Research on the Land Use Structure of Asian Desert Regions at Ecological Security Level

Wang Jingai[1] Shi Peijun[2] Yue Yaojie[3] Lue Hongfeng[3] Zhou Hongjian[3] He Chunyang[2] Yan Ping[4]

(1.School of Geography, Beijing Normal University, Beijing, 100875; 2.Key Laboratory of Environmental Change and Natural Disaster of Ministry of Education of China, Beijing Normal University, Beijing, 100875; 3.Key Laboratory of Regional Geography, Beijing Normal University, Beijing, 100875; 4.Desert Research Center of China, Beijing Normal University, Beijing, 100875)

Abstract: Desertification has become the global environmental problem, and dust storm has seriously impact on the regional ecological security and even the whole world, so it's urgent to establish the pattern of land use structure at ecological security level. Based on the macro three-circles mode of land use/cover pattern in Asian desert regions, the article took the Horqin Sandy Land as an example to expound the micro three-circles mode and the plan of land use optimization. The international and regional ecological compensation policy was proposed to provide the scientific basis for land use program and regional sustainable development in desert regions.

Keyword: Asian Desert Region, Horqin Sandy Land, China Ecological Security, land Use Structure 0ptimization

Land use/cover change is one of the most important problems of global change, desertification has become the global environmental problem and has seriously threatened the global ecological security and sustainable development [1-3].

About 1/2 of the land surface, more than 110 countries and over one billion people are deeply impacted by desertification in the whole world, which results in 42 billion dollars loss every year [4]. One of the environmental problems resulted from desertification is Dust Storm. The main regions of Dust Storm include Northwest China, Mongolia, Southwest Asia, Central Asia, North Africa, Southwest America and Australia etc [5-7]. Dust Storm not only causes the ecological disaster to the source area, but also spreads to the circumjacent countries and influences the stability of the global climate [8-11]. The Dust Storm occurs in Asia spreads to Southeast Europe, South Asia, Northeast Asia, Southeast Asia，and even the Northwest Pacific Ocean, badly affecting local people's life and health[12-15].

Researches indicated that global warming and aridification are the main climatic factors of desertification [16,17]. Unreasonable human activity (water use, land exploitation) is the dominant factor speeding up the modern desertification process [18-21]. Otherwise, dust storm is more related to the change of the underlying surface resulted from unreasonable land use in desertification areas. The key points of sustainable development in desert regions are vegetation planting, efficient water use, reasonable land use, and the final goal is ecological and food security. In nature, we must establish the sustainable land use pattern at ecological security level of reasonable allocation of water, soil, and vegetation. Many scientists have been focused on this field [22-24].

1. Land use/cover pattern and dust transfers in Asia

Asian desert regions are mainly in Northwest China, Mongolia, Central Asia, Southwest Asia and Saudi Peninsula. The deserts in Northwest China, Mongolia and Central Asia are the largest desert regions in the temperate zone, which called "sore of the earth".

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* Corresponding author: Wang Jing'ai, E-mail: sqq@bnu.edu.cn

1.1 The macro three-circles mode of land use/cover in Asian desert regions

The terrain, distribution of population and cities, and land use/cover in Asia show circle structure obviously. Supported by GIS, the digital maps of population density, land cover and terrain were overlaid. By quantitative classification and regionalization the macro three-circles mode of land use/cover in Asian desert regions was gained（Fig1）.

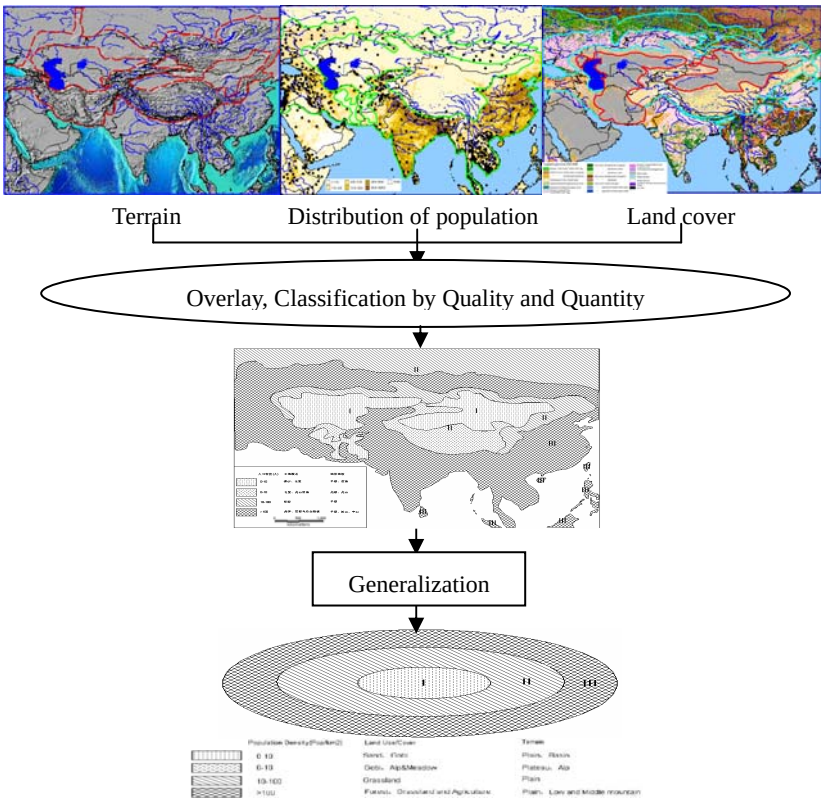


Fig.1 Macro Three-circles Mode of Land Use/Cover in Asia

The characteristic of the three circles is as follows: In Zone I, there are little precipitation and aridity climate because of its embedding into the hinterland of the Asia and the blocking by Iranian and Qingzang Plateaus, the southeast and the southwest monsoon cannot arrive. Its sandy surface is also prone to desertification. Unreasonable land and water use since 1930s in this area had destroyed the primary structure of water, soil, and vegetation, intensifying desertification and dust storm [25]. Water resources condition in Zone II is better than in Zone I. The north is the Europe-Asia temperate grassland zone, and the south is the northern Iran Plateau and Qingzang Plateau. The landscape in this area is alpine steppe and Gobi. There is little agriculture in the north and south due to the small population. The population is large and the agriculture is developed in the farming-pastoral zone in the southwest. The intensive underlying surface disturbance by human activities made it the zone with most vulnerable ecosystem, the most outstanding contradictions between man and the earth, the severest desertification, and the most frequent dust storm. Zone III has good water conditions, large population, and developed agriculture, while suffering the dust storm.

1.2 The macro three-circles mode and dust transfers in Asia

Based on the macro three-circles mode of land use/cover in Asia, we gained the combined mode of macro three-circles pattern and prevailing wind direction by combining the wind direction of January in Asian continent（Fig2）. In view of this, the three zones have the different function in establishing the land use structure in Asian desert regions at ecological security level: Zone I is desert with natural conservation. Zone II is artificial grassland with natural grassland restore. Zone III is the compound of farmland, forest, and pastoral grassland.

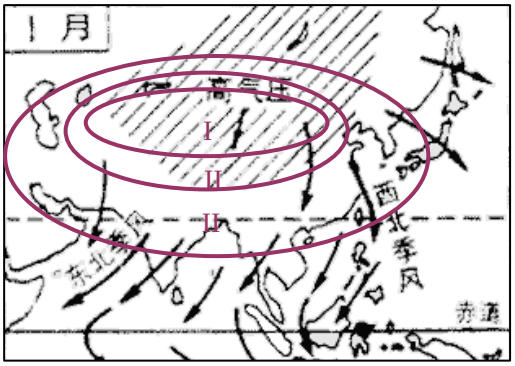


Fig.2 Macro Three-circles Mode and Prevailing Wind Direction in Asia

Zone I is the core of Asian desert regions and one of the main

source areas of dust storm on the globe. The dust directly affects the East Asia and spreads to the Pacific Ocean and North America. The east of the three circles is primarily the Zone I and Zone II where China lies. The strong winter monsoon and dusty weather affect the downwind areas including East China, Korea and Japan. Zone II is the natural environment transition region with high spatio-temperal variation in precipitation. Especially in the farming-pastoral zone of China in Zone II, the instable land use and many sandy lands made it a dust source.

2. The land use pattern and dust transfers in North China

China lies in the east of the three-circles pattern of Asia, of which the landscape from the west to the east in turn takes on desert, meadow, and the compound of agriculture, forest and animal husbandry. Besides the large area and population, China is also a great agricultural country with long agriculture history. The land use pattern in North China directly affects the ecological security of East Asia.

2.1 The land use and desertification in North China

Seen from the land use map of North China (Fig.3), this region from the west to the east is in turn the mountain forest – irrigated farmland area, the grassland - farming-pastoral zone, and mountain forest–grassland – desert oasis farmland area, which clearly shows the regional differentiation. Most deserts, Gobi, sandy lands and potential sandy lands of China are here (Fig.4). Meanwhile, this region is the important source region of the dust storms in China and East Asia, which move through 3 routes: northeast, north, west, and northwest (Fig.4).

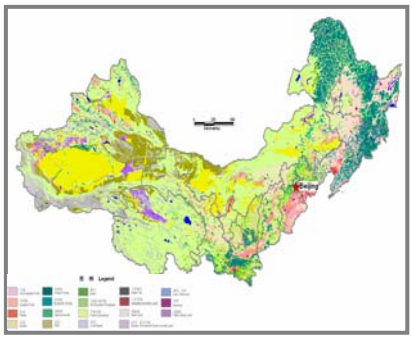


Fig.3 Land Use in North China

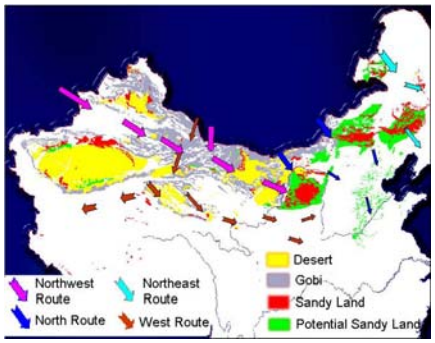


Fig.4 Desert Regions in China

Research shows that the variations in soil water, vegetation coverage, and vegetation structure of different land use/cover directly influence the wind erosion intensity. It means that the soil water is linear with the wind velocity of sand movement. When the soil moisture content is 2-4%, the wind velocity of sand movement is 6-8 m/s. When the soil moisture content is 7-8%, the wind velocity of sand movement is 12-13 m/s. The vegetation coverage is also in direct proportion to the wind velocity of sand movement, at the wind velocity of 15 m/s, compared to the vegetation coverage of 10%, the soil erosion under the vegetation coverage of 70% decreases as 7 times. Because of the different influence to erosion wind velocity, the different land use/cover has the prominent effects to the intensity and thickness of dust storm (Table 1).

Table.1 Wind Erosion Rate in Different Structural Combinations of Artificial Forest

Structural Combinations	Flora	Wind erosion rate (mm/year) [a]	Sample Numbers
Tree	Poplar	~10	28
Tree+Bush	Poplar+Caragana intermedia	3~5	26
Tree+ Bush	Poplar+ Artemisia ordosica	2~3	22
Tree+Bush+ Grass	Poplar+Artemisia ordosica+ Caragana intermedia+ Stipa capillata	<1	20

[a] Wind erosion rate = average depth of root exposure divided by tree age

Special attention should be paid to the farming-pastoral zone, which lies in the tail of the East Asian monsoon, with greatly fluctuant precipitation and uncertain human activities. The big population, overfarming, overgrazing and excessive fuel wood gathering destroy the original vegetation, which is difficult to recover due to the precipitation. Thus the area has the most vulnerable ecosystem and the severest land degradation. Therefore, the macroscopic reasonable land use collocation according to the demand and the microscopic land use optimization according to the supply are able to provide evidence to land use adjustment, and also the important measure to reduce dust storm.

2.2 Land use structure optimization in North China

Based on the System Dynamics (SD) model and the Cellular Automaton (CA) model, Land Use Scenarios Dynamics (LUSD) model was developed. The ecological benefit, economical benefit and national population policy were integrated in the model to adjust the land use structure. Based on the land use in 1999, the land use change scenarios in the future 20 years of the 13 provinces in North China were simulated [26,27]. The result (Table 2) shows that, the outstanding character of the optimized land use is the ratio decline of farmland, especially the sandy farmland and slop farmland, which returned to grassland. This answers for the mode of "large area ecological construction whilst small area production developing".

Table2 Land Use in 1999 and the Optimization Result in 2020

Land use	1999		2020	
	Area (10^4hm^2)	Ratio (%)	Area (10^4hm^2)	Ratio (%)
Farmland	1685.08	23.2	1362.8	18.76
Forest	926.49	12.8	926.89	12.76
Grassland	4304.0	59.2	4623.53	63.64
Water	7.9	0.1	7.9	0.11
Town	7.21	0.1	9.55	0.13
Bare land	334.28	4.6	334.28	4.60

3. Land use structure optimization in the sandy land at the ecological security level

The Horqin Sandy Land lies in the west of Northeast China (Fig. 5), the transition zone of the Inner Mongolia Plateau and the Northeast Plain, with the area of $5.2\times10^6hm^2$ and annual average temperature of 5.8-6.4℃. The annual average precipitation is 300-450 mm, 70%-80% of which concentrates during July and September. The landscape is sparse sylvosteppe and aeolian deposit desert. The landform is the compound of dune, marsh, smooth desert and inter-dune lowland.

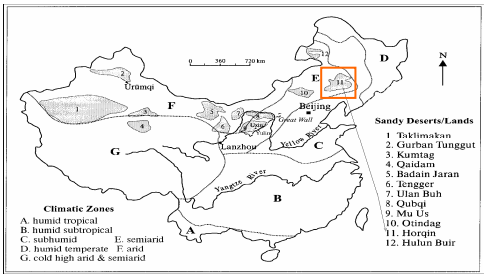


Fig.5 Location of Horqin Sandy Land

3.1 The three-circles structure of land use/cover in the sandy land

According to the landform feature mentioned above, the microscopic three-circles mode of land use in the Horqin Sandy Land was put forward. Taking the marsh and dune of good water resource as center, the mode divided the land use from the inter-dune lowland to the top of the dune into three circles (Fig. 6). Because of the heat and water reallocation due to landform, the inter dune zone (zone Ⅰ) has the best natural condition and is the most suitable for plant growing, where human activities cluster. The transitional zone between the

dune and the inter dune (zone Ⅱ) has the worse condition, which may be dry farmland, wasteland or natural grassland. Human's interference makes its environment most unstable. The water condition at the top of the dun (zone Ⅲ) is the worst, which is mostly moving sand and semi-moving sand, with some shrub and grass. In primitive producing ways, people cultivated extensively and depended on natural precipitation, so the harvest was uncertain while the vegetation was broken. The land desertification developed quickly because the uncertain precipitation couldn't guarantee natural vegetation recovery.

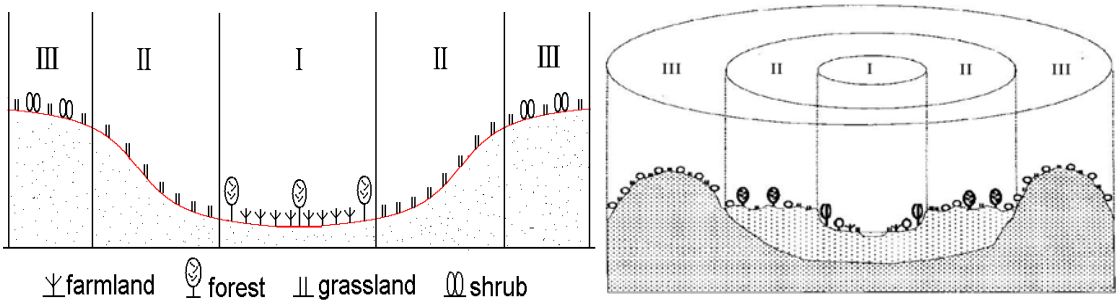


Fig.6 Three-Circle Land Use Mode

3.2 Land use optimization method

Based on the TM image, the land use was classified with supervised classification. With the method of mutual human-computer interpreter, the ecological insecurity factors were extracted from the TM image and the ecological security was assessed with support of GIS. Finally, according to the result of the ecological security assessment and the principle and the model of land use optimization, the land use of the study area was optimized.

In the sandy land of North China, the natural factors that affect land use security are mostly soil wind erosion, secondary saline-alkalization, paludification and flood [28].

Each ecological insecurity factor has an intensity standard to identify it into different intense level. For the sake of calculation, intensity standard of each factor was predigested with the graded standard of quantity, thus translated into its insecurity level. In this paper, the ecological insecurity factor was classified into three insecure levels: light insecure, middle insecure, high insecure, figured 1, 2 and 3 accordingly. After confirming the type and denotation of each ecological insecurity factor, they were ready to be extracted and the single factor vector database would be built for the assessment of ecological insecurity. The ecological security assessment adopts integrated index model as follows:

$$D = \frac{1}{n} \cdot \sum_{i=1}^{n} D_i \qquad (1)$$

The symbol D in the model stands for integrated intensity index of ecological insecurity, i stands for ecological insecurity factor in patches, D_i stands for intensity index of certain ecological insecurity factor, n is the number of insecurity factor. We choose the method of standard deviation and Geo-analysis, divide D into four ecological security classes (S), then create assessment database. Since there is no land use information in the ecological security assessment database, we combine land use with ecological security by overlaying to get land use ecological security assessment database. Furthermore, land use ecological security index constructed in order to express the security conditions, the mathematical model shows as follows:

$$LS = L * 10 + S \qquad (2)$$

Where *LS* stands for land use ecological security index, *L* stands for type coding of land use, *S* stands for ecological security class. *LS* contains the information of both the land use type and ecological security level, which provide the evidence for land use optimization under the condition of ecological security. Finally, according to "large area ecological construction whilst small area production development ", gradually establish optimization plan in the light of determinant standard system (1.land use function standard, 2.land use insecurity index standard, 3.landform relief standard, 4.single insecure factor insecurity index standard, 5.natural zone standard) in land use structure optimization (Fig.7), then we make optimization scenarios supported by GIS.

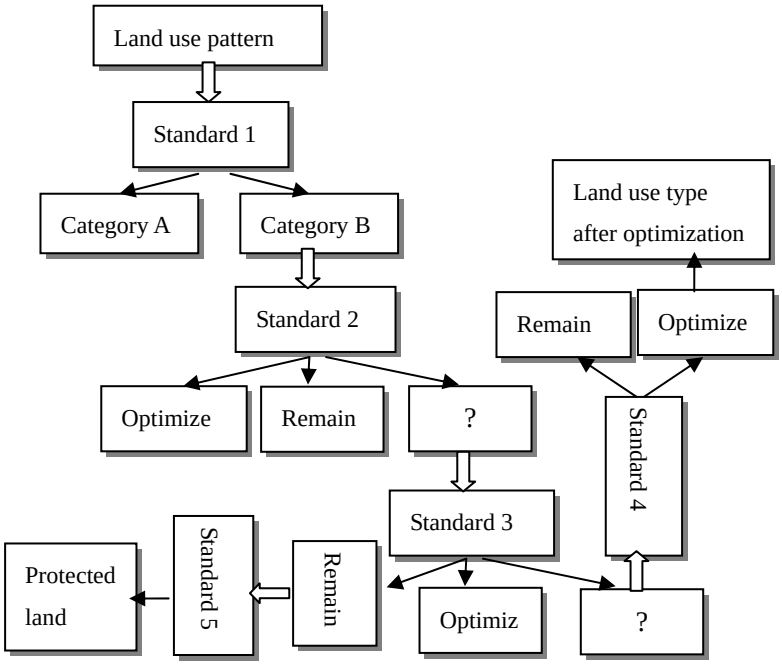
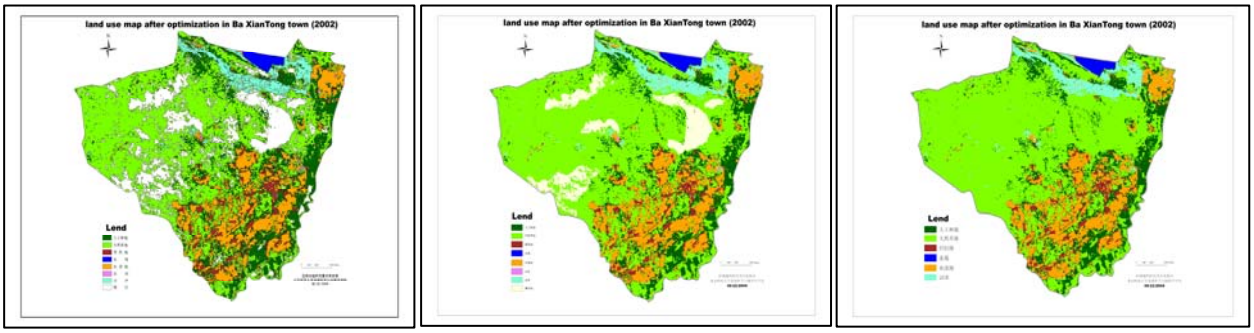


Fig.7 Land Use Structure Optimization Determinant System

3.Sandy land use optimization

The key of sandy land use structure optimization is to implement micro-three circles mode under the ecological security level: the outer zone of natural resume ecological grass land—the middle zone of grassland under "large area ecological construction whilst small area stock raising production development"—the inner zone is high efficiency agricultural production land. In the near future, the goal of land use optimization is to return 5 to 10 percent of non-irrigated farmland into grassland, return 25 to 30 percent of grazing grassland into irrigated grassland.

In order to achieve the goal and guarantee ecological security, we should adjust land use structure as follows: Zone I is production land, where intensive and high yield agriculture is developed, with farmland protection forest around it; Zone II should be closed as natural grass recovery land or artificial grassland; Zone III is completely closed as ecological land use, grass and shrub is seeded to fix the dunes. According to the land use condition at present, there will be an objective transition process of the large area ecological construction and small area production, so we should make plans step by step according to the program time limit. The key is to return farmland to grassland or forest, to adjust crop pattern, to change cultivation manner. Only in this way, the resident in sandy land will get out of the difficulties in extensive cultivation to the scientific road of intensive cultivation, while the environment will also recover and contrarily facilitate agricultural production, reaching the strategic goal of mutual benefit between ecology and production. Thus, we established micro-three circles land use structure optimization plan of Horqin sandy land in three stages: near (a), middle (b), far future(c). The scenarios show as Fig.8



a b c

Fig.8 Land Use Structure of Ba Xian-tong Town Before and After Optimization (Horqin Sandy Land)

Through optimization, bare sand land could be fathered, grassland will increase 21.7 percent of total area and distributes in patches. Forest, irrigable land and inhabitant land will keep steady and decrease little, accounting for 12.8, 11.7, and 3.5 percent of total area respectively. After optimization, the land use types are mainly grassland, forest, irrigable land, inhabitant land and marsh, accounting for 66.7, 12.8, 11.7, 3.5 and 4.4 percent respectively, the ratio of ecological land and production land is 5.6:1, realize the land use structure of “large area ecological construction whilst small area production development”.

4. Conclusion and discussion

(1) Put forward Asian land use/cover macro-three circles mode established in ecological security and with a view to dust storm disaster prevention, which will be favourable for the ecological security of Asian sandy area and neighboring area.

(2) Put forward desert region land use /cover micro-three-circles land use mode, which will benefit the construction of eco-productive paradigm and lead to high efficiency land use.

(3) The technique and method developed for land use structure optimization will hope to establish a series of scientific and convenient technology regulation through practice verification and modification, which can be used to support land use optimization in similar area.

(4) In order to guarantee the implement of Asian sandy area macro-three-circles land use mode, we suggest establishing international ecological compensation policy. Just as mentioned in introduction and conclusion, implementing ecological compensation in sand storm combating is the objective demand of ecological construction. While fund and technology support can’t satisfy the demand of international and regional sand combating project and regional sustainable development, so carrying out ecological compensation is imperative under the situation.

There are three problems in implementing ecological compensation: (1) The definitions of compensation area and receiving compensation area, (2) The ecological—economy calculation of compensation quantity, (3) mechanism of compensation (policy). Compensation area and receiving compensation area can be defined by the location. According to the role three-circles plays in constructing ecological security land use structure, their relationship is that the Zone III should provide compensation to II and I, the whole countries in Zone I and part countries of Zone II should receive the compensation. The countries in Zone II receiving the compensation or not depend on if its dust storm source land. If it is, receive the compensation, otherwise, should provide compensation to support the ecological construction in source land countries.

There have been many researches in the ecological compensation among all industries and between regions, involving ecological compensation theory discussion, legislation and policy, compensation mechanism,

compensation extension and the definition of compensation receiver. The northern sandy land of China locates in the area of major ecological construction projects led by government, which contain returning farmland to forest or grass land, natural forest protection, returning cropping land to forage, San-Bei shelter forest construction and Jing-Jin sand source management etc. The investments of these projects are mainly national finance fund and national debt fund, and ecological compensation manners are financial transfer payment and specialized fund. The compensation to the plot and the ecological domain should be improved in the sides of ecological tax collection and compensation market mechanism establishment, and perfect ecological compensation system should be based on ecological compensation legislation in national or regional range.

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