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# Ecological Vulnerability Assessment of the Sanjiangyuan Region Based on "Pressure-State-Response-Management" Model

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## Abstract

**The contradiction between human activities and the natural environment has become increasingly prominent with the rapid development of modern economy and society. The Sanjiangyuan region is located in the Qinghai-Tibet Plateau in the northwest of China, where natural conditions are extremely complex and ecological environment is very fragile, also the relationship between man and land is tense in some areas, which is very representative in the world. Based on the data of natural environment and human economic activities in 2000, 2010 and 2020, this study taked the Sanjiangyuan region of Qinghai Province as the research object, selected 15 indicators, adopted the pressure-states-response-management model (PSRM) to construct the index system of ecological vulnerability assessment, quantitatively evaluates the ecological vulnerability of Sanjiangyuan region through ArcGIS and other platforms, and analyzed the spatial differences at that time. The main conclusions are as follows:(1) In PSRM model, the spatial distribution of each level has changed obviously in the past 20 years, and the average score has also changed greatly with the passage of time; (2) The spatial distribution of ecological vulnerability in the Sanjiangyuan Region was uneven; (3) According to PSRM model, from 2000 to 2010 and then to 2020, the ecological vulnerability index of the majority area was increased.**

## Keywords

**Sanjiangyuan region; Ecological vulnerability; PSRM Model.**

## 1. INTRODUCTION

Human activities are increasingly disturbing the ecosystem, the service function of the ecosystem is declining [1], and the level of human welfare is severely challenged. Protecting the ecological environment and maintaining human well-being have become the focus of international scientific research programs. Following the Millennium Ecosystem Assessment Project, the Convention on Biological Diversity and the Intergovernmental Science Policy Platform for Ecosystem Services, the United Nations further takes "protecting, restoring and promoting the sustainable use of terrestrial ecosystems, managing forests sustainably, preventing and controlling desertification, stopping and reversing land degradation and curbing the loss of biodiversity" as its actions in Changing Our World: Agenda for Sustainable Development in 2030.

The concept of ecological vulnerability is not uniform, but different scholars have similar views [2-3]. On the general level, vulnerability may mean potential loss or injury [4]. Turner et al. defined vulnerability as "the degree to which a system, subsystem or system component may be harmed by exposure to hazards (disturbances or stressors)" [3]. Vulnerability research is

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widely carried out in social science [5], ecology [6], natural disasters [7] and land use [8]. The concept of ecological vulnerability is first used in the study of ecological environment resilience [4]; Van Straalen analyzed the vulnerability of ecological receptors from three dimensions: exposure, inherent sensitivity and resilience [9]. With the deepening of research, ecological vulnerability research is gradually introduced into a larger scale of ecosystem research. Williams and Kaputska concluded that "ecosystem fragility is the potential of an ecosystem to regulate its response to stressors in time and space, which is determined by the characteristics of an ecosystem including many organizational levels" [10]. With the improvement of human awareness of environmental protection, especially in the context of increasing disasters and climate change, the policy's interest in ecological vulnerability research is also increasing [11]. Researchers actively explored different ecosystems, including groundwater [12-13], forests [14], basins [15-16], fragile habitats [17-18] and nature reserves [19-20].

The nature reserve was established in August 2000 in Sanjiangyuan region [21], and was selected as the first batch of national parks in China in October 2021 [22]. It is of great significance to objectively evaluate the ecological fragility of the Sanjiangyuan region for the regional ecological management of nature reserves and national parks. Sanjiangyuan region is the birthplace of three major rivers, with uneven distribution of natural resources and complicated division of ecological function areas. Its development needs to be based on sustainable development and ecological civilization construction. Therefore, it is urgent to explore the influence of human and natural factors on local ecology, fully consider and select scientific research routes and contents, and apply the methods to the ecological environment exploration in Sanjiangyuan region, Qinghai-Tibet Plateau and even larger scale, so as to seek a new way out for national development and the future of mankind as a whole. The Sanjiangyuan region is irreplaceable and typical in China and even in the world, and the ecological vulnerability evaluation of key ecological protection areas and the first batch of national parks in China provides a reasonable reference for the sustainable development goal, and provides a scientific basis for the harmonious coexistence between man and nature and the construction of ecological civilization.

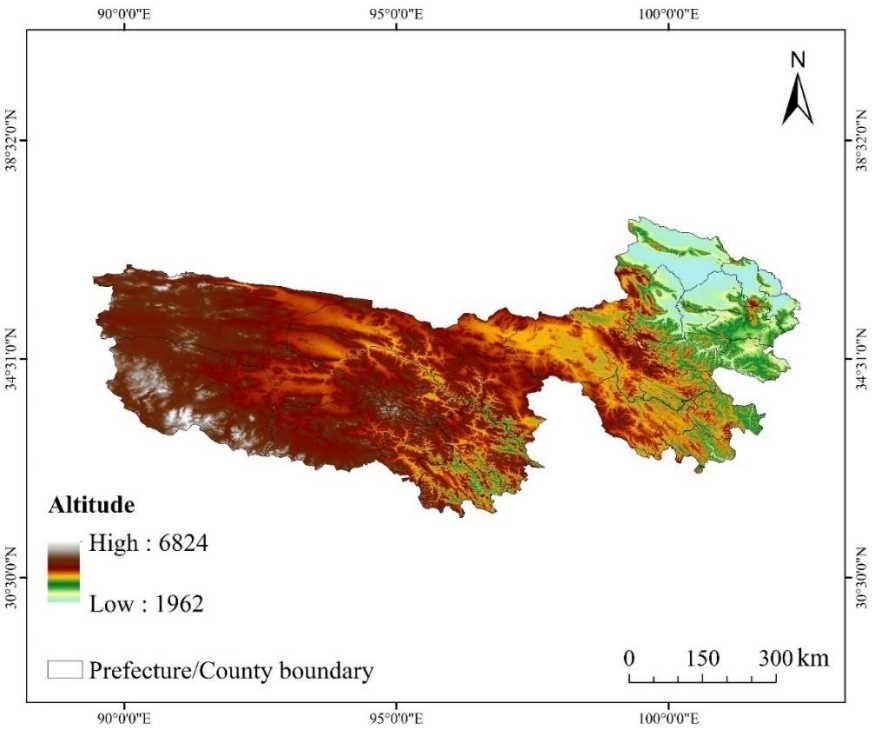


**Figure 1.** Study area

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# 2. MATERIALS AND METHODS

## 2.1. Data

According to the 15 index factors required by PSRM model, this study collected the data of natural environment, human activities and management behavior every 10 years in 2000, 2010 and 2020 to assess the local ecological vulnerability. The DEM map in the study area comes from the SRTMDEMUTM satellite data set product in the Geospatial Data Cloud (https://www.gscloud.cn/) with a resolution of 90m; The regional boundary of the study area comes from the 1: 100,000 administrative boundary data product of Sanjiangyuan region; a space-time three-level environmental big data platform (https://poles.tpdc.ac.cn/zh-hans/). The road network density, slope data and NDVI data are from the Center for Resources and Environmental Science and Data, Chinese Academy of Sciences (http://www.resdc.cn); the annual average temperature, annual precipitation, land use data and water area come from the Qinghai-Tibet Plateau Scientific Data Center. As for population density, residents' education level, government policies, per capita GDP, and the number of livestock at the end of the year are all from the statistical yearbook of Qinghai Provincial Bureau of Statistics and the work reports of Qinghai provincial government in various years.

In order to ensure the consistency of different data research scales, the above natural environment data and socio-economic data were rasterized by inverse distance interpolation method in ArcGIS 10.8, and the resolution of all data was unified to 1km×1km by resampling, and the WGS_1984_UTM_Zone_51N projection coordinate system was used.

## 2.2. Methods

The "pressure-states-response-management" model (PSRM) includes pressure, states, response, management 4 layers. Based on the actual situation in the Sanjiangyuan region, this study selected 15 indicators and follows the principles of scientificity, practicality and accuracy. The interaction of 15 index factors in 4 layers forms the logical relationship of "what happened, why it happened, how to deal with it, and on what basis" [23]. In this paper, the influence of human activities and economic development on ecology in the study area constitutes the pressure layer, while the living state of natural ecological environment constitutes the state layer, which can change under the influence of human economic development, such as road construction and other infrastructure activities will change the slope. The response layer is the result of the ecological environment's pressure and states changes, and it can also be fed back to the state layer, and the pressure changes and responses of the ecological environment are fed back to human beings. The government, educational and scientific research institutions and individual organizations take corresponding management measures to protect the ecological environment, thus forming the management layer.

(1) The pressure layer mainly refers to the influence of human activities and social and economic development. In recent years, the pressure brought by the rapid economic and social development in the Sanjiangyuan region is increasing, which makes the natural environment in the alpine region more fragile and the ecological balance is greatly destroyed. The economic development of Sanjiangyuan region is based on resource-oriented industries such as animal husbandry, which will inevitably lead to the shrinking of woodland and grassland. Economic development, population concentration and infrastructure construction will inevitably have a negative impact on the local ecological environment, while the development of green new tertiary industry can achieve sustainable development, and the increase in per capita income will make the local government invest more in ecological environment protection. Therefore, based on the local actual situation, this level selected per capita GDP(P1), the proportion of tertiary industry (P2), population density (P3), annual livestock inventory (P4) and road

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network density (P5) as indicators [24], in which the former two have a positive impact on the ecological environment, while the latter three are negative.

(2) The state layer refers to the state of the natural environment in the ecosystem [24]. The Qinghai-Tibet Plateau, which belongs to the Sanjiangyuan region, has complex natural conditions, unique animal and plant species and rich biodiversity, which are very sensitive to climate change and topographic conditions. Precipitation and temperature are the most important scales to measure climate conditions, and they are also the most important natural reasons that affect the distribution and abundance of local organisms. Vegetation distribution and animal survival zone depend on altitude and slope, which constitutes the vertical zonation of the Sanjiangyuan region. Therefore, this study selected annual precipitation (S1), annual average temperature (S2), slope (S3) and elevation (DEM)(S4) as the hierarchical factors.

(3) The response layer represents the tolerance of vegetation and water bodies (rivers, lakes, etc.) to environmental changes. Due to the high average altitude, cold climate, frozen soil development and poor soil, the most widely distributed natural vegetation in the Sanjiangyuan region includes alpine meadow and alpine grassland. As the birthplace of the three major rivers, the precipitation is scarce and mainly solid precipitation, and the surface runoff is complex. There are a large number of continental glaciers, many wetlands, and various types of saltwater lakes and freshwater lakes are scattered all over the country, with a vast water area. Based on this situation, the response layer of this study selected three factors: normalized vegetation index (NDVI)(R1), grassland coverage area (R2) and water area (R3). The formula [25] for calculating NDVI is as follows:

$$\mathrm{NDVI}=\frac{NIR-R}{NIR+R} \quad (1)$$

Among them, NIR represents the value of near infrared band in MODIS image, and R represents the value of infrared band in remote sensing image.

(4) Management mainly refers to the activities of reducing and preventing the adverse effects of human beings on the natural environment at the social and personal levels, including reducing and preventing negative behaviors from organizations and individuals for the survival and development of human beings, as well as actions taken by all parties to restore the ecological environment and remedial measures taken against changes in the ecological environment [26]. The main management measures are the management control policies and relevant laws and regulations issued by local governments. Compared with the Sanjiangyuan area in the 1980s and 1990s, this aspect is reflected in strengthening the establishment of residents' self-governing organizations for small-scale management of social communities, supporting social mass organizations, setting up environmental protection groups and foundations, and delineating the scope and setting up Sanjiangyuan nature reserves and national parks. On the individual level, it is reflected in the enhancement of environmental awareness, consciously observing the regulations on nature protection, spontaneously protecting the natural environment and improving the quality level of local residents, which are ultimately related to the development of education level [27]. Therefore, this study chooses policy support (M1), residents' education level (M2) and the area of national parks and nature reserves (M3) as indicators of the management subsystem, in which policy support is specifically quantified as the number of local social organizations (social organizations, private non-enterprise units, foundations) and autonomous organizations (villagers' neighborhood committees, community neighborhood committees), while residents' education level is quantified by the number of ordinary middle school graduates in that year. These indicators reflect the changes of people's consciousness and behavior towards ecological protection.

15 indicators include positive indicators and negative indicators. The positive or negative index means that the index plays a role in aggravating or reducing ecological vulnerability, while

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the increase of the positive index value means that the habitat conditions improve and the ecological vulnerability index is higher. For the increase of negative index value, it means that the ecological vulnerability index is lower with the deterioration of habitat conditions. The positive indicators include GDP per capita (P1), the proportion of tertiary industry (P2), annual precipitation (S1), altitude (S4), normalized vegetation index (R1), grassland coverage area (R2), water body area (R3), policy support (M1), residents' education level (M2) and the area of national parks and nature reserves (M3). Negative indicators include population density (P3), annual livestock inventory (P4), road density (P5), annual average temperature (S2) and slope (S3). The selected indicators are used to calculate the ecological vulnerability index, and in order to exclude the influence of different dimensions of each factor, it is necessary to standardize the dimensionless transformation of the selected evaluation indicators by using the efficacy coefficient scoring method, which is the standardization of data processing. For positive indicators, if the positive index value increases, the habitat conditions will improve (Formula 1). For negative indicators, if the value of negative indicators increases, the habitat conditions will deteriorate (Formula 2).

$$X_i = \frac{x_i - \min(x_i)}{\max(x_i) - \min(x_i)} \tag{2}$$

$$X_i = \frac{\max(x_i) - x_i}{\max(x_i) - \min(x_i)} \tag{3}$$

Where $X_i$ is the standardized value of each index i, $x_i$ is the actual value of each index i before standardization, $\max(x_i)$ is the maximum value of each index i before standardization, and $\min(x_i)$ is the minimum value of each index i before standardization.

The positive and negative nature of indicators are shown in Table 1.

**Table 1.** The positive and negative nature of indicators

| Layers | Indicators | Index property |
|---|---|---|
| Pressure | Per capita GDP(P1) | Positive |
| | Proportion of tertiary industry(P2) | Positive |
| | Population density(P3) | Negative |
| | Annual livestock inventory(P4) | Negative |
| | Road network density(P5) | Negative |
| State | Annual precipitation(S1) | Positive |
| | Annual average temperature（S2） | Negative |
| | Slope(S3) | Negative |
| | Elevation(S4) | Positive |
| Response | Normalized vegetation index (NDVI) (R1) | Positive |
| | Grassland coverage area(R2) | Positive |
| | Water body area(R3) | Positive |
| Management | Policy support(M1) | Positive |
| | Residents' education level(M2) | Positive |
| | Area of national parks and nature reserves(M3) | Positive |

The weight of each index above is determined by analytical hierarchy process (AHP) method. The attribute hierarchy of AHP method is divided into three levels: the overall goal of ecological vulnerability is at the top level, the multiple criteria of defining index factors such as pressure, states, response and management are at the middle level, and the 15 indicators that affect

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ecological vulnerability are at the bottom. Figure 3 shows the weight of each index calculated by AHP.

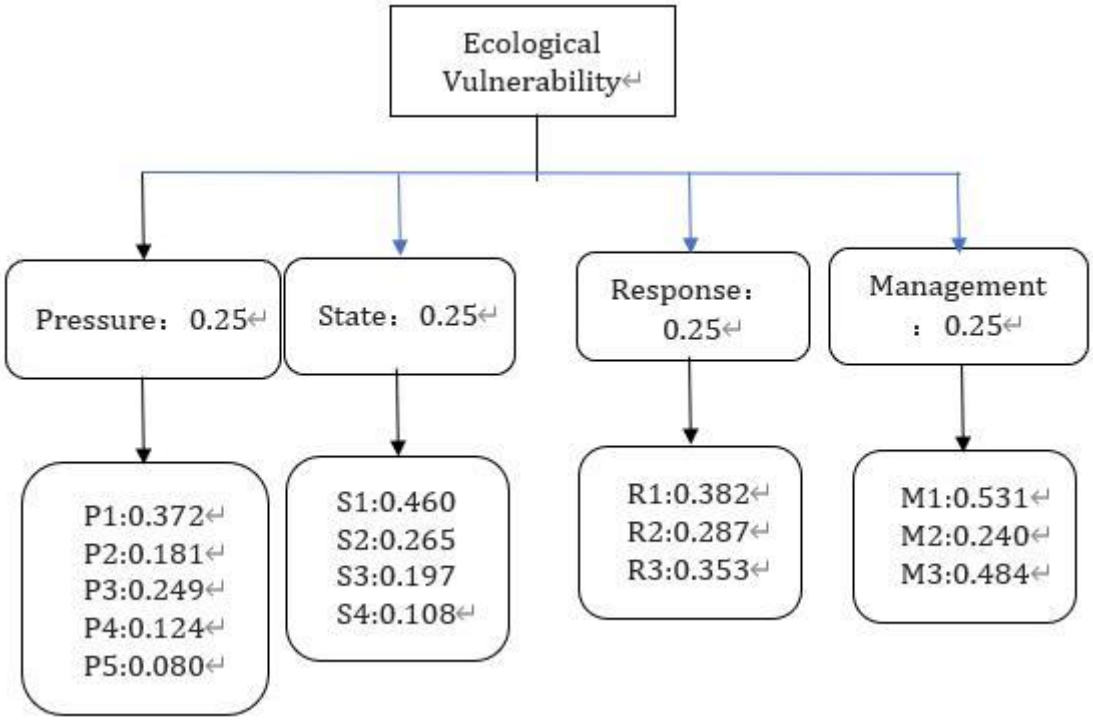


**Figure 3.** The weight of each index

The ecological vulnerability index (EVI) is used to indicate the degree of ecological vulnerability. In this paper, the value is between 0 and 1. The lower the value, the more sensitive the regional ecosystem is to external environmental changes, the weaker its ability to resist the deterioration of the ecological environment and its resilience, and the more likely it is to be destroyed. The higher the EVI value, the more ideal the ecological environment is. The calculation method of EVI is as follows:

$$\text{EVI} = \sum_{i=1}^{n} W_j \times X_{ij} \quad (4)$$

Where EVI is the ecological vulnerability index, $W_j$ is the weight index of j, $X_{ij}$ refers to the standardized data of indicators at all layers of pressure, states, response and management, and n is the number of evaluation indicators.

In order to quantify the temporal and spatial variation characteristics of ecological vulnerability, the EVI value obtained in this study is divided into five grades after standardization, and the breakdown is as follows: Class I is extremely fragile area (0~0.2), Class II is highly fragile area (0.2~0.4), Class III is moderately fragile area (0.4~0.6), Class IV is slightly fragile area (0.6~0.8), and Class V is non-fragile area (0.8~1). The specific grading results are shown in Table 2.

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**Table 2.** Classification standard of ecological vulnerability

| Class | Vulnerability | EVI value | Ecological characteristics |
|---|---|---|---|
| I | Extremely fragile | 0~0.2 | The ecosystem structure has been seriously damaged, the ecological pressure is enormous, the anti-interference ability and self-recovery ability are extremely poor, it is very difficult to recover and reverse, the ecological problems are serious, and the ecological vulnerability is extremely high. |
| II | Highly fragile | 0.2~0.4 | The structure and function of the ecosystem are destroyed, and it is under great pressure, sensitive to external interference, with poor self-recovery ability, many ecological problems and high ecological fragility. |
| III | Moderately fragile | 0.4~0.6 | The structure and function of the ecosystem are unstable, and it is under great pressure. It is sensitive to external interference, and its self-recovery ability is poor. Existing ecological problems are prominent and its ecological vulnerability is high. |
| IV | Slightly fragile | 0.6~0.8 | The structure and function of the ecosystem are relatively stable, with less pressure, insensitive to external interference, strong self-recovery ability, few ecological problems and low ecological vulnerability. |
| IV | Non-fragile | 0.8~1 | The structure and function of the ecosystem are very stable, with almost no external pressure interference, strong self-recovery ability, no ecological problems and low ecological vulnerability. |

## 3. RESULTS

Based on PSRM model, the weight proportion of each index indicator in different levels was calculated. Figure 4 shows 4 layers spatial changes of scores in three periods in the study area. The spatial distribution of each level has changed obviously in the past 20 years, and the average score has also changed greatly with the passage of time.

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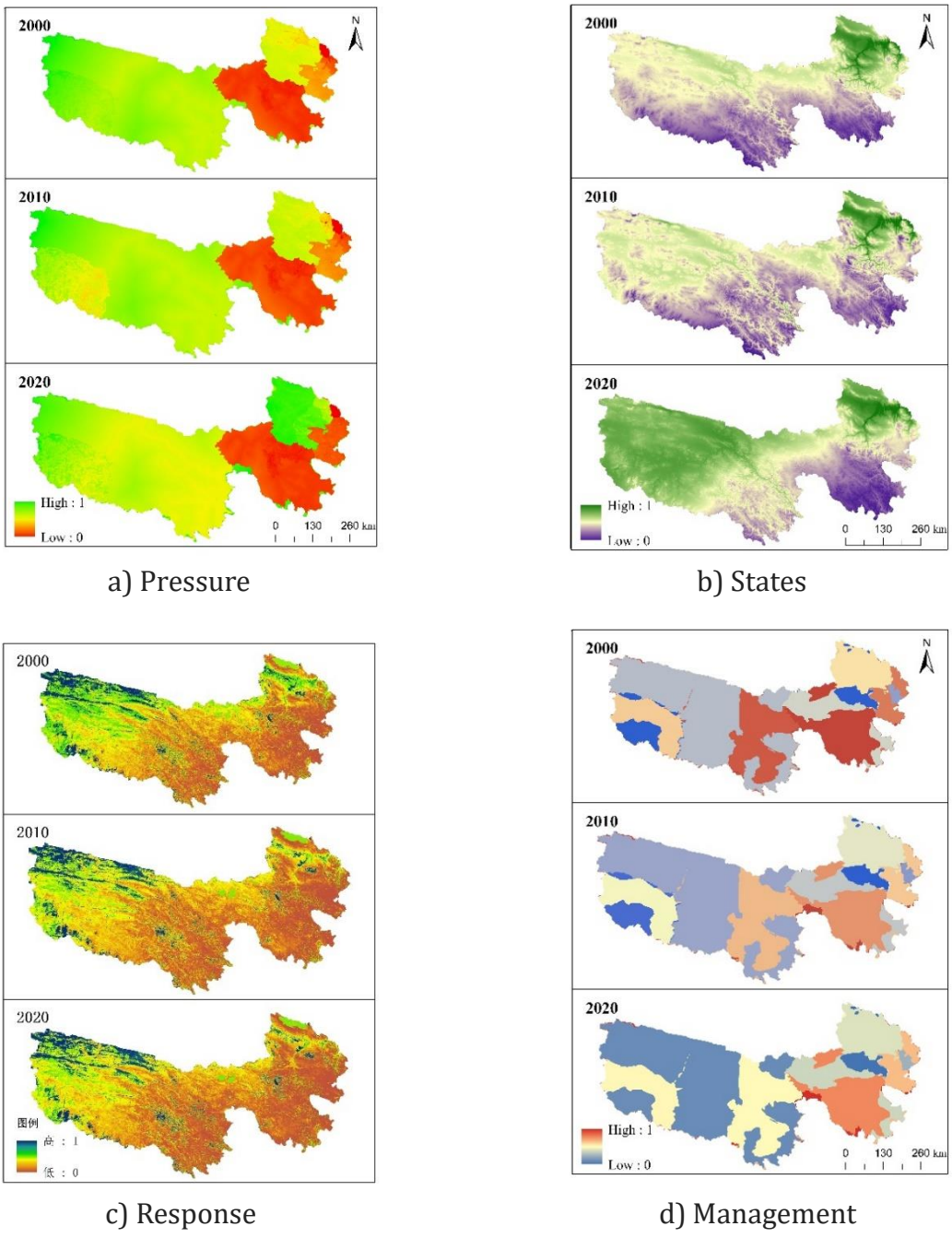


**Figure 4.** 4 layers spatial changes of scores in three periods

## 3.1. Score situation of Pressure Layer

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The decrease of the pressure layer score means that the ecological pressure in this area increases and the impact of human economic activities on the ecological environment increases. In the 20 years from 2000 to 2020, the center of the lowest score has been in Guoluo Prefecture in the east and southeast of the study area (Figure 5). In 2000, the lowest scores of Yushu Prefecture and Haixi Prefecture were 0.62 and 0.73 respectively, and the highest scores were 0.84 and 0.82 respectively, while the average score of Guoluo Prefecture was only 0.08. By 2010, the lowest scores of Yushu Prefecture and Haixi Prefecture dropped to 0.58 and 0.46, while the scores of Huangnan Prefecture and Guoluo Prefecture also decreased, while the scores of Hainan Prefecture increased, with an average of 0.45, indicating that the ecological pressure of Hainan Prefecture gradually decreased, while the ecological pressure of the other four States increased. In 2020, the pressure layer scores of the four states except Hainan in the study area further decreased, and the natural ecological environment pressure was still increasing, with the average score of Hainan reaching 0.86.

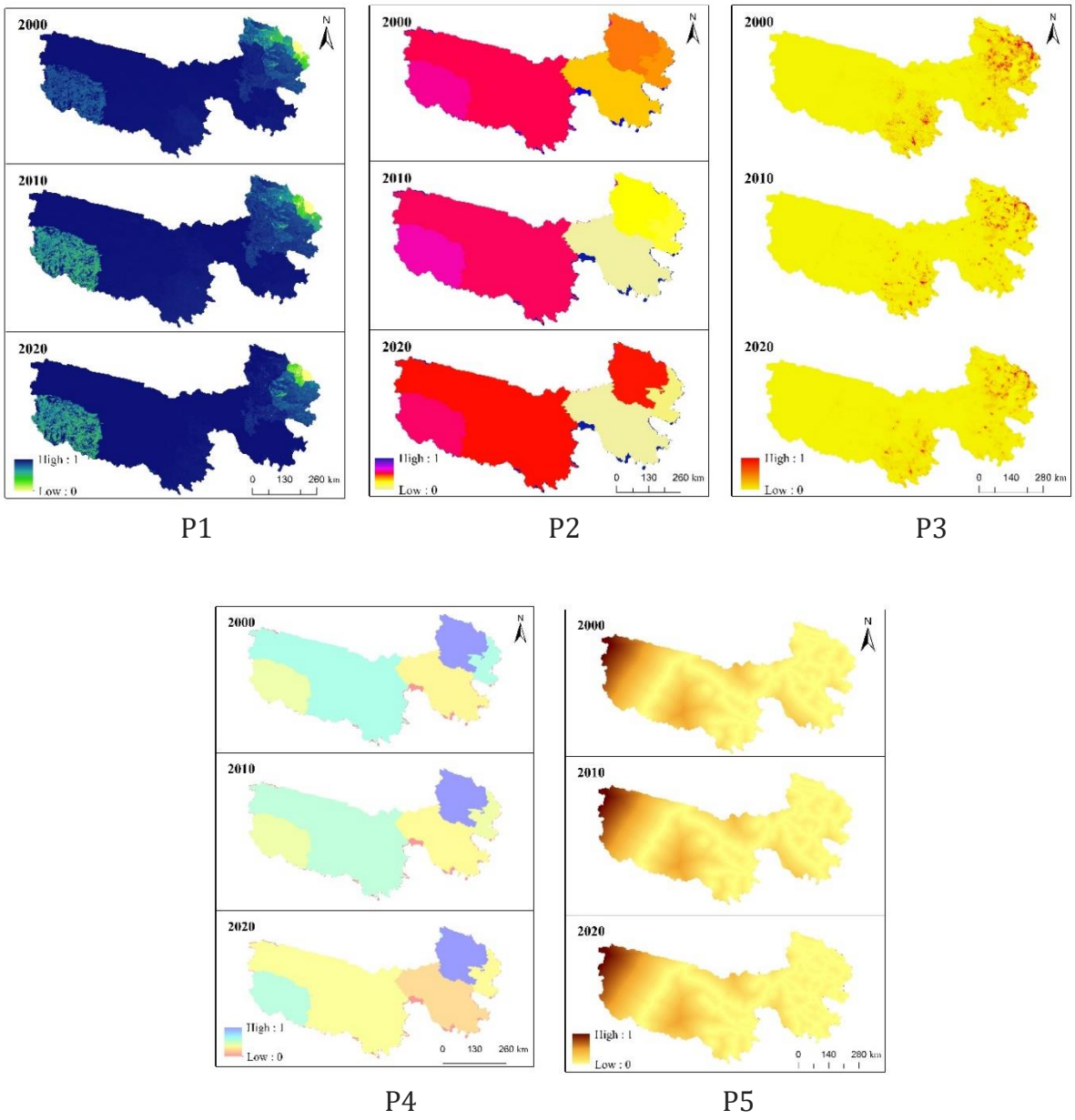


**Figure 5.** Spatial variation of each indicator of pressure layer in three periods

From 2000 to 2020, the per capita GDP(P1) and the proportion of the tertiary industry (P2) of all counties in the Sanjiangyuan region are rising, which is positively correlated with the

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scores of the pressure stratum, indicating that the economic development, the wealth growth of the people, the decline of traditional agriculture and industry, and the optimization of industrial structure brought about by the rise of new sustainable green agriculture and tertiary industry, such as tourism, service industry and photovoltaic power generation, have a positive role in improving the ecological environment. However, the population density (P3) was at a high level in 2000, and it continued to decline in 2010 and 2020. The adjustment of industry and the trend of urbanization made the local population move to the surrounding more convenient urban agglomeration such as Lanxi. From 2000 to 2020, the annual stock of livestock in Hainan and Haixi showed a rising trend, while the year-end stock of livestock in Yushu, Huangnan and Guoluo in 2020 decreased by about 35%, 38% and 37% respectively compared with that in 2000. Compared with the spatial distribution of pressure layer scores, the year-end stock of livestock had obvious negative effects on it. From 2000 to 2020, the rapid development of infrastructure in China has increased the density of road network (P5), which indicates that the increase of human activities has further reduced the natural ecological restoration capacity in the Qinghai-Tibet Plateau and increased the pressure on the ecosystem. In the future, with the implementation of the relocation plan for high-altitude areas in Qinghai, many people will move to areas with relatively high urbanization and relatively dense population in the east.

### 3.2. Score situation of State Layer

TThe score of the state layer increased, indicating that the natural ecological environment has been improved. From the perspective of spatial distribution, the average score of each state in the study area decreases from northwest to southeast (Figure 6), with the highest score of 0.75 in Yushu Prefecture and the lowest score of 0.12 in Guoluo Prefecture. On the whole, from 2000 to 2020, the score of the state layer fluctuated slightly with time. From 2000 to 2010, due to the improvement of annual precipitation (S1) and annual average temperature (S2), the average score of each state and county level increased slightly from 0.28 to 0.29. However, from 2010 to 2020, due to the global warming trend and frequent extreme weather, the annual average temperature in the study area dropped from −0.13°C to −0.38°C, and the annual precipitation dropped from 572 mm to 267 mm, resulting in the average score of the state layer in each state and county dropped to 0.25. The slope (S3) and elevation (S4) in the study area are higher in the west and lower in the east as a whole, which is contrary to the spatial distribution trend of the score of the state layer. The annual precipitation and annual average temperature are higher in the east and lower in the west, which is roughly the same as the spatial distribution trend of the state layer score. The annual precipitation in the western region increases year by year, and its state layer score gradually decreases, while the state layer score in the eastern densely populated area gradually increases, suggesting that human activities have positive significance for natural environmental conditions.

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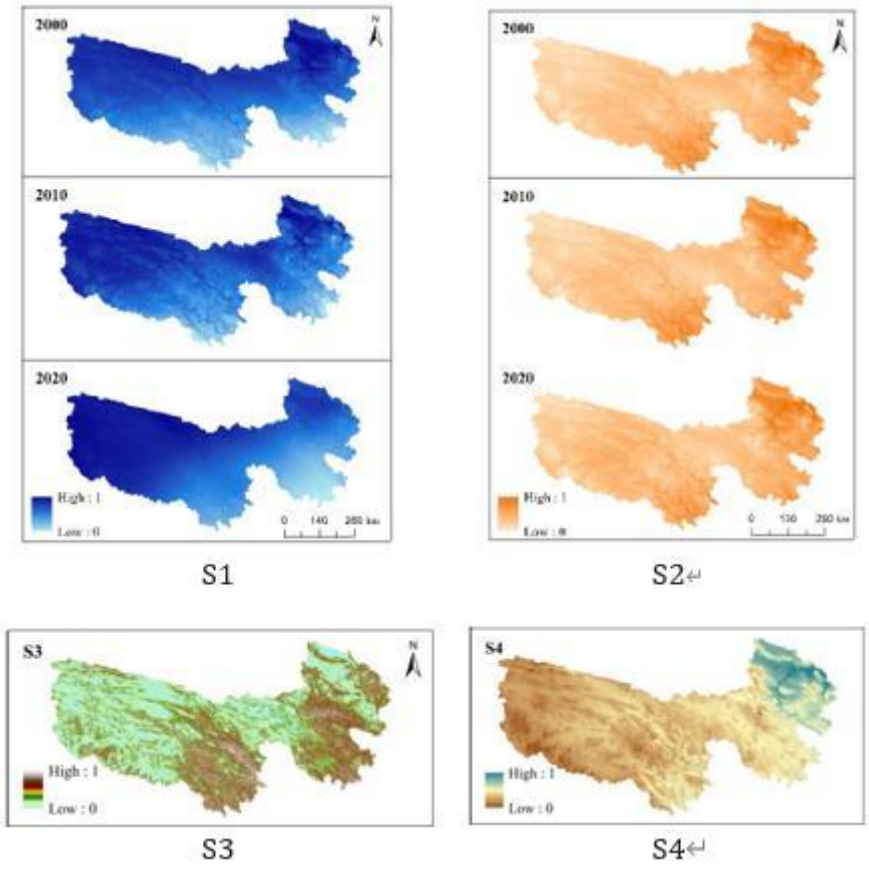


**Figure 6.** Spatial variation of each indicator of state layer in three periods

### 3.3. Score situation of Response Layer

In the response layer, with the increase of regional score, it means that the ecological environment has been improved. On the whole, the overall trend has not changed in a large scale, and the score of each period has gradually decreased from northwest to northeast (Figure 7). In 2020, the score of west to east will gradually decrease from 0.7 to 0.1, which is consistent with the changes of NDVI value (R1) and grassland coverage area (R2) (from 0.92 in northwest to 0.25 in northeast). Most of the areas with high NDVI value and grassland coverage area are located in Yushu and Haixi, and the average score of response layer exceeds 0.6, while the areas with low NDVI value and grassland coverage area are mainly located in relatively densely populated areas such as Hainan and Huangnan, and the average score of response layer is < 0.2. Because climate change and human activities also affect the spatial distribution of scores, Hainan and Huangnan, located in the northeast of the study area, are close to Xining, the provincial capital. Before 2010, they will vigorously develop urban construction, with high population density, high urbanization, low altitude, relatively heavy greenhouse effect, and reduced NDVI value and grassland coverage, resulting in lower scores in the response layer; The number of tourists visiting Nianbaoyuze Scenic Spot in Guoluo Prefecture in the southeast is increasing year by year, which leads to the destruction of the natural landscape and the decrease of vegetation coverage area in the scenic spot. However, the eco-environmental protection policy implemented by the Qinghai provincial government has led to an increase of more than 30,000 hectares of grassland coverage in the Sanjiangyuan area after 2010, which is four times higher than that in 2000, making the improvement of NDVI index more obvious in 2020, and the grassland coverage area has been greatly improved compared with that in 2010, making the scores of response layers in all counties in the whole region have been on the rise for 20 years. The water body area (R3) is greatly influenced by natural climatic conditions, and it is mainly distributed in the main streams and tributaries of the Yangtze River, the Yellow River and the

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Lancang River in the west and middle of the study area. From 2000 to 2020, the overall area showed a wave rising trend, which is the same as the NDVI index and grassland coverage. Climate change and active protection by human beings have a positive effect on its area recovery, and the influence trend on the score of the response layer also showed a positive fitting trend.

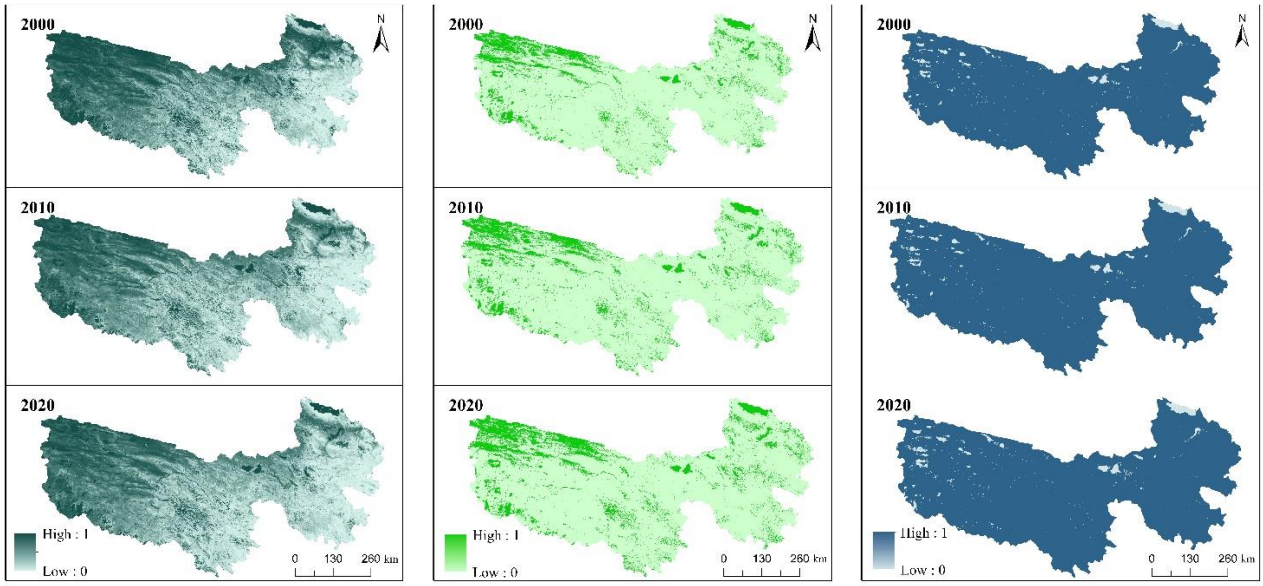


**Figure 7.** Spatial variation of each indicator of response layer in three periods

### 3.4. Score situation of Management Layer

For management, with the increase of regional scores, the management level will also increase. The management level includes three indicators: policy support (M1), education level (M2) and the area of national parks and nature reserves (M3). There are great differences in administrative policies, residents' education level and management level in different administrative regions, which leads to great spatial and temporal differences in the three indicators (Figure 8). In 2000, Sanjiangyuan still lacked ecological environment protection policies, and the number of social organizations and autonomous organizations that could provide policy support was very limited. The national protection measures were the main measures. At this time, Yushu Prefecture, which had established the Hoh Xil Nature Reserve at that time, scored the highest with 0.68, followed by Guoluo Prefecture with 0.76, followed by Huangnan Prefecture with 0.60, and the scores of the other two prefectures, Haixi Prefecture and Hainan Prefecture, were all below 0.2. After 2010, a series of ecological protection projects such as afforestation, grassland contract responsibility system, nature reserve construction and ecological migration were carried out, and local autonomous units such as villagers' neighborhood committees and community neighborhood committees were established to promote the implementation of relevant policies among the masses and strengthen local management, and the management score was significantly improved. In 2020, except for Huangnan Prefecture, Hainan Prefecture and Haixi Prefecture, the management scores of Yushu Prefecture and Guoluo Prefecture will be further improved, which is mainly due to the increased investment in policy management, the continuous improvement of residents' education level and the enhancement of ecological protection awareness; At the same time, for the management of national parks and nature reserves, on December 9, 2015, the 19th meeting of the Central Leading Group for Comprehensive Deepening Reform adopted the "China Sanjiangyuan National Park System Pilot Program"; In 2017, Qinghai Province announced the permanent

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closure of Animaqing Scenic Area and Nianbaoyuze Scenic Area in the core area of Sanjiangyuan Nature Reserve, so as to restore its ecological environment naturally. In terms of residents' education, with the comprehensive popularization of national compulsory education, the number of ordinary middle school graduates in various counties and counties keeps increasing. From 2010 to 2020, the number of ordinary middle school graduates in Yushu Prefecture increased by 4,984, and that in Hainan Prefecture increased by 3,286. However, the number of ordinary middle school graduates in Huangnan Prefecture has only increased by 828, resulting in an insignificant increase in management scores in 2020 compared with other prefectures.

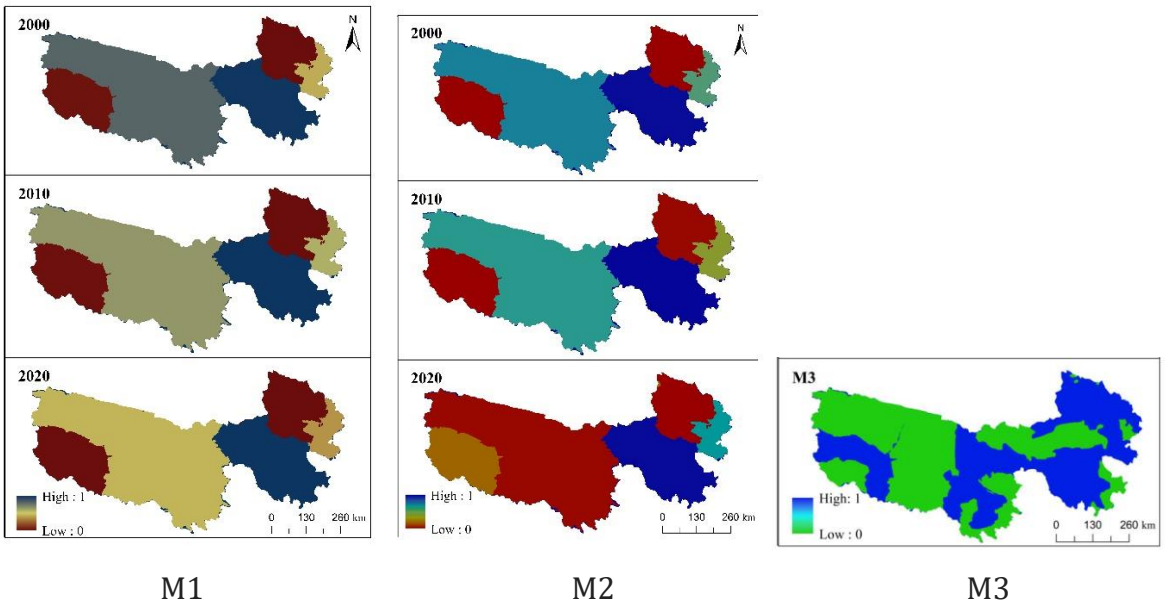


**Figure 8.** Spatial variation of each indicator of management layer in three periods

### 3.5. Spatial-temporal pattern characteristics of ecological vulnerability index

In 2000, about 53% of the study area was in an extremely fragile state, mainly in the west and south with high altitude and harsh climatic conditions (Figure 9). The moderately vulnerable areas, lightly vulnerable areas and non-vulnerable areas only accounted for 8%, 14% and 6% of the total area respectively, and most of the ecological environment was very fragile and the ecological pressure was extremely high. With the establishment of national nature reserves and the improvement of social and economic level after 2000, extremely vulnerable areas tend to be transformed into highly vulnerable areas and moderately vulnerable areas, and the problem of ecosystem fragility has been optimized. In 2010, the proportion of extremely vulnerable areas decreased to 38%, while the proportion of highly vulnerable areas and moderately vulnerable areas increased to 24% and 15%. Since then, the government's management ability, residents' education level and awareness of social and ecological protection have been further improved, and the local industrial development structure has been optimized. In 2020, the proportion of moderately vulnerable areas and lightly vulnerable areas will further increase, from 15% to 23% and 16% to 19% respectively. In addition, due to the optimization of urbanization process and the intervention of government management, the urban areas in Hainan, Huangnan and Guoluo with low altitude are classified as non-fragile areas, and the proportion has increased from 3% in 2000 and 5% in 2010 to 11% in 2020.

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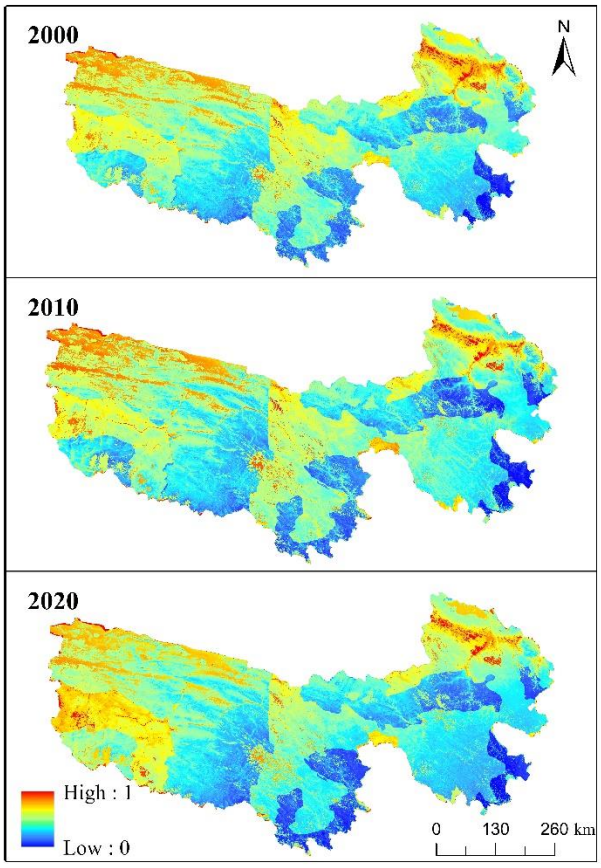


**Figure 9.** Spatio-temporal distribution of ecological vulnerability index (EVI)

In three time points, the change trend of ecological vulnerability index of each prefecture (county) level administrative region is as follows: most counties in Yushu, Haixi, Hainan and Huangnan showed a gradual upward trend, while most counties in Guoluo first declined and then rose, which indicated that the establishment of Sanjiangyuan Nature Reserve and government policy support were very useful. In some weeks, the ecological vulnerability index decreased in some counties, such as Xinghai County and Gonghe County in Hainan Prefecture, which are located at the edge of Qaidam Basin and include parts of Qinghai Lake. Due to climate changes such as the decrease of annual precipitation and the increase of annual average temperature, the degree of land salinization increased, and the area of lakes, seasonal rivers and other water bodies decreased. At the same time, in recent years, human activities such as tourism and salty lake exploitation have increased, which has destroyed the local ecological balance. Multiple reasons have led to the deterioration of the ecological environment in some areas and the decline of the EVI.

## 4. CONCLUSIONS

The results of the study reveal that:

(1) In PSRM model, the spatial distribution of each level has changed obviously in the past 20 years, and the average score has also changed greatly with the passage of time.

(2) In the pressure layer, the center with the lowest score moves from northwest to southeast from 2000 to 2020. The score of the pressure layer in the west of the study area increased, while the score in the east decreased, which was generally "high in the west and low in the east", but with the passage of time, the score in the whole study area was on the increase, because the per capita GDP and the proportion of the tertiary industry in each prefecture were rising, and the

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development of human economy had a positive effect on the improvement of the ecological environment. However, the population density of all prefectures in the study area is decreasing, and the road network density is increasing, which shows that the increase of human activities has further reduced the natural ecological restoration ability in the Qinghai-Tibet Plateau, and at the same time, the livestock inventory at the end of the year has obvious negative effects on the local ecological environment.

(3) In the state layer, the average score of each state in the study area decreases from northwest to southeast in space, while it rises slightly first and then decreases in time. This is due to the deterioration of natural environmental factors such as annual precipitation and annual average temperature in the state layer under the background of global climate change, and the improvement of human protection activities has little effect.

(4) In the response layer, the scores of each period gradually decreased from northwest to southeast, which was consistent with the change of NDVI value. The average scores of Yushu Prefecture and Haixi Prefecture with high NDVI value, grassland coverage area and water area exceeded 0.6, while the average scores of Hainan Prefecture and Huangnan Prefecture with low altitude and frequent human activities with low NDVI value, grassland coverage area and water area were less than 0.2. However, the eco-environmental protection policy implemented by the local government has increased the NDVI value and grassland coverage area of all prefectures in the whole region, and the scores of response layers in all prefectures have been on the rise from 2000 to 2020, while the water area is greatly affected by natural climate conditions, and the impact on the scores of response layers is relatively low.

(5) In the management, due to the great differences in administrative policies between different administrative regions, the three indicators are quite different in time and space. In 2000, the protection measures at the national level were the main measures. At this time, the highest score of management was 0.3 in Yushu Prefecture, which had established the Hoh Xil Nature Reserve at that time, followed by 0.2 in Guoluo Prefecture, and the scores of the other three prefecture were all lower than 0.1. Since then, a series of local ecological protection projects have been carried out, including popularizing compulsory education to increase the number of ordinary middle school graduates, and establishing local autonomous units such as villagers' neighborhood committees and community neighborhood committees to promote the implementation of relevant policies among the masses and strengthen local management， the scores of management have been significantly improved.

(6) According to the PSRM model, the ecological vulnerability index of the Sanjiangyuan region was obtained, and the regional vulnerability was divided into five grades according to the ecological vulnerability index: extremely vulnerable area, highly vulnerable area, moderately vulnerable area, slightly vulnerable area and non-vulnerable area. From 2000 to 2010 and then to 2020, the spatial distribution of ecological vulnerability in the Sanjiangyuan region is uneven, and the extremely vulnerable areas are mainly concentrated in the west and south with high altitude and harsh natural environment, and their areas are gradually decreasing; The area of highly vulnerable areas increased first and then decreased because of the improvement of ecological conditions; The areas of moderately vulnerable areas, lightly vulnerable areas and non-vulnerable areas have continued to increase, mainly concentrated in eastern towns and densely populated areas, indicating that the local ecological environment has continued to improve and human activities have played a positive role in ecological protection.

## 5. DISCUSSION

In order to maintain the ecological environment carrying capacity and self-recovery ability, a series of ecological security policies can be implemented to control industrial and resource development activities. However, the sustained social and economic development still brings

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pressure to the fragile and sensitive ecosystem in the Sanjiangyuan region. The development of regional economy may bring challenges to the ecological environment [28], and the increase of population, primary industry and tertiary industry further intensifies the conflict between people and land [29]. In addition, with the global warming, uncertainties such as glacier melting, snow line rising, vegetation degradation and soil erosion are increasingly affecting the regional ecosystem [30]. Under the current natural conditions and human destruction and management behavior, the ecological fragility of the Sanjiangyuan region has decreased in the past 20 years, and the overall ecological environment has undergone positive changes. However, when it comes to the scores at all levels, some indicators in some areas are deteriorating; At the same time, it is found that human economic development and management activities have a positive effect on reducing ecological vulnerability, but not all of them have side effects. According to the results of factor detection, the driving intensity of natural environmental factors for ecological vulnerability accounts for the main part, indicating that protecting the natural ecological environment can play a good role in improving local ecological vulnerability. Therefore, in the future, we should develop environment-friendly industries and feed back the economic benefits to the environment. Government departments should strengthen management, focus on local protection, maintain the current boundary between national parks and nature reserves, draw more ecological red lines in ecologically fragile areas that are not managed, and build an ecological corridor that dialectically balances economy and nature. The ecological fragility of the Sanjiangyuan region will be further reduced, the environmental carrying capacity will be increased, and the ability to resist external risks and pressures will be enhanced.

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