Analysis on the Dynamic Variation of Ecological Security of Farmland in Yuxi, Based on the Combinational weighting Method

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Abstract: With the rapid development of society and economy, the safety and protection of farmland has been urgent. This research built an evaluation system from natural, social and economic perspective, by adopting the Nature-Society-Economy Concept Framework Model; and with the help of comprehensive assessment model, the ecological security indexes of farmland from 2006 to 2015 of Yuxi city had been worked out. Besides, it analyzed dynamic variation feature of ecological safety of farmland within 10 years; and correlation analysis had been made by SPSS to ecological security indexes. The outcomes revealed that though the Yuxi's ecological safety indexes of farmland was slight going up in 2013, overall, the variation tended to go down notably and the main driving factors for this variation were nature and society.
Key Words: Analytic Hierarchy Process; Entropy Weight Method; Farmland Security; Correlation Analysis; Dynamic Variation

1 Introduction

Farmland is the foundation for human survival, development and food safety. With the rapid development of social economy, natural disaster, the burden of increasing population and the abuse of pesticide and fertilizers make the farmland polluted, degraded so that the burden of land is increasing and the ecological safety is seriously threatened. Through ecological safety evaluation, the reasons and ways to improve ecological safety can be founded, which is of great both theoretical and realistic significance for relieving conflicts between human and land, ensuring food safety and promoting substantial development.

So far, the research on ecological safety has gone through 3 stages, the initial research was about building a framework of regional security [1-6]. With the research continuing, Scholars like Peng Buzhuo etc. [7-11] began to study the evaluation of ecological environment, and an evaluation system had been established and confirmed, which could be regarded as the second stage of development. In recent years, the ecological safety of farmland has been emphasized so that the research of farmland safety has become an important independent research subject and a series of researches of ecological safety evaluation has been conducted [4-5,12], and it is usually considered as a brand new study area. In this stage, the researchers focused the study from five aspects, such as the definition of ecological safety of arable land[13-14], feature analysis[15], evaluation scale analysis[16], evaluation methodology[15] and technology, and evaluation index system building[15,18]. From the practice of farmland ecological safety evaluation research in China, evaluation has been varied from national scale, provincial scale[19] and watershed large-scale area assessment to middle[12,15] and small[20] scale research of city and county. However, the recent researches are mostly concentrated on the middle-scale research, less of small-scale researches have been done. Mature evaluation methodologies include the application of GIS [20], fuzzy matter-element model construction [21], entropy method [22], PSR model [23], entropy weight extension element model [24-26], mathematics model and spatial analysis technology of GIS.

Above all, there are still two problems existed in land ecological safety evaluation. The first one is that most of researches put the emphasis on the holistic land safety, and few studies reported the farmland in this area; the second is the evaluation of ecological safety just showed up and many studies focused on the research of present situations, lacking of dynamic observations and simulations. This research took Yuxi city, located in the middle of Yunnan province, as an example, to analyze and explore the dynamic variation rules and reasons of farmland ecological safety from natural, social and economic perspectives by using array and entropy weight mode, so that this can be beneficial to the land reclamation and city planning of Yuxi City.

2 Overview of Study Area

Yuxi City, whose longitude and latitude are 101° 16′ ~103° 9′ and 23° 19′ ~24° 53′ respectively, is located in the middle part of Yunnan province. It is next to Kunming in the east and north, Honghe State in the east and south, Puer City in the west and south, and Chuxiong Yi Autonomous Prefecture in the west north. With a terrain of weat north higher and east south lower, the terrain of Yuxi is complicated because of the staggered distribution of lots of hills, valleys, plateaus and basins. The lakes and rivers in Yuxi belong to the Pearl River and Honghe River System, and there are four plateau lakes sparkled in Yuxi, such as Fuxian Lake, Xingyun Lake, Qilu Lake and Zong Lake etc. The climate is mild and belongs to the sub-tropical humid and cold winter plateau monsoon climate, with an average temperature from 17.4℃ to 23.8℃ and precipitation from 670 to 2412mm.

The total area of Yuxi was 22.4132 million mu in 2015 and 3.8065 million mu of it was arable land, taking the percentage of 16.99%. The yearly completed GDP of Yuxi was 124.57 billion Yuan, rising up at a rate of 8.5%, and the average GDP of population had reached to 52,887 RMB, with a rising rate of 8.0%. The disposable income of urban residents was 29,631 RMB, which increased 8.8% comparing with last year, and the disposable income for rural residents was 10,977 RMB, with an increase of 10.1% as well.

3 Materials and Methodology

3.1 Source of Data

The data came from Statistics Almanac of Yunnan Province (Year 2007-2016), Statistics Almanac of Yuxi City (Year 2006-2015), Almanac of Yuxi (Year 2006-2016), National Economic and Social Development Report (Year 2006-2016), the land use variation data of Yuxi from 2006 to 2015 and some relative materials from Land Resource Management Department, Statistics Department and City Planning Department.

3.2 Research Methodology

This study referred to the widely-used nature-society-economy model, combining the reality of Yuxi City and principle of data-accessibility to construct the farmland ecological safety evaluation index system from natural, social and economic aspects; besides, by using hierarchical analysis method and entropy method to determine the weights of indexes, the farmland ecological evaluation model had been built to analyze the dynamic variation of farmland ecological safety of Yuxi from 2006 to 2015. And SPSS had also been used in analyzing the correlation among indexes of farmland ecological safety, in order that the reasons of dynamic variation of Yuxi farmland ecological safety could be explored.

3.2.1 Constructing Evaluation Index System

Farmland ecological safety refers to the state in which farmland ecosystem can maintain its normal function structure and satisfy the sustainable development of social economy in a certain time and space; under this condition, farmland ecosystem has a stable, well-balanced and enough natural resources to use so as to make the whole ecological environment in a healthy state [23]. Based on the relationship of farmland ecological safety and nature, society and economy system, following the principle of scientificity, comparability, accessibility and systematization and referring to some relative documentaries [26-27], this study built a 15-index ecological safety evaluation system which aimed at ecological safety of arable land, and followed the principles of taking natural, social and economic factors into consideration.

Tab. 1 Farmland Ecological Safety Evaluation Indexes

Target Tier A	Principle Tier B	Index Tier C	Safety Change Trend
Farmland Ecological Safety	Natural Factors B_1	Farmland Per Capita C_1	Positive
		Proportion of FarmlandC_2	Positive
		Forest Coverage C_3	Positive
		Proportion of Unused Land C4	Positive
	Economic Factors B_2	Per Capita GDP C_5	Positive
		Per Unit Cultivated Area GDP C_6	Positive
		Dose of Pesticide Per Unit C_7	Negative
		Dose of Fertilizer Per Unit C_8	Negative
		Amount of Mulch Use Per Unit C_9	Negative
		Amount of Industrial Waste Water Discharging C_{10}	Negative
	Social Factors B_3	Population Intensity C_{11}	Negative
		Natural Population Growth Rate C_{12}	Negative
		Rural Per Capita Net Income C_{13}	Positive
		Per Capita Share of Grain C_{14}	Positive
		Urbanization Level C_{15}	Negative

3.2.2 Index Weight Determination

Weighting method was applied to determine the index of weight in this research. The analytic hierarchy process was initially used to Fig. out the subjective weight, then the entropy method was employed to give objective weight, and arithmetic mean methodology was to confirm weight vector.

(1) After the index system was constructed according to the Nature-Society-Economy Concept Framework Model, the subjective weight of indexes were calculated by comparing matrix and applying analytical hierarchy process which processed hierarchical single sequencing and hierarchical total sequencing.

Tab. 2 Evaluation Index Weight Value (AHP)

Principle Tier B	Hierarchy Single Sequencing	Index Tier C	Hierarchy Single Sequencing	Hierarchy Total Sequencing
Natural Factors B_1	0.4934	Farmland Per Capita C_1	0.1170	0.0577
		Proportion of FarmlandC_2	0.1453	0.0717
		Forest Coverage C_3	0.2943	0.1452
		Proportion of Unused Land C4	0.4434	0.2188
Economic	0.3108	Per Capita GDP C_5	0.1645	0.0511

Factors B_2		Per Unit Cultivated Area GDP C_6	0.1642	0.0510
		Dose of Pesticide Per Unit C_7	0.1350	0.0420
		Dose of Fertilizer Per Unit C_8	0.1350	0.0420
		Amount of Mulch Use Per Unit C_9	0.1779	0.0553
		Amount of Industrial Waste Water Discharging C_{10}	0.2235	0.0695
Social Factors B_3	0.1958	Population Intensity C_{11}	0.1565	0.0306
		Natural Population Growth Rate C_{12}	0.0595	0.0117
		Rural Per Capita Net Income C_{13}	0.2748	0.0538
		Per Capita Share of Grain C_{14}	0.2748	0.0538
		Urbanization Level C_{15}	0.2344	0.0459

(2) Entropy method is an objective weight method that applies information entropy to calculate the weight of indexes (Tab.3). The index entropy of No. j is $E_j = -k\sum_{n=1}^{m} y_{ij} \ln y_{ij}$, and after the entropy is calculated, the index weight of No. j is $W_j = (1-E_j)/\sum_{j=1}^{n}(1-E_j)$.

(3) The index weight calculated by AHP and entropy method and comprehensive weight did by arithmetic mean method was showed in the following Figure.

Tab.3 Evaluation Index Weight (Combination Weighting Method)

Index Tier C	AHP Weight	Entropy Method Weight	Comprehensive Weight
Farmland Per Capita C_1	0.0577	0.0540	0.0559
Proportion of FarmlandC_2	0.0717	0.0620	0.0669
Forest Coverage C_3	0.1452	0.1386	0.1419
Proportion of Unused Land C4	0.2188	0.2093	0.2141
Per Capita GDP C_5	0.0511	0.0499	0.0505
Per Unit Cultivated Area GDP C_6	0.0510	0.0498	0.0504
Dose of Pesticide Per Unit C_7	0.0420	0.0423	0.0422
Dose of Fertilizer Per Unit C_8	0.0420	0.0413	0.0417
Amount of Mulch Use Per Unit C_9	0.0553	0.0556	0.0555

Amount of Industrial Waste Water Discharging C_{10}	0.0695	0.0656	0.0676
Population Intensity C_{11}	0.0306	0.0415	0.0361
Natural Population Growth Rate C_{12}	0.0117	0.0233	0.0175
Rural Per Capita Net Income C_{13}	0.0538	0.0592	0.0565
Per Capita Share of Grain C_{14}	0.0538	0.0593	0.0566
Urbanization Level C_{15}	0.0459	0.0483	0.0471

3.2.3 Standardized Processing of First-hand Data

Standardized processing of the first-hand data is the prerequisite and foundation of evaluating the ecological safety of arable land. Before data-processing, evaluation indexed was divided into positive index and negative index which respectively means that the larger the positive index, the safer the farmland in ecologic; and conversely, the smaller the negative index, the safer the arable land. Then positive and negative index would be applied into standardizing the raw data (Tab.4). And the calculating formulas were as follows:

Positive index: $$Z_{ij}=\frac{x_{ij}-\min(x_j)}{\max(x_j)-\min(x_j)} \qquad (1)$$

Negative index: $$Z_{ij}=\frac{\max(x_j)-x_{ij}}{\max(x_j)-\min(x_j)} \qquad (2)$$

In the formula, x_{ij} ---- original data of index *j* in year *i*; Z_{ij} ---- standardized data of index *j* in year *i*; $\max(x_j)$ and $\min(x_j)$ ---- maximum and minimum data of index *j*.

Tab.4 Standardized Data of Farmland Ecological Safety Evaluation Index

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Farmland Per Capita（P）Mu/ Per Person	0.0779	0.0240	0.0000	1.0000	0.9796	0.9033	0.8780	0.8632	0.8371	0.8078
Proportion of Arable Land（P）%	0.0106	0.0000	0.0040	0.9938	0.9953	0.9818	0.9883	0.9998	1.0000	0.9968
Forest Coverage（P）%	0.9845	0.9831	1.0000	0.9558	0.0193	0.0000	0.0069	0.0342	0.0338	0.0348
Proportion of Unused Land（P）%	1.0000	0.9997	0.9692	0.0034	0.0012	0.0000	0.0010	0.0017	0.0021	0.0029
Per Capita GDP（P）Yuan	0.0000	0.0949	0.2204	0.2785	0.3911	0.5616	0.7116	0.8339	0.9307	1.0000
Per Unit Cultivated Area GDP（P）Yuan/Mu	0.0000	0.1283	0.2881	0.1982	0.3209	0.5104	0.6743	0.8082	0.9178	1.0000
Dose of Pesticide Per Unit（M）Kilogram/Mu	1.0000	0.8937	0.7154	0.5880	0.3412	0.3678	0.1023	0.1069	0.0000	0.0522
Dose of Fertilizer Per Unit（M）Kilogram/Mu	0.3610	0.1433	0.0000	1.0000	0.8903	0.7596	0.4973	0.4183	0.2818	0.0828
Amount of Mulch Use Per Unit（M）Kilogram/Mu	1.0000	0.9874	0.8145	0.5349	0.4855	0.5374	0.0721	0.3922	0.0382	0.0000
Amount of Industrial Waste Water Discharging（M）Ton/Mu	0.8653	0.8571	0.9008	0.9588	1.0564	0.0000	0.1337	0.1362	0.0835	0.0564
Population Intensity（M）Per Person/Mu	1.0000	0.8421	0.7368	0.6404	0.5702	0.3684	0.2632	0.1754	0.0877	0.0000
Natural Population Growth Rate（M）‰	0.0000	0.0664	0.6213	0.1296	1.0000	0.1561	0.0897	0.1279	0.1595	0.1096
Rural Per Capita Net Income（P）Yuan	0.0000	0.0637	0.1649	0.2130	0.2973	0.4141	0.5500	0.7243	0.8646	1.0000
Per Capita Share of Grain（P）Kilogram/Per Person	0.0124	0.1890	0.3689	0.4268	0.0000	0.4409	0.8086	0.9425	1.0000	0.9895
Urbanization Level（M）%	1.0000	0.9124	0.7993	0.6622	0.5479	0.3833	0.2222	0.1556	0.1000	0.0000

3.2.4 Calculating the Ecological Safety Index of Farmland

The formula of comprehensive model calculating is:

$$F = \sum_{i=1}^{n} W_i \times X_{ij} \qquad (3)$$

In this formula, F is the index of ecological safety of arable land, W is the weight value of index i, X_{ij} is the standardized value.

From year 2006 to 2015, farmland ecological safety indexes of Yuxi (Tab.5) were calculated according to Formula 3.

Tab.5 Farmland Ecological Safety Index of Yuxi from 2006 to 2015

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Natural Factors	0.3589	0.3549	0.3497	0.2587	0.1243	0.1162	0.1164	0.1204	0.1189	0.1174
Economic Factors	0.1712	0.1677	0.1619	0.1851	0.1858	0.1311	0.1080	0.1358	0.1128	0.1104
Social Factors	0.0839	0.0888	0.1053	0.0928	0.0807	0.0824	0.0984	0.1102	0.1161	0.1144
Comprehensive Indexes	0.6140	0.6114	0.6169	0.5366	0.3908	0.3297	0.3228	0.3663	0.3478	0.3422

4 Outcomes and Analysis

4.1 Natural Factors

It was notable that the farmland ecological safety index of Yuxi tended to go down, from 0.3589 in 2006 to 0.1174 in 2015, with an averaging decreasing rate of 11.67%. As was shown in Fig. 1, three different stages could be seen. The first stage was unstable (from 2006 to 2008), which showed a higher ecological safety index because of good natural environment; and in the second stage (from 2008 to 2010), the situation of natural environment deteriorated rapidly with an result of per capita arable land, forest coverage and the area of unused land going decreasing obviously, so did the ecological safety index; while, in the third stage (from 2010 to 2015), as natural environment had been well-improved, the ecological safety index picked up slightly and went down gradually.

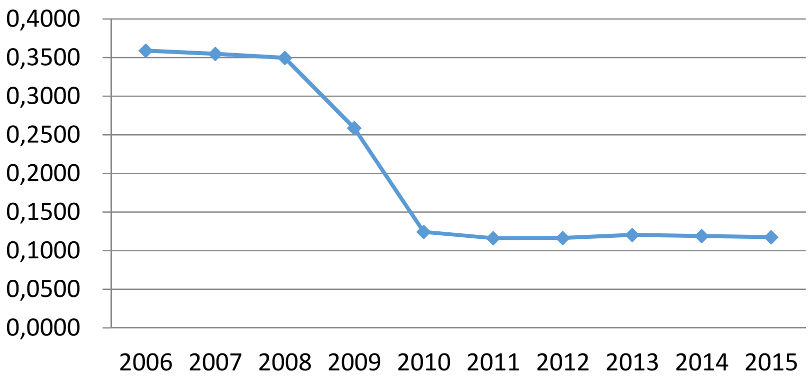

Fig.1 The Index Curve of Natrual Factors of FarmlandEcological Safety of Yuxi City from 2006 to 2015

4.2 Economic Factors

Though the economic factors of ecological safety index was rising up slightly in year 2008 and 2012, the overall tendency was keeping down still. It meant that the rapid growing in economy gave some compensation to the ecological safety of farmland in some certain; however, generally speaking, the development of economy bought many negative impact to farmland and threatened the ecological safety due to over exploitation of arable land, and overuse of fertilizers, mulch and pesticides etc., which made the safety condition of farmland ecological safety keep worsening.

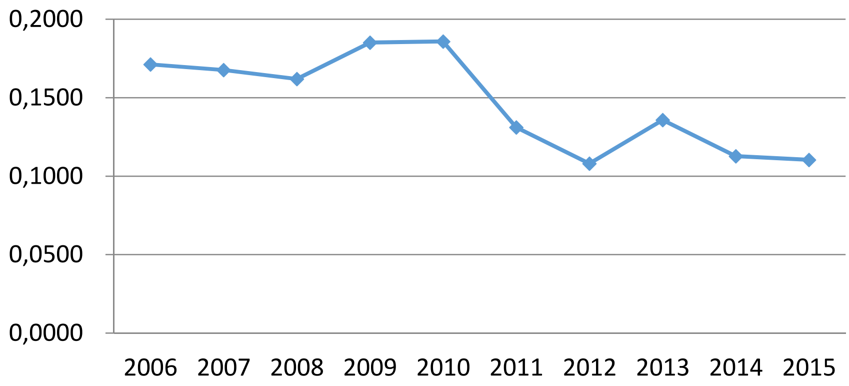

Fig.2 The Index Curve of Economic Factors of FarmlandEcological Safety of Yuxi City from 2006 to 2015

4.3 Social Factors

The ecological safety index curve of social factors of farmland in Yuxi displayed a gradual upward tendency. Over the ten years, the population density and natural growth rate both tended to go down; whereas the average per capita net income of farmers' per capita share of grain kept increasing, which made the general ecological safety index of social factors grow slowly. However, the drought from 2008 to 2010 resulted in a notable decreasing in per capita share of grain, and a short-time decrease of ecological safety index as well.

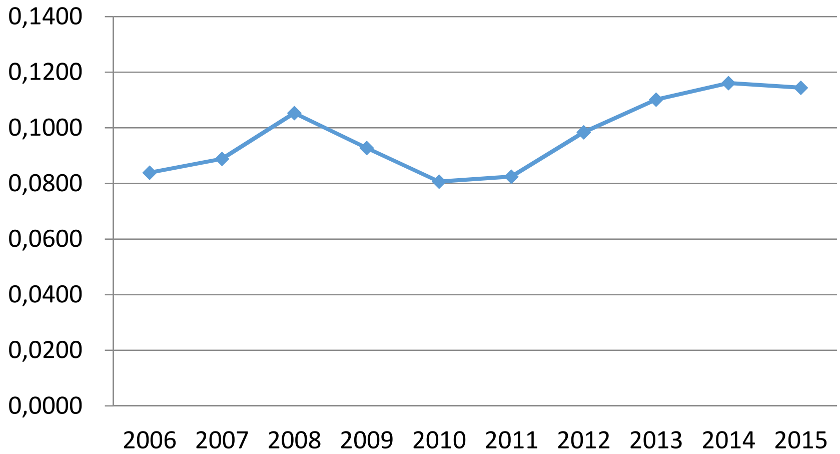

Fig.3 The Index Curve of Social Factors of FarmlandEcological Safety of Yuxi City from 2006 to 2015

4.4 Comprehensive Factors

Seen from the overall tendency (Fig. 4), the comprehensive index of farmland ecological safety had been going down from 0.6140 in 2006 to 0.3422 in 2015, with an average decreasing rate of 6.29%, which showed that the ecological safety of farmland of Yuxi was obviously deteriorating. Though there was a slight going-up in the process of decreasing, the situation of ecological safety was still worse than the initial stage, only half of the beginning. Three stages could be divided in the Fig. of index curve of comprehensive factors, in which the first stage was keeping stable and then went down straightly, finally it was relieved but still keeping a tendency of going down. From 2006 to 2008, it was the initial stage, the index of ecological safety was stable, which meant farmland ecological safety was in a good condition. From 2008 to 2012, the index curve of ecological safety went down straightly, with sharp decreasing from 0.6969 in 2008 to 0.3228 in 2012 (the minimum data). Meanwhile, it reached a yearly-down of 0.0735 on average and the rate was as high as 14.95%. The main reasons could be concluded as the rapid development of economy of Yuxi, resulting in the increasing use of pesticides, fertilizers, mulch and discharging of industrial waste water. The third stage was from 2012 to 2015, during which ecological safety index bounced back a little. It went back to 0.3663 in 2013 and then it kept in a situation of going down slightly in 2014 and 2015. All above analyzed the dynamic changing rules of farmland ecological safety of Yuxi from 2006 to 2015 to learn the ecological security in ten years.

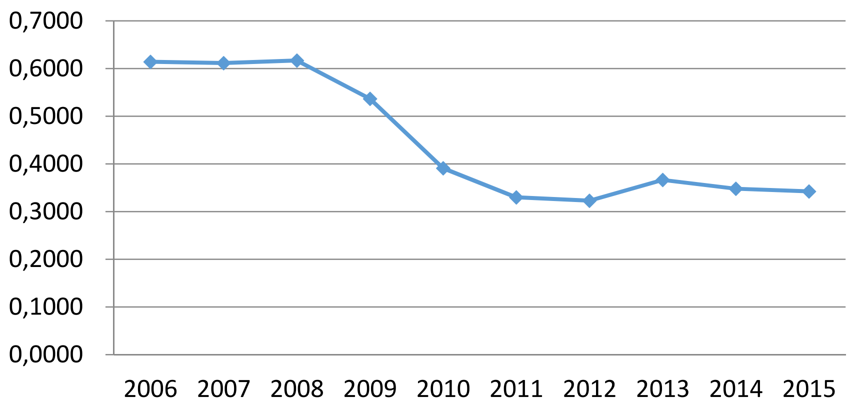

Fig.4 The Index Curve of Comprehensive Factors of FarmlandEcological Safety of Yuxi City from 2006 to 2015

4.5 Correlation Analysis

With the assistance of SPSS, some correlation analysis had been done and the results were shown in Fig. 6. The significance level of natural and comprehensive factors was less than 0.01, which was an extremely significant degree; the correlation index of economic and comprehensive factors was less than 0.05, which was in a remarkably significant level; and the significance index of social and comprehensive factors was larger than 0.05, and it meant that they were not that correlated. All these explained that the main driving factor that made the farmland ecological safety index change was natural factors, and economic factors followed.

Tab.6 Correlation of Farmland Ecological Safety Index

	Natural Factors	Economic Factors	Social Factors	Comprehensive Factors

Natural Factors	Pearson Correlation	1	.633*	-.296	.989**
	Sig. (2-tailed)		.049	.406	.000
	N	10	10	10	10
Economic Factors	Pearson Correlation	.633*	1	-.642*	.722*
	Sig. (2-tailed)	.049		.045	.018
	N	10	10	10	10
Social Factors	Pearson Correlation	-.296	-.642*	1	-.306
	Sig. (2-tailed)	.406	.045		.390
	N	10	10	10	10
Comprehensive Index	Pearson Correlation	.989**	.722*	-.306	1
	Sig. (2-tailed)	.000	.018	.390	
	N	10	10	10	10

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

5 Conclusion and Discussion

Based on some theoretical researches in China, 15 evaluation indexes that could influence the ecological safety level from natural, economic and social aspects were selected according to the reality of Yuxi and the model of "Nature-Economy-Society Concept" to construct the evaluation system of farmland ecological safety of Yuxi. Analytical Hierarchy Process was used to confirm the weight value of different indexes, evaluation model to work out the indexes of ecological safety from 2006 to 2015, and meanwhile SPSS was applied to do the correlation analysis among ecological safety indexes. The outcomes showed that the comprehensive index of ecological safety from 2006 to 2015 was keeping dropping down, which meant that during this time, the situation of farmland of Yuxi was worsening all the time and its change could be defined as the following three stages. The first stage was stable and unchanged, and the second stage went down in a straight way and the third stage was going down slowly. Besides, the main driving factors of making farmland ecological safety change were natural and economic.

Seen from the outcomes, the farmland ecological safety index tended to decline continuously and it was not that optimistic to the future of ecological situation of Yuxi. Both natural and economic actions had to be taken to reduce the non-agriculture use of arable and unused land, to rise the coverage rate of forest, to give more power on decreasing pollution and environmental protection, to control the use of pesticides, fertilizers and mulch, to make use of some bio-engineering measures to improve the quality of land and to build an efficient lac-plantation-farmland ecosystem so that the ecological security level of farmland of Yuxi can be bettered gradually and the sustainable development can be realized.

In addition, the ecological security level of different time and places needs to be analyzed further, and the trend of ecological security changing should be predicted so as to provide more specific sustainable development strategies.

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