Proceedings of ICMMGH 2026 Symposium: Biomedical Imaging and AI Applications in Neurorehabilitation
DOI: 10.54254/2753-8818/2026.PJ32173

Impact of Global Warming on Vegetation in the Tibetan Plateau

Yiyang Zhou

Beijing National Day School, Beijing, China
13581583710@163.com

Abstract. The effects of climate change on the Tibetan Plateau are most serious and the most sensitive. Changes in vegetation are some of the most important signs of ecological change. This paper examines the consequences of global warming on vegetation in the plateau. Using MODIS remote sensing data and the CN05.1 meteorological dataset, vegetation and climate change trends have been compared and analyzed. The climate of the Qinghai-Tibet plateau as a whole is becoming warmer, and wetter. In particular, the northwest is changing from warm and dry to warm and wet. Vegetation growth plateau as a whole is improving, especially in the grassland region, but regional differences do exist.

Keywords: Qinghai-Tibet Plateau, Vegetation, Climate Change

1. Introduction

Dealing with the water, land, and atmosphere cycles, vegetation changes are critical indicators to determine the state of ecosystems. Spanning 2.4 million square kilometers of land, which is a quarter of the land area of China, the Qinghai-Tibet Plateau is Wimaclrd all as the 'Third Pole' and the 'Roof of the World.' The plateaus' high altitudes and varying topography leave the vegetation there vulnerable and sensitive to changes in the global climate. The Qinghai-Tibet Plateau has been described as one of the world's prominent climate change amplifiers. Over the last several years, the Tibetan Plateau has been described to have the most rapid warming in the world with a recorded warming rate of twice the global average. This rapid change is significantly altering the spatial patterns of vegetation leading to a change in the regional water resources, carbon cycling, and biodiversity.

This paper examines data acquired from the MODIS vegetation type data (MCD12Q1) and the CN05.1 meteorological data set. It examines the data to determine the vegetation spatio-temporal patterns and dynamic changes on the Tibetan Plateau. It also seeks to improve the ability to monitor the region's long-term ecological environment. It aims to assist in providing data for the region's response to climate change and the impact of anthropogenic activities on vegetation. It attempts to contribute to the ecological security of the Qinghai-Tibet plateau.

DOI: 10.54254/2753-8818/2026.PJ32173

2. Literature review

2.1. Multi-scale observational evidence of vegetation changes on the Tibet Plateau

The last few years have seen significant developments in remote sensing monitoring technologies as they apply to vegetation on the Qinghai Tibet Plateau. Liu et al. achieved 90.52% accuracy in vegetation classification mapping by utilizing the random forest algorithm in conjunction with a terrain, climate, and spectral index information fusion [1]. Such mapping results demonstrate reliability to practical needs and validates the method's applicability to the region. Other research identified the spatio-temporal dynamics of vegetation types on the Plateau by combining the Continuous Change Detection and Classification Algorithm with MODIS data.

The classification of vegetation using a Random Forest Classifier achieved an accuracy of 81.3%, comparable to the mapping accuracy demonstrated from Sentinel-2 data [2]. Research shows the dynamic changes of vegetation, particularly the precise alterations of vegetation, are easily detected using Sentinel-2 data because of its higher spatial and temporal resolution. For instance, one of its multispectral instruments snow products retrieval demonstrated accuracy comparable to that of GF-2 data, showcasing its superior monitoring capability [3].

2.2. Terrain factors influence vegetation changes

The observation of vegetation distribution across Qinghai Tibet Plateau shows an evident vertical zoning pattern which alters along the vertically distributed altitudinal gradients. During global warming, noticeable variations have occurred to the vegetation of the elevated zones. Field surveys conducted from the 1980s to 2003 recorded an advance of the alpine meadow of 14.2 kilometers southwards into the zones previously occupied by alpine grasslands. This phenomenon caused the southward grassland to experience reduced vegetation cover and the recipient ecosystem to experience reduced aboveground biomass.Furthermore, the analysis of the δ 13C values of plant leaves at various elevations indicates that there is a consistent increase from southeast to northwest, illustrating the hydro-thermal regulatory impact on the structural properties of plant community [4]. Ecological sensitivity of the eastern Qinghai Tibet Plateau is mostly focused on the transitional belt of a steep altitude gradient. These areas are the most climate change sensitive, confirming the importance of altitude gradient in the ecosystem evolution [5] Lastly, in some studies, climate and terrain are the only factors utilized as mapping variables, with accuracy as high as 78.6%, indicating a strong predictive power [2]. This shows the terrain factor is a significant ecological parameter in analysis of vegetation evolution of the Qinghai Tibet Plateau.

Despite the differences among regions, the last 60 years have shown a generally warm and humid development trend for the Qinghai Tibet Plateau. Average temperature have consistently increased by 0.37 degrees ° C and Average precipitation has increased by 10.4 mm for 10 years [6]. Research 2005 from the early 2000s using carbon isotope analysis showed that warming and drought The center of the plateau caused the decline of the alpine meadow into alpine grassland. This is reverse succession of vegetation types at a rate of 14.2 km per decade [4]. However, the last 2022 observations showed a different pattern of the southeastern plateau warming and drying and the northwestern plateau that is warming and wetting. This phenomena explains the complexity of the plateau climate which challenges the growing body of regional climatic studies.

The difference is more evident when looking at the flow of carbon. From the years 2003 to 2008, the Haibei Alpine Meadow located in the Eastern Qinghai Tibet Plateau had been recognized for its significance as an area for carbon sink. Its annual average net carbon absorption rate was 61.64

DOI: 10.54254/2753-8818/2026.PJ32173

$g \cdot m^{-2} \cdot a^{-1}$.. Conversely, the Dangxiong grassland meadow situated in the center and western part of the region, exhibited the traits of a carbon source from 2004 to 2011, having an average annual net emission of 43.35 $g \cdot m^{-2} \cdot a^{-1}$ [7]. This disparity demonstrates that varying combinations of hydrothermal factors have different regulatory impacts on the carbon functioning of the ecosystem.

2.3. Reconstruction of carbon cycle functions

Carbon storage in an ecosystem is tied to net primary productivity (NPP), which indicates the rate vegetation absorbs and stores carbon and is a critical component of the carbon cycle. Over the years, NPP on the Qinghai Tibet Plateau has increased, although some areas show a decline in productivity over the years. NPP over the plateau has increased from the period 1982 to 2000, however, NPP increased at a slower rate after the year 2000, and in some areas of the plateau, particularly the southern and middle western regions of the plateau, and the northern Tibetan Plateau, there was a decline in NPP [6].

Li Wenhua et al. applied the CASA model to simulate that from 1982 to 2011, the NPP of alpine grasslands had increased by 19.9%, and the amount of carbon stored annually was 1.14 Tg C [7]. But it still has obvious differences among different places, some areas got worse in the west, and some improved in the east. Moreover, carbon budget differed in various ecosystems. For example, the Dangxiong grassland meadow was a net carbon source from 2004-2011, whereas the Haibei alpine meadow was a carbon sink, indicating that climate change regulates carbon functions bidirectionally.

2.4. The possible challenge in future

2.4.1. The uncertainty of the model

The model's simulation of future carbon cycle trends on the plateau is subject to significant uncertainty. The carbon release mechanisms in the permafrost regions of the Qinghai-Tibet Plateau are complex, and factors such as microbial feedback and freeze-thaw processes have not been fully parameterized. This results in systematic biases in mainstream terrestrial ecosystem models when predicting permafrost carbon emissions [8].

Moreover, although the combination of remote sensing and modeling can offer a broad assessment of the changes in ecosystem carbon storage at a large scale, the estimation of carbon functions in some types of ecosystems (such as shrublands and wetlands) is still based on insufficient field data, which does not adequately represent regional differences and thus affects the accuracy of predictions (Ou Yang et al., 2024).

2.4.2. The effects of human activities

Human activities greatly influence the ecological effects of climate change. Li Wenhua et al. (2013) noted that the grasslands in northern Tibet are seriously degraded due to human activities and climate warming and drying, such as overgrazing, which can counteract some of the benefits of climate warming. Ouyang Zhiyun et al. (2024) also stated that changes in the boundaries of grassland ecosystems are caused by climate and are jointly affected by the construction of infrastructure and changes in land use, resulting in an increase in the fragmentation of the transitional area between grassland and desert ecosystems [5].

DOI: 10.54254/2753-8818/2026.PJ32173

3. Methodology

3.1. Data sources and preprocessing

3.1.1. Data sources

Data used for this research mainly consists of MODIS vegetation type data, Qinghai-Tibet Plateau boundaries data and meteorological observation data. MODIS MCD12Q1 produced by EARTHDATA gives us the world's vegetation coverage info with a 500m resolution each year from 2001-2022, covering 17 different types of vegetation [9]. Raw data was processed through a series of steps such as masking, stitching, and changing coordinates. These steps were done so that everything would match up with the coordinate units of the following data.

Qinghai-Tibet Plateau boundary dataset was used to define the study area accurately. According to the most recent research findings, the Qinghai-Tibet Plateau of China extends from the Pamir Plateau in the west to the Hengduan Mountains in the east, and from the southern border of the Himalayas in the south to the Kunlun Mountains and Qilian Mountains in the north [10].

The meteorological observation data is designated as CN05.1. The dataset under consideration is characterized by its grid-like configuration, with a resolution of 0.25° in both latitude and longitude. The original data was also masked, stitched, and converted to a coordinate system to ensure consistency with the coordinate units of subsequent data [11].

3.1.2. Vegetation type reclassification

In terms of vegetation classification, the original 17-category IGBP classification has been screened and reclassified. Since some vegetation types have insignificant statistical values that are hard to analyze, it might be due to the plant species classification, so these were not included when drawing the scatter plot of vegetation changes. Some examples are Deciduous Needle-leaf Forests, Deciduous Broadleaf Forests, Closed Shrublands, Urban and Built-up Lands, and Cropland/Natural Vegetation Mosaic. As for cropland changes, they mainly come from people's actions, and the recognition of water areas and wetlands isn't quite good enough, so we won't talk much about those things here. For reclassification, Evergreen Needleleaf Forests, Evergreen Broadleaf Forests, and Mixed Forests are all combined into one forest category; Open Shrublands are categorized as a shrub category; Woody Savannas, Savannas, and Grasslands are combined into one grassland category; Permanent Snow and Ice and Barren are combined into one barren land category.

3.2. Vegetation dynamics analysis methods

3.2.1. Climate trend maps

To investigate the climate change trend on the Qinghai-Tibet Plateau from 2001-2022, the CN05.1 gridded dataset was processed by Python. The annual average precipitation of the Qinghai-Tibet Plateau was calculated and shown with bar chart, the annual average temperature changes were shown with line chart during the same time period [11]. In conjunction with the boundary data of the Qinghai-Tibet Plateau, spatial distribution maps of temperature and precipitation for the years 2001 and 2022 were created to aid in the comparison of their spatial features [11].

DOI: 10.54254/2753-8818/2026.PJ32173

3.2.2. Vegetation distribution change maps

Vegetation Dynamics: MODIS data was imported into Python. Together with the boundary information of the Qinghai-Tibet Plateau [10], vegetation distribution maps for 2001 and 2022 were made to compare the changes between the two time points. Also, all 12 kinds of vegetation were shown on a map to show how they changed from 2001 to 2022. The maps use red, yellow, and green to show where plants have been lost, stayed the same, or grown, which makes it easy to see what happened. Moreover, the changes in the areas occupied by various types of vegetation on the Qinghai-Tibet Plateau over the past 22 years were calculated through variance analysis to evaluate their sensitivity to climate change. These variances were also presented as bar graphs for easier comparison.

3.3. Discussion of uncertainties

The result of this study has some uncertainty, mainly due to the data and methods. Data wise, MODIS vegetation classification has a relatively low accuracy for high altitude areas, especially in differentiating between shrubland and meadow; CN05. 1 meteorological data is sparse at western locations on the Qinghai-Tibet Plateau, which could cause incorrect precipitation estimations. Methodologically speaking, the 22 year period might not be long enough to cover the whole cycle of vegetation succession, since forests generally need more than 50 years of observation data for their expansion. Also, this study did not measure the influence of people's actions (such as raising animals, building tourist attractions) on how plants changed, so it might mix up what the weather caused with other things people did.

To decrease such uncertainties, future research might integrate multiple sources of remote sensing data (such as Landsat and Sentinel-2) for better vegetation classification results, or use SEM to differentiate between the effects of climate elements and human actions on vegetation changes. These improvements can make it easier to see how much global warming has affected plants in the Qinghai-Tibet Plateau.

4. Results

4.1. Climate change on Tibet Plateau

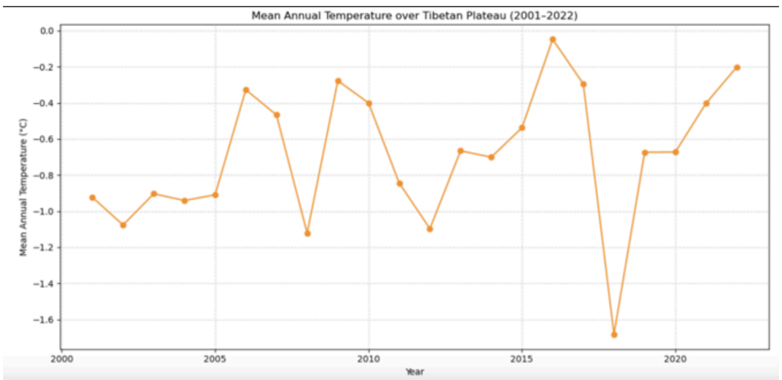

Figure 1. Mean Annual Temperature over Tibetan Plateau. The figure is based on temperature data from CN05.1 [11]

DOI: 10.54254/2753-8818/2026.PJ32173

The figure shows a line graph of the average annual temperature of the Qinghai-Tibet Plateau for the period of 2001-2022. The average annual temperature of the Qinghai-Tibet Plateau recorded in the period of 2001-2022 shows a significant fluctuation with years of recording the temperature exhibiting periodic increases and decreases. Nonetheless, the average temperature recorded in any given year was observed to be greater than the average temperature recorded in the previous year (Fig. 1). It can be observed that there is a temperature increase in the period of 2001-2022. The temperature recorded in 2022 is 0.7°C greater than the temperature recorded in 2001. The above observation is in agreement with the climate of global warming.

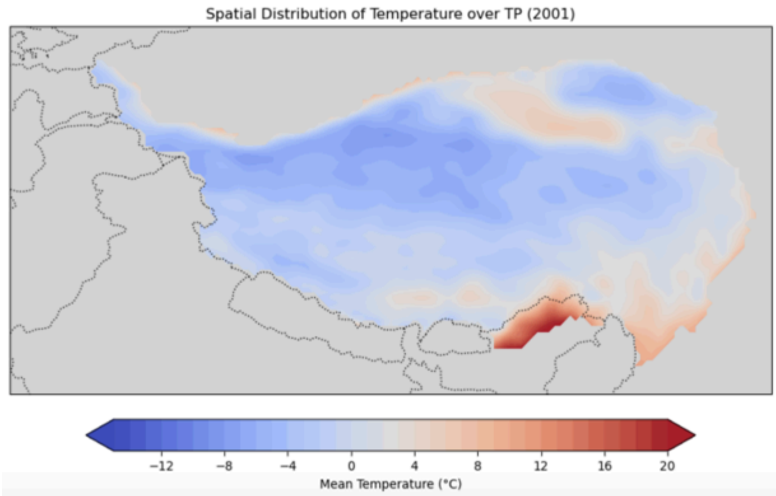

Figure 2. Temperature Distribution Across the Tibet-Qinghai Plateau for the Year 2001. The CN05.1 dataset [11] was used to retrieve the temperature data which was then merged with the boundary data of the Qinghai-Tibet Plateau [10] to create the temperature distribution map. The map was then analyzed to study the temperature patterns across various regions

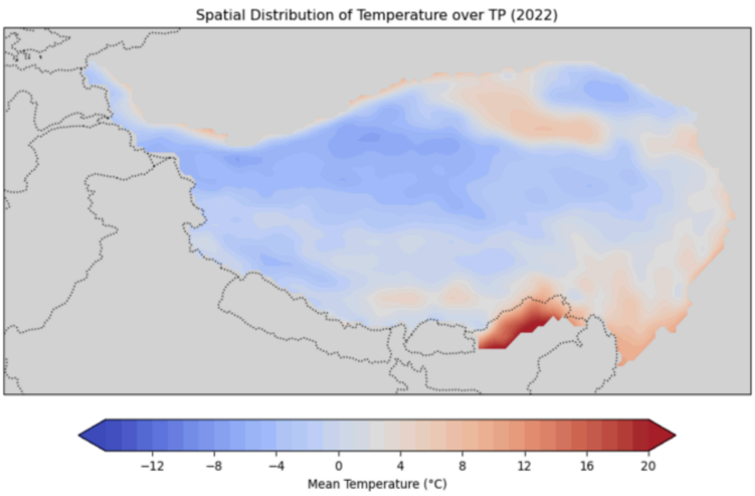

Figure 3. The CN05.1 dataset [11] and the Qinghai-Tibet Plateau boundary data [10] have been integrated to produce a temperature distribution map which shows the Spatial Distribution of Temperature over TP (2022). This also aids in the analysis of temperature trends over varying areas

The temperature gradient of the Qinghai-Tibet Plateau for both 2001 and 2022 has an even distribution in the Northwest and uneven distribution in the Southeast. With the exception of the

DOI: 10.54254/2753-8818/2026.PJ32173

Southwest region, all other Northwest temperatures have become even. N. West captured an increase in evenly distributed temperatures. South West captured an increase in evenly distributed temperatures.

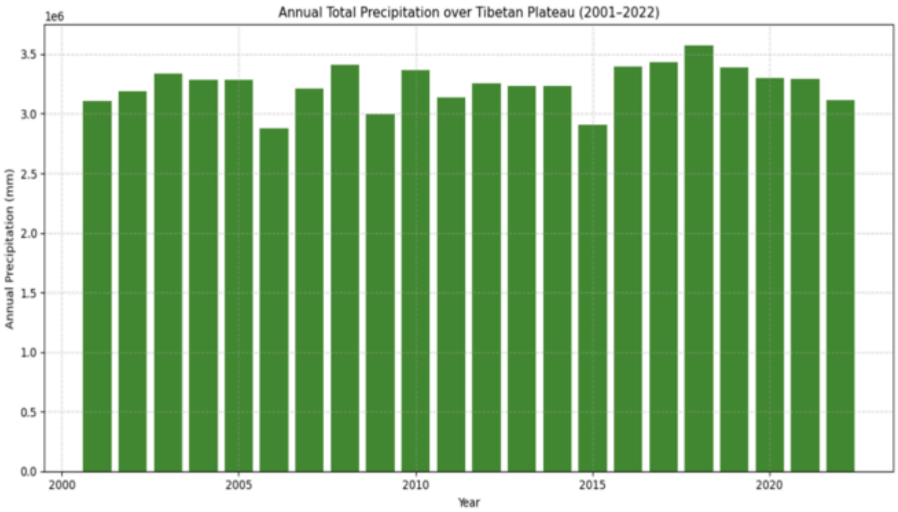

Figure 4. Annual Total Precipitation over TP (2001-2022). The data in the figure is provided by the temperature data from CN05.1 [11]. A bar graph of the annual average precipitation of the Qinghai-Tibet Plateau from 2001 to 2022

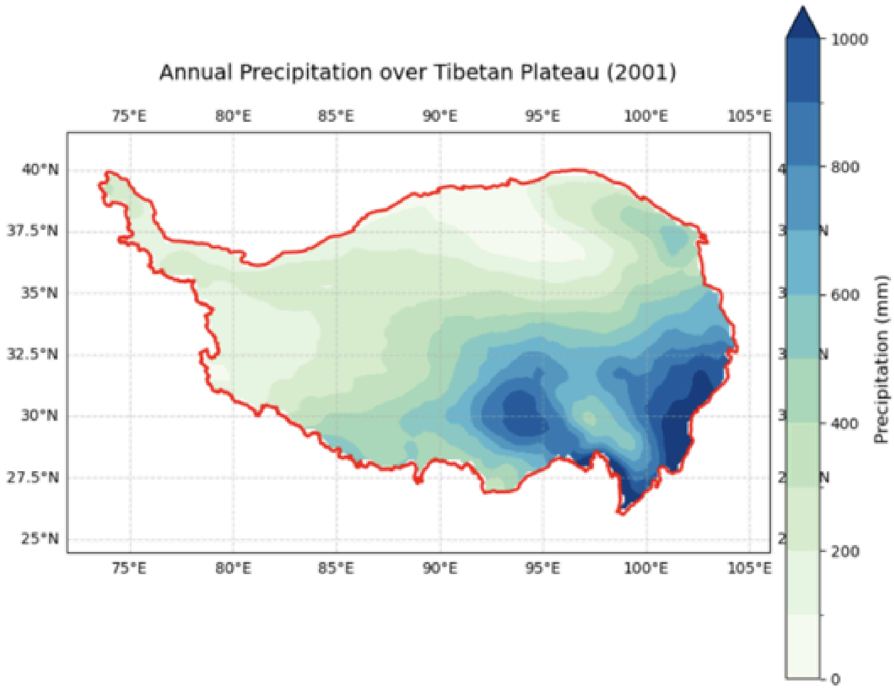

Figure 5. Annual Precipitation over TP (2001). The figure that shows the distribution of precipitation on TP in 2001. Data comes from CN05.1 [11]

DOI: 10.54254/2753-8818/2026.PJ32173

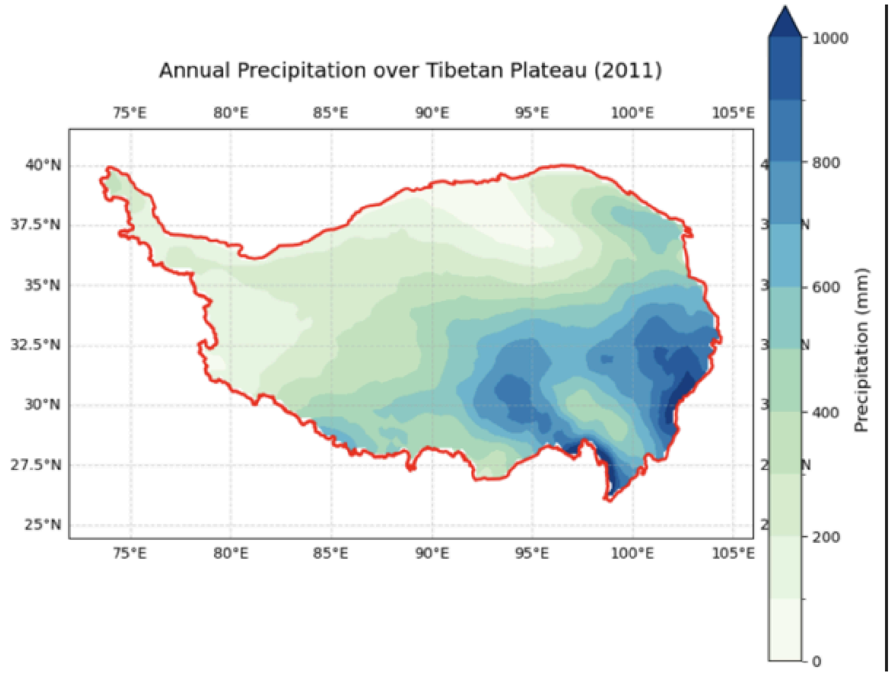

Figure 6. Annual Precipitation over TP (2011). The figure that shows the distribution of precipitation on TP in 2011. Data comes from CN05.1 [11]

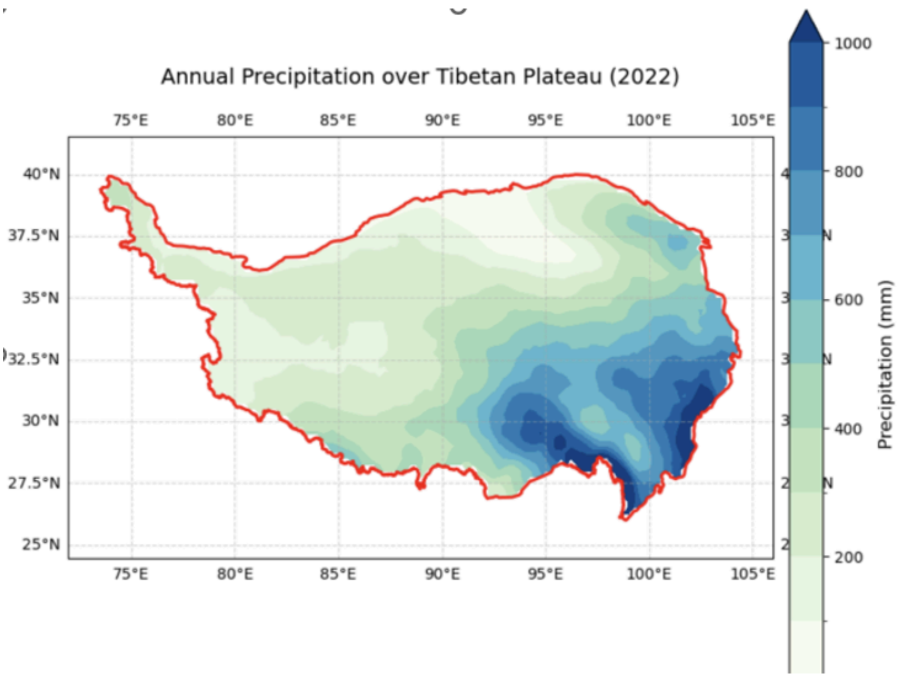

Figure 7. Annual Precipitation over TP (2022). The figure that shows the distribution of precipitation on TP in 2022. Data comes from CN05.1 [11]

Precipitation changes on the Qinghai-Tibet Plateau from 2001 to 2022 are stable but have spatial variations (Figure 4). Time series analysis shows that the annual precipitation in the study area ranges from 2.9 to 3.6 mm per year with large interannual variation.

Earlier research showed that the northwestern section of the Qinghai-Tibet Plateau had a noticeable warming and drying trend before 2011 [7]. And this conclusion is confirmed through the

DOI: 10.54254/2753-8818/2026.PJ32173

comparison shown in Figures 5 and 6. Precipitation in the northwest region decreased greatly; in 2011, the amount of precipitation in many places was much less than it was in 2001. Climatic features during this period caused the deterioration of alpine meadows and deserts in the western portion of the northern Tibetan Plateau.

However, the latest observational data (Fig.7) show that precipitation in the northwestern region in 2022 has significantly increased compared to 2001 and 2011. This finding is consistent with the conclusions of Mr.Cao and other researchers, indicating that the climate pattern of the Qinghai-Tibet Plateau has undergone a transformation:In general, it can be seen that the overall trend is towards more precipitation, especially in the northwest part of the area, which has changed from the previous warming and drying situation to the current warming and moistening state [2]. Such climate changes might bring about great effects on the plateau's ecosystem, so we need to keep watching and evaluating them.

4.2. Changes in the area of different vegetation types

4.2.1. Changes in forest type areas

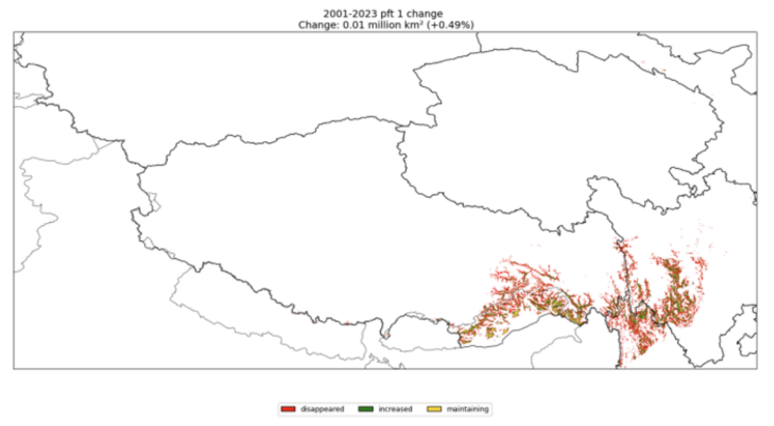

Figure 8. Changes in the distribution of Evergreen Needleleaf Forests between 2001 and 2022

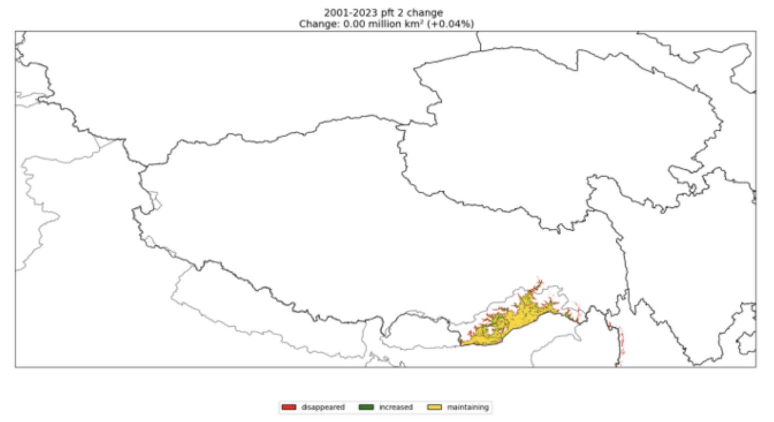

Figure 9. Changes in the distribution of Evergreen Broadleaf Forests between 2001 and 2022

DOI: 10.54254/2753-8818/2026.PJ32173

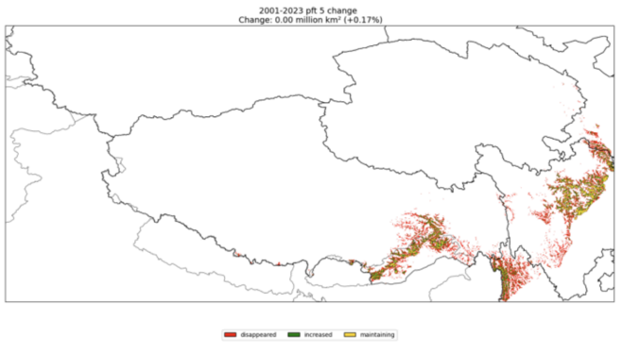

Figure 10. Alterations in the distribution of Mixed Forests between 2001 and 2022

Forests on the Qinghai-Tibet Plateau are mainly divided into three categories: evergreen coniferous forests, evergreen broad-leaved forests, and mixed forests. In 2001, evergreen coniferous forests covered around 1.31% of the total plateau area, rising to about 1.80% by 2022, which means a net increase of 0.49% (Figure 8). Evergreen broadleaf forests made up about 1.08% of the plateau region in 2001 and grew slightly to 1.11% in 2022, which is an increase of 0.04% (Figure 9). Mixed forests accounted for about 2.05% of the total area in 2001 and rose to about 2.22% in 2022, corresponding to a growth of 0.17% (Figure 10). In terms of location, forests are mostly found in the mountains of the southeast part of the Qinghai-Tibet Plateau.

In the last 22 years, all forest types have shown an upward trend. The previous researches using the NDVI data show that the growing season NDVI of the Qinghai-Tibet Plateau has been increasing and the carbon sink capacity of the ecosystem has increased, which means that the vegetation condition is getting better [7]. And there is further proof that up until 1998 when there was not much moisture available, temperature was the main limiting factor for surface vegetation and climate warming was bad for plant growth. On the other hand, since 1998, with better moisture conditions, both thermal and hydrological factors worked together to promote vegetation growth on the plateau [12].

Besides climate factors, people's efforts to protect nature are significant as well. The Natural Forest Conservation Program was launched in 1998, so protecting and restoring forests became major concerns for ecological management on the Qinghai-Tibet Plateau [5].

4.2.2. Changes in Shrub type areas

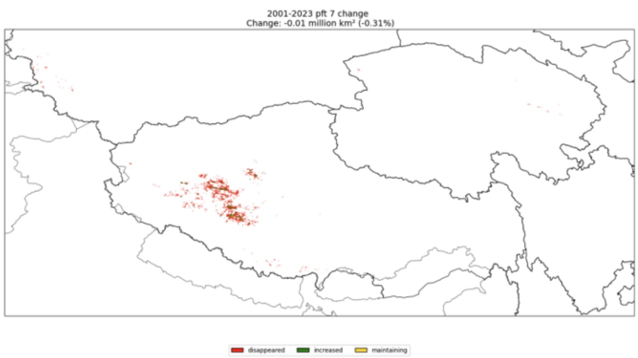

Figure 11. Changes in the distribution of Open Shrublands between 2001 and 2022

Shrub type means Open Shrublands. Open Shrublands made up about 0.55% of the total area of the Qinghai-Tibet Plateau in 2001 and around 0.24% in 2022, which is a drop by 0.31%. The shrub species mainly occur on the highlands in the southwest region of the plateau. Although shrubs are usually regarded as more adaptive to climate change than forests, under the circumstances of climate change, the environment that shrubs can survive in has been getting warmer (Fig. 3) and drier (Fig. 7). This results in a warming and drying tendency. This trend directly affects the water and heat conditions and soil fertility of shrub habitats, causing an increase in evaporation and a decrease in soil moisture. These kinds of trends also make it so there are fewer shrubs.

Also note that climate change can make extreme weather happen more often, or it might change when bugs and sicknesses show up, so that could be bad for shrubs too.

4.2.3. Changes in the area of Brassland and Barren types

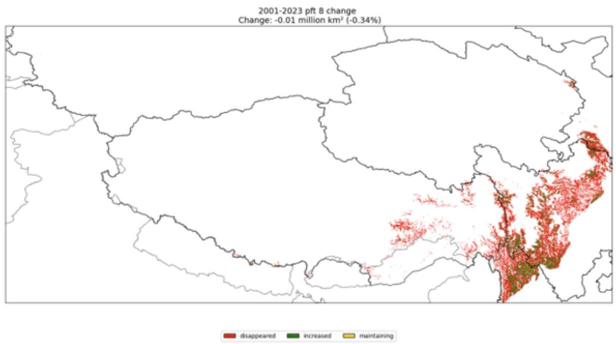

Figure 12. Changes in the distribution of Woody Savannas between 2001 and 2022

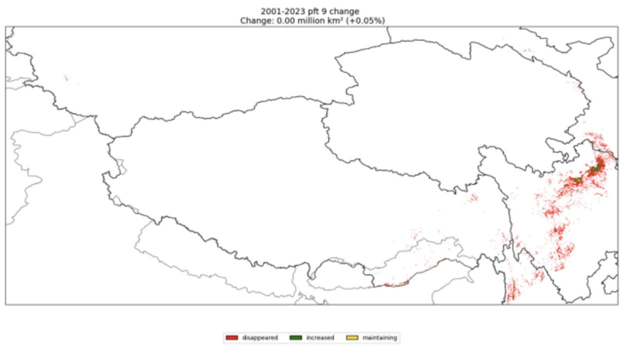

Figure 13. Changes in the distribution of Savannas between 2001 and 2022

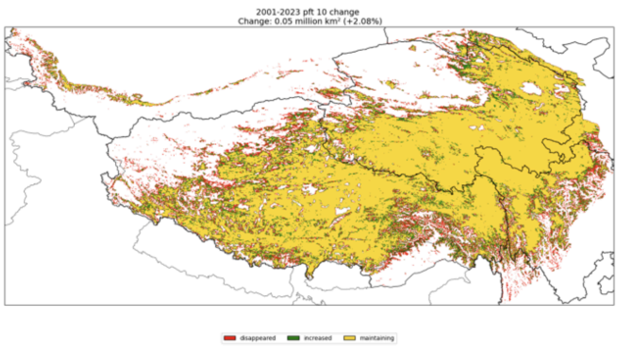

Figure 14. Changes in the distribution of Grasslands between 2001 and 2022

DOI: 10.54254/2753-8818/2026.PJ32173

The three main types of grasslands are: woody savanna, wood-grasslands, and true grasslands. Grasslands are the most dominant ecosystem of the Qinghai-Tibet Plateau. They play a vital role in the development of pastoral agriculture and in ecology provide water, regulate climate, fix loose sand, sustain diverse biological communities, and also sustain wind and sand [5]. In 2001, woody savannas were estimated at 2.68%, and in 2022 this area shrunk to 2.35% which is a 0.34% decrease of the overall area of the Qinghai-Tibet Plateau (Figure 12). In 2001, savannas were about 0.63% and in 2022 this area increased to almost 0.69% which is an increase of 0.05% of the overall area of the Qinghai-Tibet Plateau (Figure 13). Grasslands of the Qinghai-Tibet Plateau increased from about 49.82% in 2001 to about 51.90% in 2022 which is an increase of 2.08% (Figure 14).

The grasslands that dominate the Qinghai-Tibet Plateau exist in a broad expanse of the region with a gradient of vegetation density from the dense southeast to the sparse northwest region. These grasslands and the woody savannas that border them are mostly southeast on the plateau in the intrusive mountainous regions of the southeast.

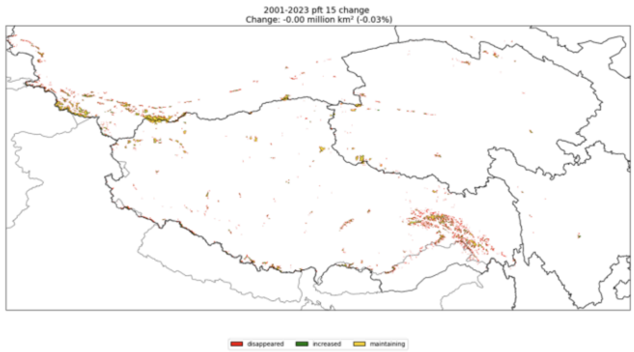

Figure 15. Changes in the distribution of Permanent Snow and Ice between 2001 and 2022

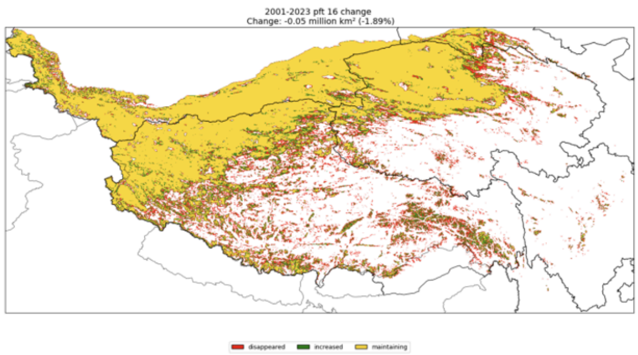

Figure 16. Changes in the distribution of Barren between 2001 and 2022

Barren includes Permanent Snow and Ice and Barren. Permanent Snow and Ice made up about 1.15% of the total area of the Qinghai-Tibet Plateau in 2001 and around 1.12% in 2022, a drop of 0.03% (Figure 15). Barren land took up roughly 38.43% of the total area of the Qinghai-Tibet Plateau in 2001 and about 36.54% in 2022, down by 1.89% (Figure 16). Barren land, as the second most extensive type of vegetation on the Qinghai-Tibet Plateau in terms of land area, refers to areas where plants cannot survive and are not available for human use. But because of the climate getting warmer, some places with permanent snow and ice have started melting, which means there are now places where plants can grow.

DOI: 10.54254/2753-8818/2026.PJ32173

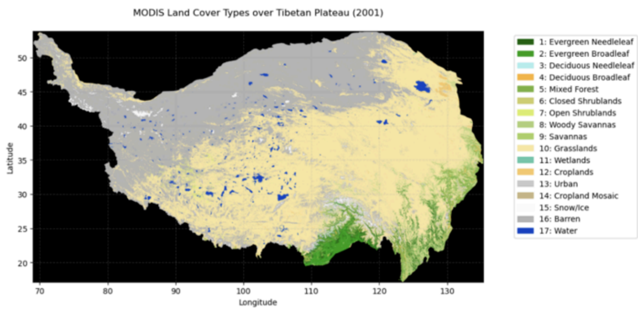

Figure 17. MODIS Land Cover Types over TP in 2001. The distribution of different vegetations demonstrated by different colors. Data comes from NASA Land Processes DAAC, 2023

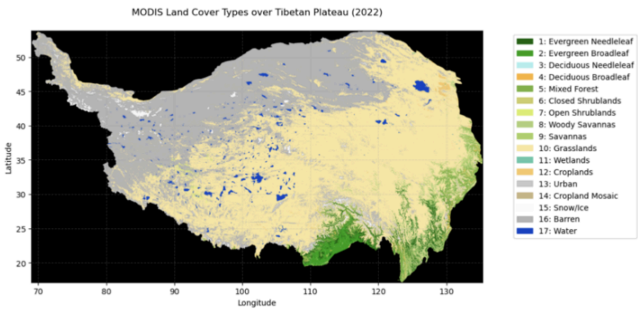

Figure 18. MODIS Land Cover Types over TP in 2022. The distribution of different vegetations demonstrated by different colors. Data comes from NASA Land Processes DAAC, 2023

In the trend of warming and humidifying climate in the northwest area, the carbon fixation ability and soil conservation ability of grasslands are improved, and they begin to expand into desert areas (Fig. 17 & Fig. 18). Multiple sources of observation data indicate that the rate at which vegetation activity improves (NDVI grows by 1.2-1.7%/yr) within the 4,000-4,500 m elevation range is notably greater than that within the 3,000-4,000 m elevation range (0.7-0.9%/yr), suggesting that alpine meadows are more responsive to rising temperatures [10]. This shows how climate warming has a good effect on plants in the Qinghai-Tibet Plateau. Moreover, once grasslands start growing, the water-retention capacity of those previously barren regions increases too, which helps preserve biodiversity [5].

But it is not a positive trend all around. In the Northwest area that is still warming and drying up, the Western Desert Grassland and some other grasslands got even hotter and drier, so there was less grass for animals to eat, and more land turned into a desert, which hurt nature. From the deterioration of grasslands to their growth, apart from the most crucial climatic elements, people's actions such as stopping grazing and restoring grasslands also had significant effects. Grassland fencing projects carried out on the Qinghai-Tibet Plateau after 2003 showed that the soil carbon pools of grasslands throughout the plateau increased by 290.9 Tg of carbon between 2003 and 2010, indicating a strong restorative effect [7].

DOI: 10.54254/2753-8818/2026.PJ32173

4.2.4. Sensitivity of different vegetation types to climate

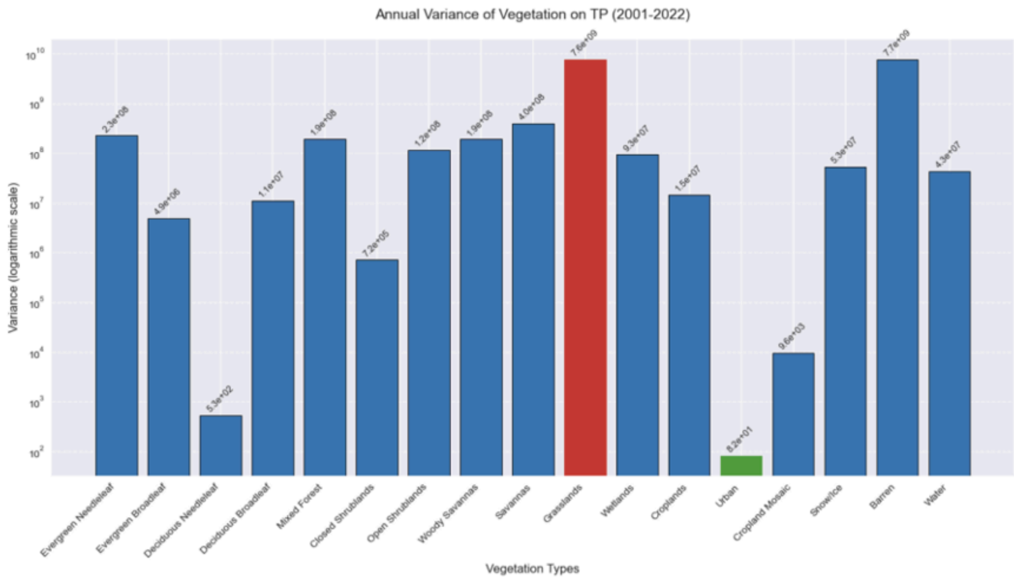

Figure 19. Interannual variance in the distribution area of multiple types of vegetation on the Qinghai-Tibet Plateau between 2001 and 2022 (expressed on a logarithmic scale) to characterize the sensitivity of different vegetation types to climate change. Data comes from NASA Land Processes DAAC, 2023

Different kinds of plants have different amounts of variation, showing how much they changed because of the weather over the last twenty years. Grasslands and Barren show the greatest yearly change with 7.6x10^9 and 7.7x10^9 respectively, which is much bigger than other plant types, so they have a lot of difference in space. Grasslands are the most common kind of natural ecosystem on the Qinghai-Tibet Plateau, and bare places mostly exist in high mountains and very dry areas. Variance is extremely high, which means that these regions are quite sensitive to changes in temperature, precipitation, and freeze-thaw cycles, possibly resulting in frequent degradation, succession, or even functional changes, indicating the instability of the ecosystem's structure and function.

On the contrary, the area variances of Urban and Cropland Mosaic were 8.2×10^1 and 9.6×10^3, which were the smallest among all vegetation types and showed almost no change. These places are mainly controlled by people's actions, so they don't get much changed by how the weather is acting.

Forest vegetation (Evergreen Needleleaf Forests, Mixed Forests), shrub community (Closed Shrublands, Open Shrublands) have moderate variance, fluctuation range is 10^6-10^8. Because they have a good ecosystem stability, slow rate of succession and some kind of ecological adaptive regulation ability, so their reaction to annual climate change is not too strong.

These results illustrate the distinct alterations experienced by various ecosystems located within the Qinghai-Tibet Plateau in accordance with the shifting weather patterns, elucidating the nuances surrounding the sensitivity of distinct plant species to such modifications.

5. Discussion

In the span of more than two decades (2001-2022), extensive vegetation shifts have prompted an assessment of the Qinghai-Tibet Plateau for which the dominant features of vegetation changes have

DOI: 10.54254/2753-8818/2026.PJ32173

been collected, analyzed, and presented. Based on the collected data, the vegetation on the plateau has indicated an increase in temperature and precipitation. Also, climatic shifts in the northwest plateau have transitioned from an arid environment to a wetter regime, and numerous studies regarding the distribution of vegetation in response to climate change have documented an upward movement of plant communities. In particular, there has been an increase in woody species of trees and a reduction in adult shrubs/end shrubs, and a shift from grass to desert species. The overall enhanced vegetation index (EVI) illustrated a positive trend in plant growth; however, the data indicated significant sub-regional variability.

This article confirms and evaluates the findings of various year's studies, observing that many conclusions appear to be stage specific over the duration of the studies, including the warming and drying trend in the northwestern region of the Qinghai-Tibet Plateau [5]. Moreover, the use of accurate MODIS data, along with color mapping in Python, enhances comprehension of the presented vegetation data and distribution patterns. The variance data, which is calculated, offers a new angle, and provides a data foundation pertaining to the sensitivity of various vegetation types, which could be beneficial for the future conservation of highland plants.

While the present condition of the vegetation is positive, the challenges of the future are unavoidable. Climate change is unpredictable. Sudden drought, and prolonged warming and humidification might bring about adverse effects. In addition, the effects of humans are also relevant. In some places, the ecologic engineering projects of the restoration of grasslands and the cessation of grazing have positive results [6]. However, in some places, there is still prevailing overgrazing. Therefore, in the context of the future climate change, more flexible climate adaptive management plans are needed.

Numerous issues concerning climate change and the ecosystems of the Qinghai-Tibet Plateau remain to be examined in a holistic and systematic manner, despite the plethora of existing documentation and research. This study is limited by the following:: (1) Vegetation type classification via remote-sensing and MODIS data is a work in progress and there is no established ecosystem classification methodology for remote-sensing and Qinghai-Tibet Plateau ecosystem classification within the study area; (2) a 22-year period may be too limited to capture the complete cycle of succession of the vegetation; (3) There is still a lack of clarity regarding the quantification of factors of human activities. Future research has the opportunity to investigate the area through alternative methodologies combined in a multidisciplinary approach to assess the impacts of climate change and human activity on vegetation within the Plateau.

6. Conclusion

Only the rewritten text should be output. No explanations, titles, numbers, or additional symbols should be included. 2. Do not make up or add citation markers / reference numbers (e.g., [1,6]). 3. Do not repeat these requirements in your output.

This study integrates research findings from different periods, verifies the phased characteristics of climate change impacts, conducts precise data mapping, and provides a new perspective for calculating variance to assess vegetation sensitivity.

However, this study also has some limitations, the biggest one being that the change in vegetation distribution over a 22-year period is not large enough to capture the entire cycle of vegetation succession.

Future research should create a complete classification system for the Qinghai-Tibet Plateau ecosystem. And MODIS remote sensing data should be combined with ground survey data to fully understand the spatial distribution of vegetation on the Qinghai-Tibet Plateau.

DOI: 10.54254/2753-8818/2026.PJ32173

References

[1] IPCC. (2021). Climate change 2021: Physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.
[2] Liu, T. (2018). Remote sensing mapping and change analysis of vegetation on the Tibetan Plateau. Journal of Remote Sensing, 22(3), 456-467.
[3] Su, X., Jiang, L., & Wang, G. (2021). Estimation and Validation of Fractional Snow Cover from Sentinel-2 MSI over the Tibet Plateau. In 2021 IEEE International Geoscience and Remote Sensing Symposium (IGARSS). IEEE.
[4] Wang M, Li Y, Huang RQ, et al. (2005) Effects of Climate Warming on Alpine Vegetation in the Inland Region of the Tibetan Plateau. Acta Ecologica Sinica, 25(6).
[5] Ou, Y. Z., Zhang, G. S., & Ying, L. X. (2024). Summary of the influence of climate change on the distribution and function of ecosystems on the Tibetan plateau. Climate Change Research, 20(6), 699-710.
[6] Cao, X.Y., Zhou, B.R., Zhou, H.K., et al. (2022). Research progress on the effect of climate change on the vegetation ecosystem in the Tibetan Plateau. Journal of Arid Meteorology, 40(6), 1068-1080.
[7] Li WH, Zhao XQ, Zhang XZ, et al. (2013) Change mechanism of major ecosystem and effect on carbon source/sink function of Qinghai-Tibetan Plateau. Chinese Journal of Nature, 35(3): 172-178.
[8] Wang, G., & Han, L. (2012). Progress on studies of effects of climate change on terrestrial ecosystems in the Tibetan plateau. Journal of Anhui Agricultural Science, 40(7), 4274-4276.
[9] NASA Land Processes DAAC. (2023). MCD12Q1 Terra+Aqua Land Cover Type Yearly L3 Global 500m SIN Grid V061 [Dataset]. NASA EOSDIS Land Processes DAAC.
[10] Zhang, Y. (2019). Integration dataset of Tibet Plateau boundary. National Tibetan Plateau / Third Pole Environment Data Center.
[11] Wu, J., & Gao, X. J. (2013). A gridded daily observation dataset over China and its comparison with other datasets. Chinese Journal of Geophysics, 56(4), 1234-1245.
[12] Li, Z. (2025). Response of Growing Season Vegetation to Climate Warming-Wetting and Future Projections on the Qinghai Plateau. China National Knowledge Infrastructure (CNKI).