Evaluation of Suitability of Typical Fragile Areas and Study on Ecological Governance Model Based on GIS Technology: A Case Study in Naiman Banner of Tongliao City

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Abstract

The suitability evaluation of ecological environment is the basis of the implementation of land use master plan and ecological management. Naiman Banner, which is located in the southern margin of Horqin sandy land, has become a typical fragile area in the northern agricultural and pastoral ecotone because of the perennial wind and sand disaster. Therefore, environmental factors are selected, evaluation system is established, the suitability of resources and environment is studied, and the purpose of providing scientific and effective basis for the implementation of ecological governance, the combing of ecological governance model and the development of the whole society and economy is achieved. Supporting of Geographic Information System (GIS) and Remote Sensing (RS) technology, using expert scoring method and analytic hierarchy process, quantitatively evaluates the suitability of Naiman Banner's resources and environment from three aspects: land use type, desertification degree and vegetation coverage, and divides it into five grades: extremely high suitability, high suitability, medium suitability, low suitability and very low suitability. The research shows that; The appropriate index of study area is between 0.16-1.94, and the proportion is 8.06%, the fitness index is 0.16-0.6. According to the statistics, the proportion of low and medium suitable areas are 79%, which of the areas are 6.47×10^5 hm^2, indicating that the low and medium suitable areas are most widely distributed. The results also show that highly suitable area is 1.06×10^5 hm^2 in Naiman Banner. Based on the final suitability index of the ecological environment with the results of the division, the governance model can be summarized as follows, unsuitable areas should adopt the development governance model and the protection governance model. Low suitable, medium suitable and high suitable areas are should be selected with protecting and protecting-developing governance models. Based on the remote sensing technology, expert scoring method and analytic hierarchy process (AHP), it can effectively and objectively make a comprehensive evaluation of the suitability of local resources and environment, and the evaluation results based on the research data can provide scientific basis for the protection, planning and management of ecological environment, such as overall land use planning and resource and environment prevention measures.

Keywords

Suitability of Ecological Environment; Remote Sensing Technology; Expert Evaluation Method; Analytic Hierarchy Process; Ecological Governance Model; Naiman Banner.

1. Introduction

Naiman Banner, belongs to the southwest of Tongliao City in Inner Mongolia Autonomous Region, it is located in the southern margin of Horqin Sandy Land, the largest sandy land in China. The

ecological environment of Naiman Banner has been greatly damaged because of the long-term suffering from natural factors such as arid climate, wind and sand, and irrational land use, which has become a typical fragile area of ecological environment in northern farming-pastoral transitional zone [1]. As the uncoordinated degree between the stability of ecological environment and the development of human society increases year by year [2, 3], it causes a series of ecological environment problems, a typical example is desertification. The assessment of land suitability, as an assessment of the suitability of land for a particular purpose or work, can effectively support the ecological management and ecological planning of ecologically fragile areas or ecological protected areas. Therefore, it has always been the tradition and mainstream of land evaluation in China. "Suitability" is a kind of technical term for land resource utilization and planning, since the end of the 20th century, the land suitability has been studied systematically all over the world. The research was proposed and put into practice by Scottish landscape architect, IanMcHarg and his team. The research methods, such as the qualitative analysis of the resources and environment protection, tourism, housing construction, commercial and industrial land development of Staten Island in New York [4], are analyzed by the suitability qualitative analysis, and the ecological suitability analysis and ecological planning with layer superposition as the main characteristics are made. As a result, the study of suitability evaluation is more and more numerous. Until the 1990s, many countries at home and abroad put forward the concept of "urban ecological functional zoning", and applied the suitability evaluation technology to ecological functional zoning, which is involved in many fields, such as agriculture [5], geology [6], urban expansion [7], species habitat [8], landscape planning [9], and environmental impact assessment, and the research methods include factor group legitimacy, integrated holistic approach, mathematical statistics method, factor analysis and many other types.

Overseas researchers such as Longlin and Pearce based on the map overlay method, put forward the linear combination method, such as weight and score, and apply it to the study of ecological suitability of urban and rural construction land. Westman based on this research, the content of suitability study is refined, including three ecological factors: slope, soil texture and drainage, and semi-quantitative research on the suitability of housing construction is carried out. Compared with foreign countries, the domestic research mainly focuses on the evaluation of agricultural ecosystem. Until 2003, the state promulgated the "ecological province, ecological city, ecological county construction index", and transferred the focus of suitability research from a single agricultural ecosystem to the area of regional comprehensive development. Concrete studies such as Zhao Ke [10], and other researchers [11], evaluate the ecological environment influencing factors and regional planning of Anyang City by constructing composite ecological indexes such as soil erosion, land desertification, water quality, soil quality and ecological sensitivity. In recent years, following the introduction of the concept of "land main function area", the study of ecological suitability evaluation has been widely used in the planning of regional main function. For example, Zhao Mingyue and others applied the theory of urban complex ecosystem and the study of ecological suitability to the evaluation of urban human settlement environment, and based on the entropy weight synthesis method of pressure-state-response model, established a multidimensional evaluation system of nature, humanities and economy in the study area, and comprehensively analyzed the local suitability.

On the basis of the above research, this paper selects the typical fragile area of northern China's agricultural and pastoral ecotone (Naiman Banner, Tongliao City, Inner Mongolia Autonomous Region) as the study area, takes Geographic Information System (GIS) and Remote Sensing (RS) as the technical support, combines the characteristics of resources, environment and human factors in the fragile ecological environment area, selects the degree of desertification, vegetation coverage and land use type as the evaluation index, and uses the expert scoring method to give weight to each index. Then using the GIS spatial superposition technology to realize the purpose of suitability evaluation of Naiman Banner in Tongliao City. In order to provide scientific basis for the protection of ecological environment and the combing of ecological governance model.

2. Materials and Methods

2.1 Study area

Naiman Banner is located in Tongliao City, Inner Mongolia Autonomous Region, north of western Liaoning Mountain and south end of western Liaohe Plain (120°19′40″—121°35′40″E, 42°14′40″—43°32′20″N). Belongs to the northern temperate continental semiarid climate, the maximum temperature is 39.2 degree Celsius the lowest is -31.6 degree Celsius, the average temperature in July-August is 23-24 degree Celsius, and the annual average temperature is 6.4 degree Celsius. The east-west width is 68 kilometers, the north-south length is 140 kilometers, the total area is 8137.6 square kilometers, is a flag county with the geomorphological characteristics of "mountain-stripping aeolian inclined plain" from south to north. The north-central plain is part of the alluvial plain of the West Liaohe River and the Jiaolai River, and the terrain is flat and open.

2.2 Data sources and processing

Natural resources data are obtained by remote sensing image interpretation and data processing, in which land use change data are derived from Landsat 4-5 TM and Landsat 8 OLI_TIRS image data with 30 meters×30 meters resolution of Geospatial Data Cloud. The processing of land use data is to use GIS to carry out TM7 (R), 4 (G), 3 (B) false color band combination, to carry on the geometric correction, image enhancement and other image processing work to carry on the supervision classification, and to divide the land type into 6 kinds of land use types according to the actual situation of the study area. Vegetation coverage is based on the metadata of atmospheric correction and radiometric calibration. The normalized difference vegetation index (NDVI) is calculated by using the b1-b7 band value. According to the vegetation value, it is divided into five vegetation coverage grades: extremely low <low<medium<high<extremely high. Ultimately, based on land use data and normalized difference vegetation index values, desertification data are extracted by using the method based on normalized difference vegetation Index (NDVI)-Albedo desertification information extraction, and they are divided into four grades of suitability evaluation indicators: mild desertification, medium desertification, severe desertification and extremely severe desertification.

3. Methods

3.1 Suitability evaluation process

In order to achieve the purpose of ecological environment management, select the influencing factors of the development of resource [12], and environment suitability in the study area, take this factor as the evaluation index of ecological environment suitability, and use the expert scoring method [13]. Based on the degree of influence of the selected factors, different ecological factors are given the corresponding weight. For this reason, 0.5: 0.2: 0.3 weight value is given to the degree of desertification, vegetation cover and land use type. Therefore all ecological factors are superimposed and classified by GIS [14] software spatial superposition function, made the evaluation map of resource and environment suitability of Naiman Banner in Tongliao City, Inner Mongolia Autonomous region. Based on the suitability evaluation chart, the most effective governance model is combed according to different suitability, and the local ecological protection enterprises are used as typical cases to divide the best suitable enterprises, that can be developed by different suitable grades in space, make the area in ecological governance at the same time create certain economic value. By means of Geographic Information System (GIS) and expert evaluation method, concluding that the suitability index of the study area is between 0.16-1.94, among which the unsuitable grading standard is 0.16-0.6, the low suitability is 0.6-1.1, the medium suitability is 1.1-1.5, and the high suitability index is 1.5-1.94, and it is divided into four grades according to different suitable indexes: unsuitable, low suitable, medium suitable and high suitable. Then according to the appropriate degree, combined with the characteristics of ecological management, sorting out the unsuitable and low-suitable areas suitable for developing and protecting governance model. Low and medium suitable areas and high suitable areas are suitable for protecting and protecting-developing governance models.

3.2 Evaluation model of suitability

The so-called expert evaluation method (also called Delphi method) is a qualitative description and quantitative research method, which sets several evaluation indexes according to the specific requirements of the evaluation. Then according to the evaluation index to formulate the evaluation criteria, hired a number of representative experts based on their own experience according to the evaluation criteria to give the evaluation score of each index. The formula is as follows [15, 16, 17].

$$W_i = \sum_{i=1}^{n} F_{ij} B_j \quad (1)$$

Where the W_i represents the superposition score of the i evaluation unit, F_{ij} represents the score of the j evaluation factor for the i evaluation unit.

3.3 Calculation model of vegetation cover

3.3.1 Normalized difference vegetation index(NDVI)

Vegetation coverage is an important indicator to show the quality of ecological environment, and the premise of vegetation coverage analysis is to calculate the normalized vegetation index [18, 19, 20, 21]. By calculating the normalized index and combining the GIS natural point method technology, in order to grading the vegetation index.

$$NDVI = \frac{Wsn-Inr}{Wsn+Inr} \quad (2)$$

Where the *Wsn and Inr* are representing the red band and near infrared band respectively, *float* means the type of red band and near infrared band is floating point.

3.3.2 Vegetation coverage

Vegetation coverage is based on the normalized difference vegetation index, which is divided into 5 grades: very low vegetation cover, low vegetation cover, medium vegetation cover, high vegetation cover and extremely high vegetation cover.

3.4 Calculation of desertification levels

3.4.1 Calculation formula of albedo

There are many methods to extract desertification information, because the study area is a typical area affected by wind and sand, so the benefit of governance is more prominent. Therefore, the method NDVI - Albedo is selected to extract desertification value [22, 23, 24, 25]. That is, the TM image band is used to calculate. Taking into account the benefit of the work, the processed data select cloudless remote sensing images in the study area, and carry out atmosphere correction and radiometric calibration to eliminate the outliers caused by radiation, and then extract the albedo values on this basis. Where the Albedo is reflectivity, and the extraction of reflectivity is based on blue, red, near-infrared and mid-infrared band meters. For this purpose b1-b7 the details of the band required for reflectivity calculation.

$$Albedo = 0.356 \times b_1 + 0.13 \times b_3 + 0.373 \times b_4 + 0.085 \times b_5 + 0.072 \times b_7 - 0.0018 \quad (3)$$

3.4.2 NDVI-Albedo quantitative formula

The premise of desertification information extraction is to calculate the normalized difference vegetation index (NDVI) and Albedo, and the quantification of them is based on remote sensing images. The relationship [26, 27, 28, 29] was established between 300 sampling points with the same latitude and longitude in the image corresponding to the normalized difference vegetation index and the remote sensing image corresponding to reflectivity, the formula is as follows.

$$DDI = S \times NDVI - Albedo, S = -\frac{1}{M} \quad (4)$$

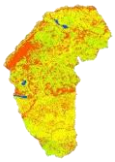
The *DDI* is the desertification difference index, the *S* is *-1/ M*, *a* as the first order equation parameter in the quantitative formula.

4. Results

4.1 Weight results analysis

Based on the land use data, vegetation coverage and desertification information of Naiman Banner in Tongliao City, combined with expert scoring method (EGM) and analytic hierarchy process (AHP), the corresponding weights of each index are calculated by using all the formulas in the evaluation model of 3.2 in this paper [30, 31, 32, 33], specific information is as follows (Tab.1). That is, the evaluation index is divided into three levels: land desertification, land use type, and the degree of vegetation coverage, of which the proportion of desertification is the highest (accounting for 50%), followed by the type of land use (accounting for 30%) and the degree of vegetation coverage (accounting for 20%).The main reasons for the different weights are that the degree of desertification is extremely serious in the study area as a desertification area, and the difficulty of ecological control is also caused by the serious desertification of the ecological environment is extremely fragile. For the ecological control work, the degree of desertification is divided into 4 grades: mild, medium, severe and extremely severe, while it is the most suitable area for ecological environment, so the corresponding weight value is also largest. And this method is used to assign the weight of vegetation coverage, that is, the extremely high vegetation coverage is a good area of ecological environment, the corresponding value is the largest, and the extremely low vegetation coverage is the worst area, as well as the corresponding weight value is lowest. In the weight assignment of land use suitability, the waters is best suitable, the corresponding weight value is 1.8, followed by forest land and grassland. While unused land, other land and sandy land are suitable general areas, and the corresponding weight value is less than 1, see Table 1.

Table 1. Weight of Eco-Environmental Suitability Evaluation Factor and Grading Threshold

Target layer	Criteria layer	Weight	Code	Indicators	Evaluation
E1-Degree of desertification		0.5	E11	Mild desertification	2
			E12	Medium desertification	1.4
			E13	Severe desertification	0.8
			E14	Extremely severe desertification	0.2
E2-Land use type		0.3	E21	Unused land	1
			E22	Waters	1.8
			E23	Sandy land	0.4
			E24	Grassland	1.2
			E25	Forest land	1.4
			E26	Other land	0.6
E3-Vegetation coverage		0.2	E31	Very low vegetation coverage	0
			E32	Low vegetation coverage	0.5
			E33	Medium vegetation coverage	1
			E34	High vegetation coverage	1.5
			E35	Extremely high vegetation coverage	2

4.2 Evaluation of Single Factor Suitability of Ecological Environment

4.2.1 Land use type evaluation

The evaluation data of land use type suitability is based on the supervision and classification of metadata from 2000 to 2018 in Naiman Banner, and the spatial distribution information of ground class is obtained by continuous precision verification. According to the actual use the results of suitability evaluation are based on each category: waters, forest land, grassland, unused land, other land and sandy land, meanwhile these types are given 1.8>1.4>1.2>1>0.6>0.4 of evaluation. In which the water resources are belong to the best suitable area for the development of ecological environment, followed by forest land and grassland, while other land, unused land and sandy land are controlled by several restrictive factors, belong to the more difficult suitable area.

4.2.2 Evaluation of desertification levels

Based on the calculation results of vegetation normalization index and Albedo, establishing quantitative formula between them. Results show that the parameter values from 2000 to 2018 are -0.76, -1.2162, -0.4.84. Using Envi Classic to calculate the degree of desertification, which is divided into four grades: mild, medium, severe and extremely severe, and the four grades are given 2>1.4>0.8>0.2 respectively. So the lower degree of desertification have higher suitability, and the higher quality of its habitat. On the contrary, serious degree of desertification, have more serious environmental damage, and the place of primary governance.

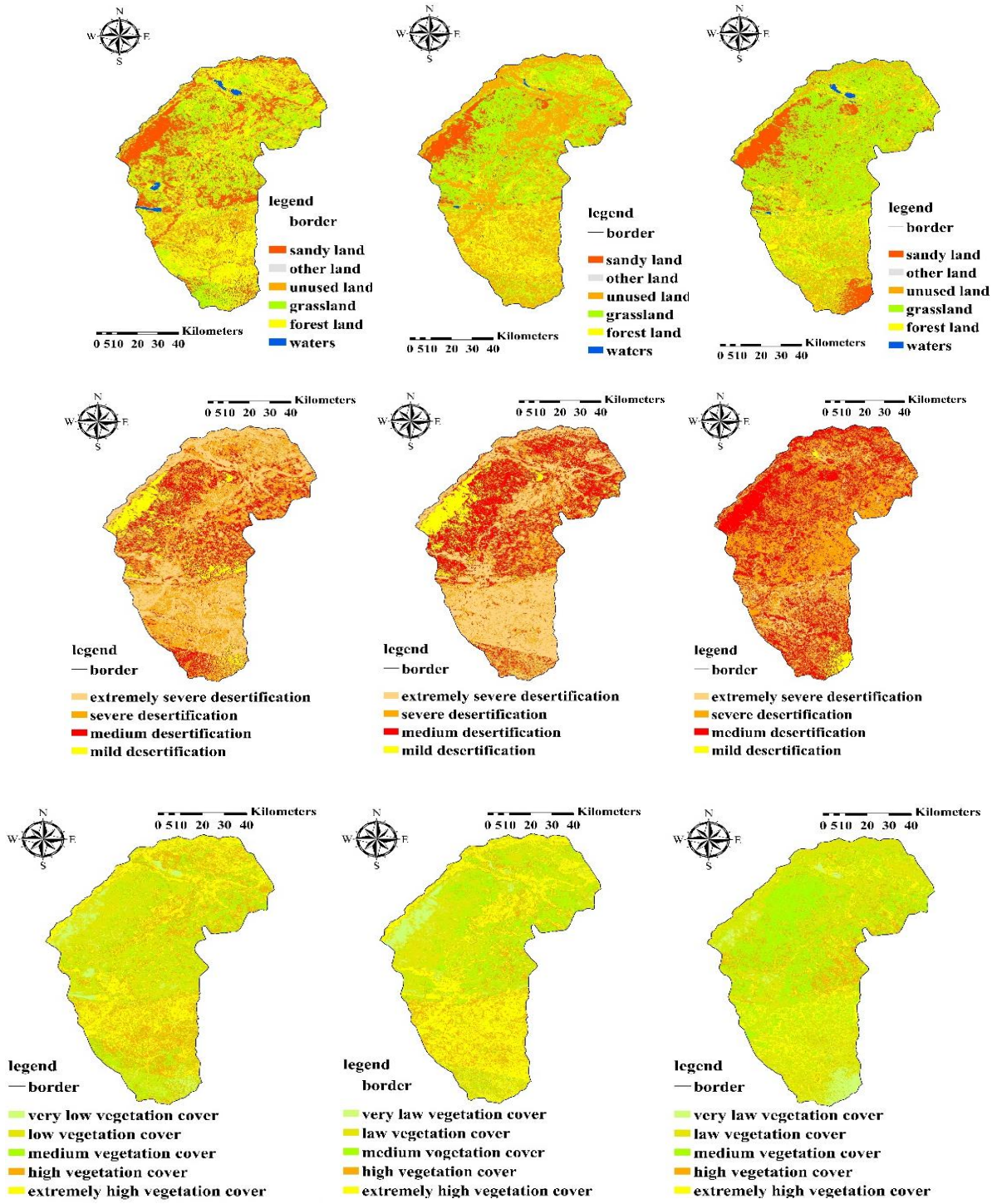


Fig. 1 Spatial distribution of land use types, desertification and vegetation cover in Naiman Banner, Tongliao City, 2000-2018

4.2.3 Evaluation of vegetation coverage

The suitability evaluation for vegetation resources with different coverage levels is based on the expert scoring method and the analytic hierarchy process, which gives a score of 2>1.5>1>0.5>0 for extremely high, high, medium, low and very low vegetation cover, respectively. Among them, 0 indicates the suitability is very low, which is belongs to most difficult development area; the area with weights of 0.5 and 1 has certain resource advantages over the extremely low vegetation cover. The scores of high vegetation cover and extremely high vegetation cover are 1.5 and 2. The evaluation of vegetation resource suitability is based on the degree of vegetation coverage. The higher the coverage, the better the environmental quality and the higher its suitability. On the contrary, the lower the coverage, the worse the suitability. The following is a spatial distribution map of land use type, desertification degree and vegetation coverage between 2000 and 2018 in Naiman Banner, Tongliao City, see Fig 1.

4.3 Comprehensive evaluation of ecological environment suitability

The evaluation of ecological environment suitability is based on the information of land use type, vegetation cover and desertification degree, and Arcgis software is used to obtain the results by superposition analysis for this evaluation in the study area. As shown in the figure, the comprehensive evaluation index of suitability in the study area from 2000 to 2018 is between 0.16-1.94, in which the habitat quality of 0.16-0.6 interval is poor and belongs to the unsuitable area. 0.6-1.1 interval is a low suitable area, 1.1-1.5 is a moderate suitable area, and 1.5-1.94 is belongs to a highly suitable area. The resource area and proportion under different grades are shown below, see Fig 2.

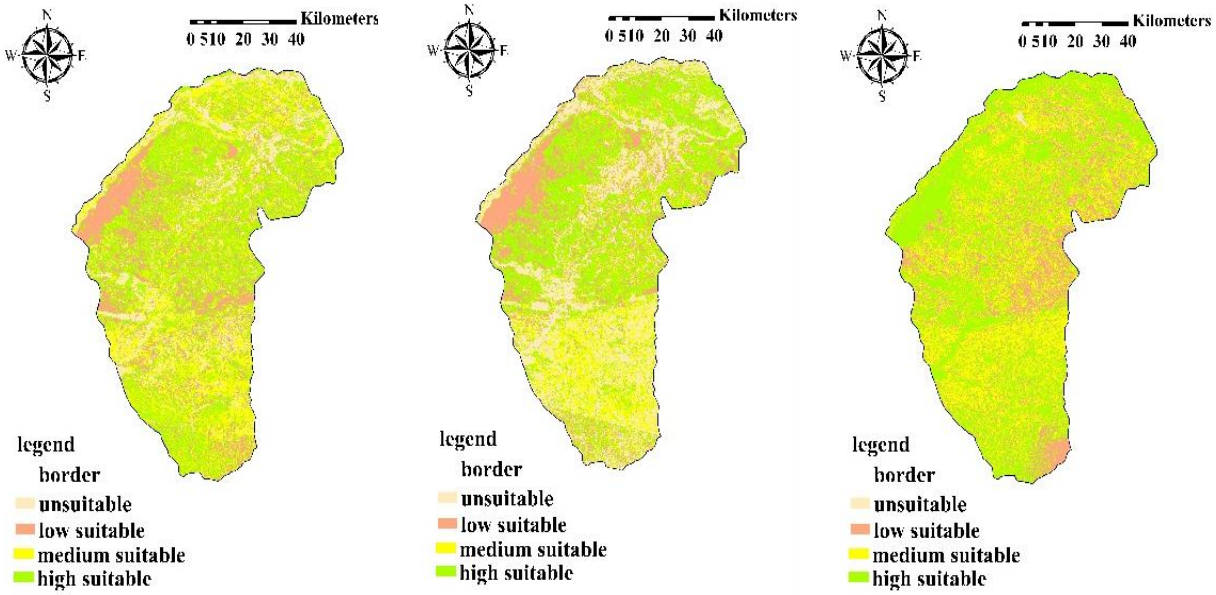


Fig. 2 Comprehensive assessment of ecological environment suitability

The statistical results show that the proportion of unsuitable land decreased gradually between 2000 and 2018, from 1.18×10^5 hm^2 in 2000 to 0.66×10^5 hm^2 in 2018, from 14.44% in 2000 to 8.06%, that is, the ecological environment of low vegetation cover and desertification areas has been improved to a certain extent, so the degree of environmental suitability has also increased. Moreover, the area of low and medium suitable areas is 2.68×10^5 hm^2, 3.79×10^5 hm^2, respectively, accounting for 79%, see Fig 3.

In 2000 and 2010, the proportion is 61.2% and 54.07%. The area of highly suitable area is 1.06×10^5 hm^2, accounting for 12.94% of the total land. It belongs to the excellent local environment, and the environmental quality is the highest and the suitability is the largest, and this result is also the ultimate, see Fig 4.

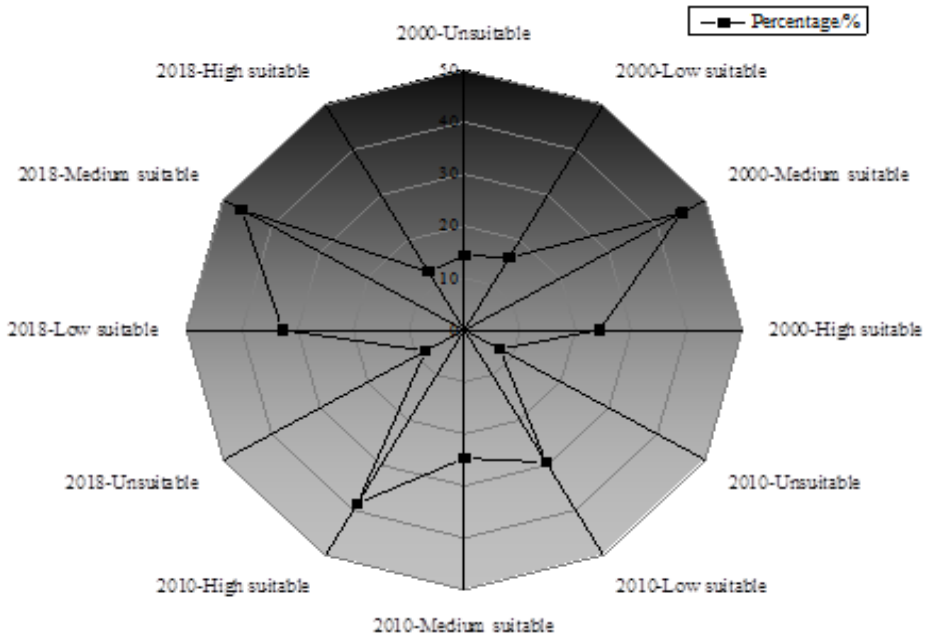


Fig. 3 Proportion of different suitable areas in Naiman Banner, 2000-2018

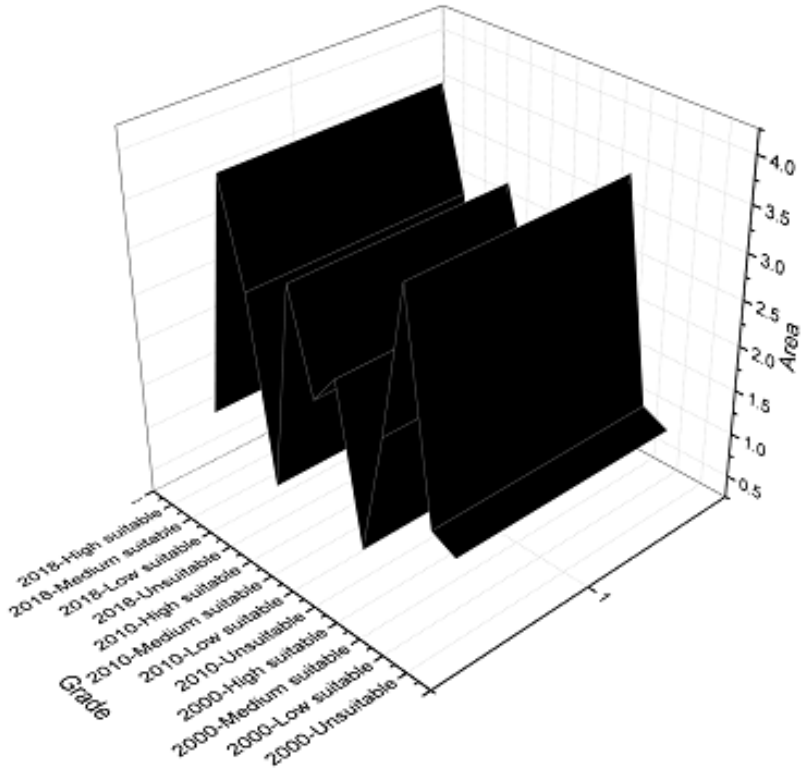


Fig. 4 Area of different suitable land in Naiman Banner, 2000-2018

4.4 The Management Model of Ecological Environment

For typical fragile areas, ecological environment governance is the most basic and important work. Based on the characteristics of the ecological environment and the nature of the management work in the study area, the model of ecological management work is divided into three categories: protection management, development management and protection-development management. Developmental governance refers to the development of certain land with the purpose of generating economic benefits, such as the development of Chinese herbal medicine in sand areas [34, 35, 36, 37, 38, 39,

40]. The third governance model is a composite model combined with the two, the purpose of which is to develop certain land while protecting the ecological environment.

Because the ecological control of different suitable areas should take different control measures, for non-appropriate areas, should adopt development management, the reason of choosing this model is that the unsuitable area of the study area is very low vegetation cover and the desertification degree is serious. Low suitable area and medium suitable area are suitable for protective treatment, that is, environmental protection is the main purpose, because the main land category of low suitable area is unused land and other land, so it is impossible to adopt the same governance model as the unsuitable area. The highly suitable area is the best suitable area, that is, low desertification, high vegetation cover, land type is mainly water area, woodland and grassland.

5. Discussion and conclusions

In the work of ecological environment management, the improvement of vegetation cover and the reduction of desertification are the ultimate goal of the work. The Naiman Banner, which belongs to the southwest of Tongliao City in Inner Mongolia Autonomous region and is located in the largest sandy land in China, the southern edge of Horqin Sandy Land. Due to the influence of natural and unreasonable land use factors such as wind and sand disasters in Horqin Sandy Land, the ecological environment is extremely fragile and causes changes in the natural and human environment, such as land use type, vegetation cover degree and desertification degree, and this is consistent with the results of Wang Xuan, Xu Xiaohong et al. Based on the expert scoring method and analytic hierarchy process (AHP), selects the ecological environment evaluation factors, uses Arcgis superposition function to establish the ecological environment suitability evaluation system, and gives the weight to the evaluation factors. For the ecological governance model combing and ecological environment suitability quantitative evaluation.

With the support of Arcgis technology, the three main factors of land use type, vegetation cover and desertification degree are treated as 30 meters×30 meters grid layers with related attributes, and the layers are converted into shape file superposition. The database of comprehensive resource environment and human factors is established, which breaks through the limitation of traditional point-banding and topographic and geomorphological factors on the spatial change of soil elements. Compared with traditional evaluation methods, ecological environment suitability assessment based on analytic hierarchy process (AHP) and expert scoring method on remote sensing platforms such as Arcgis can comprehensively reflect the upper and lower limits of ecological factors, and can plan three kinds of ecological governance measures in space according to the final appropriate grade map. The evaluation showed that. The suitable area of Naiman Banner in Tongliao City reached 10.6×10^5 hm^2, in 2018 and the ratio is 12.94. The distribution area is mainly in the middle and south. The moderate suitable area shows the trend of "one minus one increase" from 2000 to 2018 changed from 36.9×10^5 hm^2 to 37.9×10^5 hm^2, the proportion also decreased from 45.17% in 2000 to 24.68% to 46.28% in 2018.That is, the moderate suitable area is the largest and most widely distributed area. The proportion of low and unsuitable areas were 30.47%, 36.77% and 40.78%, finally the suitable area reached 33.4×10^5 hm^2 in 2018. The area, proportion and spatial distribution of different suitable grade areas can be obtained through the research results, which can provide data support for the implementation of sand area governance and land use planning.

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