Spatiotemporal Characteristics and Influencing Factors of Vegetation NEP in Qinghai Province from 2000 to 2020

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Abstract: In the context of global climate change and "carbon neutrality", it is important to study the detection of vegetation carbon sources/sinks and their influencing factors in Qinghai Province. Based on the improved CASA model and soil respiration model, the spatial and temporal distribution patterns and changes of NEP were analyzed using MODIS products from 2000 to 2020, combining topographic data, meteorological data and land use data, and exploring the contribution of each driver, in order to reveal the spatial and temporal characteristics of vegetation NEP in Qinghai. The results showed that: 1. The results show that: 1. from 2000 to 2020, the interannual fluctuation of vegetation NEP in Qinghai Province is obvious, showing an increasing trend, and its carbon sink capacity is increasing. 2. the spatial NEP of vegetation in Qinghai Province is high in the southeast and low in the northwest, gradually increasing from the northwest to the southeast. 3. the NEP of vegetation in Qinghai Province increases with slope and elevation, showing an increasing trend and then decreasing. The influence of slope direction on vegetation NEP was not significant. The correlation and partial correlation analyses between vegetation NEP and climatic factors showed that both temperature and precipitation mainly promoted vegetation NEP, and the coupling effect was more obvious.4. The influence of driving factors on vegetation NEP in Qinghai Province had the highest average annual precipitation, and the interaction effect was mainly enhanced by two factors.

Keywords: Net Ecosystem Productivity (NEP); Qinghai Province; Driving Factor; Geodetector

Introduction

Terrestrial ecosystems have the characteristics of fixing CO_2, air purification, water conservation, and maintaining biodiversity[1]. Among them, carbon sequestration, also known as carbon sink, plays a critical role in the context of climate change and "carbon neutrality", and the net ecosystem productivity (NEP) is commonly used to estimate the carbon source/sink of terrestrial ecosystems. When NEP>0, it means the ecosystem is a carbon sink, and vice versa. [2]. NEP is an important parameter reflecting plant activity, and its accurate estimation can not only reflect the health of the ecosystem, but also quantitatively evaluate the carbon sink capacity and potential storage of the area.As the most influential ecological regulating area in the world, Qinghai has a huge potential for carbon sequestration and sink. Therefore, the study of the spatial and temporal distribution and changes of vegetation carbon sources/sinks in Qinghai Province and their main driving factors is of great significance to clarify the carbon/source sinks of vegetation ecosystems in Qinghai Province, as well as the response and impact on global climate change, and provides a certain reference basis for the rational regulation of carbon sinks in Qinghai Province and the planning and implementation of regional ecological projects. At present, the research on NEP is mainly focused on various ecosystems.[3] The size and distribution of NEP in some regions have also been studied.[4]There are also more studies on vegetation cover and vegetation NPP in relevant areas of Qinghai[5][6]Liu, Feng[7]. However, the spatial distribution and spatial and temporal variation of vegetation carbon sources/sinks on the Qinghai

Plateau have not been quantified for Qinghai Province, and the main drivers and their interactions have not been investigated. Therefore, based on the improved CASA model and soil respiration model, this study uses MODIS products from 2000 to 2020, combined with meteorological data, DEM data and land use data, to analyze the spatial and temporal distribution patterns and changes of NEP in Qinghai Province and explore the contribution of each driver, in order to reveal the spatial and temporal characteristics of vegetation NEP in Qinghai. The spatial and temporal characteristics and main drivers of vegetation NEP in Qinghai were investigated.

1. Data sources and research methods

The data are remote sensing image data, meteorological data, topographic data, vegetation cover data and other data, and the years are 2000, 2005, 2010, 2015, 2020. The remote sensing data come from NASA official website (http://edcimswww.cr.usgs.gov/pub/imswelcome/) EOS/MODI product MOD13Q1 - NDVI dataset, with 250m spatial resolution and 16d temporal resolution. The meteorological data come from the China Meteorological Data Network (http://cdc.nmic.cn/), including monthly total precipitation and monthly average temperature observations from meteorological stations in Qinghai Province and its surrounding provinces, as well as monthly total solar radiation data from eight solar radiation stations. The month-by-month NDVI data and meteorological element data were obtained after processing. DEM data were obtained from the geospatial data cloud platform providing STRM data products with a spatial resolution of 30m, and slope and slope direction data were extracted based on DEM data. The vegetation cover data were obtained from Earth System Science.

2. Research Methodology

2.1 NEP estimation model

The NEP estimation model is an important indicator of vegetation carbon source and sink in the region. Without considering the influence of other natural and anthropogenic factors, NEP is equal to the difference between vegetation NPP and soil microbial respiration carbon consumption, calculated as follows[8]The formula is as follows

(1) $NEP(x, t) = NPP(x, t) - RH(x, t)$

where NEP (x, t) is the net ecosystem productivity of vegetation of image element x in month t in gC/m^2, NPP (x, t) is the net primary productivity of vegetation of image element x in month t (gC/m^2), and RH (x, t) represents the soil microbial respiration of image element x in month t (gC/m^2). When NEP > 0, it means that vegetation fixes more carbon than soil respiration emits carbon, and vegetation carbon sequestration is reflected as a carbon sink, and vice versa, it is a carbon source.

The improved CASA model of Zhu Wenquan et al.[9] The improved CASA model of Zhu et al. was used to achieve the estimation of vegetation NPP for 2000-2020 in Qinghai Province, in which the NPP was calculated from the photosynthetically active radiation absorbed by vegetation and light energy utilization, two drivers, with the following equations.

(2) $NPP(x, t) = APAR(x, t) \times \varepsilon(x, t)$

where APAR (x, t) represents the photosynthetically active radiation absorbed by image x in month t (MJ/m^2); ε (x, t) represents the actual light energy utilization of image x in month t (gC/MJ), and the calculation of the relevant parameters in Eq. see Ref.[9].

Soil heterotrophic respiration depletion RH was estimated using the model developed by Y. C. Pei[10]The model developed by et al.

(3) $RH(x, t) = 0.22 \times (\exp(0.0912T(x, t)) + \ln(0.3145R(x, t) + 1)) \times 30 \times 46.5\%$

where T（x,t）denotes the average temperature of image element x in month t (°C); R(x, t)denotes the average monthly precipitation of image element x in month t (mm).

2.2 Spatial and temporal variation analysis methods

The annual average of NEP was calculated to examine the spatial distribution of NEP with the following formula:

$$\overline{NEP} = \frac{\sum_{i=1}^{n} NEP_i}{n} \tag{4}$$

$\overline{NEP}$ is the multi-year average of the NEP for a given image element.

The inter-annual variation rate of NEP was analyzed by the one-dimensional linear regression method, and the slope of the multi-year regression trend line was calculated in the study area, which was used to reflect the inter-annual variation rate of vegetation NEP.[11] The slope of the multi-year regression trend line is used to reflect the interannual rate of vegetation NEP change. The calculation equation is as follows:

$$\theta \text{slope} = \frac{n \times \sum_{i=1}^{n} i \times NEP_i - \sum_{i=1}^{n} i \sum_{i=1}^{n} NEP_i}{n \times \sum_{i=1}^{n} i^2 - \left(\sum_{i=1}^{n} i\right)^2} \tag{5}$$

where θslope denotes the trend slope, n denotes the number of years of estimation, NEP denotes the vegetation NEP in the first i year of vegetation NEP, and the correlation between NEP values and time series is used to express the significance of interannual variation in NEP. θslope > 0 indicates an increase and vice versa.

2.3 Correlation analysis

The correlation between vegetation NEP and climatic factors (precipitation, temperature) was analyzed using image-by-image spatial analysis to determine the correlation coefficient between climatic factors and NEP, as well as the partial correlation coefficient. The partial correlation analysis is to calculate the relationship between two variables while eliminating the influence of other variables.[7]

The linear correlation coefficient is calculated as:

$$R_{xy,z} = \frac{\sum_{i=1}^{n} [(x_i - \overline{x})(y_i - \overline{y})]}{\sqrt{\sum_{i=1}^{n} (x_i - \overline{x})^2 \sum_{i=1}^{n} (y_i - \overline{y})^2}} \tag{6}$$

where.,R-xy,z. is the correlation coefficient of the variables x_i,y_i is the correlation coefficient of the variable x,y in the firsti year; is the value of, x̅,y̅. is the mean value of multiple years. Based on the results of the linear correlation coefficient calculation, the partial correlation coefficient is calculated by the formula:

$$R_{xy,z} = \frac{R_{xy} - R_{yz} R_{xz}}{\sqrt{\left(1 - R_{xy}^2\right)\sqrt{\left(1 - R_{yz}^2\right)}}} \tag{7}$$

where Rxy, Ryz, and Rxz denote the correlation coefficients of variables x and y, y and z, and x and z, respectively, and Rxy. z refers to the partial correlation coefficient between variables x and y after the variable z is fixed.

2.4 Geographic probes

The geodetector is a statistical method for detecting spatial variability and revealing its main drivers. The geodetector consists of four detection modules: factor detection, interaction detection, ecological detection and risk detection.[12]

Factor detection: detecting the spatial differentiation of NEP; and detecting the explanatory power of a factor on NEP, measured by the q-value ,[13] with the expressions

$$q = 1 - \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N\sigma^2} = 1 - \frac{SSW}{SST} \tag{8}$$

where: h = 1, ..., L is the number of strata of the factor, 9 strata; Nh and N are the sample sizes of factor stratum h and Qinghai Province, respectively; σ^2h and σ^2 are the variances of NEP values of factor stratum h and Qinghai Province, respectively. SSW is the sum of variance within strata, and SST is the total variance of the whole region. q has a value range of [0,1].

3. Analysis of the spatial and temporal variation of NEP

3.1 Analysis of time-varying characteristics

From 2000 to 2020, the NEP of vegetation in Qinghai was dominated by carbon sinks, and the area of the vegetation in the study area showing carbon sinks gradually increased from 356,500 km^2 in 2000 to 411,400 km^2 in 2020, and the area of carbon sources in the study area gradually decreased. During the 20-year period, the areas with NEP values between 0 and 200 $gCm^{-2}a^{-1}$ accounted for more than 30% of the total area in Qinghai Province, and the areas with NEP values greater than 600 $gCm^{-2}a^{-1}$ accounted for the least. The vegetation NEP fluctuated significantly between years, with an upward trend, and reached the maximum value in 2015, with a maximum value of about 235.20 $gCm^{-2}a^{-1}$.

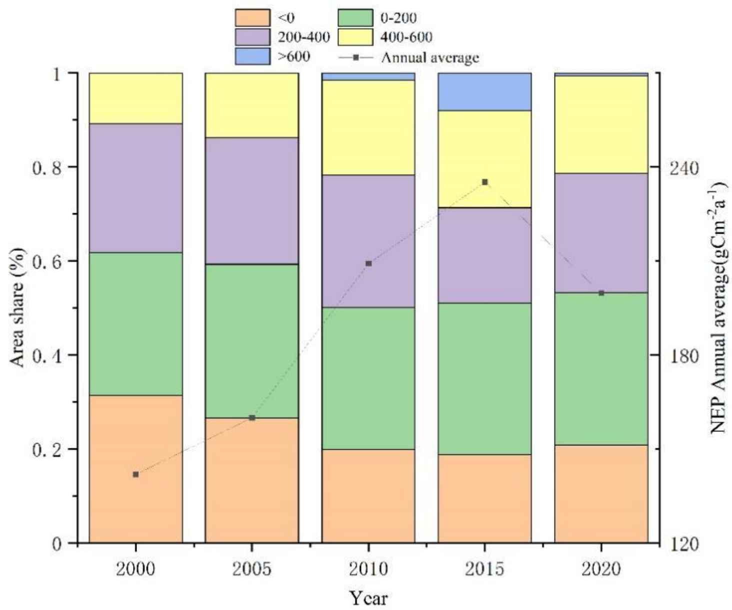

Figure 1: Interannual variation of annual average NEP and area share of vegetation in Qinghai Province

3.2 Analysis of spatial variation characteristics

3.2.1 Spatial distribution

From 2000 to 2020, the spatial NEP of vegetation in Qinghai Province was high in the southeast and low in the northwest, with a gradual increasing trend from northwest to southeast (Figure 2). The annual average NEP of vegetation in Qinghai Province is 189.18 $gCm^{-2}a^{-1}$, of which, the area of carbon sink area (NEP＞0) is about 403,600 km^2, accounting for about 77.73% of the total vegetation area, and the area of carbon source area (NEP＜0) is about 145,500 km^2, accounting for about 22.27% of the total vegetation area. The high value of annual average NEP in Qinghai is mainly located in the Qilian Mountains forest and alpine grassland ecological zone and the river source area-Gannan alpine meadow grassland ecological zone, which have high vegetation cover and excellent water and heat conditions, and the average annual vegetation NEP is between 66.08 and 303.07 $gCm^{-2}a^{-1}$. The low value of annual average NEP is mainly distributed in the desert ecological sub-region of Arjinshan, the alpine desert-steppe ecological sub-region of the eastern part of Kunlun Mountains, and the alpine desert-steppe ecological sub-region of North Qiangtang. Soil erosion, desertification and salinization exist in this area, grassland degradation is serious, desertification is intensified, and the whole area is a carbon source area with an annual average NEP value of -134.70 $gCm^{-2}a^{-1}$.

3.2.2 Spatial distribution change characteristics

From 2000 to 2020, the vegetation NEP in Qinghai Province showed a stable increasing trend with an average trend coefficient of 3.43 (Figure 3), in which the area with basically stable vegetation NEP accounted for 58.3% of the total area, from the northern Qiangtang alpine desert steppe ecological subzone to the area of the eastern Qilian Mountains spruce forest-alpine meadow ecological subzone. The areas with slight increase in vegetation NEP accounted for 39.17%, mainly in the Sanjiangyuan area and the southern part of Qinghai Lake. The areas with significant increase in vegetation NEP account for 2.17% of the total vegetation area, and their spatial distribution is more concentrated, mainly located in the Huangshui Valley agro-ecological sub-region and the Republican Basin alpine grassland ecological sub-region, which have better water and heat conditions and less climate change, while a series of ecological projects have been implemented since 2000, which have significantly improved the ecological environment of the region and are conducive to the improvement of vegetation carbon sequestration function. The NEP of vegetation in these regions has been significantly improved, which is conducive to the improvement of vegetation carbon sequestration. The area where the vegetation NEP shrinks is only 0.36% of the total vegetation area, sporadically distributed in the southeastern part of the East Qilian Mountains Ecoregion and the northeastern part of the Qinghai Lake Wetland Ecoregion. The warming and humidification of the climate in these areas intensifies year by year, leading to the increasing consumption of carbon by soil respiration, which makes its vegetation NEP show a decreasing trend.

3.3 Driving force detection

3.3.1 Vegetation NEP and topographic drivers

Altitude affects the combination of regional water and heat, and different water and heat conditions develop different soil types, which further affect their vegetation types; therefore, altitude is an important factor affecting ecological environment [14], and the magnitude of vegetation NEP varies at different altitude ranges. The elevation of Qinghai province was graded according to DEM data, and as shown in Table I, there are obvious differences in the NEP values of vegetation in each elevation range, and the NEP shows a trend of increasing and then decreasing with the elevation. the high value of NEP occurs in the range of 3500~4500m, about 256.81 gCm-2a-1, where the NEP values in the area with elevation of 2500~3500m The NEP values were also higher in the altitude range from 2500 to 3500 m, but because some areas in this altitude range belonged to unvegetated areas, mainly in the desert ecological zone of the Qaidam Basin, the NEP values were lower compared with those in the altitude range from 3000 to 4500 m. As the altitude continued to rise, the NEP values were higher in the altitude range from 4,500 to 4,500 m. As the elevation continues to rise, the average NEP value gradually decreases, and when the elevation >5500m, the lowest NEP value is -65.52 $gCm^{-2}a^{-1}$, which has less influence on NEP because it occupies a relatively small area.

The slope directly affects the soil erosion status and the distribution of agricultural, forestry and animal husbandry land, and the vegetation grows differently on different slopes. According to the slope situation in Qinghai Province, there are 8 grades (Table II), in which more than 90% of the areas in Qinghai Province have slope <25°, among which the area occupied by the slope range of 5°~15° is the largest, accounting for 32.7% of the total area. Overall, the vegetation NEP in Qinghai Province showed a trend of increasing and then decreasing with the increase of slope. The mean NEP value was 249.06 gCm-2a-1 in the area of slope from 15° to 25°, and the NEP value was 101.82 $gCm^{-2}a^{-1}$ in the area of slope >55°. Although the NEP value was higher in the area of slope from 35° to 45°, it did not contribute much to the overall NEP due to the small area occupied by it. Slope orientation affects the distribution of natural zones. The slope orientation data were extracted from the DEM data of Qinghai Province and divided into nine orientations (Table III). Overall, the slope orientation in Qinghai Province has little effect on the vegetation NEP.

	Altitude（/m）				
Statistical quantities	<2500	2500~3500	3500~4500	4500~5500	>5500
Area ratio（%）	1.08	13.41	41.7	43.64	0.17
NEP mean（gCm^{-2} a^{-1}）	111.01	194.97	256.81	125.68	-65.52

Table I Altitude and NEP

	Slope（/°）							
Statistical quantities	<2	2~5	5~15	15~25	25~35	35~45	45~55	>55
Area ratio（%）	22.1	18.02	32.7	18.1	8	1.04	0.045	0.003
NEP mean（gCm^{-2} a^{-1}）	112.13	171.98	216.16	249.06	215.94	188.26	138.77	101.82

Table II Slope and NEP

	Slope direction								
Statistical quantities	Plane	North	Northeast	East	Southeast	South	Southwest	West	Northwest
Area ratio (%)	1.67	13.16	15.06	12.24	10.20	12.62	13.76	11.19	10.10
NEP mean gCm^{-2} a^{-1})	-1.01	44.93	45.31	51.01	49.54	42.51	43.50	49.20	48.96

Table III Slope direction and NEP

3.3.2 Vegetation NEP and climate drivers

Climatic factors govern vegetation growth, and temperature and precipitation also influence soil respiration consumption, and are therefore important influences on NEP values. On this basis, the correlation between vegetation NEP and climate factors was quantitatively explored.

The areas where NEP was positively correlated with precipitation accounted for 62.49% of the total vegetation area. It is mainly distributed in the Qilian Mountains, the wetland area around Qinghai Lake, the agricultural area of Huangshui valley, and the northern part of the river source area, and the vegetation NEP of these areas increases with the increase of precipitation; the area where the vegetation NEP is negatively correlated with precipitation accounts for 31.51% of the total vegetation area, and is distributed in the central part of the agricultural subzone of Huangshui valley and the southeastern part of the river source area, with the increase of precipitation, the vegetation NEP decreases and the carbon sink capacity Weakening. Because of the high altitude in southern Qinghai, the vegetation transpiration is relatively small, so the vegetation NEP is mainly constrained by the temperature, and the rainfall is more abundant and the water system is well developed in this region, when the rainfall increases continuously and exceeds the maximum water required for the vegetation growth and development, it inhibits its growth instead, so the rainfall and vegetation NEP are negatively correlated in this region. The partial correlation analysis between NEP and precipitation in Qinghai province with constant temperature showed that the positively correlated area accounted for 59.75% of the total vegetation area. It was mainly distributed around the wetlands of Qinghai Lake and the desert ecological subzone of Qaidam Basin in the northeast of Qinghai region.

The average correlation coefficient between vegetation NEP and temperature was 0.11, which was mainly positive, and the positively correlated area accounted for 67.35% of the total vegetation area, occupying most of the vegetation distribution area on the Qinghai Plateau, indicating that the increase in temperature promoted the accumulation of NEP, which might be due to the accelerated growth of vegetation at suitable temperature due to the increase in temperature, resulting in an increase in the total amount of vegetation accumulation. The area of negative correlation between vegetation NEP and temperature accounted for 32.65% of the total vegetation area, mainly distributed in the alpine meadow and grassland ecological sub-region of Lancang River source, the agro-ecological sub-region of Huangshui valley and the alpine grassland ecological sub-region of Republican basin. Under the condition of controlling the influence of precipitation on NEP, the partial correlation between temperature and NEP is basically the same as that between temperature and NEP correlation coefficient. The correlation and partial correlation analysis between vegetation NEP and climatic factors showed that both temperature and precipitation were mainly promoting the accumulation of NEP, and the coupling effect was more obvious.

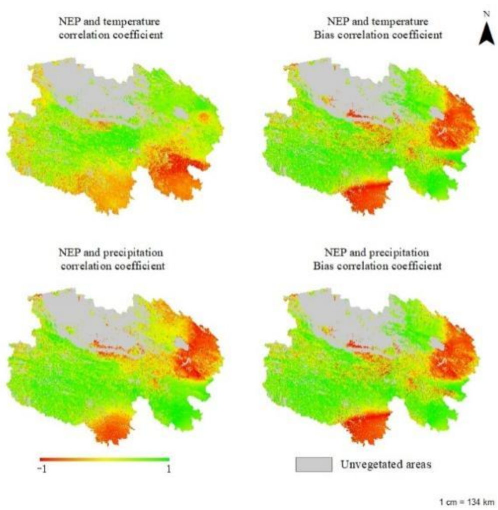

Figure 4: Correlation, bias correlation of NEP with climate elements

3.3.3 Detection of main driving forces

According to the climatic characteristics of Qinghai Province and other references, six factors, namely average annual precipitation, average annual temperature, elevation, slope, slope direction, and land use data, were selected for detection. The results of the factor detection are as follows.

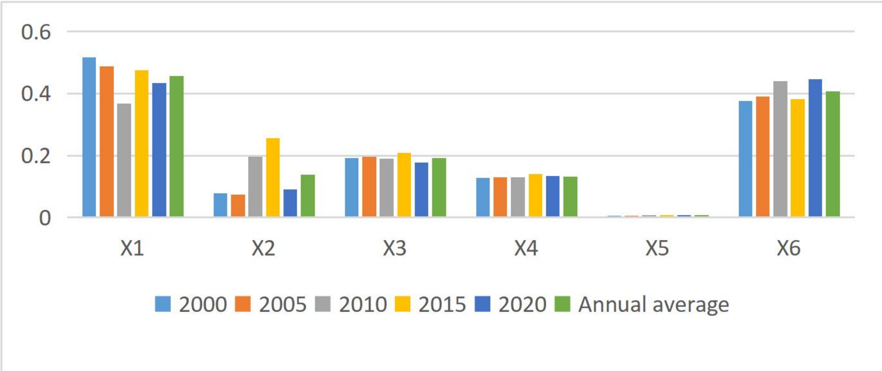

Figure 10: Factor probing each factor q-value

Note: where X1, X2, X3, X4, X5, X represent average annual precipitation, average annual temperature, elevation, slope, slope direction, and land use data, respectively. p-values are all 0.000

In a comprehensive view, the influence of six factors on NEP in Qinghai region is ranked as average annual precipitation > land use type > elevation > average annual temperature > slope > slope direction (Figure 9), indicating that the contribution of average annual precipitation to NEP is the most important factor affecting vegetation NEP in Qinghai region; among the six factors, slope direction has the least explanatory power on vegetation NEP. 2000 - 2020, the q-value of climate influence factor average annual precipitation on vegetation NEP generally shows a decreasing trend. -2020, the q-value of annual average precipitation of climate influence factor showed a decreasing trend in general, indicating that the contribution rate of annual average precipitation to vegetation NEP in Qinghai region may decrease in the future. The q-value of land use factor, on the other hand, shows an increasing trend, and the influence on Qinghai region may be further strengthened in the future. The influence of elevation, slope and slope direction of topographic factors on vegetation NEP remains basically unchanged.

4. Discussion and Conclusion

4.1 Discussion

In this paper, the relationship between six natural factors and vegetation NEP is discussed separately, and the contribution of each factor to vegetation NEP is detected by using geographic probes, and its single-factor contribution rate is analyzed to explore the most important driving factors of vegetation NEP in Qinghai Province. However, the influence mechanism of vegetation NEP is complex, and there are many factors influencing it. In this paper, we mainly detect the influence of natural factors on vegetation NEP, and the human activity factor is only the land use type factor with more comprehensive and perfect data, but the livestock industry is developed in Qinghai Province, and the influence of human activity is also expanding. The influence mechanism of NEP is explored.

4.2 Conclusion

From 2000 to 2020, the interannual fluctuation of vegetation NEP in Qinghai Province is obvious, showing an increasing trend, and the overall vegetation carbon sink, whose carbon sink capacity is increasing. The average trend coefficient is 3.43, which shows a stable increasing trend. The spatial NEP of vegetation in Qinghai Province is high in the southeast and low in the northwest, and the trend increases gradually from northwest to southeast.

The vegetation NEP of Qinghai Province showed a trend of increasing first and then decreasing with the increase of slope and elevation, and the influence of slope direction on vegetation NEP was not significant. The correlation and partial correlation analysis between vegetation NEP and climatic factors show that both temperature and precipitation mainly promote vegetation NEP, and the coupling effect is more obvious.

The influence of driving factors on vegetation NEP in Qinghai Province was ranked as average annual precipitation > land use type > elevation > average annual temperature > slope > slope direction.

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