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Coordinative Development Between Land Use Change and Regional Population-Resources-Environment-Development System —A Case Study of Jiangsu Province

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Abstract: Land use change has significant influence on the operation of the Population-Resources-Environment-Development (PRED) System. Moderate land use is the key factor to ensure the coordinative and sustainable development between land use and PRED system. Based on the internal relationship between land use and PRED system, a PRED evaluation index system and a Press-Status-Response (PSR) model were established in this study. According to the expounding on the mechanism of the PSR model, we investigated the coordinative development between the changes of regional land use and PRED system taking Jiangsu Province as an example. The results showed that the orders of the Synthetic Index of Land Use (SILU) and the Variation of PRED Index (VPI) in Jiangsu are both the southern Jiangsu>the central Jiangsu>the northern Jiangsu. A cubic curve model was used to fit the relationship between the VPI and SILU. The inflection point of VPI was situated in 5.0 of SILU. When SILU was below 5.0, VPI increased with SILU, which will be helpful to the coordinative development between land use and PRED system. Based on those results, it is suggested that the land use degree of the southern Jiangsu, especially that of Nanjing City, should be moderately controlled at present, while land resources of the central Jiangsu and the northern Jiangsu should be further exploited.

Keywords: land use change; Population-Resources-Environment-Development (PRED) system; Press-Status-Response (PSR) model; coordinative development; Jiangsu Province; China

1 Introduction

Land use is the activity that people use land resources to produce living substance according to certain socio-economic purposes (Luo et al., 2003). Reasonable land use is the base for coordinative development among sub-systems such as population, resources, environment and development, while unreasonable land use will do harm to the sub-systems and affect the sustainable use of land resources. However, the research on land utilization and its ecological effects had not caused public concern until the 1990s, when the International Council of Scientific Unions (ICSU) and International Social Scientific Unions (ISSU) under the research of the Global Environmental Change promoted the studies on land use/cover changes. In 1995, the book named *Land Use/Cover Changes Research Plan* was published by International Geosphere-Biosphere Programme (IGBP) and International Human Dimensions Program (IHDP). Since then, land use/cover changes study has been gradually given priority in the field of the global environmental changes (Li, 1996). Especially in recent years, all kinds of acute crises, such as global population explosion, resources shortage, environmental degradation, etc., made the research of the regional land use change to be an important component of the "International Human Dimensions Program on Global Environmental Change" (Turner et al., 1995; Lambin et al., 1999; Liu, 2002).

Nowadays, studies abroad concentrate on the processes, mechanisms and forecasts of global or regional land use change (Xu et al., 2002; Helen, 2001; Rik and Suzanne, 2004). Chinese scholars focus on the classifi-

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cation, dynamic monitoring and environmental impact assessment of land use/cover in the whole country or some typical areas (Shi et al., 2000; Li, 1999; Yang, 2002; Lin and Liu, 2002; Lai et al., 2003). Moreover, research of the impacts of land use on ecological environment has been generally laid on the relationships between land use and single factors like population, resources, environment and economy. For example, some researchers investigated the impact of land use on population (Tang and Zhao, 2005; Liao and Li, 2003), others mainly concentrated on the impact of land use on the soil, water and atmosphere (Gao et al., 2005; Zheng et al., 2005; Zhao et al., 2004; Zhang and Fu, 1998; Wang et al., 2002; Li et al., 2003). However, comprehensive analysis of the effects of land use on the organic system of "Population-Resources-Environment-Development" (PRED) has rarely been reported. Therefore, it is difficult for us to grasp the land use from the whole, and to achieve coordinative development between the regional PRED system and land use.

As an open system with high complexity, uncertainty and multiple hierarchy, PRED system aims at coordinative development of its sub-systems including population, resources, environment and development. PRED index is used to measure the degree of coordination among the sub-systems. In addition, those sub-systems are also composed of more minor sub-systems. There are some corresponding relationships among those minor sub-systems, such as interdependence and interaction, mutual promotion and restraint, and positive and negative effects (Feng and Wang, 1996). Thus, the effects of land use on the whole PRED system can not be simply treated as the sum of its effects on the sub-systems. Based on the definition of the concept and characteristic of the effect of land use on PRED system, the objective of this study is to establish both a PRED evaluation index system and a Press-Status-Response (PSR) model to analyze regional coordinative development between land use and PRED system, particularly in Jiangsu Province.

2 Methods

2.1 Synthetic index of land use change (SILU)

This synthetic index mainly explains the depth and breadth of the regional land use change degree by reflecting the overall changes in the quality structures of various land use types.

$$\Delta T_{b-a} = T_b - T_a = \left\{ \sum_{i=1}^{n} A_i \times C_{ib} - \sum_{i=1}^{n} A_i \times C_{ia} \right\} \times 100 \quad (1)$$

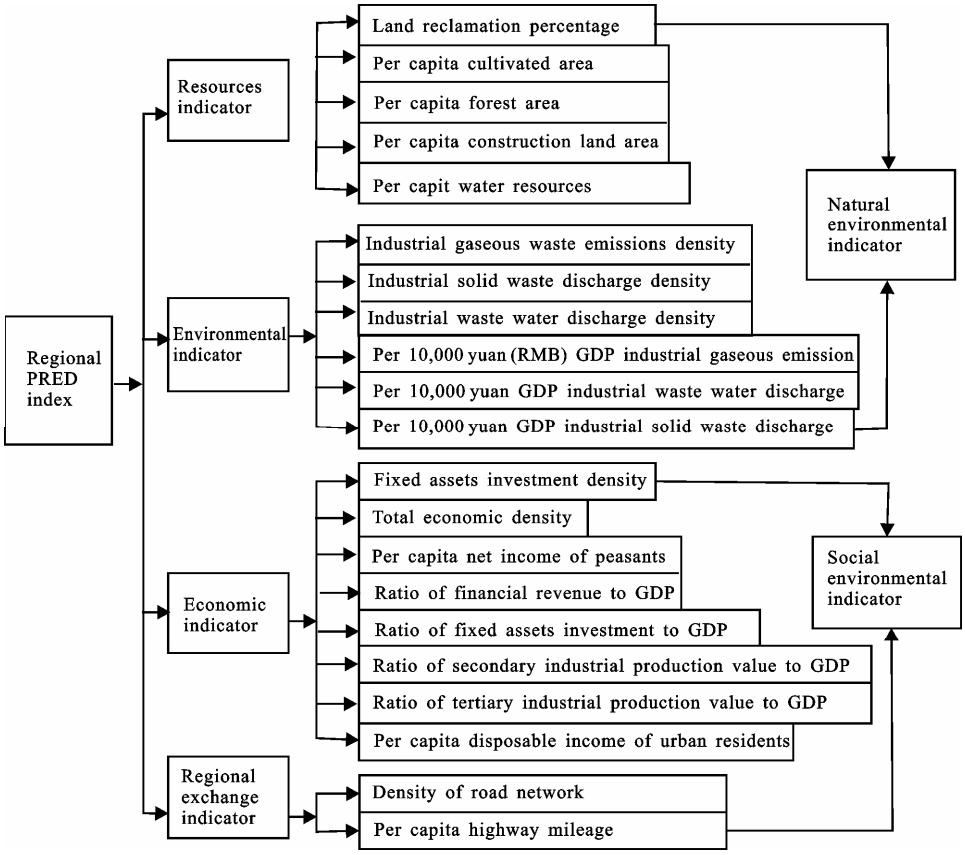
where ΔT_{b-a} represents SILU change. If $\Delta T_{b-a}>0$, the regional land use is in a period of development, if $\Delta T_{b-a}=0$, the regional land use is never changed obviously, and if $\Delta T_{b-a}<0$, the regional land use is in adjustment or recession period. T_a and T_b are the SILUs at time a and b, respectively. A_i, land use grading index of land use type i. C_{ia} and C_{ib}, the area percentages of land use type i at the time a and b. n is the number of land use grades (Jin et al., 2003; Zhuang and Liu, 1997).

2.2 Regional PRED index

PRED index was calculated by establishing the PRED evaluation index system in this paper. Firstly, an evaluation index system was designed to take on the stability of the responding body, namely PRED system. This index system can provide us with the highly condensed information after synthesizing data. Therefore, the main goal of the evaluation on the regional PRED system is to get a comprehensive index, i.e., PRED index.

In this index system, indicator selection not only complies with the intercommunity principle (e.g. comparability, stability, sustainability, scientificity, operation and compendiousness) (Xie, 2003; Chen et al., 2004), but also takes into account whether there exist the inevitable links between the land use and sub-systems of PRED system, in the mean time considers the traditional elements of the PRED system such as population, resources, environment and development. Hence, based on the existed achievements, we choose natural environmental indicators (including the indicators of resources and environment) and social environmental indicators (including the indicators of economy and regional exchange) to construct the regional PRED evaluation index system (Fig. 1).

During the whole processes of evaluating, the most important thing is to determine scientific evaluation index system, to choose feasible comprehensive evaluation method, and to transform indicators. So, the means of index value standardization is used to eliminate dimension, which would be helpful to maintain the stability of evaluation indicators, and to increase the comparability of the comprehensive index. Entropy method can be applied to assessing the weight of indicators (Guo, 1998).



The value of fixed assets investment density, total economic density, and the density of road network are equal to fixed assets investment per unit area, total GDP per unit area and road network per unit area respectively

Fig. 1 PRED index system

It is assumed that the number of the regions of PERD index is m, i.e., P_i (i=1, 2, 3,…, m), and the number of the indicators composed P_i is n, i.e., P_{ij}=(P_{i1}, P_{i2}, P_{i3}, ..., P_{in}).

$$P_{ij}' = P_{ij} / (P_{\max} + P_{\min}) \tag{2}$$

where P_{ij} represents the index value before standardization; P_{ij}' is the value of P_{ij} after standardization; $P_{\max}$ and $P_{\min}$, the maximum and minimum index value before standardization. Meanwhile, based on the evaluation method designed above, the following equation is employed to weigh indicators, so we attain:

$$P_i = \left| \sqrt{\sum_{j=1}^{n} W_j P_{ij}'^2} \right| \tag{3}$$

where P_i stands for the comprehensive index of the regional PRED system; W_j, the indicator weight obtained by the entropy method. In addition, $\Delta P_{(b-a)i}$ is the variation of PRED index (VPI) from the time a to time b. P_{ia} and P_{ib} represent the regional PRED indexes at the time a and b, respectively.

$$\Delta P_{i(b-a)} = P_{ib} - P_{ia} \tag{4}$$

If VPI>0, the stability of PRED system is enhanced; if VPI≤0, PRED system stability is unvaried, or reduced.

2.3 Press-Status-Response (PSR) model

In order to describe the coordinative developmental relationship between PRED system and land use change, we established the Press-Status-Response (PSR) model, which is composed of three main parts (Fig. 2).

(1) Press. Regional land use should meet the need of the social sustainable development, which is the source of "pressure". It mainly derives from two aspects. First, regional construction land quickly increases along with the evolution of the industrialization and urbanization strategy. Second, it also shows different degrees of fluctuation because of the administrative and marketable land allocation, as well as the governmental macro-control on the land resources. Since land is the basic resources and environmental condition for human's sur-

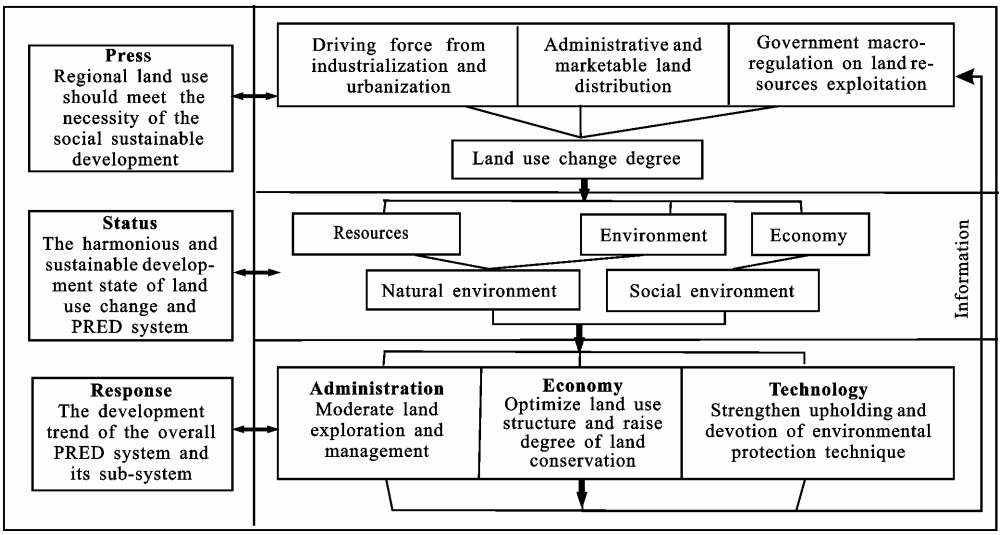


Fig. 2 Press-Status-Response model

vival and development, it is inevitably that land use change will have enormous influences on human production, daily life, resources and environment, which are all the sources of the pressure existing in this model.

(2) Status. The pressure concerned above can increase the contradictions between socio-economic development and the need of land resources. The excessive land use will further threaten the sustainable development of the society. For a particular region, the sustainable development can be attributed to the development of the regional PRED system including population (P), resources (R), environment (E) and development (D) (Xie, 2003). Therefore, under the pressure caused by the land use change, the internal sub-systems and their minor sub-systems of PRED system will respond the changes of the overall PRED system. The positive effects will increase the stability of the PRED system, as well as the further exploration of the land resources. While the negative ones will decrease the stability, mainly reflecting in the decline of the PRED index, the shortage of the per capita possession of resources, the increase of environmental pollution, and the decline of regional economic development.

(3) Response. Based on the "response" signal from the "status", a series of policies and measures, such as the administrative, economic, technological means will be adopted in response of the regional land use change and the subsequent disorder of the PRED system. By doing those, we should control the system's inner structure, change its inner organizing mechanism and make response to the surrounding pressures caused by the land use change. Meanwhile, this kind of response will also act as the new information entering the next new cycle and affect the "pressure" part of this model, thus leading to the changes in the parts of "pressure" and "status" in the oncoming cycle. So, only under the circumstances of benign cycle, can the regional land use and PRED system develop sustainably.

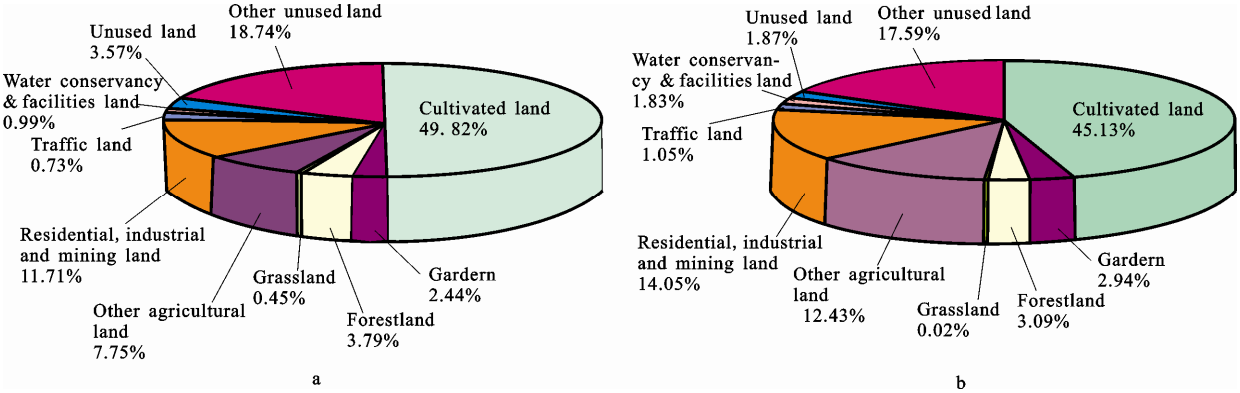
Obviously, after a cycle, the status of the regional land resources is not the same as its beginning. Along with the changes of land use degree, regional PRED system has also changed. In order to maintain the sustainable development of the regional land use and PRED system, a benign cycle of the sub-systems in the PSR model and the moderate land use change are required. From the above analysis, it can be seen that, in the scope of PRED system stability, the increasing of land use will attribute to the coordinative development among the regional population, resources, environment and development, together with the further exploration of the land use. Nevertheless, once beyond the threshold, further increase of the land use degree will hinder the development of the regional PRED system. At this time, we should take some measures to adjust the structure, the extent and the mode of the land utilization. So, making clear the relationship between the changes of land use degree and PRED index is important not only to the moderate land exploration and management, but also to the regional coordinative development between land use and PRED system.

3 Case Study

In this study, we take Jiangsu Province as an example to analyze the relationship between land use degree and PRED system. Jiangsu Province, an eastern province of China, is in the middle of mainland coastal area, and in the downstream plain area of the Changjiang (Yangtze) River and the Huaihe River. Its total area is 102.6×10^3 km^2, accounting for 1.07% of China. It is composed of 13 major cities, including Nanjing, Wuxi, Changzhou, Suzhou, Zhenjiang in the southern Jiangsu, Nantong, Yangzhou, Taizhou in the central Jiangsu and Lianyungang, Xuzhou, Huai'an, Yancheng and Suqian in the northern Jiangsu. In 2004, the total population of Jiangsu Province was 720.605×10^6, accounting for 5.51% of China, and the province's population density was 702.34 persons/km^2, which is one of the largest population density regions in China. In recent years, Jiangsu's land resources faced with tremendous pressure due to the industrial structural adjustment and optimization, the rapid urbanization and the increasing growth of population, regional human-land contradiction, which further increased the land use degree and consequently affected the stability of the PRED system.

3.1 Land use change

From 1989 to 2004, the conversion of land resources occurred dramatically in Jiangsu Province. Regional cultivated land and unused land were reduced fast along with an increase in the urbanization development and the demand for construction land (Fig. 3).



Unused land includes unused grassland, saline-alkali land, sandy land, marshes and swamps, barren earth and bare exposed rock or gravel; other unused land includes glacier and perennial snowfields, and parts of river, lake, reed pond, beaches, which has not been used by the human

Fig. 3 Land use structure of Jiangsu Province in 1989 (a) and 2004 (b)

In 2004, the area of cultivated land and construction land in Jiangsu Province was 482×10^6ha and 181×10^6ha, respectively. The proportion of cultivated land, construction land and unused land accounted for 63.61%, 16.93% and 19.46%, respectively. Compared with those of 1989, the proportions of its cultivated land and unused land reduced by 0.64% and 2.86%, while the construction land increased by 3.50%.

The regional SILU is obtained according to Equation (1) (Table 1). From 1999 to 2004, 12 major cities, except for Huai'an, had positive values of the SILU, indicating that those 12 cities were all in the land use developing period. Moreover, the SILUs of these cities, including Nanjing, Wuxi, Changzhou, Suzhou, Zhenjiang and Taizhou, were greater than the average of Jiangsu (1.71). Except for Taizhou, the other five cities, which had fast development of the social economy, are all located in the southern Jiangsu. Among them Nanjing had highest SILU. The SILU in other seven cities (Xuzhou, Lianyungang, Huai'an, Yancheng, Suqian, Nantong and Yangzhou) were all lower than the average one. Those in Yangzhou and Nantong, which are parts of the central Jiangsu, were 1.54 and 1.21, respectively. The five cities in the northern Jiangsu had lower socio-economic development. Lianyungang and Suqian had lower SILU, 0.28 and 0.44 respectively. Nanjing's SILU was 21 times as much as that of and Lianyungang. Finally, regional SILU was in the order of the southern Jiangsu (4.61)>the central Jiangsu (1.71)>the northern Jiangsu (0.41), which demonstrated that the SILU has a close relationship with the regional economic development.

Table 1 Regional land use change degree of Jiangsu Province in 1999–2004[①]

City	Nanjing	Wuxi	Changzhou	Suzhou	Zhenjiang	Nantong	Yangzhou
SILU	5.86	4.12	5.35	3.59	4.49	1.21	1.54
City	Taizhou	Xuzhou	Lianyungang	Huai'an	Yancheng	Suqian	Jiangsu Province
SILU	2.84	1.20	0.28	−0.59	0.56	0.44	1.71

3.2 Regional PRED index analyses

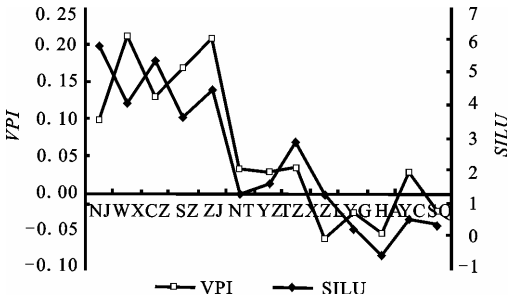
The regional PRED index and the VPI of Jiangsu Province between 1999 and 2004 were calculated by equations (1), (2) and (3) (Table 2).

Table 2 PRED index of Jiangsu Province in 1999–2004

City	Natural environmental index			Social environmental index			Regional PRED index		
	1999	2004	Variation	1999	2004	Variation	1999	2004	VPI
Nanjing	0.50	0.50	0.00	0.32	0.49	0.17	0.60	0.70	0.10
Wuxi	0.29	0.34	0.06	0.28	0.51	0.22	0.40	0.61	0.21
Changzhou	0.28	0.31	0.02	0.25	0.41	0.16	0.38	0.51	0.13
Suzhou	0.24	0.34	0.11	0.28	0.41	0.13	0.36	0.53	0.17
Zhenjiang	0.35	0.56	0.21	0.24	0.30	0.06	0.43	0.64	0.21
Nantong	0.18	0.18	0.00	0.21	0.26	0.05	0.28	0.31	0.03
Yangzhou	0.22	0.20	–0.02	0.21	0.26	0.05	0.30	0.33	0.03
Taizhou	0.20	0.20	–0.01	0.19	0.25	0.05	0.28	0.32	0.04
Xuzhou	0.33	0.24	–0.09	0.22	0.23	0.02	0.40	0.34	–0.06
Lianyungang	0.33	0.27	–0.05	0.20	0.23	0.03	0.39	0.36	–0.03
Huai'an	0.31	0.24	–0.07	0.22	0.23	0.01	0.38	0.33	–0.05
Yancheng	0.24	0.25	0.01	0.17	0.20	0.03	0.29	0.32	0.03
Suqian	0.26	0.20	–0.06	0.17	0.20	0.03	0.32	0.29	–0.03

Sources: Environmental Protection Bureau of Jiangsu Province, 2005; Environmental Protection Bureau of Jiangsu Province, 2000–2005; Statistics Bureau of Jiangsu Province, 2000–2005

Compared to that of 1999, PRED indexes of Xuzhou, Lianyungang, Huai'an and Suqian in 2004 fell down, which indicated that the stability of their regional PRED systems trends to decline. Meanwhile, PRED indexes of the remaining cities were increasing steadily. Among those cities, Wuxi and Zhenjiang had the most notable increase by 0.21, Yangzhou and Yancheng only had a slight increase by 0.03. Together, those results showed that along with the strengthening of the economic and environmental renovation, the pressures resulted from regional economic development on the environment in the southern Jiangsu and the central Jiangsu was less than those in the northern Jiangsu, and the regional PRED system of the southern Jiangsu and the central Jiangsu were more stable than that of the northern Jiangsu. So, the higher PRED index largely owed to an increase of the social environmental index. Additionally, combined with the above analyses, we can see a relationship between changes of the regional PRED system and land use.



NJ: Nanjing, ZJ: Zhenjiang, WX: Wuxi, CZ: Changzhou, SZ: Suzhou, NT: Nantong, YZ: Yangzhou, TZ: Taizhou, XZ: Xuzhou, LYG: Lianyungang, HA: Huai'an, YC: Yancheng, SQ: Suqian

Fig. 4 Response of variation of PRED index (VPI) to Synthetic index of land use (SILU)

3.3 Regional PRED Index

The results of the relationship between regional land use and PRED system are showed in Fig. 4.

In general, regional VPI had approximately the same trend with SILU, with highest VPI in the southern Jiangsu and lowest in the northern Jiangsu. The major reason was that different regions can afford diverse support for regional environmental and technological development. With the highest level of economic development in Jiangsu, the southern Jiangsu had the ability to provide more of this kind of support, thereby modera-

① Ministry of Land and Resources, Government of Jiangsu Province of People's Republic of China, 1999–2004.

ting the influence of the SILU on PRED system. But the northern Jiangsu was unable to solve the contradiction existing among the economic development, land resources utilization and the PRED system's stability. Meanwhile, the fluctuation degree of SILU was obviously larger than that of VPI when considering the whole province. The above analyses clearly showed that low level of socio-economic development, poor economic strength and some contradictions existing between the development of economy and environment were all contributed to the regional PRED system depression.

Based on the above analyses and the fact that regional economic development cannot afford infinite support for the environment, science and technology, regional PRED index will not unlimitedly increase along with the increase of SILU. Therefore, in order to reflect the finite character of increase, cubic curve-fitting method was chosen to fit a regressive equation between VPI and SILU (Fig. 5).

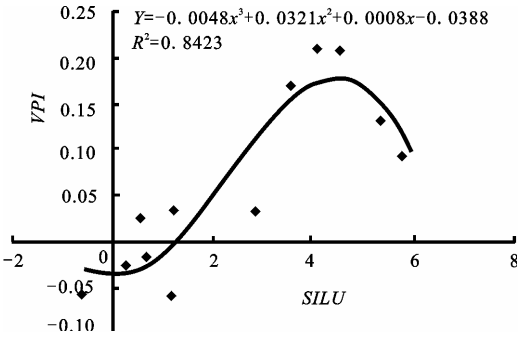


Fig. 5 Curve fitting between variation of PRED Index (VPI) and synthetic index of land use (SILU)

The correlation coefficient of this equation is 0.8423, which indicated that the regional VPI has preferably response to the SILU. The inflexion point of the regional PRED index change is situated around 5 of the SILU. That is to say, when the SILU does not reach the value of the inflexion point, along with the rise of the SILU, the VPI will continue to rise along with the rise of the SILU. Once the SILU reaches to, or over the value of the inflexion point, and continues to rise, regional PRED index will show a declining trend. The above analyses showed that in the stability range of the PRED system, the rise of the SILU could further increase the stability of the PRED system. Conversely, when the land use degree is more than a certain threshold, further strengthening and consolidation on the land utilization will increase the instability in PRED system. Under this circumstance, regional economic development will be at the expense of its resources and environment, and the land use and PRED system of Jiangsu Province will enter into an un-sustainable development situation.

4 Conclusions

Combined with the above analyses, we can see that land use change has significant influence on the operation of Population-Resources-Environment-Development (PRED) System, and there exists response relationship between SILU and VPI. SILU and VPI were sorted as the southern Jiangsu>the central Jiangsu>the northern Jiangsu. A cubic curve model was used to fit the relationship between VPI and SILU. The inflection point of the regional PRED index was situated around 5.0 of SILU. When SILU was below 5.0, VPI increased, which will be helpful to the coordinative development between land use and PRED system.

According to the theoretical understanding of PSR model, it is necessary for Jiangsu Province to take certain policies and measures, such as moderately developing and using land resources, optimizing land utilization structure, raising the saving degree of land resources utilization and so on. After that, Jiangsu Province would obtain the economic takeoff and a good circle between land use and regional PRED system. However, it should be noted that the stable range of the regional PRED system is highly variable, possibly caused by the indices choice of PRED system and other factors, such as the changes of type and quantity of resources, the promotion of technology, the improvement of the management level and so on. Therefore, Jiangsu Province should extend the stable range, promote the stability of PRED system by deepening cognition of environment, carrying out scientific developmental viewpoints as well as taking effective measures to strengthen scientific and technological knowledge in the near future. Only in this way, can Jiangsu Province achieve the sustainable, coordinative development between land use and PRED system without damage to the regional human security, resources and its environment.

Furthermore, the above results only obtained by choosing Jiangsu Province for example. Whether there exists the cubic curve response relationship between

VPI and SILU commonly in other regions or not still needs us to carry further studies.

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