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CATASTROPHIC ECO-ENVIRONMENTAL CHANGE IN THE SONGNEN PLAIN, NORTHEASTERN CHINA SINCE 1900S

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ABSTRACT: Although the Songnen Plain in the northeastern China was developed relatively late in the temperate zone of the world, its eco-environment has changed greatly. This paper analyzes the changes of land cover and the rates and trends of desertification during the past 100 years in the Songnen Plain. According to the macroscopic analysis, we find that the eco-environment in the plain has reached to the threshold of catastrophic change since the 1950s. The Thom Needle Catastrophic Model was used to determine and validate this conclusion. Human activities, including large-scale construction projects, such as huge dams and dikes, and excessive grazing were the primary factors contributing to regional eco-environmental catastrophe. And irrational reclamation of the wilderness also affected the eco-environmental change. The results reveal the complex human-land interactions.
KEY WORDS: eco-environment; catastrophe; modeling; Songnen Plain

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1 INTRODUCTION

The Songnen Plain in the northeastern China has very unique and integral natural environment. Although it was developed relatively late, only for about 100 years, in the temperate zone of the world, its eco-environment has changed alarmingly. Therefore, the Songnen Plain is an ideal experimental area for understanding the interactions between the human society and the natural environment. There have been many reports about the environmental change in the plain (GUO, 1982; LI *et al.*, 1998; LI, 2000; QIU, 2001). Much attention has been paid to the modern processes of the extensive surface desertification. However, the studies concerning environmental catastrophe and its modeling and classification were rare. To date, only GUO Shao-li (1982) has preliminarily analyzed the spatial distribution of catastrophe regions in the Songnen Plain.

In this paper, according to the analysis of the process of environmental change in recent 100 years, the threshold of catastrophic environmental change of the Songnen Plain will be obtained. The Needle Catastrophe Model will be used to validate the conclusions from the study. And the dominant factors affecting environmental catastrophe will be studied. This paper aims at providing essential theoretical support for understanding the environmental sensitivity, and for protecting and restoring the fragile environment in the plain.

2 STUDY AREA

The Songnen Plain (43°30′-48°41′N, 121°30′-127°0′E), with an estimated area of 215.4×10^3km^2, is surrounded by the piedmont plateaus of the Da Hinggan Mountains, Xiao Hinggan Mountains and Changbai Mountains and the divides of the Songhuajiang River and the Liaohe River watersheds (YANG, 1998; LI, 1997).

The Songnen Plain was formed by alluvial, lacustrine and aeolian deposits. Tectonically, the plain was a large Mesozoic sediment basin developed on the base of Paleozoic folds and a part of the Cenozoic Song-Liao Fault Basin (SUN, 1990). It has the temperate semi-humid and semi-arid continental monsoon climate, with an average annual air temperature of 4.9℃± 1.5℃, average annual precipitation of 450mm±50mm, and average annual evaporation of 1450mm±203mm (YANG, 1996). Its hydrological environment is unique that there were centripetal, out-flowing water system

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formed by the Nenjiang River and the Songhuajiang River. The main types of soils in the area include black soil, chernozem, meadow soil, swamp soil, halic soil, sandy soil, and paddy soil, and the typical zonal soils are black soil and chernozem (SONG, 1961). Owing to the agricultural expansion, grasslands are mainly distributed in the west of the Songnen Plain and interlaced with farmland. The landscape vegetation in the area is *Leymus chinesis* meadow (LI *et al.*, 2001). The Songnen Plain is one of the main bases for grains production and animal husbandry in the northeastern China, and one of the areas with clusters of poverty countries in China.

3 MACROSCOPIC ANALYSES OF ENVIRONMENTAL CATASTROPHE

The process of environmental changes in the Songnen Plain during the past 100 years was greatly affected by human activities. The rapid growth of population has raised a series of environmental problems. The unscrupulous reclamation has caused serious deforestation and the retreat of grasslands. The illogical construction projects and excessive grazing have also resulted in land degradation. Owing to the natural evolution and human influences, deserts and semi-deserts have appeared in the middle of the plain. This indicates that human activity was a strong forcing factor in environmental changes in the Songnen Plain. A fragile ecosystem with relatively small threshold values mutates easily under the influence of external forcing inputs.

3.1 Change of Land Cover

Land cover is the comprehensive representation of a regional eco-environment. The land cover change is caused by both natural and artificial factors. By analyzing the changes in land cover, regional eco-environment and the mechanism how various factors works to affect the environment can be better understood. Based on the correlative patterns between geomorphology and vegetation, soils and vegetation, climate and vegetation, and pollen analyses, field surveys, and recovery extrapolation, the map of land cover in the 1900s in the Songnen Plain was completed (JIANG and GAO, 1990; LI Jian-cai, 1995) (Fig. 1). At the same time, according to the relevant data of regional vegetation distribution and land use in 2000, field surveys and calibration, the map of land cover in the 2000s was also completed (Mapping Committee of Vegetation Atlas, 2001) (Fig. 1). Fig. 1 shows that the changes of land cover have reached to catastrophic threshold during the past 100 years in the plain.

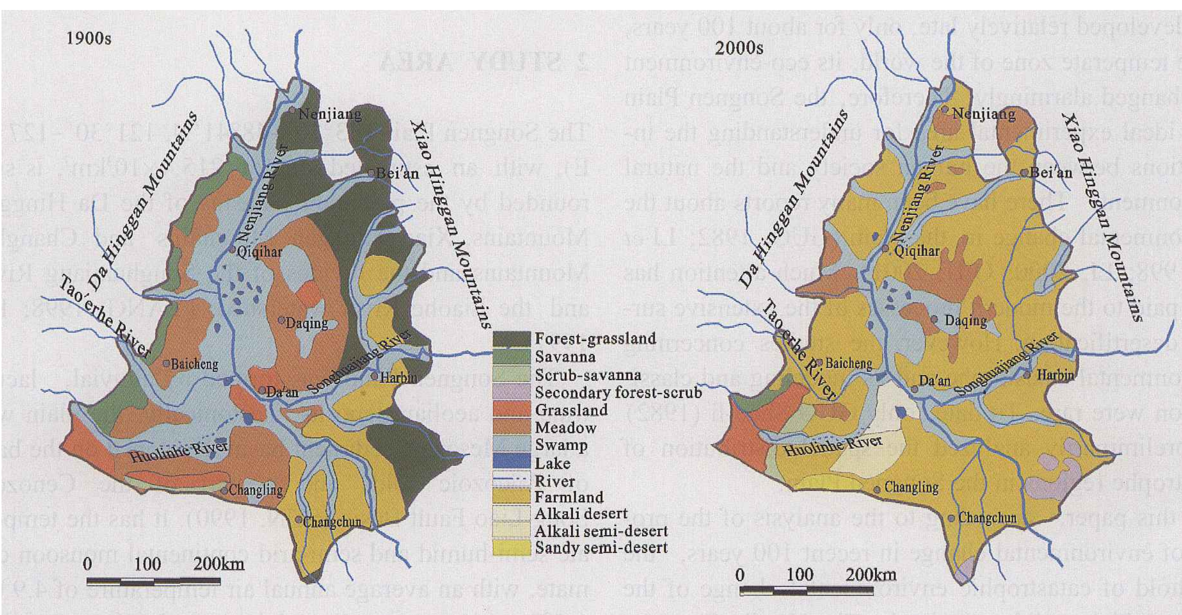

Fig. 1 Land cover change of the Songnen Plain in recent 100 years

From Fig. 1, farmlands and corridors appeared only in the black soil zone of forest steppe in the Songnen Plain in the 1900s. The pristine environment was largely intact. But in the 2000s, the landscape of the plain has changed apparently. With the assistance of GIS, the changing values of the land cover were calculated (Table 1). According to Table 1, the changes of the natural cover in the Songnen Plain reached to 70% in the 2000s.

Since the 20th century, along with the construction

Table 1 Changing values of different land types in the Songnen Plain for recent 100 years

Types of land cover	1990s (km^2)	2000s (km^2)	Changing values (km^2)	Changing ratio (%)
Forest-grassland	39685	0	-39685	-18.42
Savanna	8158	1319	-6839	-3.17
Scrub-savanna	0	334	+334	+0.16
Secondary forest-scrub	0	3738	+3738	+1.74
Grassland	20198	14587	-5611	-2.60
Meadow	44263	15304	-28959	-13.44
Farmland	26516	131329	+104813	+48.66
Swamp	74917	38710	-36207	-16.81
Lake	1690	1452	-238	-0.11
Alkali desert	0	2051	+2051	+0.95
Alkali semi-desert	0	4829	+4829	+2.24
Sandy semi-desert	0	1774	+1774	+0.82

of railway and highway net in the region, immigration reached to climax and the regional population experienced an explosive growth. The large-scale dikes and other infrastructures have been built for rapid urban expansion since the founding of the People's Republic of China in 1949. Therefore the natural vegetation was largely destroyed and the natural environment greatly changed, resulting in disappearance of whole forest-grassland and large parts of savanna. Grasslands, meadows on the high terraces and wetlands adjacent to rivers in the middle of the plain have been generally developed or heavily over-grazed.

3.2 Change of Water System

Before the 20th century, the water system structure and hydrological process was largely intact in the Songnen Plain. Periodical flooding and wandering of the Songhuajiang River and its tributaries provided sufficient water supplies for lakes and wetlands. With population increase, and the accompanied construction of various projects such as highways and railways, and water diversion and flood-control dikes, some open outflow regions were closed, resulting in semi-inflow water systems. In the meantime, the standing water body in the reservoirs affected the quality and quantity of surrounding waters, which caused some lakes and swamps to be shallower, drier and more halic (LU *et al.*, 2000). As a result of the construction of Xianghai Reservoir, the flood peak runoff in the downstream of the Huolinhe River decreased sharply and even lead to the break of Emqin River in drainage area of the Huolinhe River (LI *et al.*, 1998). The total alkalinity changed from 310–350mg/L in upstream to 560–580mg/L in middle-downstream. All mentioned above indicate that the water system structure and hydrological process in the plain have generally changed.

3.3 Desertification Development

According to the *International Convention to Combat Desertification* (The Secretariat of UNCCD, 1994), desertification includes all kinds of environmental degradation such as sandy desertification, saline-alkalization, grassland degradation, and soil erosion. During the past 100 years, the development rates of desertification in the plain were alarming, resulting in the formation of large areas of deserts and semi-deserts.

3.3.1 Sandy desertification

Sandy desertification of the Songnen Plain mainly occurred in Songnen sandy land. The basic geomorphology of the area is an alluvial plain overlain by dune (ZHU and LIU, 1989). The total area of the Songnen sandy land is 6.15×10^6ha, being 27% of the total land area (LI, 1999; QIU *et al.*, 1995).

The large-scale development of Songnen sandy land began in the mid-20th century, but the rate of desertification was alarming. In the beginning of the 20th century, there was not flaky sandy land; but by the end of the 20th century, the area of desertified land had reached to 5.96×10^6ha (LI and ZHOU, 2001). Since the late 1980s, sandy desertification has been increasing at a rate of 0.8% (LI, 1997).

3.3.2 Saline-alkalization

The Songnen Plain is one of the three major distribution regions of soda saline-alkali soil in the world. The halic soils are mainly distributed in the western part of the plain. The area of saline-alkalization land amounted to only 2.40×10^6ha in the 1950s; but by the beginning of the 1990s, it had reached to 3.20×10^6ha; and it is still increasing at a rate of 20×10^3ha/a. The recent development of the saline-alkalization land was caused mainly by saline-alkalization of grassland, farmland and wetland (LI, 2000). Since the 1900s, the land saline-alkalization has been accelerating at a rate of 1.5% per year (QIU, 2001).

3.3.3 Grassland degradation

The grasslands in the Songnen Plain were located in the central part of the northeastern China. However, most of those grasslands had degraded in the end of the 20th century. In the degraded land, the slight-degraded land accounted for 20%, the moderate-degraded land 30% and the severe-degraded land 30% (LI Jian-dong, 1995). The primary results of grassland degradation were soil saline-alkalization and decrease in grass quality and productivity. Saline-alkalized grasslands accounted for one third of the total area of the degraded grassland, half of which has been turned into saline-alkali patches. In the 1950s, there was 787×10^3ha of grasslands, of which 80% was alkali grasslands. The area of saline-alkalizati on was only 10% of the total area. By the end of the 20th century, however, the area of saline-alkalization had increased to 69.1% of the total area, of which 30%–50% was saline-alkali patches. At present, the rate of saline-alkalization has been accelerating at a rate of 1.85% per year. The grass yield has decreased by 35%, and the grass quality has been increasingly poorer.

3.3.4 Soil erosion

The Songnen Plain is one of the three major distribution regions of black soil in the world. The farmland area was 8.12×10^6ha from statistical data, but 10.72×10^6ha from remote sensing data in a previous study (WANG and WANG, 2001). In present study, the total farmland area of the plain was 13.13×10^6ha in 2000 by remote sensing technique (Table 1). Owing to the reclamation of black soil during the past 40 years, the total organic carbon (TOC) of black soil has deceased by 5.88%, the nitrogen content by 0.37%, and the phosphorus content by 0.06%. The remote sensing data of soil erosion, obtained by the Water and Soil Conservation Institute of Heilongjiang Province, indicate that the erosion area of black soil regions in the northeastern China reached to 4×10^6 km^2, being 37% of the total black soil area. Of the eroded land, the area of water erosion was 3.63×10^6km^2, and the area of wind erosion amounted to 370×10^3km^2 (LI and ZHOU, 2001; ZHOU and LIN, 2003).

3.3.5 Sandy and saline-alkali deserts and semi-deserts

According to the analyses of the four processes of land degradation mentioned above, we can reach the conclusion that the Songnen Plain has been desertified extensively. The developmental rate of desertification and saline-alkalization was 2.3% per year. Large area of sany and saline-alkali deserts and semi-deserts have appeared. These were mainly distributed along the triangular belts from the northern Changling arc sandy belt to Da'an, Tongyu and Qian'an counties. There were also patchy semi-deserts, or desert grasslands in the southern part of the Qiqihar City. Sandy and saline-alkali deserts and semi-desert has already reached 4.0% of the total land area of the Songnen Plain.

4 MODEL DETERMINATION OF ENVIRONMENTAL CATASTROPHE

4.1 Model Selection

Thom firstly advanced a catastrophe theory in the 1970s. Through rigorous demonstration, he pointed out that all kinds of catastrophe processes in nature could be summarized to 7 basic catastrophe types when the factors of continuous change causing catastrophe were less than 4 (NIU, 1992) (Table 2).

Table 2 Seven basic catastrophe models

Model type	Controlling variable	State variable	Trend function(E)
Folding	1	1	$1/3x_1^3 + u_1x_1$
Needle	2	1	$1/4\, x_1^4 + 1/2u_1x_1^2 + u_2x_1$
Swallowtail	3	1	$1/5\, x_1^5 + 1/3u_1x_1^3 + 1/2u_2x_1^2 + u_3x_1$
Hyperboloid	3	2	$1/3\, x_1^3 + 1/3x_2^3 + u_1x_1x_2 - u_2x_1 - u_3x_2$
Ellipse	3	2	$1/3\, x_1^3 - 1/2\, x_1x_2^2 + 1/2u_1(x_1^2 + x_2^2) - u_2x_1 - u_3x_2$
Butterfly	4	1	$1/6\, x_1^6 + 1/4u_1x_1^4 + 1/3u_2x_1^3 + 1/2u_3x_1^2 + u_4x_1$
Paraboloid	4	2	$1/2\, x_1^2x_2 + 1/4x_2^4 + 1/2u_1x_1^2 + 1/2u_2x_2^2 - u_3x_1 - u_4x_2$

Considering the features of selected variables and easy expression, and also for simplifying calculation and reducing the loss of variable information as possible as we could, the Thom needle catastrophe model was selected for the study.

Needle catastrophe model can describe the mathematics expression of a system when there were 2 outside controlling variables (u_1 and u_2) and 1 inside state variable (x). The process of needle catastrophe shows a process that x_1 makes the result of the trend function E reach to minimum when u_1 and u_2 are given.

The trend function of needle catastrophe model is:

$$E = 1/4x^4 + 1/2u_1x + u_2x \quad (1)$$

where x is state variable; u_1, u_2 are controlling variables.

The mathematics expression of needle catastrophe model is:

$$x^3 + u_1x + u_2 = 0 \quad (2)$$

let

$$\triangle = (u_1/3)^3 + (u_2/2)^2 \quad (3)$$

When $\triangle<0$, u_1 and u_2 are in the needle region, and the change type is in potential catastrophe region.

When $\triangle>0$, u_1 and u_2 are outside the needle region, and the change type is in catastrophe region when $u_2>0$ and in stable region when $u_2<0$.

When $\triangle=0$, $u_1=u_2=0$, $x=0$, u_1 and u_2 are on the needle, so u_1 and u_2 that fulfil l the condition $(u_2/2)^2 = -(u_1/3)^3$ are on the boundary of needle region (Fig. 2) (GUO, 1982).

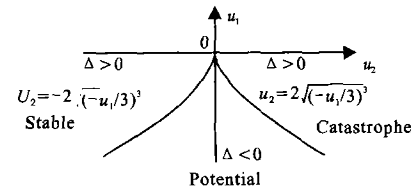

Fig. 2 Region of needle catastrophe

4.2 Model Determination

According to the macroscopic analysis of environmental change, we can conclude that human activities were the dominant factors influencing environmental change in the Songnen Plain in recent 100 years. Consequently, some human factors are selected to validate the conclusion by using the catastrophe model. The selected parameters are listed in Table 3.

The needle catastrophe model requires one state variable and two controlling variables. Therefore, we take environmental change as the state variable and group the seven factors into two kinds, using principal component analysis, of which one is project measure including railway, dike, highway and reservoir's cubage, and the other is destructive action of human beings including reclamation, raising big livestock and sheep (TANG, 2002). The modeling results are as follow:

$$u_1 = 0.000185X_1 + 0.000336X_2 + 0.000053X_3 + 0.002559X_4 - 1.149 \quad (4)$$

$$u_2 = 0.001478X_5 + 0.003573X_6 + 0.002139X_7 - 1.671 \quad (5)$$

According to the determining result of the model, the effects of the selected factors on environmental change are different, i.e., the contributions of the seven factors

Table 3 Artificial factors influencing environment change in the Songnen Plain in past 100 years

Years	X_1 Railway (km)	X_2 Dike (km)	X_3 Highway (km)	X_4 Reservoir's cubage ($\times10^9m^3$)	X_5 Reclamation ($\times10^6$ha)	X_6 Big livestock ($\times10^3$)	X_7 Sheep ($\times10^3$)
1900s	/	/	/	/	1.1367	302*	18*
1910s	402	27	250	/	1.4673	390*	19*
1920s	593	110	450	/	3.4828	926*	45*
1930s	1134	194	910	/	7.3794	1962*	95*
1940s	2176	258	1800	0.028	6.3636	1692*	82*
1950s	2430	543	2015	10.911	5.3477	1422	69
1960s	2684	1192	3710	12.072	6.3711	1947	245
1970s	2939	1566	5927	13.608	6.3100	1941	1064
1980s	3144	1734	9742	16.555	6.9917	2322	2308
1990s	3529	1781	10697	24.266	7.3425	2385	3009
2000s	4110	1781	13742	26.511	7.5516	4322	4940

Notes: /—particle or 0; *—the value is calculated according to the correlation with plantation

to the two united variables (u_1 and u_2) are different and the correlation degree between the seven factors and the united variables were also different. Therefore the needle catastrophe region is not symmetry about coordinate axis of the rectangular coordinates affirmed by u_1 and u_2. The coordinates must be transformed and the transformed rectangular coordinates are affirmed by u_1' and u_2' (Fig.3).

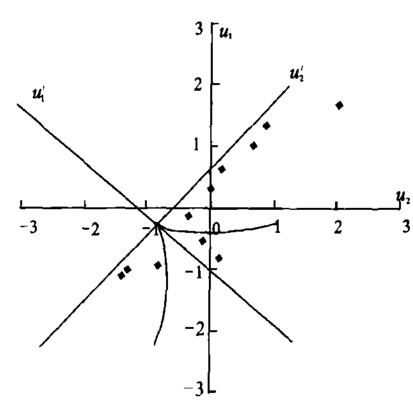

Fig. 3 Confirmation of catastrophe region

From the determining results, it can be seen that when △>0, the environmental change was in stable period from the 1900s to the 1920s; when △<0, it was in potential catastrophe period from the 1930s to the 1940s; when △>0, it was in catastrophe period from the 1950s to the 2000s.

Before the 1900s, large-scale development did not begin, so the environmental condition was still stable and environmental change belonged to a gradual evolution to the beginning of the 1900s. Subsequently as a result of population increasing, construction of railway and dike, reclamation and herding in the 1920s, environmental condition began to deteriorate and environmental change entered into potential catastrophe stage to the beginning of the 1930s. Because the invasion of foreigners led large-scale resources exploitation and large-scale project construction from the 1930s to the 1940s, environmental condition deteriorated much and environmental change entered into catastrophe stage to the 1950s. Subsequently on account of the negative effect of political and economic policies on the Songnen Plain in the early 1950s, the environmental condition did not be improved. When entering the 1980s, the greatly increasing environmental projects led environmental catastrophe to sharp degree. Despite the actuality of environmental degradation has been known and some measures has been done, the partial change of environment condition and the hysteresis of environmental degradation did not change the whole environment actuality and environmental degradation was more and more heavy to the 1990s.

The analyses indicate that these factors play a dominant role in modern environmental change in the Songnen Plain and also validated the conclusion that human power was the primary driving force of modern environmental change (SUN *et al.*, 2001).

4.3 Analysis of the Primary Human Factors

It is shown that the human factors were the integration of the 7 factors in Table 3. Here, the primary factors of them would be confirmed.

The correlations between u_1 and X_1, X_2, X_3 or X_4 and the correlations between u_2 and X_5, X_6 or X_7 were all positive. That is, the largening orientation of u_2 was the deteriorative orientation of environment. The larger the changing degree of u_1 and u_2, the sharper the environmental change.

The correlation coefficients of u_1 and X_4 or X_2 were higher, so u_1 was determined by reservoir's cubage and dike. The correlation coefficient of u_2 and X_6 was the highest, so u_2 was determined by big livestock number. For the larger the reservoir's cubage, the longer the dike and the more the big livestock, the greater the destruction to environment. Therefore, reservoir's cubage, dike and livestock (excessive grazing) were the primary factors to affect environmental catastrophe in the Songnen Plain. If we want to change the actuality, we should consider these factors for the restoration of the environment.

5 CONCLUSIONS

Based on the macroscopic analysis on the environmental change of the Songnen Plain in recent 100 years, the process of environmental evolution was simulated by Thom needle catastrophe model. Moreover the mechanism of environmental evolution and the dominant artificial factors that affected environmental catastrophe were analyzed. Following conclusions have been reached in the paper.

(1) In recent 100 years, the change of land cover was great in the Songnen Plain. Its changing degree has reached to 70%.

(2) The structure of water system in the study area has changed from the outflow state of free flooding to mixed state of semi-inflow and outflow. The hydrological process and water quality have changed obviously.

(3) The developmental rate of sandy desertification and saline-alkalization has reached to 2.3% per year. The area of sandy and saline-alkali desert and semi-desert accounted for 4.0% of the total area of the plain.

(4) According to the results of needle catastrophe model, to the beginning of the 1930s, the environmental change came into the period of potential catastrophe; until the 1950s, the environmental change has come into the catastrophe period.

(5) The analysis by the model also proved that the increasing of reservoirs' cubage and dikes, and excessive grazing are dominant factors affecting the environmental catastrophe in the plain.

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