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Policy-Driven Vegetation Restoration in Qinghai Province: Spatiotemporal Analysis and Policy Evaluation

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Abstract: The Chinese government has implemented numerous ecological policies in Qinghai Province aimed at protecting and restoring the natural ecosystem. Yet, amid global climate change, the precise effects of these policies on ecological improvement remain ambiguous. There is an urgent need for a comprehensive evaluation of the effects of these policies at a regional scale and an analysis of the changes in policy implementation stages to optimize the strategic direction of regional ecological policies. In this study, using mathematical statistics and spatial analysis, we analysed the spatial and temporal characteristics of the Normalized Difference Vegetation Index (NDVI) in Qinghai Province from 2000 to 2023. Further, by systematically reviewing ten major ecological policies currently or previously implemented in the region, we explored the response of vegetation restoration to these policies through both horizontal and vertical evaluations by reasonably delineating the policy study sub-zones. The study identified distinct stages of policy implementation—regreening, stabilizing, and natural recovery—and correlated these stages with the efficacy of policy impacts. Our findings indicate significant vegetation coverage improvements across Qinghai Province over the past two decades, with all ecological policies positively influencing the environment. The main contribution of this study is that it comprehensively evaluates the impact of multiple ecological policies on vegetation restoration at the regional scale, providing a reference for the formulation and adjustment of subsequent ecological policies.

Keywords: NDVI; spatiotemporal variations; vegetation restoration; ecological policy; Qinghai Province

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1. Introduction

Amid intensifying climate change and the rapid pace of urbanization and industrialization, global ecosystems are increasingly endangered, prompting an intensified focus on ecological protection and restoration [1]. In response to mounting global ecological challenges, the United Nations introduced the Sustainable Development Goals in 2015, notably Goal 15, which focuses on the protection, restoration, and sustainable utilization of terrestrial ecosystems [2–4]. Additionally, in 2019, the United Nations launched the "Decade of Ecosystem Restoration 2021–2030", a plan dedicated to restoring large-scale degraded and damaged ecosystems and preserving intact ones [5]. In recent years, many countries have actively participated in ecological protection and restoration efforts, guided by the United Nations' strategic goals [6,7]. China's extensive contributions to these efforts over the past three decades are well recognized. However, since its economic reforms in 1978, China has experienced rapid industrial growth, which has significantly damaged its ecological environment [8]. This degradation is largely due to unsustainable practices

such as overgrazing, excessive deforestation, and the rapid development of impermeable surfaces in urban settings [9–11]. These activities have degraded ecosystems, affecting various functions and services and potentially causing further harm to human settlements and well-being [12]. In addition, the manifestation of ecosystem degradation varies depending on local natural conditions [13].

Since the 1970s, the Chinese government has implemented a series of ecological policies to mitigate ecosystem damage and degradation with the goal of protecting and restoring the ecological environment [14–17]. In 1978, to enhance the ecological environment and increase forest coverage in northwest, north, and northeast China, the government initiated the Three-North Shelterbelt Project (TNSP), also known as the "Great Green Wall". This project marked the country's first major ecological construction effort and is renowned for its substantial benefits [18,19]. Subsequently, China launched several significant ecological initiatives, including the Natural Forest Protection Program (NFPP), Grain for Green Program (GGP), Grassland Ecological Compensation Policy (GEC), Yangtze River Shelter Forest Construction Project (YFC), Beijing–Tianjin Sandstorm Source Control Project (BTSSCP), and integrated conservation and restoration projects of mountains, rivers, forests, farmland, lakes, grasslands, and deserts (ICRP), etc. These policies have facilitated the partial restoration of various degraded natural ecosystems and significantly curbed ecological degradation. Over the past two decades, China has emerged as a global leader in environmental greening. Research indicates that despite China's vegetation area accounting for only 6.6% of the world's total, its growth in vegetation leaf area from 2000 to 2017 contributed 25% to the global total [20]. However, the long implementation periods and substantial investments associated with these policies have led to regional disparities in their execution, obscuring the precise impact of the policies [21]. Thus, it is crucial to assess the effects of these policies at a regional level, understand the phase differences in their implementation, and provide insights for enhancing their future effectiveness.

Vegetation is an important part of the terrestrial ecosystem and plays a variety of important ecological functions such as water conservation, wind protection and sand fixation, soil and water conservation, and biodiversity maintenance [22–24]. Vegetation displays marked inter-annual and seasonal variations, making it a prominent indicator of land cover changes [25,26]. The NDVI, as a straightforward and effective measure, is extensively employed in examining the dynamic alterations in vegetation cover [27,28]. Most scholars represent the change in regional vegetation through the annual and monthly average variations in the NDVI. The interactions between the NDVI and various climatic and human activity factors have been thoroughly explored [29]. While there is broad agreement that both climate and human activities significantly influence the NDVI, the extent and mechanisms of this influence remain subjects of debate [30–32]. For instance, numerous studies have verified that rising temperatures generally enhance vegetation growth in the Qinghai–Tibet Plateau [33,34]. However, some studies indicate that the impact of temperature on vegetation is not consistent. In regions with optimal water and thermal conditions, increased temperatures may restrict vegetation growth [35–38]. This indicates the presence of threshold effects and regional variability in how climate factors influence vegetation production. Moreover, extensive research has been conducted to determine whether natural or anthropogenic factors contribute more significantly to vegetation growth [39–43]. Some studies have identified natural climatic factors, such as atmospheric carbon dioxide concentration and nitrogen deposition, as well as growing season precipitation, as the main factors influencing vegetation restoration. However, some studies still confirm that human activities play a leading role in vegetation recovery.

Since the 1990s, a variety of ecological policies and construction projects have been implemented globally [44]. With significant financial investments, the ecological, economic, and social benefits derived from these initiatives have been highly valued, highlighting the urgent need for comprehensive evaluations of their effectiveness [45,46]. The effectiveness of policies can be measured by the extent of local vegetation restoration [47]. Numerous

empirical studies have assessed the effectiveness of these ecological policies [48]. Most findings indicate that the implementation of these policies or projects significantly enhances local ecological conditions. However, certain policies exhibit a noticeable time lag, with effects that are not immediately apparent but become significantly evident over extended periods [49,50]. While existing studies have compared the influences of afforestation programs on fractional vegetation cover in China [51], the extent to which ecological policies contribute to vegetation restoration is controversial [52–55]. Therefore, it is necessary to determine how vegetation restoration processes respond to the implementation of ecological policies. In terms of methodology, current research on assessing the effectiveness of policy implementation consists of two main categories: field research and modelling evaluation. Field research assesses the implementation of policies by interviewing relevant institutions, implementers, and local residents in the areas where the policies are implemented [56]. Constructing statistical models is a common method for policy evaluation, and the models used mainly include trend analysis [57], regression analysis [58], grey comparison models [59], fuzzy mathematics [60], difference-in-differences (DID) models [61], and policy modelling consistency (PMC) index models [62].

The impact of ecological policies and construction projects on vegetation restoration is currently a highly debated topic, as evidenced by a review of existing studies. However, few studies have integrated multiple ecological policies and construction projects at a regional scale to conduct empirical research on their combined effects on vegetation restoration. Consequently, this paper develops a framework to evaluate the integrated response of vegetation restoration to various ecological policies at the regional level, with the aim of systematically assessing the effectiveness of these policies by mitigating the influence of natural factors like climate and topography. The specific objectives of this paper are (1) to employ statistical and spatial analyses to investigate the spatial and temporal characteristics of vegetation changes in the study area; (2) to assess the impacts of different policies on vegetation restoration under identical climatic conditions and to explore the characteristics of policy implementation stages. This study identifies stage-specific characteristics of vegetation restoration in response to multiple ecological policies, providing a reference for evaluating the effectiveness of such policies at the regional scale and informing future policy formulation.

The remainder of this paper is organized as follows: Section 2 introduces the research framework, data sources, and methodology. Section 3 analyses the spatial and temporal characteristics of vegetation in the study area and presents the phased response of vegetation restoration to multiple ecological policies. Sections 4 and 5 discuss the findings of the study and provide conclusions, respectively.

2. Materials and Methods

2.1. Study Area

Qinghai Province is located in western China, in the northeastern part of the Qinghai–Tibet Plateau. The entire province falls within the scope of the Qinghai–Tibet Plateau, geographically positioned between 89°35′ E–103°04′ E and 31°36′ N–39°19′ N (Figure 1). The province spans over 1200 km from east to west and more than 800 km from north to south, with a total area of 722,300 square kilometres, accounting for 1/13 of China's land area. Qinghai governs 2 prefecture-level cities and 6 autonomous prefectures. It is a key area for national ecological civilization and serves as an important ecological security barrier, encompassing 79 nature reserves, as well as a major ecological product export and supply region. It is one of the most influential ecological regulation areas globally. Grassland is the predominant land cover, and the elevation ranges from 1672 to 6564 m. In areas near human settlements, grasslands are often used for grazing. Qinghai primarily belongs to the plateau sub-cold temperate and plateau temperate climate zones, with annual average temperatures ranging from −5.1 °C to 9.0 °C and precipitation varying from 15 to 750 mm. Most areas receive less than 400 mm of annual precipitation. The province experiences high solar radiation intensity, long sunshine duration, and abundant

solar energy resources. Due to its unique geographical location and climatic conditions, Qinghai Province's ecological environment is simple, fragile, and highly sensitive to human activities and climate change.

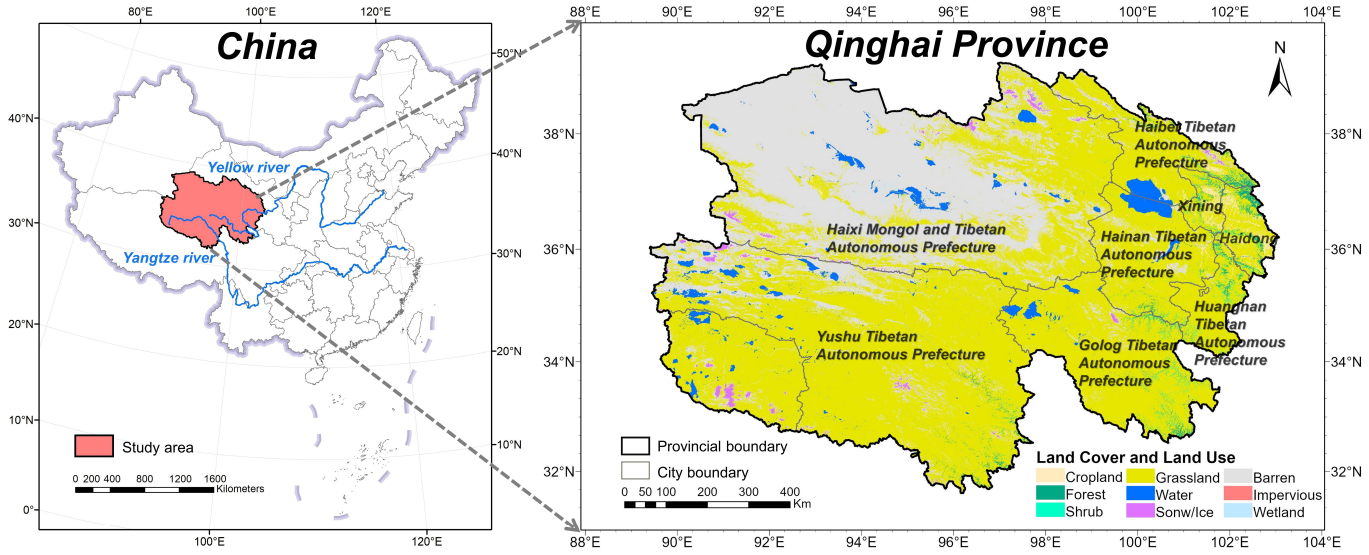


Figure 1. Study area (the land use data are from [63]).

2.2. Considerations for the Study Framework

The ecological environment of Qinghai Province is under threat from climate change and unsustainable human activities. In response, the Chinese government has enacted various ecological policies aimed at restoring and protecting the region's environment. These policies vary in their inputs and focuses, necessitating an assessment of their actual effects on soil conservation, water conservation, vegetation restoration, and biodiversity conservation. This study aimed to analyse the characteristics of vegetation growth under different policies and stages. Firstly, it analysed the trend in the NDVI in Qinghai Province from 2000 to 2023 to understand its spatial and temporal dynamics. Subsequently, the province was divided into 50 sub-zones based on climate zoning and the extent of policy implementation to maintain consistency in natural conditions and policy application across sub-zones. The impacts of ecological policy implementation were then evaluated through both horizontal and vertical trend evaluations. Horizontal evaluations evaluated the impact of policy factors on vegetation recovery by comparing differences in vegetation recovery between policy-implemented and non-implemented areas with similar climatic conditions. Vertical evaluations involved long-term analysis of vegetation restoration across different policy implementation plots to explore how vegetation responds to policy changes. Ultimately, based on NDVI variations during different policy phases, the stages of policy implementation and their characteristics were delineated to provide guidelines for formulating ecological policies at different stages (Figure 2).

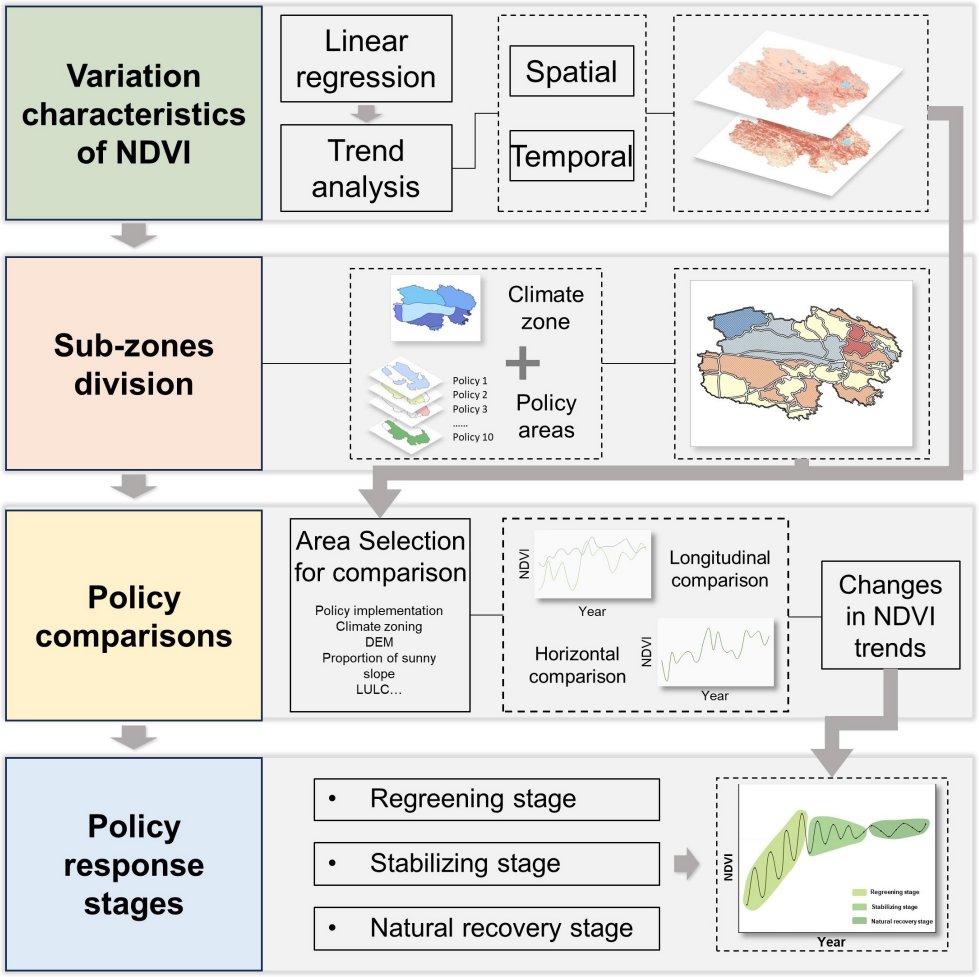


Figure 2. Research framework.

2.3. Data Sources and Preprocessing

2.3.1. NDVI Data

This study utilized MOD13A3 NDVI data, which is freely available from the National Aeronautics and Space Administration (https://ladsweb.modaps.eosdis.nasa.gov/ (accessed on 10 February 2023)). The data are a monthly product derived from daily MODIS imagery using the maximum value compositing (MVC) method, with a spatial resolution of 1 km. This method reduces the effects of interfering factors such as clouds and aerosols, improving data quality and availability. The MODIS Reprojection Tool (MRT) is used for splicing images and performing projection transformations. The Albers equal-area conic projection model with the Krasovsky datum was adopted. In order to further eliminate cloud contamination, the Savitzky–Golay filter, based on the MOD13A3 reliability data, was used to smooth the annual NDVI cycle and replace low-quality pixels [64]. Specifically, if the pixel value in the reliability layer equalled 0, the original NDVI value was retained; otherwise, the reconstructed NDVI value was used. This process resulted in a new annual NDVI data series. Based on the vegetation growth cycle in Qinghai Province, the mean NDVI value from June to August was selected to reflect vegetation growth. This more accurately reflects vegetation health and cover under optimal growing conditions, providing a better assessment of vegetation restoration and its response to climate and policy changes [65,66].

2.3.2. Ecological Policy in Qinghai Province

Through official documents released by the government, 10 important ecological policies involving Qinghai Province have been identified (Figure 3, Table 1), including

the Three-North Shelterbelt Project (TNSP), the Yangtze River Shelter Forest Construction Project (YFC), the Natural Forest Protection Program (NFPP), the Grain for Green Program (GGP), the Returning Pasture to Grass Project (RPG), the Sanjiangyuan Ecological Protection and Construction Project (SPC), the Qinghai Lake Basin Ecological Environmental Protection and Comprehensive Management Project (QLPC), the Qilian Mountain Ecological Environmental Protection and Comprehensive Management Project (QMPC), the Grassland Ecological Compensation Policy (GEC), and the Sanjiangyuan National Park (SNP).

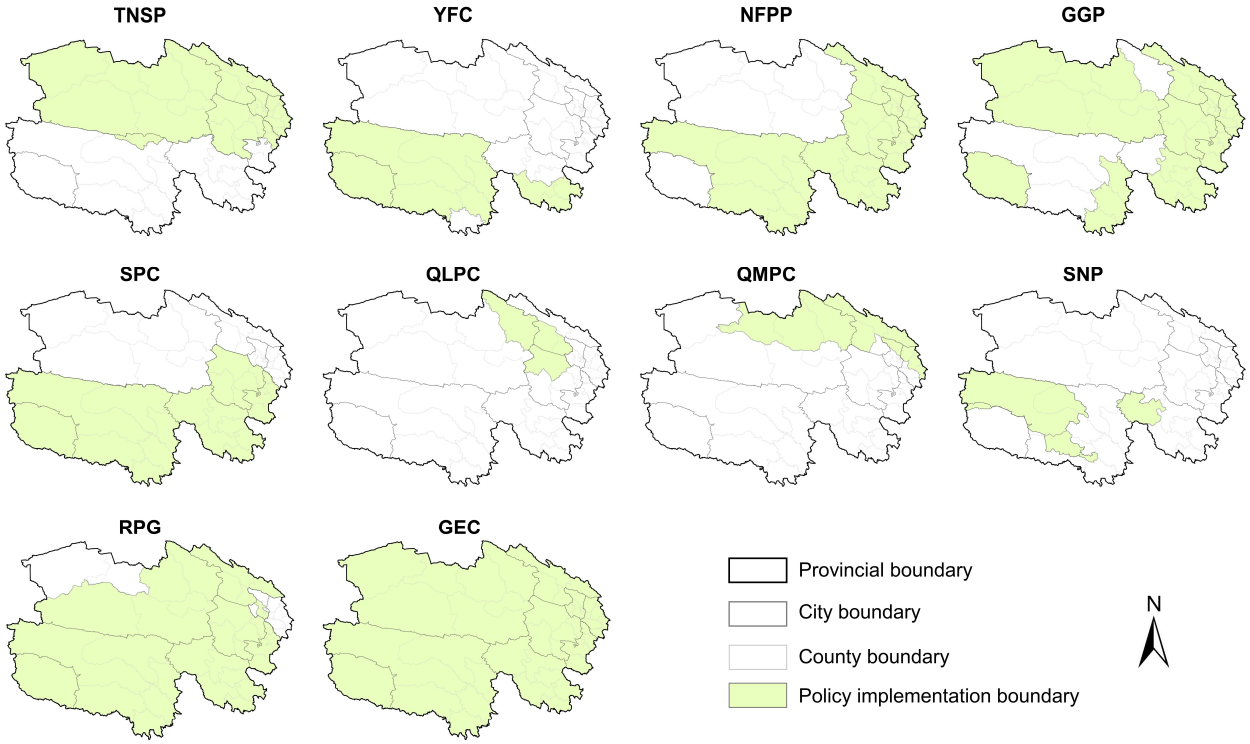


Figure 3. Spatial scope of ecological policy implementation.

Table 1. Ecological restoration polices in Qinghai Province.

Object	Name	Period	Implementation Area	Investment (Billion CNY)
Forest	TNSP	1978–2050	29 counties in Xining, Haidong, Haibei Tibetan Autonomous Prefecture, Huangnan Tibetan Autonomous Prefecture, Hainan Tibetan Autonomous Prefecture, and Haixi Mongol Autonomous Prefecture.	65.00
	YFC	1989–2020	Bama, Dari, Jiuzhi, Golmud, Chindu, Qumalai, Yushu, Zaido, and Zhiduo counties.	–
	NFPP	2000–2035	38 counties in Xining, Haidong, Haibei Tibetan Autonomous Prefecture, Huangnan Tibetan Autonomous Prefecture, Hainan Tibetan Autonomous Prefecture, Guoluo Tibetan Autonomous Prefecture, and Yushu Tibetan Autonomous Prefecture	74.7
	GGP	2002–2030	40 counties covering all prefecture-level administrative units in Qinghai Province.	–
Grassland	RPG	2003–2030	31 counties in Xining, Haibei Tibetan Autonomous Prefecture, Huangnan Tibetan Autonomous Prefecture, Hainan Tibetan Autonomous Prefecture, Guoluo Tibetan Autonomous Prefecture, Yushu Tibetan Autonomous Prefecture, and Haixi Mongol Autonomous Prefecture.	–
	GEC	2011–2025	Covers the whole province.	169.75

Table 1. *Cont.*

Object	Name	Period	Implementation Area	Investment (Billion CNY)
Important ecological functions	SPC	2005–2020	21 counties in Yushu Tibetan Autonomous Prefecture, Golog Tibetan Autonomous Prefecture, Hainan Tibetan Autonomous Prefecture, and Huangnan Tibetan Autonomous Prefecture.	180.61
	QLPC	2008–2018	Gangcha, Haiyan, Tianjun, and Gonghe Counties	15.67
	QMPC	2011–2020	Qilian, Menyuan, Gangcha, Tianjun, Delingha, Dachaidan, Minhe, Ledu, Huzhu, and Datong Counties.	35.00
	SNP	2016–2035	Zhiduo, Qumalai, Mado, and Zaoduo Counties and the Coco-Cecilia Nature Reserve.	66.12

2.4. Method

2.4.1. Delineation of Sub-Zones for Comparative Analysis

In this study, we delineated study sub-zones based on the climatic zones of the Tibetan Plateau region as identified in existing research [67], combined with the spatial extent of each ecological policy's implementation. We selected areas with minimal climate differentiation, consistent policy implementation, close proximity, similar elevation levels, and minimal slope aspect differences, all relatively near urban areas. Considering that climate change is a gradual process and our study spans only 24 years, from 2000 to 2023, we assumed similar climatic conditions within each sub-zone to minimize the effect of climate variability on vegetation growth. Additionally, in order to avoid spatial spillover effects, a buffer distance of 20 km delineated the boundaries of the sub-zones, with this buffer excluded from the sub-zones. Qinghai Province was thus divided into 8 climate zones and 50 sub-zones for this study (Figure 4, Table 2).

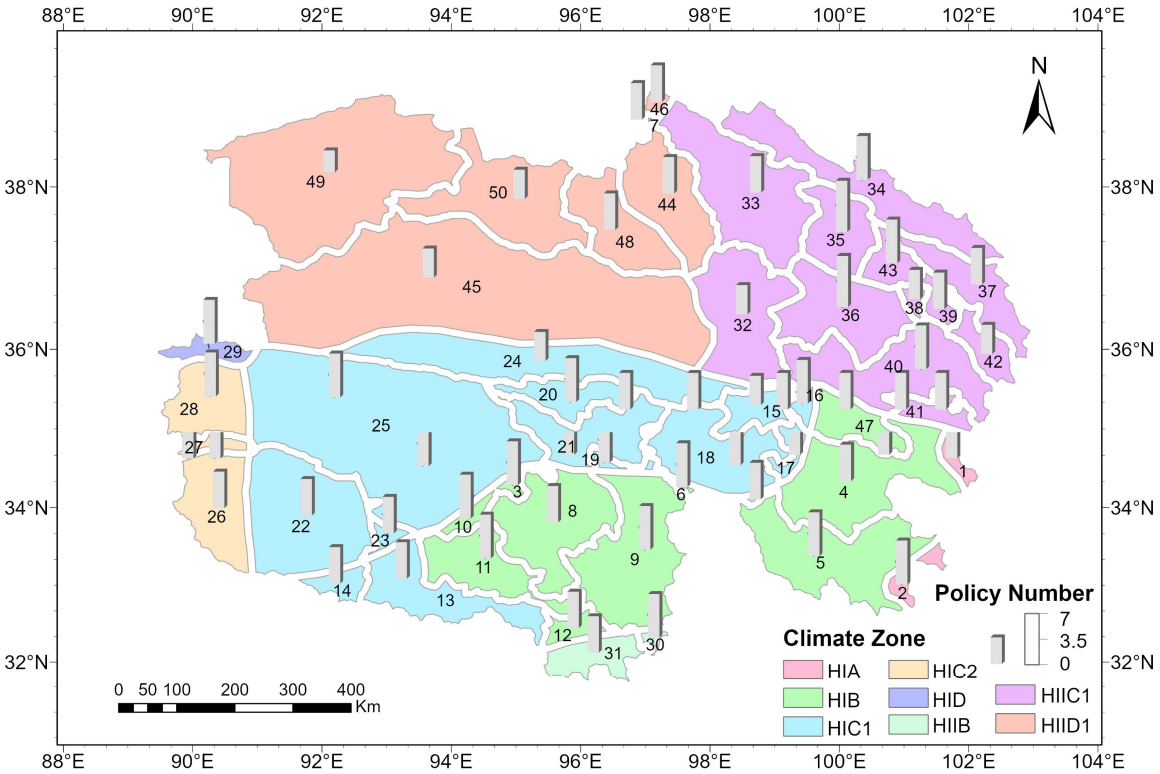


Figure 4. Spatial distribution of the study sub-zones.

Table 2. Delineation of sub-zones in Qinghai Province.

Number	Climate Zones	Ecological Policies	Number	Climate Zones [1]	Ecological Policies
1	HIA	NFPP, GGP, RPG, SPC, GEC	26	HIC2	YFC, GGP, RPG, SPC, GEC
2	HIA	YFC, NFPP, GGP, RPG, SPC, GEC	27	HIC2	YFC, GGP, RPG, SPC, GEC, SNP
3	HIB	TNSP, NFPP, GGP, RPG, SPC, GEC	28	HIC2	YFC, NFPP, RPG, SPC, GEC, SNP
4	HIB	NFPP, GGP, RPG, SPC, GEC	29	HID	YFC, NFPP, RPG, SPC, GEC, SNP
5	HIB	YFC, NFPP, GGP, RPG, SPC, GEC	30	HIIB	YFC, NFPP, GGP, RPG, SPC, GEC
6	HIB	YFC, NFPP, RPG, SPC, GEC, SNP	31	HIIB	NFPP, GGP, RPG, SPC, GEC
7	HIB	NFPP, RPG, SPC, GEC, SNP	32	HIIC1	TNSP, GGP, RPG, GEC
8	HIB	YFC, NFPP, RPG, SPC, GEC	33	HIIC1	TNSP, RPG, QLPC, QMPC, GEC
9	HIB	YFC, NFPP, GGP, RPG, SPC, GEC	34	HIIC1	TNSP, NFPP, GGP, RPG, QMPC, GEC
10	HIB	YFC, NFPP, RPG, SPC, GEC, SNP	35	HIIC1	TNSP, NFPP, GGP, RPG, QLPC, QMPC, GEC
11	HIB	YFC, NFPP, RPG, SPC, GEC, SNP	36	HIIC1	TNSP, NFPP, GGP, RPG, SPC, QLPC, GEC
12	HIB	NFPP, GGP, RPG, SPC, GEC	37	HIIC1	TNSP, NFPP, GGP, QMPC, GEC
13	HIB	YFC, NFPP, RPG, SPC, GEC	38	HIIC1	TNSP, NFPP, GGP, GEC
14	HIB	YFC, GGP, RPG, SPC, GEC	39	HIIC1	TNSP, NFPP, GGP, RPG, GEC
15	HIC1	NFPP, RPG, SPC, GEC	40	HIIC1	TNSP, NFPP, GGP, RPG, SPC, GEC
16	HIC1	TNSP, NFPP, GGP, RPG, SPC, GEC	41	HIIC1	NFPP, GGP, RPG, SPC, GEC
17	HIC1	NFPP, GGP, RPG, SPC, GEC	42	HIIC1	TNSP, NFPP, GGP, GEC
18	HIC1	NFPP, RPG, SPC, GEC, SNP	43	HIIC1	TNSP, NFPP, GGP, RPG, QLPC, GEC
19	HIC1	YFC, NFPP, GGP, RPG, SPC, GEC	44	HIIC1	TNSP, GGP, RPG, QMPC, GEC
20	HIC1	TNSP, YFC, NFPP, RPG, SPC, GEC	45	HIID1	TNSP, GGP, RPG, GEC
21	HIC1	YFC, NFPP, RPG, SPC, GEC	46	HIID1	TNSP, RPG, QLPC, QMPC, GEC
22	HIC1	YFC, GGP, RPG, SPC, GEC	47	HIID1	TNSP, GGP, RPG, QMPC, GEC
23	HIC1	YFC, NFPP, RPG, SPC, GEC	48	HIID1	TNSP, GGP, RPG, QMPC, GEC
24	HIC1	TNSP, GGP, RPG, GEC	49	HIID1	TNSP, GGP, GEC
25	HIC1	YFC, NFPP, RPG, SPC, GEC, SNP	50	HIID1	TNSP, GGP, QMPC, GEC

[1] Kunlun Alpine Plateau subarctic arid zone (HID), Golo–Naqu Alpine Valley Plateau subarctic semi-humid zone (HIB), Qilian–Qingdong Alpine Basin Plateau temperate semi-arid zone (HIIC1), Qaidam Basin and the northern flank of the Kunlun Mountains plateau temperate arid zone (HIIC2), Ruoergai Plateau sub-boreal humid zone (HIA), temperate semi-humid zone of the plateau in the central and northern parts of the Hengduan Mountains (HIIB), Qingnan Plateau sub-boreal semi-arid zone (HIC1), Qiangtang Plateau Lake Basin subarctic semi-arid zone (HIC2).

2.4.2. Trend Analysis

This study utilized ArcGIS 10.6 and R 4.3.3 for data analysis. The overall trend in regional NDVI changes was determined using the Mann–Kendall trend test. It is a non-parametric statistical method used to assess the significance of time series trends. One advantage of this non-parametric test is that it does not require the samples to follow specific distributions and is robust against the interference of outliers. For analyzing the time series of NDVI values, the Mann–Kendall statistic Z is defined as follows:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & (S > 0) \\ 0 \quad (S = 0) \\ \frac{S+1}{\sqrt{Var(S)}} & (S < 0) \end{cases} \tag{1}$$

$$S = \sum_{j=1}^{n-1} \sum_{i=j+1}^{n} \mathrm{sgn}(x_j - x_i) \tag{2}$$

$$Var(s) = \frac{n(n-1)(2n+5)}{t} \tag{3}$$

$$\mathrm{sgn}(x_j - x_i) = \begin{cases} 1 & (x_j - x_i > 0) \\ 0 & (x_j - x_i = 0) \\ -1 & (x_j - x_i < 0) \end{cases} \quad (4)$$

where n denotes the duration of the study period, and x_j and x_i indicate the mean NDVI values from June to August of the jth year and ith year. The function "sgn" is the sign function. The value of Z ranges from $-\infty$ to $+\infty$. For a given significance level of 0.05, if $|Z| > 1.96$, then the time series exhibits a significant variation at the 0.05 level.

For raster data, this study uses regression slope analysis to examine the trend in NDVI changes over the study period. By treating time (n) as the independent variable, a pixel-by-pixel regression analysis of NDVI was conducted. The slope of the regression equation was then used to determine the variable's trend during the study period. A negative slope signifies a decline in vegetation, whereas a positive slope signifies an increase.

$$\theta_{slope} = \frac{n\sum_{j=1}^{n} jx_j - \sum_{j=1}^{n} j\sum_{j=1}^{n} x_j}{n\sum_{j=1}^{n} j^2 - \left(\sum_{j=1}^{n} j\right)^2} \quad (5)$$

θ_{slope} represents the trend in the NDVI, characterized by the slope of the fitted curve of inter-annual variability.

2.4.3. Evaluation of the Effectiveness of Policy Implementation

The effectiveness of ecological policy implementation was assessed both horizontally and vertically. The horizontal evaluation involved investigating the impact of different policy implementations on vegetation restoration by comparing vegetation growth in areas with relatively uniform climatic conditions but varying policy implementations. Specifically, within the same climatic sub-zone, we selected two sub-zones differing only in one aspect of policy implementation and compared the long-term maximum NDVI trends to observe the differential response of vegetation growth to the policy. The vertical evaluation involved comparing NDVI variations preceding and following the implementation of multiple ecological policies within the same sub-zone to assess the effects of policy implementation on regional vegetation restoration.

The level of vegetation restoration can be quantified by the slope of a linear fit to the maximum value of the NDVI over many years, while the stability of vegetation growth can be expressed by the variance of the NDVI. To visualize the dynamics of vegetation recovery after policy implementation, this study calculated the difference in the slopes of NDVI changes between areas with and without policy implementation. Additionally, the difference in the variance of the NDVI between these areas before and after policy implementation was calculated. These differences were used for evaluating the effects of policy implementation on vegetation restoration.

$$D = \left(I_Slope_{after} - NI_Slope_{after}\right) - \left(I_Slope_{before} - NI_Slope_{before}\right) \quad (6)$$

$$St = \left(I_Var_{after} - NI_Var_{after}\right) - \left(I_Var_{before} - NI_Var_{before}\right) \quad (7)$$

D represents the degree of vegetation restoration, and St represents the stability of vegetation restoration. I and NI represent the policy implementation area and non-implementation area, respectively. If $D > 0$, it means that the policy implementation has a positive impact on vegetation restoration, and the larger the value, the greater the positive impact of the policy on vegetation restoration; if $D = 0$, it means that the policy implementation has not changed the ecological conditions of the region; if $D < 0$, it means that the policy implementation has no good effect on the regional vegetation restoration. If $St > 0$, it means that the policy implementation has enhanced the regional vegetation

restoration stability; if $St = 0$, it means that the policy implementation has had no effect on the regional vegetation restoration stability, and if $St < 0$, it means that the policy implementation has not played a good role in the regional vegetation restoration stability.

3. Results

3.1. Vegetation Coverage Changes in Qinghai Province 2000–2023

From 2000 to 2023, the average NDVI in Qinghai Province was 0.4238, with a spatial pattern where higher values were more prevalent in the eastern and southern regions, while lower values were more prevalent in the western and northern regions. (Figure 5a). Regions with NDVI values below this average, accounting for 55.27% of the province, were primarily located in the Haixi Mongol and Tibetan Autonomous Prefecture and partly in the Yushu and Hainan Tibetan Autonomous Prefectures. In areas with minimal human activity, such as the Hainan Tibetan Autonomous Prefecture and the Haixi Mongol and Tibetan Autonomous Prefecture, NDVI values were notably higher, particularly around urban areas. The Mann–Kendall trend test revealed a significant upward trend in the NDVI in Qinghai Province from 2000 to 2023, with a Z of 3.2494. This trend can be segmented into three phases: a rapid growth phase from 2000 to 2009, with a Z of 2.0241, exhibiting an annual growth rate of 0.38%; a fluctuating decline phase from 2010 to 2016, with a Z of -2.1026, showing a significant annual decline rate of 0.19%; and a steady growth phase from 2017 to 2023, with a Z of 0.8660, with an average annual growth rate of 0.27% (Figure 5b).

Using least squares regression, the spatial distribution and significance of NDVI slope changes over the past 20 years were analysed in Qinghai Province. Most regions in Qinghai Province exhibited an upward trend in the NDVI, with areas where the slope was greater than 0 accounting for 88.42%, and those where it was less than 0 accounting for 11.58% (Figure 6a). The Hainan Tibetan Autonomous Prefecture, Haidong City, the eastern Haixi Mongolian Autonomous Prefecture, and the northwestern Guoluo Tibetan Autonomous Prefecture were the main regions with significant increases in the NDVI. Conversely, notable decreases in the NDVI were primarily found around several salt lakes in Golmud City, central regions of Yushu Tibetan Autonomous Prefecture, and Guoluo Tibetan Autonomous Prefecture, as well as urban areas of Xining City. The distribution of areas with improved vegetation in Qinghai Province was more concentrated, while areas with degraded vegetation were more dispersed, and the areas of improved vegetation significantly outweighed those of degraded areas. The western Qilian Mountains and the surrounding areas of the Qaidam Basin saw marked improvements in vegetation cover due to proactive afforestation efforts, altering the original desert ecosystem pattern. Similarly, in the central and western parts of Yushu Tibetan Autonomous Prefecture, vegetation cover significantly improved due to measures such as fencing, afforestation, grass planting, and ecological migration. In the eastern Qilian Mountains and the southern part of the Sanjiangyuan area, overgrazing along with unregulated digging and mining slightly degraded vegetation cover. The artificial vegetation around salt lakes and alluvial fans in the central Qaidam Basin and Huangshui Valley deteriorated significantly due to human activities such as farmland reclamation, tourism, and road construction. The semi-desert and desert zones in the central and northwestern parts of the Qaidam Basin saw little change in vegetation cover, attributed to the arid climate and minimal human activity. Regarding statistical significance, 55.69% of the regions had a p value less than 0.05, indicating a significant variation (Figure 6b). Except for the northwest area, these regions roughly coincided with areas where the slope was greater than zero, suggesting a more pronounced trend in vegetation improvement in Qinghai Province. Moreover, most areas with declining NDVI showed no significant change, and there was a noticeable correlation between NDVI change characteristics and altitude, with less significant NDVI changes at higher altitudes.

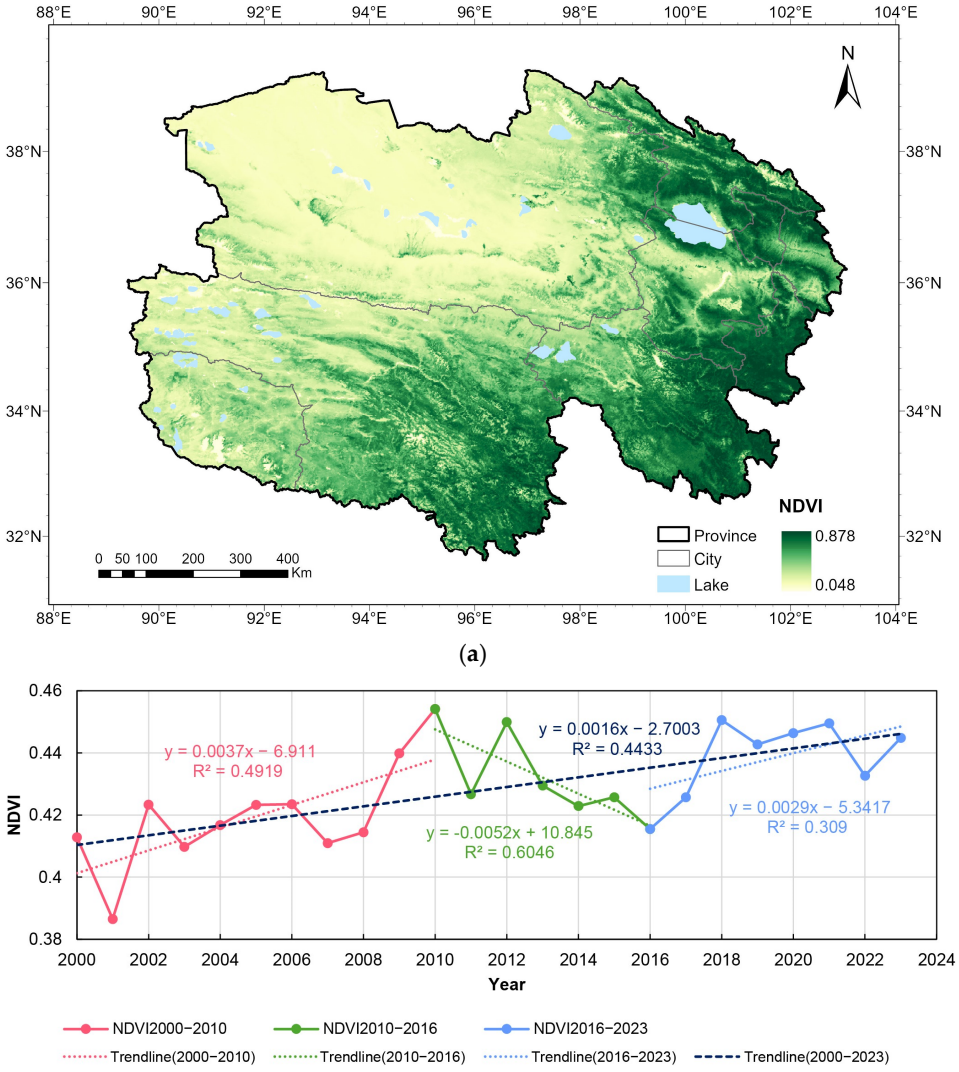


Figure 5. Spatial and temporal variations in NDVI in Qinghai Province. (**a**) Spatial distribution of the average NDVI in Qinghai Province from 2000 to 2023; (**b**) changing trends in NDVI in Qinghai Province from 2000 to 2023.

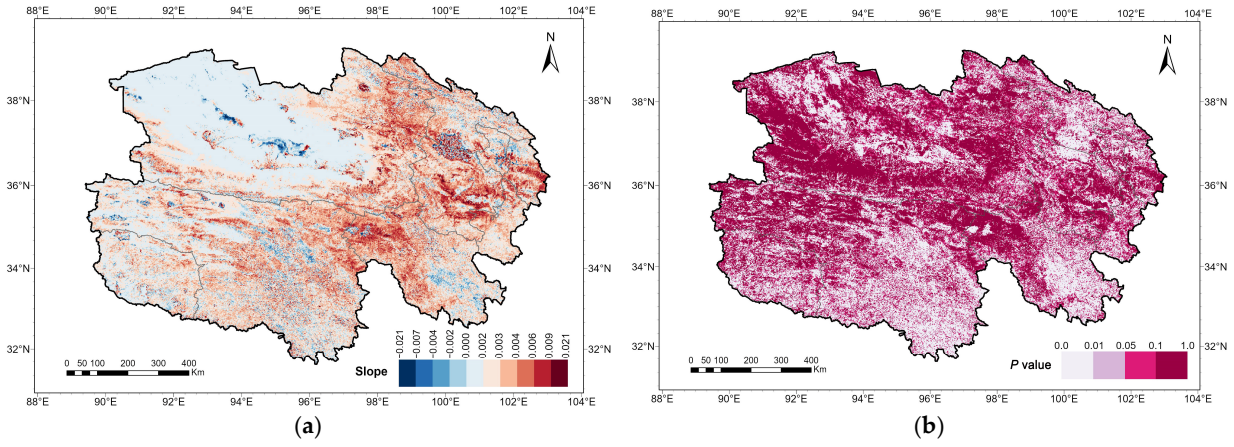


Figure 6. The spatial patterns of the NDVI trend in Qinghai Province: (**a**) Changes in NDVI slope from 2000 to 2023; (**b**) corresponding significance of the NDVI slope.

3.2. Horizontal Evaluation of the Impact of Ecological Policies on Vegetation Restoration

Qinghai Province began to implement the TNSP in 1978. NDVI changes in both the implementation and non-implementation areas of TNSP are shown in Figure 7a. Both areas exhibited a clear upward trend in the NDVI, exhibiting similar fluctuation patterns. The growth rate in the implementation area was 0.0023 per year, compared to 0.0017 per year in the non-implementation area, indicating higher stability in the implementation area. Therefore, the TNSP has effectively enhanced ecological environment improvement and ecosystem stability. YFC and TNSP exhibited similar NDVI change characteristics, as depicted in Figure 7b, where the implementation area's growth rate was 0.0012 per year, 0.0006 per year higher than in the non-implementation area, and with less variance in NDVI changes.

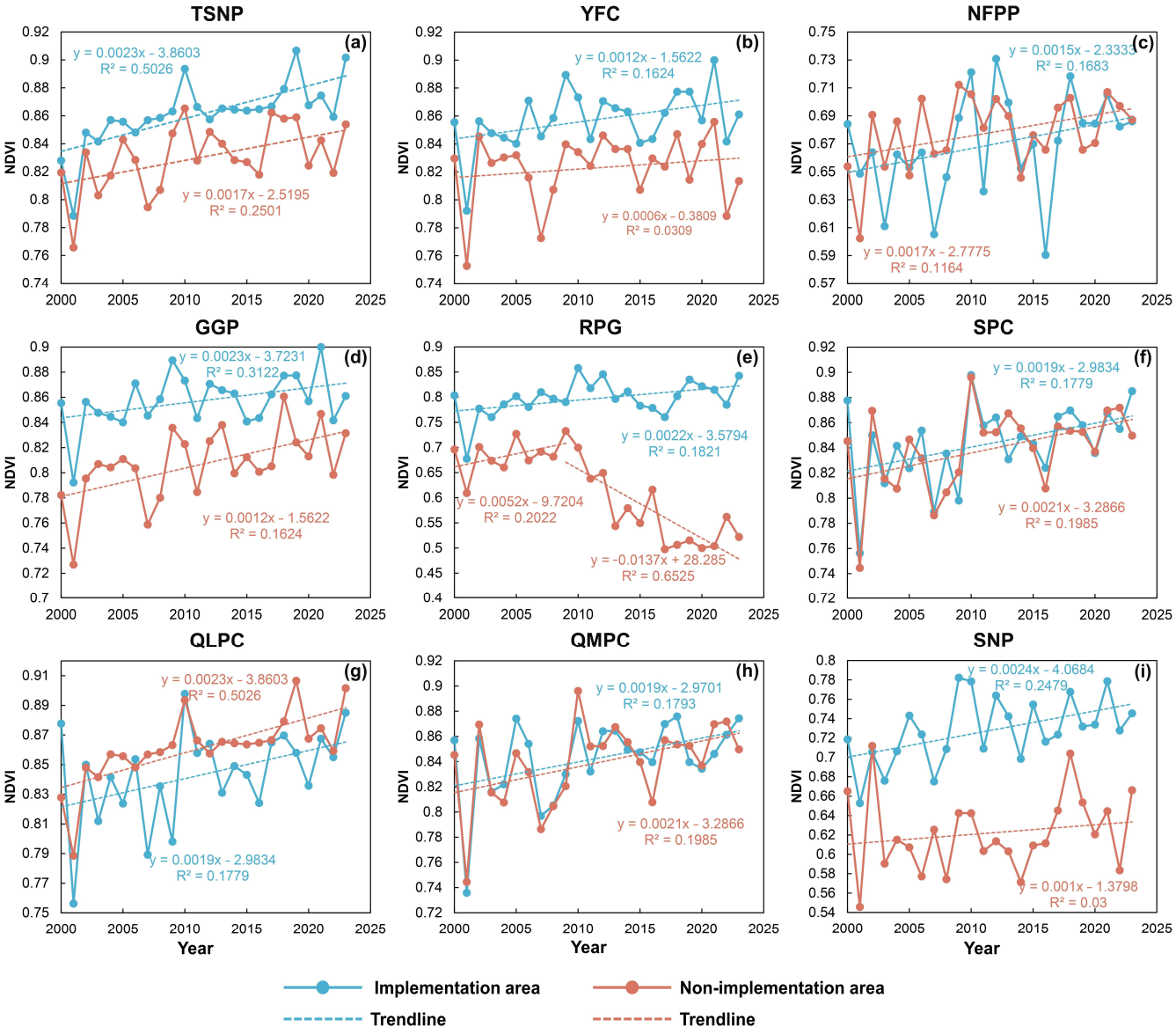


Figure 7. Horizontal evaluation of NDVI changes. Subfigures (**a**) through (**i**) correspond to different ecological policies: (**a**) TSNP, (**b**) YFC, (**c**) NFPP, (**d**) GGP, (**e**) RPG, (**f**) SPC, (**g**) QLPC, (**h**) QMPC, and (**i**) SNP.

For the NFPP, NDVI trends in both the implementation and non-implementation areas showed similar patterns of fluctuation and increase, as illustrated in Figure 7c. Initially, the NDVI in the implementation area was slightly lower than in the non-implementation area.

Post-implementation, the growth rate in the implementation area rose to 0.0021 per year, surpassing 0.0014 per year in the non-implementation area, thus enhancing the regional NDVI recovery capacity and improving the ecological environment.

The GGP policy's effect, shown in Figure 7d, indicated a fluctuating upward NDVI trend in both implementation and non-implementation areas, with the non-implementation area initially showing a higher growth rate. However, post-implementation, the difference in growth rates decreased, and stability in the implementation area improved, demonstrating the policy's positive impact on vegetation restoration. The RPG policy, initiated in 2003 alongside the GGP, showed a marked difference in NDVI changes between the implementation and non-implementation areas (Figure 7e). The implementation area had an annual NDVI increase of 0.0007, while the non-implementation area experienced a decrease of 0.0121 per year, indicating the policy's effectiveness in mitigating the environmental impact of animal husbandry.

The SPC, QLPC, and QMPC are three important ecological protection and governance projects implemented in Qinghai Province over the past two decades. The NDVI in the implementation regions of these three projects showed a significant upward trend, indicating that the ecological protection and governance projects promoted vegetation restoration (Figure 7f–h). It is noteworthy that the variance in the NDVI changes in the SPC was lower before its implementation, suggesting that while ecological degradation has been curbed, ecological stability remains fragile, and it is essential to further strengthen the construction of ecological stability in the subsequent project implementation. Sanjiangyuan National Park (SNP), established in 2016, is among the first national parks in China, encompassing the sources of three rivers, including the Yangtze, Yellow, and Lancang Rivers. Following implementation of the park's policies, the annual NDVI change rate in the implementation area was 0.0012, compared to −0.0008 in the non-implementation area. The difference in NDVI change rate was 0.0015, with a variance difference of 0.0005, as shown in Figure 7i. These figures indicate that the national park policy has effectively promoted vegetation recovery and enhanced the stability of the ecosystem.

3.3. Vertical Evaluation of the Impact of Ecological Policies on Vegetation Restoration

Figure 8a,b represent high-altitude areas (sub-zone 9 and sub-zone 31) with NDVI variances of 0.0007 and 0.0004, respectively, indicating relatively stable ecological environments. Sub-zone 9, encompassing parts of Yushu City and Chengduo County, within the Yushu Tibetan Autonomous Prefecture, lies in the Golok–Nagchu Alpine Valley Plateau sub-humid region. From 2007 to 2023, NDVI trends in this region transitioned from a significant upward trend during the initial phase (2000–2006) to a more gradual increase. This trend was driven by policies such as the YFC, NFPP, GGP, RPG, and SPC, which primarily focused on reforestation, yielding substantial improvements by 2007. Afterward, policy emphasis shifted towards enhancing ecosystem quality and stability. Sub-zone 31, located in Nangqian County of the Yushu Tibetan Autonomous Prefecture, was part of the temperate semi-humid region of the northern Hengduan Mountains plateau. Ecological policy interventions also facilitated a stable growth trend in the NDVI. Contrary to sub-zone 9, sub-zone 31 does not fall within the YFC implementation area, which resulted in lower annual NDVI growth before 2007.

The NDVI in mid-altitude, relatively flat regions, where human activity was most intense, was significantly influenced by policy interventions. Sub-zone 35, located in Gonghe County within the Hainan Tibetan Autonomous Prefecture and part of the Qilian–Qingdong Alpine Basin Plateau temperate semi-arid region, demonstrated a marked increase in the NDVI from 2000 to 2008, though with noticeable fluctuations (Figure 8c). From 2009 to 2023, with the increase in number of policies, the NDVI trends stabilized, suggesting that the gains from the earlier period were sustained, leading to reduced fluctuations and a more stable ecosystem. Sub-zone 36, situated in Gangcha County and also within the Qilian–Qingdong Alpine Basin Plateau temperate semi-arid region, exhibited an upward NDVI trend with considerable fluctuations from 2000 to 2007. However, between 2008 and

2015, while fluctuations decreased, the NDVI showed a downward trend (Figure 8d). From 2016 to 2023, also with an increase in the number of policies, the NDVI decline reversed to an upward trend, indicating that the ecosystem has undergone substantial restoration and improvement.

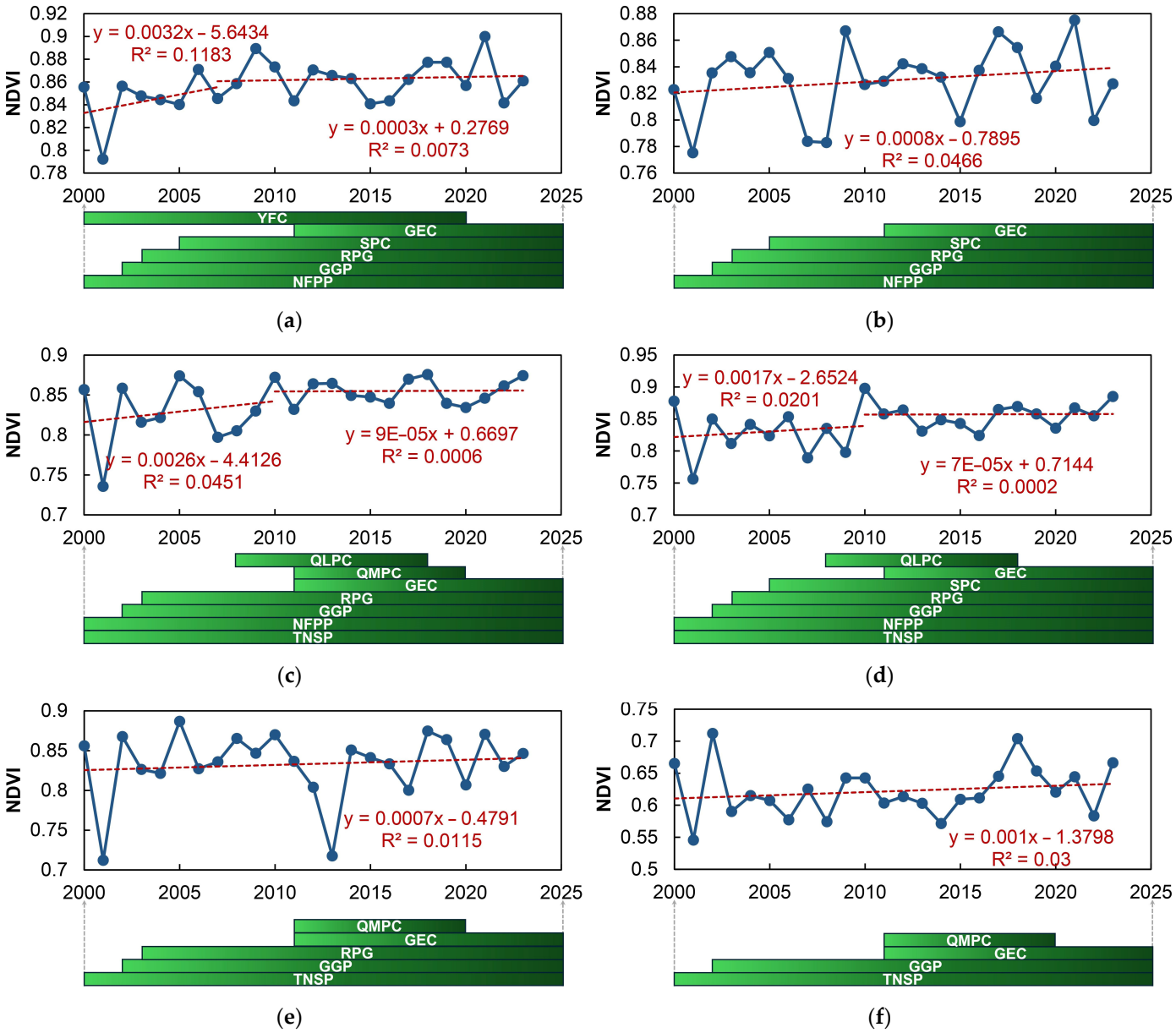


Figure 8. Vertical evaluation of NDVI changes. (**a**) NDVI changes in sub-zone 9; (**b**) NDVI changes in sub-zone 31; (**c**) NDVI changes in sub-zone 35; (**d**) NDVI changes in sub-zone 36; (**e**) NDVI changes in sub-zone 48; (**f**) NDVI changes in sub-zone 50. The green rectangle under the NDVI changes indicates the period of policies.

Low-altitude regions were more susceptible to climatic fluctuations due to suboptimal hydrothermal conditions, resulting in a lower and more variable NDVI compared to mid- and high-altitude regions. Sub-zone 48, located in Delingha City within the Haixi Mongol and Tibetan Autonomous Prefecture, lay in the arid region of the Qaidam Basin and the northern slopes of the Kunlun Mountains. Here, the NDVI showed a minimal overall growth trend (Figure 8e). Although this area was within the policy implementation zone before 2010, it was not a primary focus. Sub-zone 50, located in the directly administered county of Haixi Mongol and Tibetan Autonomous Prefecture, was also in the Qaidam

Basin and on the northern slopes of the Kunlun Mountains, within a temperate arid region. In contrast to sub-zone 48, sub-zone 50 experienced gradual growth with significant fluctuations. After 2012, the growth trend in this zone markedly increased, suggesting that policy interventions positively impacted local ecological conditions (Figure 8f).

4. Discussion

4.1. Implications and Applications

With the gradual increase in global ecological protection and construction projects, the impact of ecological policy implementation on vegetation restoration has become a significant focus. China, placing high importance on ecological issues, has continuously increased its investment in ecological protection and restoration. As various ecological policies are proposed and implemented, their social, economic, and ecological benefits have been widely discussed and debated. It is crucial to use scientific methods to evaluate the effectiveness of ecological policies, as this can inform the subsequent adjustment and optimization of these policies. Qinghai Province, a key region of the Qinghai–Tibet Plateau, serves as the birthplace of many rivers and acts as a crucial ecological safeguard for China. The ecological status of this region is vital, carrying major ecological responsibilities. Over the past 40 years, Qinghai Province has implemented numerous significant ecological policies. However, the extent to which these policies have contributed to ecological restoration in the province remains unclear. To address this issue, this study investigates the effects of ecological policy implementation on vegetation restoration. It uses long-term NDVI data to measure vegetation responsiveness and examines the response of vegetation to ecological policies through both horizontal and vertical evaluations. The findings of this research are of significant importance for improving and optimizing existing policies and for proposing new ones.

The promulgation and implementation of ecological policies have significantly enhanced vegetation restoration in Qinghai Province. Over the past 20 years, the NDVI in most areas of Qinghai Province has demonstrated a fluctuating yet upward trend, aligning with findings from previous studies (1982–2003, 2000–2019) [68,69]. In the horizontal comparison, most of the compared regions exhibit similar NDVI fluctuation patterns, indicating that these fluctuations are not driven by policy implementation. The decline in the NDVI in some areas is primarily due to changes in precipitation and temperature, with urban expansion being a contributing factor as well [69]. Moreover, vegetation restoration in Qinghai Province exhibits distinct phased characteristics (Figure 9). Based on the NDVI trends and the timing and duration of various ecological policies, vegetation restoration can be categorized into three stages, the regreening stage (2000–2007), the stabilizing stage (2008–2015), and the natural recovery stage (2016 to present), similar to previous studies [70]. During the regreening stage, Qinghai implemented multiple projects including the TNSP, the YFC, the NFPP, the GGP, the RGP, and the SPC. To facilitate vegetation restoration, extensive artificial afforestation and grass planting were undertaken, significantly reducing desertified and saline–alkali degraded lands. Among these, the TNSP, YFC, and the NFPP primarily aimed to restore regional forest vegetation, while the GGP and the RGP focused on converting farmland and pastures into natural green spaces. The contrast of the RGP is particularly striking, as the selected sub-zones are located in the important pastoral areas of Dulan County and Golmud City in Haixi Prefecture. In the non-implementation areas, extensive grazing practices have evidently caused significant ecological damage. After the policy implementation, the areas adopted more sustainable grazing measures, including rotational grazing and resting pastures. Consequently, the NDVI exhibited a marked upward trend, improving the status of vegetation degradation in Qinghai Province. During the stabilizing stage, Qinghai Province initiated several projects, including the QLPC, the QMPC, and the GEC. While existing policies continued to be implemented, key tasks were adjusted to align with current needs. This stage not only consolidated and enhanced the outcomes of previous artificial greening efforts but also refined the management strategies and methods of various policies. During this phase, the QLPC and

QMPC implemented integrated management of mountains, rivers, forests, farmland, lakes, grasslands, deserts, and glaciers from an engineering perspective. The emphasis during this stage was on more localized and targeted management of the ecological environment, achieved through engineering restoration and assisted regeneration techniques. During the natural recovery stage, forest and grassland protection and restoration in Qinghai Province have transitioned to regularized construction and management, marked by the implementation of the Sanjiangyuan National Park (SNP). This project aims to protect the local ecological environment by establishing a national park and to foster natural ecological recovery through conservation and protection. At this stage, the ecosystem stability in Qinghai has notably improved, and NDVI fluctuations have substantially decreased, exhibiting a stable and modestly ascending trend.

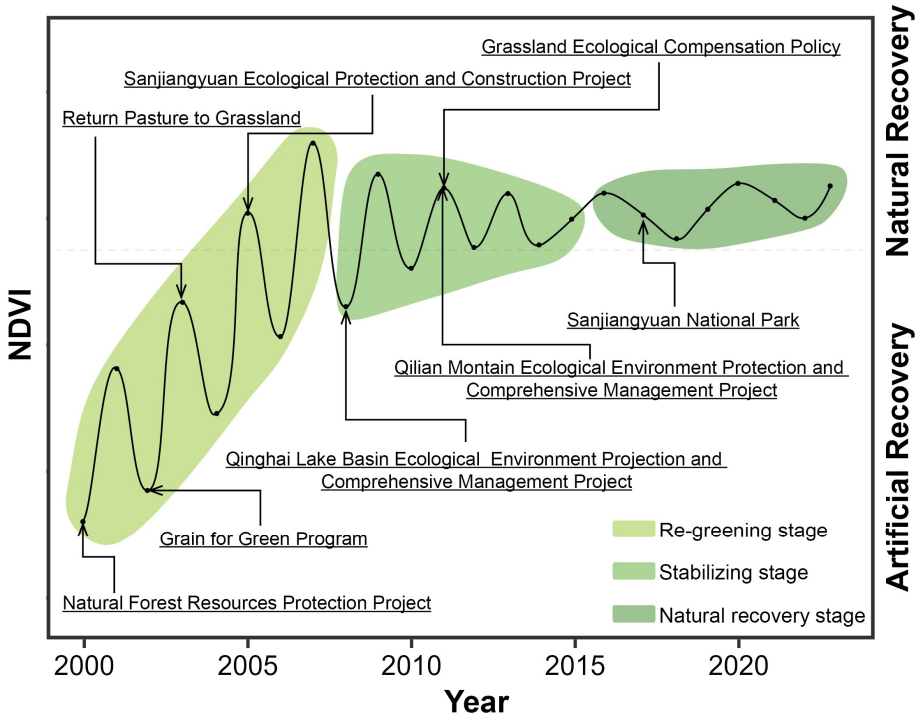


Figure 9. Phased response characteristics of vegetation restoration to ecological policies.

During the implementation of ecological policies, vegetation restoration primarily involves artificial assistance through tree and grass planting, alongside natural restoration facilitated by conservation and protection measures. Additionally, reasonable grazing practices also contribute to local ecological recovery [71,72]. At the regional level, the implementation of ecological policies exhibits variability in progress. Initially, due to limited government funding for ecological projects, policies targeted areas with the most severe ecological degradation. As financial investments increased, these policies expanded across all implementation zones. And the vertical evaluation results indicate that in areas with a higher concentration of population and urban distribution (mid-altitude areas), the implementation of policies is more effective; in high-altitude areas, which are predominantly uninhabited, the implementation of policies faces obstacles; in low-altitude areas, vegetation is more constrained by thermo-hydrological factors, and thus, cannot demonstrate a more apparent response to the policies. Consequently, ecological restoration in Qinghai Province demonstrates spatial heterogeneity and distinct temporal phases. Although the primary focus of ecological policy was on the rescue restoration of damaged ecosystems, each policy went in a different direction. Some policies, such as the NFPP, were primarily aimed at restoring vegetation through natural conservation and rehabilitation. Others, like the TNSP, YFC, GGP, and RPG, employed artificial assistance and engineering measures for vegetation restoration. The GEC used financial compensation as a means of support.

Comprehensive methods were used to achieve vegetation restoration in ecological functional zones, as seen in policies like the SPC, QLPC, and QMPC. Additionally, protection and enclosure methods, as implemented in the SNP, facilitated natural vegetation recovery. As vegetation in the policy implementation areas began to recover, it became necessary to adjust the policy focus towards optimizing the ecological structure and enhancing ecosystem stability and service quality. The overlapping of different ecological policies leads to varying effects on vegetation restoration. The multiple ecological policies implemented in Qinghai Province are interconnected, with some overlap in content and areas of implementation. For example, apart from the YFC and the NFPP, which do not explicitly state objectives related to soil desertification control, the other eight policies studied in this paper address the issue of soil desertification from different perspectives. Thus, the impact of these policies is not merely the sum of individual efforts but rather an enhancement and consolidation of previous policies. For example, the management of desertification land includes subsequent vegetation cover, which helps further consolidate the results of desertification control [73]. Additionally, the GEC has increased financial investment in grassland areas, further strengthening herders' recognition and support for these policies. These policies interact within the region, aiming to generate a synergistic effect that exceeds the sum of their individual contributions.

Studies have proven that vegetation growth in Qinghai Province is sensitive to climate change during the growing season, and the region's vegetation cover has improved as a result of the interactive effects of temperature and precipitation. However, this study proposes a sub-region comparison method based on climate zoning to eliminate the heterogeneity of vegetation changes due to climate factors as much as possible. Under consistent climatic conditions, comparing vegetation changes in policy implementation areas and non-implementation areas can better explain the contribution of policy formulation to vegetation restoration. In the vertical evaluation of the effects of ecological policy implementation, it is evident that more ecological policies and construction projects have been carried out in areas with higher human activity at mid-altitudes, resulting in more significant policy impacts. This demonstrates the close relationship between the effectiveness of policy implementation and the intensity of human activities. Areas with intensive human activities often experience more severe ecological disturbances. Therefore, the incentives and constraints of relevant ecological policies can significantly improve the ecological environment in these regions. However, after regions with severe ecological degradation undergo large-scale ecological reconstruction and artificial assistance, it is essential to explore ways to enhance ecosystem stability and the quality of ecological services through natural restoration. This shift aligns more closely with the nature-based solutions concept. For example, the TNSP has undergone five phases since its inception. The first four phases primarily relied on artificial intervention measures, aiming to build a protective forest system through afforestation and to address land degradation. In 2011, the fifth phase was introduced, marking a shift in focus from purely quantitative goals to an equal emphasis on both quantity and quality. This phase also transitioned from decentralized management to large-scale management and from predominantly artificial measures to a combination of artificial interventions and natural restoration. In areas with relatively sparse human activities, ecological policies typically focus on protecting ecosystems by designating nature reserves or national parks. However, it is important to note that overly strict ecological protection policies do not necessarily lead to higher ecological restoration effects [55]. Thus, policies should be dynamically adjusted based on the region's actual conditions.

4.2. Limitations and Prospects

This study evaluated the stage characteristics and effects of ecological policy in Qinghai Province by comparing NDVI changes in the policy implementation area with those in non-implementation areas (horizontal evaluation) and examining NDVI changes in the implementation area before and after policy deployment (vertical evaluation). Employing a zoned and phased comparative analysis enabled a more objective and precise evaluation

of the ecological policy effects in Qinghai Province and informed the development of regional ecological policies. However, this study's scope is limited to the impact of these policies on vegetation restoration. Although NDVI is a standard indicator for assessing vegetation condition, various vegetation indicators could be integrated in further research for a more scientific and detailed assessment of vegetation condition. The improvement of the ecological environment is multifaceted, encompassing vegetation, water, soil, and biodiversity. Future research should therefore expand to assess the impact of ecological policies on the comprehensive improvement of the ecological environment and integrate various vegetation indices, such as biomass data and species diversity, to provide a more thorough assessment of ecosystem health. Additionally, while ecological policy assessment involves complex interrelations among ecological, economic, and social factors, this study concentrated only on the ecological dimensions and did not account for the socio-economic benefits of the policies. The zoning method employed in this study primarily considers policy implementation status and climate conditions, excluding other natural and socioeconomic factors such as economic development levels, topography, and land cover changes. By focusing on climate conditions for zoning, this method aims to minimize the impact of climate variability on the evaluation results. While the main objective of this zoning method is to isolate the effects of climate on vegetation restoration and more accurately assess the impact of ecological policies on vegetation restoration, this approach may inadvertently overlook certain microclimatic phenomena, such as differences between sun-facing and shaded slopes or variations between valley bottoms and mountain tops. Therefore, future research should take into account a broader range of factors and enhance the precision of the study.

5. Conclusions

This study provides a comprehensive and comparative assessment of the impacts of ecological policy implementation in Qinghai Province, highlighting how vegetation restoration responds to ecological policies. Over the past 20 years, the ecological environment in Qinghai Province has improved significantly, with vegetation cover showing a significant growth trend. This improvement is attributed to the combined effects of climate change and ecological policy implementation. The effectiveness of policies is more pronounced in areas with dense populations. While the impacts of various ecological policies vary, all have generally contributed positively to the region's ecological environment. The TSNP and YFC policies have had the most pronounced effects on NDVI growth, significantly enhancing vegetation cover and effectively curbing degradation caused by human activities. The SPC and QLPC policies have shown fluctuating impacts on NDVI, reflecting their significant roles in ecosystem restoration and stability. The study also reveals that the success of ecological policy implementation is closely linked to the policy's stage of implementation. The implementation can be segmented into three phases, regreening, stabilization, and natural restoration, with policy strategies tailored to the specific ecological conditions of different regions. Vertical NDVI data analysis over several years indicates that varying combinations of policies have distinct impacts on the ecological environment, underscoring the necessity for well-formulated policies to protect and restore regional ecosystems. Additionally, the application of ecological policies varies across regions, with different areas within the same policy zone possibly experiencing different stages of implementation. The insights into ecological policy effects and the delineation of policy stages in this study provide valuable references for the rational formulation of regional ecological policies.

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