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Analyzing the environmental evolution of the Tibetan Plateau based on open-source data

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Abstract. The conflict between humanity and nature has recently gained prominence due to the ongoing development of human society and rising tensions caused by man-made conditions. Therefore, the Tibetan Plateau, known as the ecological environment's treasure house, is now experiencing environmental degradation and losing biodiversity, which has increased its ecological vulnerability. This study quantitatively analyses the environmental evolution and driving factors of the ecological vulnerability of the Tibetan Plateau from 2005 to 2020. The three aspects chosen for evaluation factors are social economy, natural environment, and social response. The weights of the parameters that were chosen using the AHP method are then evaluated using a PSR model that is constructed. The vulnerability map for the local ecological environment is then created using the GIS model. Additionally, the GeoDetector method is used in the study to examine how the spatial-temporal differences change and the variables that influence those changes. The findings demonstrate that the interaction between vegetation cover, altitude, precipitation, and local human activities is the primary factor causing ecological vulnerability. And this study will advance ecological protection and development of the Tibetan Plateau, and make new strides in the study of topics.

1. Introduction

With the rapid development of the global social economy and the intensification of human activities, the ecological environment on the earth's surface has become extremely fragile. For example, soil erosion, water shortages, vegetation destruction, accelerated desert degradation, environmental carrying capacity decline, badly affecting the daily production and life of human beings, regional economic development as well as global climate change. Simultaneously, the world's resources have been rapidly depleted by humans' growing demand, leading to serious imbalances in the ecosystem's structure and function and impairing the sustainability of both human society and the environment. These deteriorating ecological problems have aroused the attention of researchers around the world and thus have led them to launch research on ecological environmental protection.

Studying how vulnerable the ecological environment is is crucial to ecological environmental protection. The ecological transition zone serves as the origin of the idea of ecological vulnerability. Ecological vulnerability, in general, is the variability of ecosystems under the influence of natural or human factors, which is unfavorable to the development of ecosystems and human society [1]. The idea of an ecological transition zone was first introduced into the field of ecological research by American ecologist Clements at the turn of the 20th century [2] who carried out research on the ecological vulnerability of interleaved communities around the world. Subsequently, the concept of ecological vulnerability has been constantly evolving. Some researchers believe that ecological vulnerability is sensitive to external disturbances on a specific spatial and temporal scale, which is an inherent property of the system itself and is manifested under the disturbance of external factors. The assessment of the ecological environment's vulnerability can serve as a foundation for local ecological construction, fostering the coexistence of nature and society in a sustainable way [1], [3].

Although the model for assessing ecological vulnerability and the procedure for determining the weight of parameters are relatively developed, there are still gaps in the analysis of the evolution of ecological vulnerability in the long-term dimension against the backdrop of rapid urban development. In order to evaluate the temporal and spatial evolution of ecological vulnerability in the region from 2005 to 2020, this study chose the Tibetan Plateau as its research object and chose the Pressure-State-Response (PSR) model. It also used Geodetector to analyze the factors that were responsible for this development. The entire study aims to provide new insights for other related ecological vulnerability research as well as a scientific basis for an assessment of the Tibetan Plateau's ecological vulnerability.

2. Methods

2.1. Study area and data

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The Tibetan Plateau, also referred to as the "Third Pole" and the "Roof of the World," is situated in southwest China. This plateau is both the largest in China and the highest in the world, with a total area of about 20.5 million square kilometers and an average elevation of 4000 meters, having unique, fragile alpine ecosystem and extremely limited environmental carrying capacity [5]. Except for parts of the southwest which are located in Pakistan, Nepal, and other foreign countries, most of the Tibetan Plateau is located in China, such as Qinghai Province, Tibet Province, and Sichuan Province (Fig. 1).

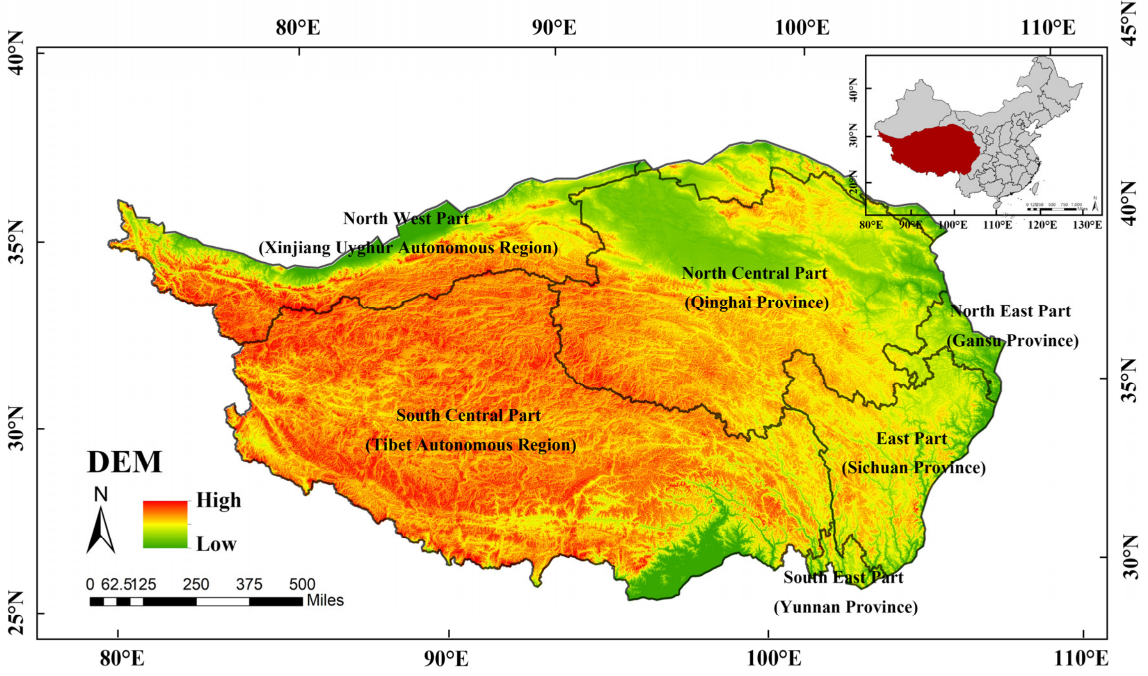

Fig. 1 The geographic location of the Tibetan Plateau, China.

The Tibetan Plateau is rich in biological resources and complex diverse vegetation landscape types and has experienced serious problems such as glaciers melting, land desertification and soil erosion in recent years, which have weakened the stability of the ecological security barrier function. And this study uses multi-source datasets and serial statistical analysis to evaluate the ecological environment vulnerability of the Tibetan Plateau, which are panel data related to regional socioeconomic and natural climate (GDP, year-end livestock inventory, total passenger traffic, annual average temperature, annual average humidity, forest coverage rate, total water resources, cultivated land area, PM2.5 concentration) from the National Bureau of Statistics China Statistical Yearbook (http://www.stats.gov.cn/), DEM elevation data (https://www.resdc.cn/), population density data (https://www.worldpop.org/), annual land cover dataset [6], Annual mean monthly precipitation [7] and atmospheric carbon dioxide concentration data at AIRS. The time dimension of all data covers 2005-2020, and the geographic resolution is unified at 5km (Fig.2).

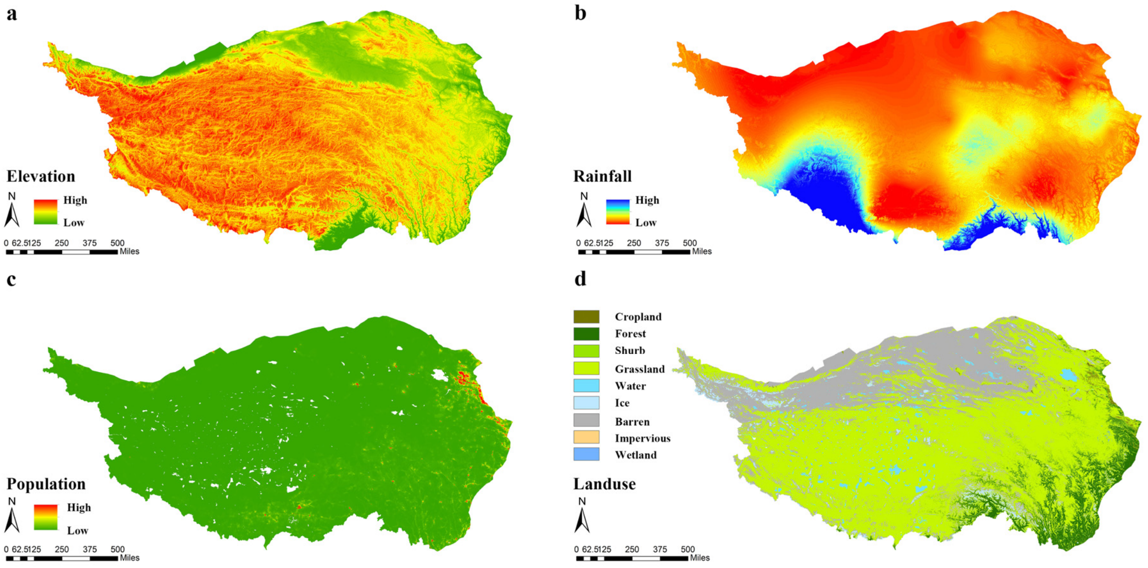

Fig. 2 Conditions of the study area, a. elevation; b. annual average precipitation in 2020; c. population density in 2020; d. annual Chinese land cover data in 2020.

2.2. Parameter evaluation with PSR model

In terms of the parameter evaluation of the ecological vulnerability, this study selects the PSR model [8], which can clearly express the causal relationship between variables, and combine the internal change factors of the ecosystem, natural, human and other factors, and could also evaluate when the system lacks the ability to cope and develops in the unfavorable direction. In this model, "P" represents the development pressure of the social economy, "S" represents the state of the natural environment, and "R" represents social response [9]. The "P" parameters in this study are the gross domestic product, population density, livestock inventory at year's end, annual Chinese land cover data, and total passenger traffic. The "S" parameters include annual average precipitation, temperature, humidity, forest coverage rate, water resources, cultivated land area, PM2.5 index, and elevation dem. The "R" which emphasizes the relationship between nature, society, and ecology, makes use of parameters such as carbon dioxide concentration, per capita disposable income, per capita water consumption, and education level [10].

2.3. Determination of weights using AHP

The Analytic Hierarchy Process (AHP) is used in this study to determine the weight of parameters after data cleaning, resolution unification, and normalization of all grid data of PSM in GIS. The problem is divided into various factors at different levels, depending on the nature of the issue and the overall objective. Then, qualitative and quantitative analysis is conducted using a multi-level weight decision analysis methodology [11]. The operation steps are as follows: 1. Establish a hierarchical model and divide the problem into multi-level aspects according to the relationship between the problems and decision-making criteria. 2. Construct a paired comparison matrix, use a specific criterion to compare each factor, and construct a matrix according to 9 importance levels and sort them. 3. Check the random consistency ratio (CR) of the matrix and get the weight (equation 1-3). 4. Weight the importance weight of different levels relative to the highest level.

$$CI = \frac{\alpha - n}{n-1} \qquad (1)$$

$$RI = \frac{CI_1 + CI_2 + \cdots CI_{500}}{500} \qquad (2)$$

$$CR = \frac{CI}{RI} \qquad (3)$$

where α means maximum characteristic root, n is the number of variables. In general, if $CR < 0.1$, it is considered that the matrix conforms to the test, otherwise it does not have satisfactory consistency.

2.4. Assessment of ecological vulnerability

In order to evaluate the vulnerability of the ecosystem, after solving the problem of constructing the index system and determining the level and weight of the parameters [12], this study based on the GIS model, overlapped and extracted the data of each parameter, then an optimized hotspot analysis was carried out after assigning values to the grid, and finally realized the drawing. Ecological vulnerability map, and then calculate the Environmental Vulnerability Index (EVI), which is often used to reflect the ecological vulnerability of a certain area (equation 4). The higher the EVI, The higher the EVI, the lighter the ecological Vulnerability of the region.

$$EVI = \sum_{i=1}^{14} w_i \cdot r_i \qquad (4)$$

where i means the number of variable, the w_i and r_i are the weight and score of i respectively.

2.5. Measurement the causal relationship with GeoDetector

In general, the spatial distribution change of a geographical phenomenon is usually caused by different factors, which leads to the similarity in its influencing factors. Geo-Detector is an auxiliary variable specially used to measure the causal relationship between variables and to identify regression models as well as the spatial differentiation and coupling of variables [13].

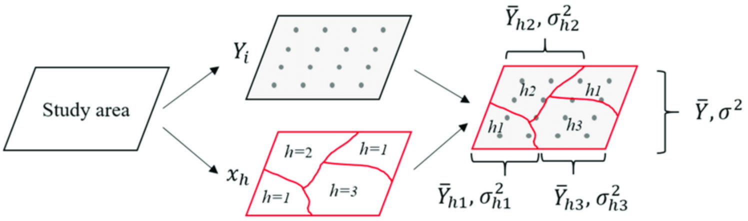

Fig. 3 Principle of the geodetector approach.

In the geodetector approach, if factor F is associated with the dependent variable D, then the distribution (spatial or temporal) of D will be similar to that of F. The higher the similarity between F and D patterns, the higher the sensitivity of D to F. In recent years, it has been widely used in biological and environmental adaptive factors. Therefore, on the basis of previous research, this paper uses this model to carry out research on the driving factors of ecological environment vulnerability in the Tibetan Plateau. The q-statistic formula used for the measurement is as equation 5.

$$q = 1 - \frac{\sum_{h=1}^{L} N_h \delta_h^2}{N\delta^2} = 1 - \frac{SS'W}{SS''T} \qquad (5)$$

where $h = 1, \cdots, L$ is the stratification of variable Y or factor X (Fig 3); N_h and N are the number of cells in stratum h and the whole area, respectively; δ_h^2 and δ^2 are the variance of Y values in stratum h and the whole area, respectively. $SS'W$ and $SS''T$ are the sum of within Sum of Squares and Total Sum of Squares, respectively. The q has a value range of [0, 1], so if the stratification is generated by the independent variable X, a higher value of q indicates a stronger explanatory power of the independent variable X on the attribute Y, and vice versa. In the extreme case, a q value of 1 indicates that factor X completely controls the spatial distribution of Y, a q value of 0 indicates that factor X has no relationship with Y, and a q value indicates that X explains $100 \times q$ % of Y.

3. Results

3.1. Spatial-temporal evolution characteristics of ecologically vulnerable areas

In this study, the ecological environment vulnerability value of the Tibetan Plateau from 2005 to 2020 was optimized by hotspot analysis and then re-divided into 7 categories, and the vulnerability classification results of the four periods in the region were obtained (Fig. 4) based on GIS.

The results show that there are notable differences in the spatial distribution of ecological vulnerability in the Tibetan Plateau between 2005 and 2020. The southern Tibetan Plateau showed a general trend of increasing and then decreasing ecological vulnerability. In general, a continuing weakening trend can be observed in the northern, western and eastern regions. In particular, the ecological vulnerability in the southern region showed an increasing trend from 2005 to 2010, while the ecological vulnerability in the northern, western and eastern regions showed a decreasing trend. The ecological vulnerability of the southern region increased from 2010 to 2015, particularly on the southwestern and south-eastern edges of the region. On the other hand, ecological vulnerability has been further reduced in the northern, western and eastern regions. Apart from a slight increase in the eastern edge, the ecological vulnerability of the Tibetan plateau has generally decreased between 2015 and 2020.

3.2. Driving force analysis

The study used GeoDetector to collect a variety of indicators, and Factor Detector and Ecological Detector to analyze the variables that affected the spatiotemporal shift in the ecological vulnerability of the Tibetan Plateau's environment. The indicators of stress, state, and response have the greatest impact on the ecological vulnerability of the Tibetan Plateau in the following order, according to the findings of the identification of factors (Table 1): Stress > Response > State. The Tibetan Plateau's ecological vulnerability is most strongly influenced by the stress index, followed by the response, and least so by the condition factor. However, the ecological study's findings (Table 2) show that there are notable variations in the ways that pressure, state, and response indicators affect the spatial distribution of ecological vulnerability in the Tibetan Plateau. As a result, the growth of human economic and social civilization has the biggest influence on ecological vulnerability. If human activities continue to harm the ecological environment, ecological vulnerability will increase significantly. However, this also demonstrates that human society actively preserves the ecological environment. the ecological vulnerability of the area is severely diminished.

Table1: The result of factor detection.

	Pressure	State	Respond
q-statistic	0.6377737	0.3857168	0.6067087
p-value	0.000116991	0.3632363	0.04080407

Table2: The results of ecological exploration.

	Pressure	State	Respond
Pressure	FALSE	TRUE	FALSE
State	TRUE	FALSE	TRUE
Respond	FALSE	TRUE	FALSE

3.3. Discussion

By combining the conditions of the study area, the spatial variation of the ecological vulnerability, and the convolution plot of the PSM model, certain characteristics of the local distribution of environmentally sensitive areas can be identified (Fig. 5).

The southern region includes the entire Tibet Autonomous Region and parts of Yunnan Province, whose stress and condition are relatively stable, and the response indicators fluctuate slightly, especially from 2015 to 2020, showing a general trend of growth. The eastern region includes parts of Sichuan Province, and the indicators and EVI in this region are relatively stable, which is related to the high altitude, small population, and small changes in precipitation.

The Northern Region includes most of Qinghai Province, Xinjiang Uyghur Autonomous Region, and parts of Gansu Province. The pressure and condition indicators in Qinghai Province are relatively stable, and the response indicators and the EVI generally show an upward trend with a sharp increase.

And Gannan Tibetan Autonomous Prefecture, Linxia Hui Autonomous Prefecture, Dingxi, Tianshui and Longnan in Gansu Province have lower altitudes than other regions and have abundant precipitation. They are one of the more suitable areas for human settlement in the Tibetan Plateau. In addition, the area has a large population, and human economic and social activities are prone to damage and disturbance to the local environment. These are all important reasons that affect the overall increase in pressure indicators and EVI in Gansu Province.

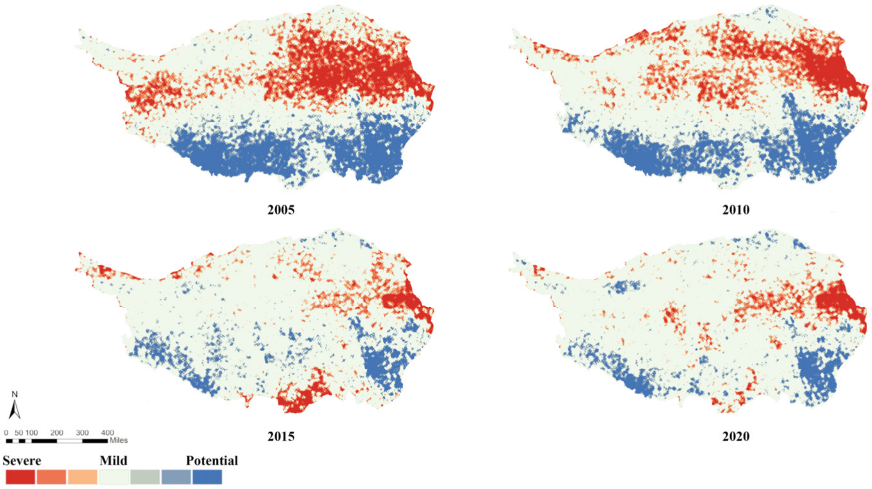

Fig. 4 Spatial variation of ecological vulnerability level of Tibetan Plateau from 2005 to 2010

4. Conclusion

This study constructs an ecological vulnerability assessment model for the Tibetan Plateau based on the PSR model and uses GeoDetector to analyze the driving factors of the spatial-temporal evolution of the ecological vulnerability in the region from 2005 to 2020.

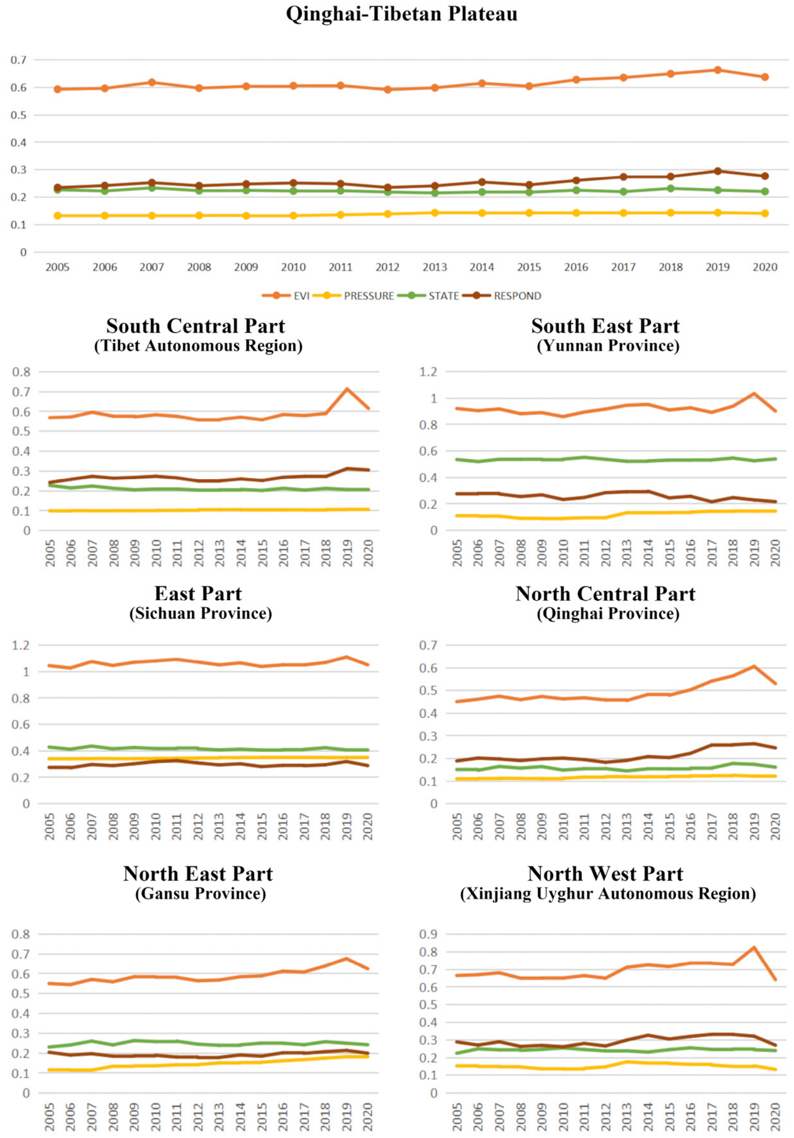

Fig. 5 Diagram of the PSM model for each part of the Tibetan Plateau

The conclusions are as followed: (1) The pressure indicators on the Tibetan Plateau from 2005 to 2020 are mainly population density and agricultural dependence, which are high in the southern and northeastern valleys, and low in other regions. Climate change and human activities are the main factors affecting the state indicators. The response index is mainly affected by human activities and local policies, with its change range, being small, as well as the eastern region, is relatively stable. (2) From 2005 to 2020, the ecological vulnerability of the Tibetan Plateau was mainly moderately vulnerable. The southern regions with high vegetation coverage and more precipitation have low ecological vulnerability intensity. The northern, western and central parts are mountainous, and the high-altitude areas dominated by plateaus have less human activities, relatively stable ecosystems, and moderate ecological vulnerability intensity. The northeast has a high population density and a high dependence on agriculture, so the intensity of ecological vulnerability is high.

These findings demonstrate that the primary determinant of the Tibetan Plateau's ecological vulnerability is the interaction of vegetation cover, altitude, precipitation, and local human activities with the PSR model and GeoDetector. As a result, this study can serve as a guide for the ecological growth and protection of the Tibetan Plateau, support regional ecological development, and advance knowledge on subjects with extremely low vulnerability.

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