:

$$I_{LT} = w_{t1} \cdot I_T + w_{t2} \cdot I_{EI} + w_{t3} \cdot I_{MLY} \quad ......(2)$$

In formula (2), I_T stands for the index of terraced land and terraced field, I_{EI} for index of effective irrigation of cultivated land, I_{MLY} for index of medium and low-yield land area, and w_{t1}, w_{t2} and w_{t3} for the weighted values.

3) Index of land protection (I_{LP}). Based on the reality of the mountainous areas and the basic material data that can possibly be obtained, four targets are chosen, namely, forest cover, wetland area proportion, bare ground (naked soil and naked rock) area proportion and flood-drought disaster area proportion. During actual calculation, the adopted area of forest land, area of various wetlands, area of naked soil and area of naked rock of the counties are the land investigation data in 2004. The flood-drought disaster area is the annual average from 1986 to 2004 (19 years in total), which are based on the numbers from 1986 to 1991 collected by us from 1993 to 1995 during the *Regionalization of Agriculture Natural Disaster in Yunnan Province* and the numbers from 1992 to 2004 of the counties. The agricultural statistic numbers of the counties are adopted as the annual average crop planting areas. I_{LP} is calculated in the following way:

$$I_{LP} = w_{p1} \cdot I_{FC} + w_{p2} \cdot I_{WA} + w_{p3} \cdot I_{BGR} + w_{p4} \cdot I_{FDD} \quad ...(3)$$

In formula (3), I_{FC} stands for the index of forest acreage, I_{WA} for index of wetland area, I_{BGR} for index of bare ground areas, I_{FDD} for index of flood-drought disaster area, and w_{p1}, w_{p2}, w_{p3} and w_{p4} for the weighted values.

4) Index of soil and water conservation (I_{SC}). I_{SC} is a basic target reflecting the degree of soil and water conservation in mountainous areas. It can be indicated by two basic targets, proportion of soil and water loss area and ratio of soil and water loss intensity, which can reflect regional soil and water loss scale, and intensity and degree in soil and water conservation. During actual calculation, the relevant data obtained by the Water Conservancy Department of Yunnan and Water Conservancy and Hydropower Scientific Research Institute of Yunnan during 2004 soil erosion status quo remote sensing are adopted as the counties' soil and water loss area and soil erosion modulus. I_{SC} is calculated in the following way:

$$I_{SC} = w_{c1} \cdot I_{SLA} + w_{c2} \cdot I_{SLI} \quad ....(4)$$

In formula (4), I_{SLA} stands for the index of soil and water loss area, I_{SLI} for index of soil and water loss intensity, and w_{c1} and w_{c2} for the weighted values.

The value of R_{SLI} is calculated by using "satisfaction conversion method", which means that if the ratio of soil and water loss intensity is ≤1.00 (actual soil erosion modulus ≤ soil loss tolerance), the favorable condition, the value of I_{SLI} is 1.00 and that if the ratio of soil and water loss intensity is ≥4.00 (actual soil erosion modulus exceeding three times the soil loss tolerance), the unfavorable condition, the value of I_{SLI} is 0. When the ratio of soil and water loss intensity falls between 1.00 and 4.00, the value of I_{SLI} is calculated by using the satisfaction conversion method (see the formula in Table 1).

Based on the aforesaid serial target calculation, the value of D_{EF} can be calculated with the following formula:

$$D_{EF} = w_{11} \cdot I_{EE} + w_{12} \cdot I_{LT} + w_{13} \cdot I_{LP} + w_{14} \cdot I_{SC} \quad (5)$$

In formula (5), w_{11}, w_{12}, w_{13} and w_{14} stand for the weighted values of I_{EE}, I_{LT}, I_{LP} and I_{SC}, respectively.

1.2.2 Basic target system of D_{EV} and its calculation method

D_{EV} plays a core role in the entire sustainable land use evaluation. People use land to obtain certain land products and income to meet their needs for survival and development. Based on the reality of the mountainous areas, and taking into consideration the basic data's availability and evaluation needs, this paper mainly considers such dominant targets as grain yield per hectare, index of agricultural land output value, index of constructing land output value and index of GDP of land to reveal, in a quantitative manner, the economic viability status of land use in the counties.

1) Index of yield of grain crops per hectare (I_{YGC})

Grain production is the most important basic task for land use in mountainous areas. It plays an extremely significant role in sustaining the people living in the areas and keeping social stability. The index of grain yield per hectare can be gotten by the following formula and it can reflect the present yield standard of the cultivated land and the extent to which the grain production potential is brought into play.

I_{YGC} = (Annual average grain yield per hectare ÷ grain production potential) × 100 ………………(6)

In formula (6), the annual average grain yield per hectare refers to the actual average grain yield per hectare in recent years, which can be obtained by adopting the statistical data of the agriculture economic years. The grain production potential can be estimated by using the method of Agriculture Ecological Zone developed by FAO or the domestically applied method of light - thermo - water - soil serial production potential. This paper adopts the latter one.

The higher the I_{YGC} value, the higher the grain yield per hectare of a place and the greater the degrees of economic viability in land use.

2) Index of output value of agricultural land per hectare (I_{OVA})

According to China's active land use classification system, agricultural land includes cultivated land, garden, forest, grassland and other agricultural lands. They are the major land types in China's mountainous areas. Here, the output value of agricultural land means the output value of agricultural land per hectare or OV_{AL} for short. Its calculation formula is as follows:

OV_{AL} =(Output value of the first industry ÷ Area of agricultural land) × 100 ……………… (7)

In formula (7), the output value of the first industry is from the national economy statistic data. The area of agricultural land is from the land investigation data.

The greater the value of OV_{AL}, the higher the output rate of the agricultural land in a certain place. However, its concrete evaluation standard is another question. Normally, only by comparative analysis of a regional OV_{AL} value and the national average OV_{AL} value can the relative income standard of the agricultural land be soundly reflected. I_{OVA} is just an index to do such comparative analysis. Its calculation formula (with system conversion index already being considered) is as follows:

I_{OVA} =(A regional OV_{AL} ÷ National average OV_{AL}) × 100 ……………………………………(8)

When I_{OVA} value is >100, meaning the regional OV_{AL} is greater than the national average, the value of I_{OVA} is set as 100.

The higher the I_{OVA} value, the higher the output value of the agricultural land of the certain place and the greater the degrees of economic viability in land use.

3) Index of output value of constructing land per hectare (I_{OVC})

Constructing land includes the land for residential quarters in urban and rural areas, land for industry and mining, land for road and land for water conservancy facilities. They are also the important land types in mountainous areas in China. Here, the output value of constructing land means the output value of constructing land per hectare or OV_{CL} for short. Its calculation formula is as follows:

OV_{CL} =(Output value of the second and third industries ÷ Area of constructing land) × 100 …(9)

In formula (9), the output value of the second and third industries can be obtained from the statistic data of the national economy years, and the area of constructing land from the land investigation data.

The greater the value of OV_{CL}, the higher the output rate of the constructing land in a certain place. However, the setting of its concrete evaluation standard needs further study. Normally, only by comparative analysis of a regional OV_{CL} value and the national average OV_{CL} value can the relative income standard of the constructing land be soundly reflected. I_{OVC} is just an index for such comparative analysis. Its calculation formula (with system conversion index already being considered) is as follows:

I_{OVC} =(A regional OV_{CL} ÷ National average OV_{CL}) × 100 ………………………………………… (10)

When I_{OVC} value is > 100, meaning the regional OV_{AC} is greater than the national average, the value of I_{OVC} is set as 100.

The higher the I_{OVC} value, the higher the output value of the constructing land of the certain place and the greater the degrees of economic viability in land use.

4) Index of GDP of land per hectare (I_{GDPL})

GDP can not only reveal a country's (or a region's) total production standard and status, but also indirectly show its output standard and status in land resources development and utilization. The index of GDP of land is calculated by using the GDP of land per hectare or GDP_{LA} for short, which can reflect the relative land output standard and status after the influence by the magnitude of regional land area is eliminated. Its calculation formula is as follows:

GDP_{LA} = (GDP value ÷ Total land area) × 100⋯(11)

In formula (11), the GDP value can be obtained from the statistic data of national economy years and the total land area from the land investigation data.

The greater the value of GDP_{LA}, the higher the output rate of the constructing land in a certain place. However, its concrete evaluation standard needs to go through comparative analysis with the national average OV_{CL} value so as to reveal the relative standard and status of the land output of the certain place. I_{GDPL} is just an index for such comparative analysis. Its calculation formula (with system conversion index already being considered) is as follows:

I_{GDPL} =(A regional GDP_{LA} ÷ National average GDP_{LA}) × 100 ……………………………………(12)

When I_{GDPL} value is > 100, meaning the regional GDP_{AL} is greater than the national average, the value of I_{GDPL} is set as 100.

The higher the I_{OVC} value, the higher the total output value of the land of the certain place and the greater the degrees of economic viability in land use.

On the basis of measuring and calculating the aforesaid I_{YGC}, I_{OVA}, I_{OVC} and I_{GDPL}, the following method can be used to measure and calculate the D_{EV} value in land use:

$$D_{EV} = w_{21} \cdot I_{YGC} + w_{22} \cdot I_{OVA} + w_{23} \cdot I_{OVC} + w_{24} \cdot I_{GDPL} \quad (13)$$

In formula (13), w_{21}, w_{22}, w_{23} and w_{24} stand for the weighted values of I_{YGC}, I_{OVA}, I_{OVC} and I_{GDPL}, respectively.

The higher the D_{EV} value, the greater the degrees of economic viability in land use.

1.2.3 Basic target system of D_{SA} and its calculation method

In land use system, the D_{SA} target reflects the degrees of social acceptability and social endurance for land resources use modes (Zhang et al. 2003). People use land to satisfy their needs for survival and development. Therefore, the social acceptability and its degrees are important contents for evaluating sustainable land use. By considering the survival and development needs of the people living in mountainous areas, availability of basic data and evaluation requirements, this paper considers such dominant targets as the index of population pressure, index of net income of rural population, index of per capita yield of grain and index of per capita GDP. These targets can basically reveal the degrees of social acceptability for land use in mountainous areas.

1) Index of population pressure (I_{PP})

People are the main body in land use system and people-land relation territorial system. The change of population has direct impact on the development and utilization of land resources. The magnitude of population pressure decides, to a great extent, whether or not the human society can realize a sustainable development in a coordinated and healthy way. In mountainous areas with only weak inherent ecological environment, the increasing of the population pressure usually causes fatal damage to the areas' ecological environment. When discussing the index of population pressure, we should always analyze and study the population-supporting capacity of land resources or PSCL for short, which can be interpreted as the population that can be sustained continuously by the possible maximum food production of a country's (or a region's) land resources under certain production conditions. It is in fact a ratio of the land's potential food output to certain amount of per capita food consumption. If a country's (or a region's) actual population falls short of the population-supporting capacity of land resources (or potential population-supporting capacity), the country's (or region's) land resources bear relatively small population pressure. On the contrary, if the actual population is close to or exceeds the population-supporting capacity of land resources, there is a big population pressure that deserves high alert and emphasis and countermeasures and solutions should be found. Therefore, population pressure (PP) can be measured and calculated in the following way:

PP = Actual population ÷ Population - supporting capacity of land resources ……………………(14)

In formula (14), the actual population can be from the annual population statistic data and the population-supporting capacity of land resources has to be obtained through special analysis and study. According to the aforesaid concept, the regional population-support capacity of land resources can be measured and calculated in the following way:

PSCL = Tenable Yield of grain of regional land (TYG) ÷ Per capita grain consumption ………(15)

TYG= Areas suitable to reclamation × Multiple crop index × Grain sowing proportion × Tenable grain yield per hectare …………………………(16)

The PP value calculated by the aforesaid method still needs to go through target system conversion and the index after the conversion is called the index of population pressure (I_{PP}), which is calculated by using the satisfaction conversion method. Specifically speaking, when *PP* is ≤1.00 (actual population ≤ population-supporting capacity of land resources), the favorable condition, PP is set as 1.00. When *PP* is ≥1.50 (actual population reaching 1.5 times of the population-supporting capacity of land resources), the unfavorable condition, PP is set as 0. When PP is between 1.00 and 1.50, the system conversion index of population pressure (I_{PP}) can be obtained via the satisfaction conversion method.

$$I_{PP}=[(1.50 - PP) \div (1.50 - 1.00)] \times 100 \quad \cdots \quad (17)$$

The greater the value of I_{PP}, the smaller the population pressure of a certain place and the greater the degrees of social acceptability for land use.

2) Index of net income of rural population (I_{NIR})

The mountainous area is the focus area for China to deal with its "three-rural" issues. The per capita net income standard of rural population is a very important target for evaluating the sustainable land use in mountainous areas since it reflects the basic degrees of social acceptability for land use in the areas. However, its specific evaluation standard usually needs to go through comparative analysis with the national per capita net income standard of rural population so as to reveal the relative standard and status of the per capita net income of a certain place. I_{NIR} is just a target to do such comparative analysis. Its calculation formula (with system conversion index already being considered) is as follows:

I_{NIR}= (Per capita net income of rural population of a certain place ÷ Per capita net income of rural population of the whole country ………………………………………(18)

In formula (18), the per capita net income of rural population can be from the annual national economy statistic data. When I_{NIR} value is > 100, meaning the per capita net income of rural population of a certain place is higher than the national value, I_{NIR} is set as 100.

The greater the value of I_{NIR}, the higher the per capita net income standard of rural population of a certain place and the greater the degrees of social acceptability for land use.

3) Index of per capita yield of grain (I_{PYG})

It is the primary task for land use in mountainous areas to "feed" people there. The per capita grain yield is a target to reflect how well this task is fulfilled and how well local people make a living. In China, 400 kg is taken as the basic standard for per capita grain possession (CAAS

1986). The white book of *China's Grain Issue* released by the Information Office of the State Council in October 1996 pointed out that by the year of 2030, China's per capita grain possession would reach 400 kg, including over 200 kg of grain ration and other animal food, so as to meet people's needs in upgrading their living standard and nutrition improvement (SCIO 1996). Therefore, although the rural per capita grain yield is lower than 400 kg in many mountainous areas, we should still set 400 kg of per capita grain yield as basic requirements and judging standards for sustainable land use in mountainous areas. Based on this, the calculation formula of the index of per capita yield of grain (I_{PYG}) (with system conversion index already being considered) is as follows:

I_{PYG}=[Actual per capita grain yield (kg/person) ÷ 400(kg/person)] × 100 ··························(19)

In formula (19), the actual per capita grain yield can be from the annual rural economic data or national economy statistic data (SBY 2005). When the value of I_{PYG} is >100, meaning the actual per capita grain yield of a certain place is › 400 kg, the value of I_{PYG} is set as 100.

The higher the I_{PYG} value, the higher the per capita grain yield of the certain place and the greater the degrees of social acceptability for land use.

4) Index of per capita GDP (I_{PGDP})

The per capita GDP can reflect the degrees of social acceptability for land use in mountainous areas from another angle. Its assessing standard should also be subject to comparative analysis with national per capita GDP. I_{PGDP} is just a target to do such analysis. Its calculation formula (with system conversion index already being considered) is as follows:

I_{PGDP} = (Per capita GDP of a certain place ÷ National per capita GDP) × 100 ··················(20)

In formula (20), the figure of population for calculating per capita GDP and GDP data are obtained from the annual national economy statistic data. When the value of I_{PGD}P is > 100, meaning the per capita GDP of a certain place is higher than the national average, I_{PGDP} is set as 100.

The greater the I_{PGDP} value, the higher the GDP of the certain place and the greater the degrees of social acceptability for land use.

On the basis of measuring and calculating the aforesaid I_{PP}, I_{NIR}, I_{PYG} and I_{PGDP}, the D_{SA} value can be quantitatively calculated in the following way:

$$D_{SA} = w_{31} \cdot I_{PP} + w_{32} \cdot I_{NIR} + w_{33} \cdot I_{PYG} + w_{34} \cdot I_{PGDP} \quad (21)$$

In formula (21), w_{31}, w_{32}, w_{33} and w_{34} stand for the weighted values of I_{PP}, I_{NIR}, I_{PYG} and I_{PGDP}, respectively.

The higher the D_{SA} value, the greater the degrees of social acceptability for land use.

1.3 Determining the weighted values of the targets

In this paper, the Delphi Method is adopted to determine the weighted values. In the process, we invited some 16 experts in the fields of geography, ecology, land management and regional economy to carry out assignment of the weighted values of the aforesaid targets for land use sustainability evaluation. Through the corresponding processing, we obtained the weighted values of the targets (See Table 2).

1.4 Land use sustainability grading system

After getting the value of land use sustainability of the studied area, we should also, based on the value, grade the degrees of land use sustainability so as to make qualitative study of the degrees of sustainability at different levels. This way, the research result can be analyzed in both qualitative and quantitative manners, which guarantees better scientific guidance and decision basis for implementing the sustainable land use strategy.

At present, there have been only few special explorations and studies on the system and standard for grading land use sustainability. In this paper, according to the overall characteristics of land use in mountainous areas, we classify the degrees of land use sustainability into five levels: Highly Sustainable, Moderately Sustainable, Lowly Sustainable, Conditionally Sustainable and Unsustainable. Meanwhile, we also set the standards for grading the overall sustainability degrees and their basic meaning (see Table 3).

2 Example: Evaluation of Land use Sustainability of Mountainous Counties in Yunnan

2.1 Calculation of land use sustainability value

This paper evaluates the status quo. It aims to reveal the overall sustainability of current land use in different counties of Yunnan and serve the strategy of promoting sustainable land use. Following the aforesaid sustainability evaluation target system and estimation method, it measures and calculates the comprehensive evaluation index, D_{OS}, of some 126 counties (cities and districts) of Yunnan, and their single indexes, including D_{EF}, D_{EV} and D_{SA}, which are omitted here. Based on D_{OS}, the comprehensive evaluation index, it then sets the levels of land use sustainability for the counties (cities and districts) in accordance with the preset grading standard. Finally, by using GIS technology, it works out the Diagram of Land Use Sustainability Evaluation at County Level in Yunnan Province (See Figure 1). This paper gives a fundamental basis for analyzing the status quo of overall land use sustainability of Yunnan Province, working out countermeasures and stipulating measures.

Table 2 Weighted value of targets at all levels of land use sustainability evaluation in mountainous areas

Target at the first level	Weight	Target at the second level	Weight	Target at the third level	Weight
Degrees of ecological friendliness	0.45	Index of land over-exploitation	0.24	Over- reclaimed rate	—
		Index of land transformation	0.26	Degree of terraced slope lands	0.40
				Rate of effective irrigation of cultivated land	0.28
				Proportion of medium and low-yield land areas	0.32
		Index of land protection	0.25	Forest cover rate	0.30
				Wetland area proportion	0.20
				Bare ground area proportion	0.22
				Flood-drought disaster area proportion	0.28
		Index of soil and water conservation	0.25	Proportion of soil and water loss area	0.55
				Ratio of soil and water loss intensity	0.45
Degrees of economic viability	0.30	Index of grain yield per hectare	0.24	—	—
		Index of output value of agricultural land	0.25	—	—
		Index of output value of constructing land	0.23	—	—
		Index of land GDP	0.28	—	—
Degrees of social acceptability	0.25	Index of population pressure	0.24	—	—
		Index of net income of rural population	0.28	—	—
		Index of grain yield per hectare	0.22	—	—
		Index of per capita GDP	0.26	—	—

Table 3 Standards for grading degrees of land use sustainability in mountainous areas and their basic meaning

Level of sustainability	Degrees of sustainability (D_{OS})	Basic meaning
1. Highly sustainable	≥90	The degrees of ecological friendliness, economic viability and social acceptability for land use are all high, which results in high overall sustainability. Land development and use have no obvious impact on and damage to ecological environment, and can bring about desirable economic and social benefits. The coordination of the "population-resources-environment-economic development" system and the sustainability of the land use system can be guaranteed.
2. Moderately sustainable	70~ 90	The degree of overall sustainability in land use is at the medium level, with different degrees of shortcomings or defects in ecological friendliness, economic viability and social acceptability. Land development and use have certain impact on and damage to ecological environment, which results in insufficient economic and social benefits. By taking normal ecological environment measures, economic measures, or comprehensive measures, the coordination of the "population-resources-environment-economic development" system and the sustainability of the land use system can be guaranteed.
3. Lowly sustainable	55 ~ 70	The degree of overall sustainability in land use is low, with obvious shortcomings or defects in ecological friendliness, economic viability and social acceptability. Land development and use have obvious impact on and damage to ecological environment, which results in low economic and social benefits. Only by taking practical and effective ecological environment measures, economic measures, or comprehensive measures can the coordination of the "population-resources-environment-economic development" system and the sustainability of the land use system be guaranteed.
4. Conditionally sustainable	40 ~ 55	The degree of overall sustainability in land use is very low, with remarkable shortcomings or defects in ecological friendliness, economic viability and social acceptability. Or any one or two of the three has great defects. If forceful ecological environment measures, economic measures, or comprehensive measures can be taken, the degree of sustainability in land use can be upgraded to guarantee the coordination of the "population-resources-environment-economic development" system and the sustainability of the land use system.
5. Unsustainable	<40	The degree of overall sustainability in land use is extremely low, with great shortcomings or defects in ecological friendliness, economic viability and social acceptability. Or any one or two of the three has extremely great defects, making the un-sustainability of land use system extremely obvious. Only by changing the basic land use mode and taking forceful ecological environment measures, economic measures, or comprehensive measures to greatly upgrade the degree of overall sustainability in land use can the coordination of the "population-resources-environment-economic development" system and the sustainability of the land use system be gradually enhanced.

Figure 1 The map for land use sustainability evaluation at county level in Yunnan

2.2 Characteristics of status quo of overall land use sustainability

From Figure 1 we can see that the current overall land use sustainability of Yunnan Province has the following two basic characters:

1) The degree of overall land use sustainability of the Yunnan is relatively low.

The calculation results show that the average D_{OS} of Yunnan is only 58.39, making the degree of overall sustainability of the province only "lowly sustainable", with obvious shortcomings or defects in ecological friendliness, economic viability and social acceptability. Land development and use have obvious impact on and damage to ecological environment, which results in low economic benefit and insufficient social benefit.

As for the level of county's land use sustainability, none of the 126 counties (cities and districts) of the whole province reaches the standard of "highly sustainable". The statistic results show that only 12 of them, 9.52 % of the total, have a D_{OS} slightly over 70, being "moderately sustainable". About 34 of them, 26.98 % of the total, have a D_{OS} between 55 and 70, being "lowly sustainable". Some 66 of them, 52.38% of the total, have a D_{OS} between 40 and 55, being "conditionally sustainable". Some 14 of them, 11.11 % of the total, have a D_{OS} below 40, being "unsustainable". All in all, most counties (cities and districts) of Yunnan Province have extremely low overall land use sustainability at present.

2) Different regions differ widely from each other in overall land use sustainability.

From Figure 1 we can know that different regions in Yunnan Province differ widely from each other in overall land use sustainability. Generally speaking, the medium-high mountain plateau area in Northeastern Yunnan has the lowest degree of overall sustainability. Most counties (districts) there have a D_{OS} below 40, being "unsustainable". The lowest counties are Yiliang and Zhenxiong, both with a D_{OS} below 30.

The medium-low mountain karst plateau area in Southeastern Yunnan also has a relatively low degree of overall sustainability. Most counties (cities) there have a D_{OS} below 55, being "conditionally sustainable". Of them, Qiubei County and Guangnan County have a D_{OS} below 40, being "unsustainable".

The degrees of overall sustainability (D_{OS}) of most counties (cities and districts) in northern Yunnan, western Yunnan, northwestern Yunnan and southwestern Yunnan are also not high, being below 55. Of them, Ninglang County and Fugong County in northwestern Yunnan have a D_{OS} below 40, being "unsustainable".

In comparison, most areas in central Yunnan and some counties (cities and districts) in Southern Yunnan and Southwestern Yunnan have a higher D_{OS}, mostly between 55 and 70, being "lowly sustainable". Some counties (cities and districts) even have a D_{OS} over 70, reaching the "moderately sustainable" level.

2.3 Basic reasons behind the low degree of overall land use sustainability and countermeasures for upgrading degree of overall sustainability

D_{OS} is decided jointly by three factors, namely, ecological friendliness, economic viability and social acceptability of land use, and is therefore their comprehensive embodiment. Yunnan is a typical mountainous province with over-reclamation (by deforestation and slope cultivation), low degree of terraced land and terraced field, serious soil and water loss, low rate of effective irrigation of cultivated land, and large proportion of medium and low-yield lands. What is more, Yunnan makes insufficient effort in ecological environment protection and thus many places of the province suffer from frequent floods and droughts. As a result, Yunnan's average D_{EF} is only 48.01. About two thirds of the counties (cities and districts) in the province have a D_{EF} below 55. Meanwhile, most counties (cities and districts) in Yunnan are of low grain yield, I_{OVA}, I_{OVC}, and I_{GDPL}. Therefore, the province also has low degrees of economic viability in land use. The province's average D_{EV} is only 58.26. Nearly 70 % of the counties (cities and districts) have a D_{EV} below 55 and that of over half of the counties (cities and districts) is below 40. In addition, as most counties (cities and district) have only low I_{NIR}, I_{PYG}, and I_{PGDP}, the D_{SA} that has been calculated on the basis of these targets is accordingly low. The province's average D_{SA} is 77.21 and over 60 % of the counties (cities and districts) have a D_{SA} below 70. Some 15 counties have a D_{SA} value below 55. Therefore, Yunnan's D_{OS} in land use is accordingly low.

In order to promote sustainable use of land resources in Yunnan, we must upgrade D_{OS} by a large margin. To do this, it is imperative to take practical and effective ecological environment measures, economic measures, or comprehensive measures in the whole province to steadily upgrade D_{EF}, D_{EV}, and D_{SA}, and finally, D_{OS} in land use, guaranteeing coordination of the "population-resources - environment - economic development" system and sustainability of the land use system. For counties evaluated as at the "unsustainable" level, they need to change their basic land use model and take forceful ecological environment measures, economic measures, or comprehensive measures to greatly upgrade the degree of overall sustainability in land use. Only by doing so can the coordination of the "population - resources - environment - economic development" system and the sustainability of the land use system be gradually enhanced.

3 Preliminary Conclusions

At present, the sustainable land use evaluation at home and abroad can hardly reflect the degree of overall regional land use sustainability. To tackle this insufficiency, this paper puts forward a concept of the "Degrees of land use sustainability", an evaluation index that can, in a quantitative manner, reflect the degree of overall land use sustainability. It also studies and works out its calculation and evaluation methods. Finally, it carries out positive analysis of land use sustainability evaluation in counties of Yunnan Province. It draws the following preliminary conclusions:

1) The Degrees of Overall Land Use Sustainability (D_{OS}) is a quantitative target based on the organic synthesis and system integration of the Degrees of Ecological Friendliness (D_{EF}), Degrees of Economic Viability (D_{EV}) and Degrees of Social Acceptability (D_{SA}) in land use. The D_{OS} can reflect the degree of overall regional land use sustainability in a comprehensive way. It can be obtained by adopting a suitable basic target system and through certain mathematic methods.

2) Based on the value of D_{OS}, the system and standards for grading land use sustainability are established and there are five levels, Highly Sustainable, Moderately Sustainable, Lowly Sustainable, Conditionally Sustainable and Unsustainable. Meanwhile, the standards for grading the sustainability and their basic meanings are determined, which allows researchers to carry out qualitative study on the degrees of sustainability at different levels. The research results, combining qualitative features with quantitative ones, can offer better scientific guidance and basis for implementation of the sustainable land use strategies and decision-making.

3) The practice in evaluating the degrees of land use sustainability in counties of Yunnan shows that the province's average D_{OS} is only 58.39, being "lowly sustainable". About two thirds of its counties are at the "conditionally sustainable" and "unsustainable" levels in land use. About 11.11% of the counties are at the "unsustainable" level. Generally speaking, the medium-high mountain and plateau area in Northeastern Yunnan has the lowest degree of overall sustainability. Most counties (districts) there have a D_{OS} below 40, being "unsustainable". The medium-low mountain karst plateau area in southeastern Yunnan also has a relatively low degree of overall sustainability. Most counties (cities) there have a DOS below 55. The degree of overall sustainability (D_{OS}) of most counties (cities and districts) in Northern Yunnan, Western Yunnan, Northwestern Yunnan and Southwestern Yunnan is also below 55. This paper also analyzes the reasons behind the low degree of land use sustainability in Yunnan and puts forward countermeasures to upgrade the low degree.

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