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Ecological Waves at Tourist Attractions on the Qinghai-Tibet Plateau Promote Greenness of Surrounding Vegetation

Zitao Yang ^{1,2}  and Li Tian ^{1,*} 
¹ Qianyanzhou Ecological Research Station, Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100045, China; yangzitao0414@igsnr.ac.cn

² University of Chinese Academy of Sciences, Beijing 100049, China

* Correspondence: tianli@igsnr.ac.cn



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Abstract: The unique tourism resources of the Qinghai-Tibet Plateau have created conditions for the development of ecotourism, while the existence of attractions may also have positive and negative impacts on the surrounding environment. This study defines the radiation waves that generate ecological effects as “ecological waves”, quantifies the ecological waves of attractions by buffer zone analysis of the normalized difference vegetation index (NDVI) within 20 km of 38 4A and 5A attractions on the Qinghai-Tibet Plateau in 2020, and elaborately explores the ecological effects of attractions on the surrounding environment. By combining the principle of ripple effects, it analyzes the impact of urban attractions on urban vegetation environments. The study found that attractions on the Qinghai-Tibet Plateau have a positive ecological effect on the surrounding vegetation, the positive ecological effect of suburban attractions has a distance threshold, effectively promoting vegetation greenness within a range of 6–14 km, and the ecological effect disappears beyond 14 km. In addition, applying the ripple effect model to urban attractions and city centers (Xining and Lhasa), the results indicated that among the five urban attractions in Xining, Kumbum Monastery, Qinghai Tibetan Culture Center, and Country Farming Ecological Park (with distance restrictions of 2–20 km) have significant positive ecological effects within the built-up area, while the ecological effects of Qinghai Province Museum and Qinghai-Tibetan Plateau Safari Park are not significant. The positive ecological effects of the five urban attractions in Lhasa within the built-up area are not significant, and different attractions have different distance thresholds for ecological effects. Furthermore, this study found that attractions in Qinghai have a better ecological foundation around them than attractions in Tibet, making them more suitable for the development of ecotourism. This study has opened up a new perspective on the ecological effects of attractions and provided scientific references for the development of ecological tourism in the Qinghai-Tibet Plateau.

Keywords: ecotourism; ecological wave; ripple effect model; Qinghai-Tibet plateau

1. Introduction

Ecotourism refers to tourism activity with dual responsibilities of protecting the natural environment and maintaining the local people’s livelihood [1,2]. Numerous studies have shown that ecotourism is well-suited for sites dominated by mountain resources [3], grassland resources [4], water resources [5], and wildlife resources [6]. However, the development of tourist attractions as a typical human activity that interferes with natural ecosystems is bound to disrupt the ecological balance of the natural environment [7]. Therefore, the ecological gain and loss effects of tourist attractions have become the focus

of attention in ecotourism and ecological conservation [8–10]. Accurately assessing the ecological effects of tourist attractions is a crucial step in the development planning of ecotourism and the conservation of ecological environments [11–13].

Tourist attractions are basic territorial units consisting of associated natural or cultural landscapes with relative independence, completeness, and aesthetic features [14]. They not only integrate elements such as climate, topography, land cover, hydrology, and geology but also represent human civilization and urban landscapes [15,16]. In academic research, environmental monitoring, ecological assessment, and ecological conservation and management of tourist attractions are important research subjects [17–19]. Currently, the ecological gain and loss effects of tourist attractions are mostly limited to studies focusing on single attractions, such as the more comprehensive evaluation of the environmental impact of tourism in the Wulingyuan Scenic Area using the improved ESV algorithm [20]. However, research on single attractions overlooks the ecological synergistic effects between multiple attractions and their complex impacts on the surrounding ecological environment, making it difficult to provide a scientific basis for regional tourism policy. There is an urgent need to explore the ecological effects of multiple attractions on the surrounding environment from an ecological perspective.

The Qinghai-Tibet Plateau (QTP), with its unique natural resources and diverse multi-ethnic religious culture, has created rich tourism resources and formed many distinctive tourist attractions, laying the foundation for the rapid development of plateau tourism. Certain research indicates that the tourism carrying capacity of the Qinghai-Tibet Plateau in 2022 reached 1,782,400 people per day, while the average daily number of visitors received in 2019 was 1,152,794 people, only accounting for 64.7% of the tourism carrying capacity [21], highlighting the strong potential and resilience of ecological tourism on the Qinghai-Tibet Plateau [22]. Simultaneously, the QTP is a globally typical ecologically sensitive area [23,24]. Its fragile ecological environment not only hinders the development of tourism but also is influenced by tourism construction. For instance, compared to other regions, the QTP has significant climate change characteristics that directly or indirectly threaten the tourism industry, affecting aspects such as tourist experiences and tourism resource consumption [25,26]. Additionally, research indicates that grassland tourism activities on the QTP have reduced the biomass of litter, soil nutrient supply, and soil enzyme activity, thereby adversely impacting the entire grassland ecosystem [27]. Nonetheless, some tourism constructions can improve the local ecological environment, as seen in Southeast Asia, where the presence of temples in urban areas enriches vegetation and water environments, enhancing the self-sufficiency of urban ecosystems [28]. From the ecological perspective, this impact could be seen as the ecological effect generated by tourist attractions. Similarly, some cities on the QTP also boast many temple landscapes, such as Kumbum Monastery, Potala Palace, and Jokhang Temple. It is necessary to conduct in-depth research on the ecological gain and loss effects of tourist attractions on the QTP.

This study focuses on several typical tourist attractions and cities on the Qinghai-Tibet Plateau (Xining and Lhasa), using the Normalized Difference Vegetation Index (NDVI) to characterize vegetation features. It particularly addresses: (a) the spatial overflow intensity of ecological effects from tourist attractions on the Qinghai-Tibet Plateau; (b) using the ripple effect model to determine if tourist attractions in Xining and Lhasa have a positive promoting effect on the urban ecological environment. These findings could stimulate reflection on the ecological waves of tourist attractions and the development of ecotourism, providing scientific reference for local tourism policy decision-making and management.

2. Materials and Methods

2.1. Study Area

The total area of the Qinghai-Tibet Plateau (within China) is 2.01 million km². With an average altitude exceeding 4000 m, it possesses a significantly influential natural environment globally, hosting the largest ice mass outside of the polar regions and a diverse range of vegetation types—from forests and shrubs in the southeast to grasslands and deserts in the northwest (Figure 1), with alpine grasslands predominating. Major Asian rivers such as the Yangtze, Yellow, Mekong, and Indus all originate here, earning it the moniker “Asia’s Water Tower”. Unique high-altitude landscapes such as the Himalayas and Mount Everest have become hotspots for tourism development.

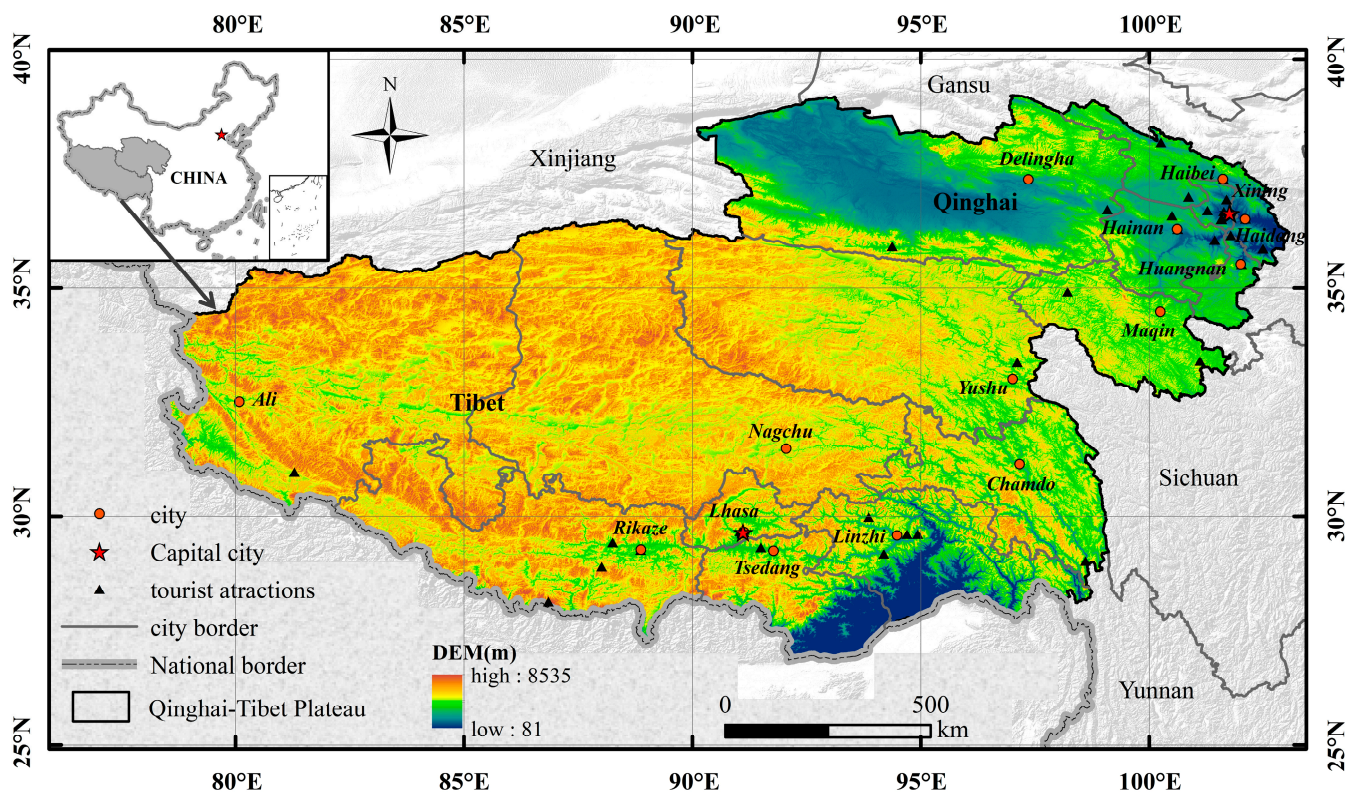


Figure 1. The spatial distributions of the elevation and the cities of tourist attractions for Qinghai-Tibet plateau (within China), including the 2 provincial capital cities of Xining and Lhasa and 13 prefecture-level cities.

Influenced by a variety of religious and ethnic cultures, numerous regional attractions have formed, including the Potala Palace and Jokhang Temple in Lhasa, and the Kumbum Monastery in Xining, which have been developed into eye-catching tourist destinations. As of 2023, there are a total of 197 A-level tourist attractions within the QTP (within China), including 8 5A attractions (the highest national level), 30 4A attractions, 108 3A attractions, 56 2A attractions, and 35 1A attractions. The number of tourists has skyrocketed from 8.43 million person-times in 2000 to 72.07 million person-times in 2023, with an annual growth rate as high as 32.80%. The overall share of tourism revenue as a percentage of the region’s GDP has steadily increased from 8.86% in 2000 to 15.12% in 2023 [29].

2.2. Data

2.2.1. NDVI Data

The 2020 maxNDVI dataset used in this study is sourced from the National Ecological Data Center (<http://www.nesdc.org.cn/>) (accessed on 18 October 2023), which is based

on the Google Earth Engine cloud computing platform. This dataset utilizes high-quality Landsat 5/7/8/9 remote sensing data throughout the year and employs data preprocessing and smoothing methods to obtain the maximum NDVI value for each pixel in 2020, with a spatial resolution of 30 m [30]. This dataset is commonly used in studies related to the vegetation environmental quality in plateau regions [31,32], which aligns with the requirements of this study. Additionally, because this research focuses on spatial changes, to ensure temporal alignment with Land Use and Land Cover (LULC) data, the decision was made to utilize the 2020 NDVI dataset.

2.2.2. Land Use and Land Cover (LULC) Data

In order to distinguish between urban and suburban attractions and the geometric center of the urban built-up area, this study utilized the 2020 national land use data with a spatial resolution of 30 m provided by the Aerospace Information Research Institute of the Chinese Academy of Sciences [33]. Through image preprocessing, including mosaicking, clipping, and masking, the land use layer for the Qinghai-Tibet Plateau in 2020 was obtained. The data is based on Landsat 8 Operational Land Imager data (OLI) (2020) satellite images, with an accuracy of 90%, meeting the data requirements of this study.

2.2.3. Tourist Attraction Data

The tourist attraction data for the Qinghai-Tibet Plateau were sourced from the Chinese Tourism Attraction Directory (https://www.gov.cn/lianbo/bumen/202402/content_6931274.htm) (accessed on 23 August 2023), which includes a total of 197 A-level attractions. For the purposes of this study, we focused solely on the statistical analysis of 38 4A and 5A attractions within the study area (Appendix A for a list of attractions). Additionally, spatial distribution point vector layers were created and located through a search on Baidu Maps (Figure 1).

2.3. Methods

In order to visualize the ecological effects of tourist spots, we introduce the concept of “waves” from physics and define the radiation waves that generate ecological effects as ecological waves. Similar to the magnetic field waves of humans, these ecological waves exert weak attractive and repulsive forces on surrounding objects, thus describing the ecological gains and losses of tourist spots in the surrounding environment. In this study, 38 tourist attractions in the QTP and the urban built-up areas of Lhasa and Xining were selected as the research objects. Firstly, LULC data was used to distinguish between urban and suburban attractions as well as the city center. Subsequently, multi-level buffer zone layers were constructed around each tourist attraction and city center to represent ecological waves, and NDVI data layers were overlaid to analyze the NDVI values within each level of buffer zone. Finally, the ripple effect model was applied to analyze the urban attractions and city centers, quantifying the strength and range of the interactive ecological impact of each, and dissecting the ecological effect of the presence of attractions within the built-up areas of Lhasa and Xining on the urban vegetation environment (Figure 2).

2.3.1. Buffer Zone Analysis

Multiple levels of buffer zone layers with a width of 1 km were established. In order to minimize the influence of factors such as topography, terrain, and climate, the buffer zone range should not be too large. Combining the scope of urban development, the buffer zone range was ultimately set at 20 km, meaning that there are 20 buffer zones around each attraction. Subsequently, the generated buffer zone layers were overlaid onto NDVI data layers after removing water bodies, and the average NDVI values within each level of the buffer zone for each attraction were calculated.

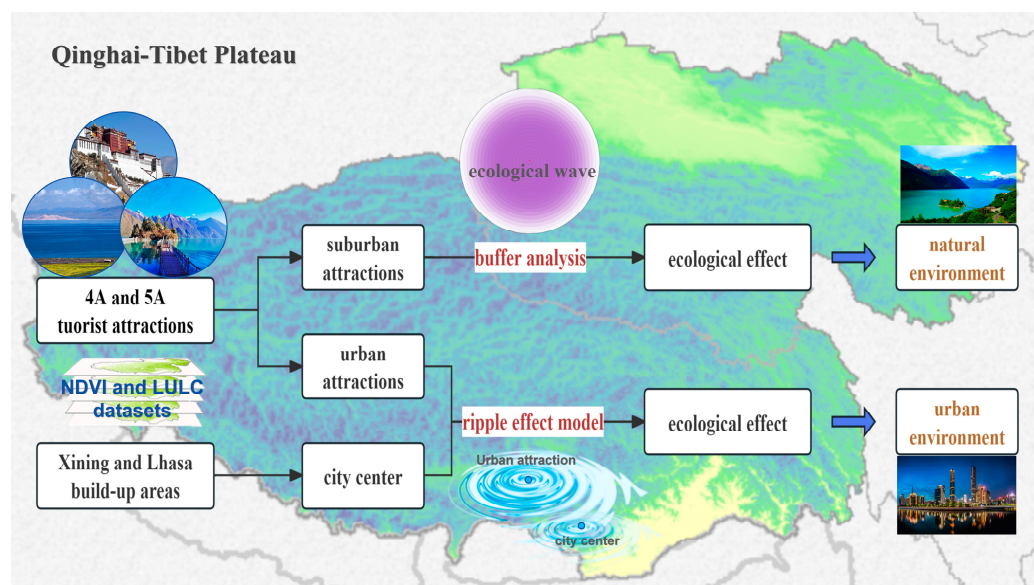


Figure 2. Research framework.

2.3.2. Classification of Tourist Attractions and Determination of City Centers

For the selected 38 attractions, this study identified 10 urban attractions and 28 suburban attractions based on the boundaries of the built-up areas of Lhasa and Xining (Appendix B). Among them, Lhasa has 5 urban attractions and 16 suburban attractions, while Xining has 5 urban attractions and 12 suburban attractions.

Using the boundary layers of the built-up areas of Lhasa and Xining, the average center tool in ArcGIS 10.8 was employed to determine the geometric center (city center) of the built-up areas. Based on this center, buffer zones of 1 km width were established, with a range of 20 km. NDVI values within each level of buffer zones were extracted by overlaying the NDVI layers.

2.3.3. Ripple Effect Model

The ripple effect was first proposed by American educational psychologist Jacob Kounin [34], and was subsequently applied in fields such as economics, psychology, and sociology [35–37]. “Ripple” refers to the phenomenon of water waves spreading outward when a drop of water or a stone falls onto a calm water surface. When two ripples intersect on the same water surface, the larger ripple will impact and influence the trajectory of the smaller ripple. In the same environment, the ripple effect can compare the strength and impact of the outward spread of waves generated by two centers (Figure 3a). The strength of the impact is determined by the wave energy of the two ripples; typically, the stronger ripple will cover the energy of the weaker ripple and continue to propagate its own wave energy.

In this study, assuming A and B are two ripple centers, with A as the urban attraction center and B as the city center, a ripple equation was constructed using the distance D as the independent variable and the wave energy W as the dependent variable (which in this context refers to the average NDVI value within the buffer zones):

$$W_A = f_1(D_A) \quad (1)$$

$$W_B = f_2(D_B) \quad (2)$$

where W_A and W_B represent the maximum range of wave energy generated by the ripple center, i.e., the NDVI value. f_1 (black line in Figure 3b) and f_2 (red line in Figure 3b)

represent the ripple equations of A and B, D_A and D_B are the distances from the center to the intersection point of the two waves, known as the Centrifugation distance.

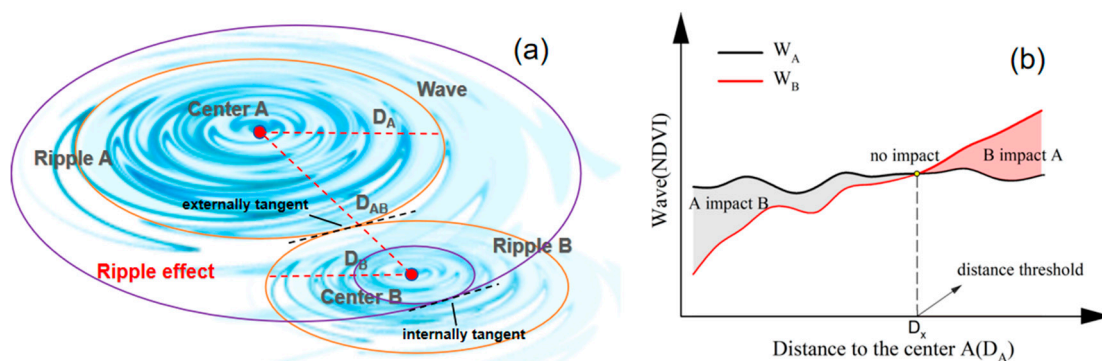


Figure 3. A, B represent the two ripple centers (Center A, B) generating ripples, with a distance of D_{AB} between them. The energy propagated outward from the two centers is the wave energy, forming multiple layers of waves comprising ripples (Ripple A, B). The two ripples will intersect (the orange wave energy represents the externally tangent situation, and the purple wave energy represents the internally tangent situation). The distance from each center to the intersection point is known as the Centrifugation distance D_A and D_B , and the impact generated from the intersection is the Ripple effect (a). The application result of the ripple effect model is illustrated, with W_A and W_B representing the wave energy of A and B, D_A representing the centrifugation distance, and D_x representing the distance threshold. In this scenario, $W_A = W_B$ (b).

Considering that the straight-line distance between attraction A and the city center B is a constant D_{AB} , and defining L as the maximum wave radius (in this context, $L = 20$ km), when A and B simultaneously produce two waves, two scenarios are possible during their outward propagation: (1) $D_{AB} > 2L$, in which case the two waves do not intersect and thus do not produce a ripple effect, i.e., they do not affect each other. (2) $D_{AB} < 2L$, in which case if the two waves intersect, a ripple effect occurs, indicating mutual influence between them.

In scenario (2), the centrifugation distance of A and B and the distance between A and B have a quantitative relationship. When $D_A < D_{AB}$, then:

$$D_A + D_B = D_{AB} \quad (3)$$

In this case, W_A and W_B are externally tangent to each other (as indicated by the orange wave energy in Figure 3a).

When $D_A > D_{AB}$, then:

$$D_A - D_B = D_{AB} \quad (4)$$

In this case, W_A and W_B are internally tangent to each other (as indicated by the purple wave energy in Figure 3a).

By combining Equations (1)–(4), the ripple effect model is obtained:

$$\left\{ \begin{array}{l} W_A = f_1(D_A) \\ W_B = f_2(D_{AB} - D_A) \end{array} \right. , D_A < D_{AB} \quad (5)$$

$$\left\{ \begin{array}{l} W_A = f_1(D_A) \\ W_B = f_2(D_A - D_{AB}) \end{array} \right. , D_A > D_{AB}$$

We employed a combination of numerical and graphical methods to evaluate the ripple effect, defining the equation curve as the ripple curve, and the comparison relationship between the curves as the ripple effect. The model results are shown in Equation (6) and Figure 3b: (1) $W_A > W_B$ indicates that the energy of wave A is greater, and after intersecting,

the influence of wave A covers wave B and continues to propagate outward, thereby showing that A impacts B; (2) $W_A = W_B$ indicates that after the intersection of A and B, they cancel each other out, with no further propagation of energy, and this corresponds to the distance threshold D_x ; (3) $W_A < W_B$ indicates that the energy of wave B is greater, and after intersecting, the influence of wave B covers wave A and continues to propagate outward, indicating that B impacts A.

$$\begin{cases} W_A > W_B, \text{ A impact B} \\ W_A = W_B, \text{ no impact} \\ W_A < W_B, \text{ B impact A} \end{cases} \quad (6)$$

In this study, the urban attraction and the city centers were designated as the ripple centers A and B (Table 1), and the multi-level NDVI buffer zones were defined as “Waves”, serving as “ecological waves”. The formation of multiple buffer zones comprises “Ripples”, aimed at exploring the ecological ripple effects of urban attraction ecological waves on the urban built-up areas of Lhasa and Xining.

Table 1. Selection of A and B centers in the ripple effect model, center A for various urban attractions and center B for Xining and Lhasa.

Center A	Center B
Kumbum Monastery, Country Interest Farming Culture Ecological Park, Qinghai Tibetan Culture Center, Qinghai Province Museum, Qinghai-Tibetan Plateau Safari Park	Xining center
Potala Palace, Luobulinka, Jokhang Temple, Drepung Monastery, Yak Museum	Lhasa center

3. Results

3.1. Analysis of Multi-Level NDVI Buffer Zones for Tourist Attractions

Taking into account a total of 38 4A and 5A tourist attractions in the study area (with 4A and 5A attractions being 18 and 4, respectively, in Qinghai, and 12 and 4, respectively, in Tibet), most of the attractions are primarily distributed in the eastern part of Qinghai and the middle and southern parts of Tibet (Figure 3b), exhibiting distinct clustering characteristics. Extending outward from each attraction center and utilizing the average NDVI value within each 1 km buffer zone to produce a curve, the results (Figure 4a) reveal that within the 1–20 km range, the NDVI values are all >0.450 , and exhibit an increasing trend with the centrifugation distance. However, the rate of increase in NDVI values varies within different distance intervals. Within the 1–4 km interval, the NDVI increases rapidly, from 0.457 ± 0.019 to 0.493 ± 0.019 , with a fitted curve slope of 0.012 (p -value = 0.000). In the 4–20 km interval, the rate of increase slows down, rising from 0.493 ± 0.019 to 0.527 ± 0.017 , with a fitted curve slope of 0.002 (p -value = 0.004).

Separate analyses were further conducted for attractions in Qinghai and Tibet, with the results showing that within a 20 km radius of 22 attractions in Qinghai, the range of average NDVI values for the multi-level buffer zones was 0.455 (± 0.021) to 0.577 (± 0.016). Within the 1–4 km range, the NDVI value increased from 0.455 ± 0.021 to 0.515 ± 0.019 , with a slope of the fitted curve being 0.020 (p -value = 0.001). In the 4–20 km range, the NDVI value increased from 0.515 ± 0.019 to 0.577 ± 0.016 , with a slope of 0.004 (p -value < 0.000) (Figure 4c). For the 16 attractions in Tibet, the range of NDVI values across the entire buffer zone was 0.450 (± 0.017) to 0.465 (± 0.021), lower than the range of NDVI variations for the buffer zones of Qinghai attractions, indicating that the ecological base surrounding attractions in Qinghai is superior to that of attractions in Tibet. Furthermore, the analysis of NDVI values within the multi-level buffer zones showed a trend of initially increasing, then decreasing, and then increasing again as they extended outward from the attractions

(Figure 4d). Within the 1–3 km range surrounding the attractions, the NDVI value increased from 0.459 ± 0.017 to 0.465 ± 0.021 , with a slope of 0.003 (p -value = 0.121). In the 3–14 km range, the NDVI value decreased from 0.465 ± 0.021 to 0.450 ± 0.017 , with a slope of -0.001 (p -value < 0.000). Within the 14–20 km range, the NDVI value increased from 0.450 ± 0.017 to 0.460 ± 0.017 , with a slope of 0.002 (p -value < 0.000).

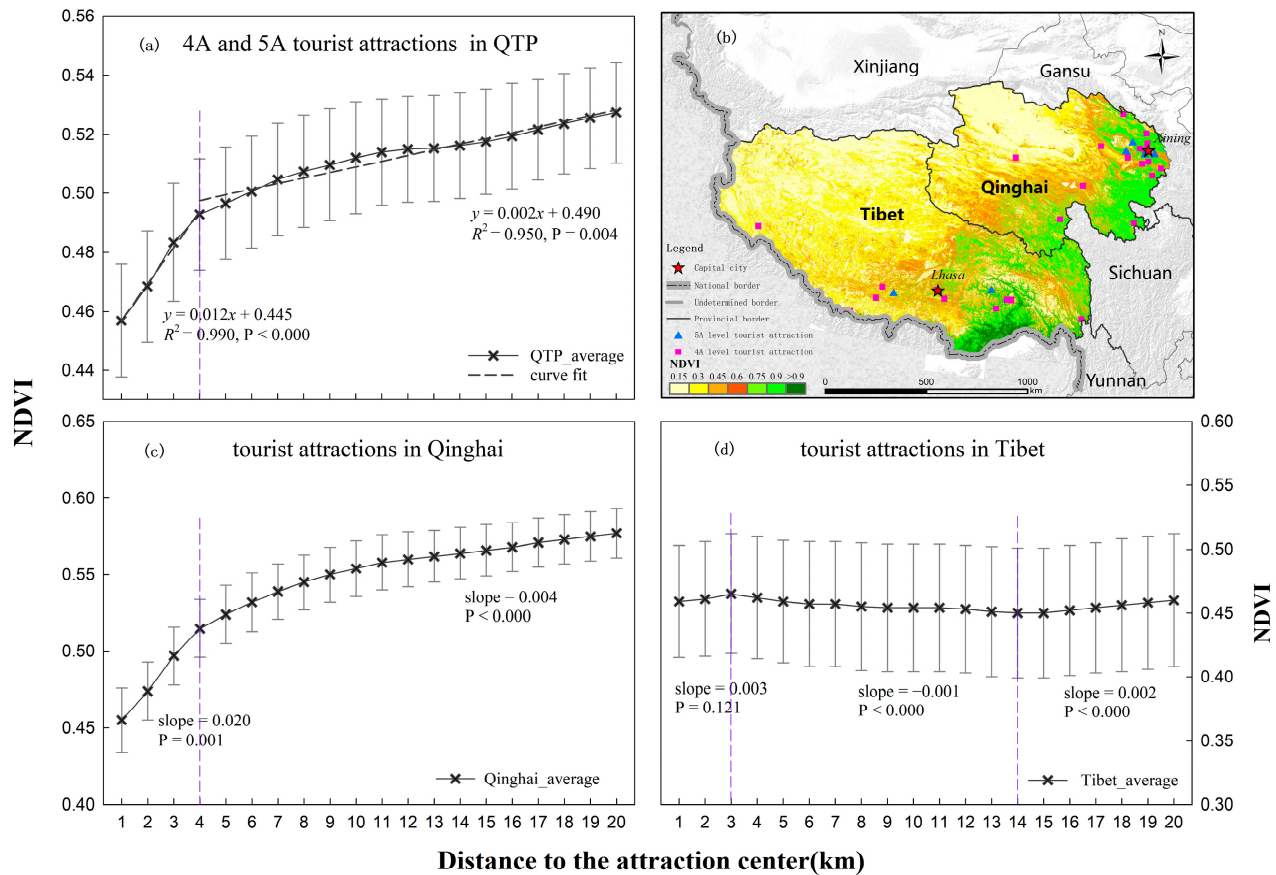


Figure 4. Changes in NDVI in the 1 km concentric buffer zone around 4A and 5A attractions within a 20 km radius in the QTP (a), Qinghai (c) and Tibet (d) in 2020, error bars indicate the standard error and vertical dash lines indicate the turning point of the curves; spatial distribution of 4A/5A attractions in the Qinghai-Tibet plateau (b).

3.2. Analysis of NDVI Buffer Zones for Urban and Suburban Attractions

A comparative analysis was conducted on the variations of NDVI values within the multi-level buffer zones surrounding 10 urban attractions and 28 suburban attractions (Figure 5). As shown in Figure 5a, the overall trend for the change in NDVI values within the multi-level buffer zones surrounding the 28 suburban attractions exhibited an initial increase followed by a decrease and then a plateau. Within the 1–6 km range, there was a gradual upward trend, with the values increasing from 0.448 ± 0.011 to 0.505 ± 0.011 , with an average increase of 0.010 for every 1 km extension outward. However, within the 7 km–14 km range, there was a slow decline in NDVI values, decreasing from 0.505 ± 0.011 to 0.502 ± 0.010 . Subsequently, within the 14–20 km range, the NDVI values showed a tendency to stabilize, with a value of 0.502 ± 0.011 . The overall trend for the change in NDVI values within the multi-level buffer zones surrounding the 10 urban attractions exhibited a decrease followed by an increase (Figure 5a). Within the 1–2 km range, there was a rapid decline, with the values decreasing from 0.477 ± 0.010 to 0.472 ± 0.010 . Then, within the 2 km–20 km range, there was a steady increase in NDVI values, increasing

from 0.472 ± 0.011 to 0.581 ± 0.009 , with an average increase of 0.006 for every 1 km extension outward.

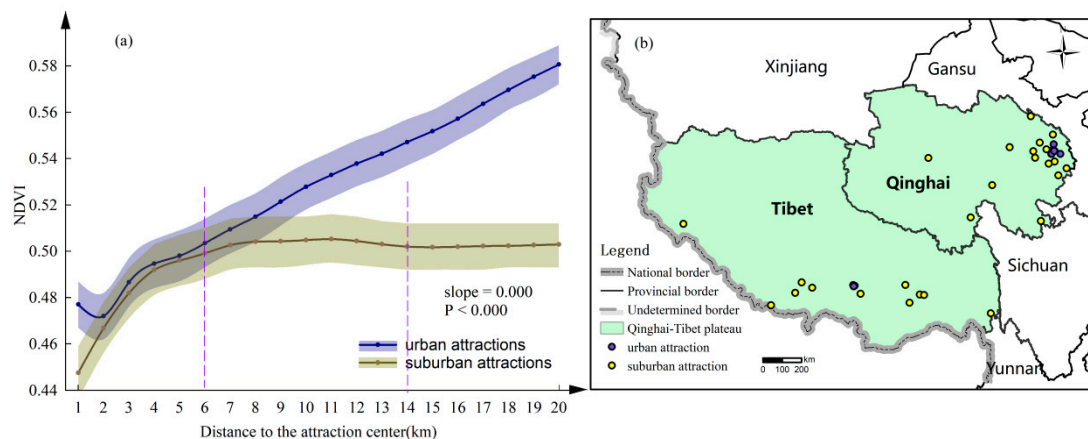


Figure 5. The line indicates NDVI variation with distance in buffer zones around urban and suburban attractions in the Qinghai-Tibet plateau, the blue and yellow boundaries indicate the standard error (a); spatial distribution of urban attractions (blue points) and suburban attractions (yellow points) in the Qinghai-Tibet plateau (b).

Additionally, as shown in Figure 6a, the analysis of NDVI values within the multi-level buffer zones surrounding the five urban attractions in Xining (Kumbum Monastery, Qinghai Province Museum, Qinghai-Tibetan Plateau Safari Park, Qinghai Tibetan Culture Center, and Country Farming Ecological Park) showed a gradual increase in NDVI values as they extended outward from the attraction centers, from 0.482 ± 0.011 to 0.636 ± 0.006 . The slope of the NDVI curve for attractions was 0.006 (p -value < 0.000), with an intercept of 0.590. Comparatively, the analysis of NDVI values within the multi-level buffer zones surrounding the city center of Xining showed a similar gradual increase in NDVI values from the center outward, from 0.368 to 0.581. The slope of the NDVI curve for the city center was 0.010 (p -value < 0.000), with an intercept of 0.530.

Furthermore, as shown in Figure 6c, the analysis of NDVI values within the multi-level buffer zones surrounding the five urban attractions in Lhasa (Potala Palace, Jokhang Temple, Drepung Monastery, Luobulinka, and Yak Museum) revealed significant fluctuations within the 1–5 km range, with an overall trend of initial decrease, followed by an increase, and then another decrease, before a steady increase within the 5–20 km range, from 0.417 ± 0.030 to 0.498 ± 0.008 . The slope of the NDVI curve for attractions was 0.005 (p -value < 0.000), with an intercept of 0.398. In comparison, the analysis of NDVI values within the multi-level buffer zones surrounding the city center of Lhasa showed similar fluctuations within the 1–6 km range, before a steady increase within the 6–20 km range, from 0.409 to 0.503. The slope of the NDVI curve for the city center was 0.004 (p -value < 0.000), with an intercept of 0.414.

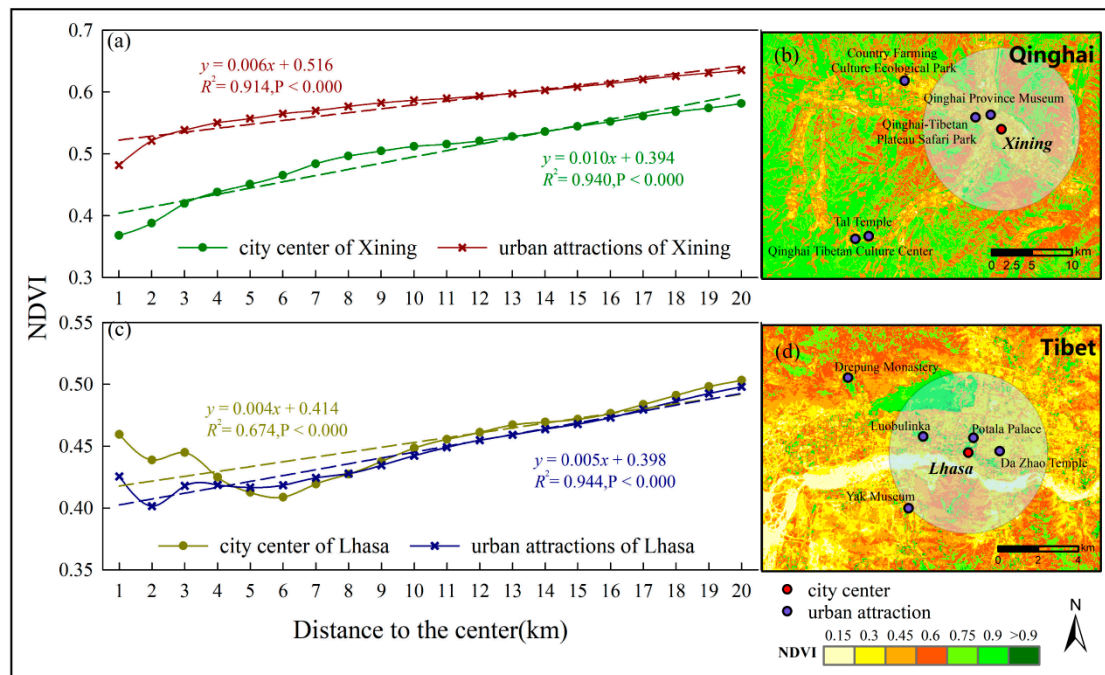


Figure 6. Comparison of NDVI changes (the colored lines) between urban attractions and the city centers of Xining (a) and Lhasa (c), the dashed line is the fitted curve; distribution of urban attractions and NDVI around the city center of Xining in Qinghai (b), distribution of urban attractions and NDVI around the city center of Lhasa in Tibet (d).

3.3. Result of the Ecological Effects of Urban Attractions on the Vegetation Environment in Urban Built-Up Areas

The ripple effect model was applied to explore the impact of urban attractions within the built-up areas of Lhasa and Xining on the vegetation environment (Figure 7). The five attractions within Xining (Qinghai Province Museum, Qinghai-Tibetan Plateau Safari Park, Country Farming Ecological Park, Qinghai Tibetan Culture Center, and Kumbum Monastery) are spatially mainly distributed in the northwest and southwest of the built-up area, at distances (D_{AB}) of 0.629 km, 1.375 km, 11.255 km, 20.903 km, and 22.363 km from the city center, respectively (Figure 6b). Each attraction (A) was analyzed in relation to the Xining city center (B) to study the ecological ripple effect. The results showed that, except for Country Farming Ecological Park intersecting with the city center at 2 km, the ripple curves of the other four urban attractions were all above the ripple curve of the city center (Figure 7a–e), indicating that the presence of attractions has a significant promoting effect on the ecological environment within the built-up area. Specifically, the NDVI difference range between Qinghai Province Museum (Figure 7c) and Qinghai-Tibetan Plateau Safari Park (Figure 7e) and the city center was 0.004–0.026, with similar NDVI changing trends. Furthermore, the mean ecological wave values of Kumbum Monastery (Figure 7a) and Qinghai Tibetan Culture Center (Figure 7d) were 0.662 and 0.670, respectively, compared to the city center's ecological wave mean value of 0.500, with difference ranges of 0.058–0.282 and 0.062–0.339, indicating that the ecological waves of these two attractions have a significant positive effect on the vegetation coverage within the built-up area of Xining.

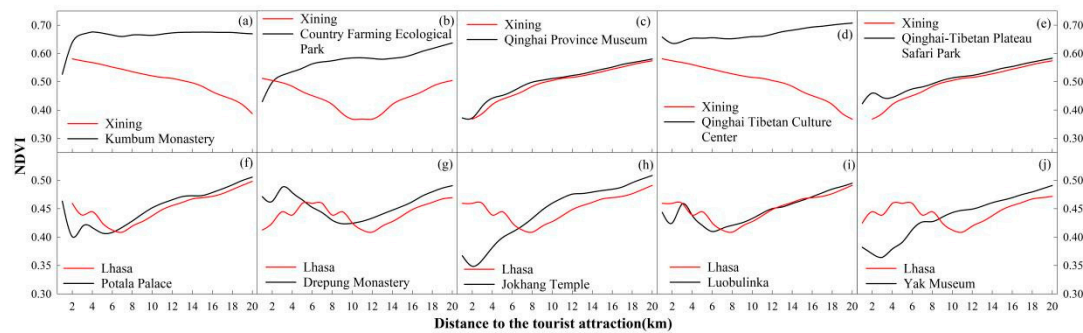


Figure 7. Results of the ripple effect model to the urban attractions (the black line) and the city centers (the red line) of Xining for (a–e) and Lhasa for (f–j).

The five attractions within Lhasa (Potala Palace, Luobulinka, Jokhang Temple, Yak Museum, and Drepung Monastery) are spatially distributed in the northeast, northwest, and southwest of the city center, at distances (D_{AB}) of 0.609 km, 1.995 km, 2.095 km, 4.605 km, and 6.401 km from the city center, respectively (Figure 6d). Utilizing the ripple effect model for each attraction (A) in relation to the Lhasa city center (B) (Figure 7f–j), the results indicated that the ripple curves of all five attractions intersected with the city center curve, with multiple intersections for Drepung Monastery and Luobulinka, and a single intersection for the other attractions. The intersections of Potala Palace and Jokhang Temple were approximately 6 km from the attractions, limiting their positive benefits to the vegetation of Lhasa within a range of 6–20 km; the intersection of Yak Museum was at approximately 9 km, limiting its positive benefits to the vegetation within a range of 9–20 km; the positive benefits of Drepung Monastery were limited to ranges of 1–5 km and 10–20 km; and the curve of Luobulinka nearly overlapped with the curve of the city center, suggesting that it did not have a significant promoting effect.

3.4. Interpretation of Ripple Effect Model Results

The results of the ripple effect model indicate that the ripple effects of urban attractions in Lhasa and Xining can be generally classified into three types: no intersection type, single intersection type, and multiple intersection type.

For attractions of the no intersection type (such as Kumbum Monastery, Qinghai Province Museum, Qinghai Tibetan Culture Center, and Qinghai-Tibetan Plateau Safari Park) (Figure 7a,c–e), the main characteristic is that the attraction's ripple curve is consistently above the corresponding city center's ripple curve within a 20 km radius of the attraction. Although there are differences in the values of multiple ecological waves for each attraction, it only indicates variations in the degree of impact of the ecological waves of the attractions on the vegetation environment within the built-up area. Nonetheless, all of them have facilitated the improvement of the ecological environment within the built-up area. Taking Kumbum Monastery as an example for analysis (Figure 8): the NDVI value of Kumbum Monastery rapidly increases within 1–3 km, fluctuating between 0.660 and 0.676 within 3–20 km. According to the results of the ripple effect, the ripple curve of Kumbum Monastery is consistently above the ripple curve of the Xining city center, and the difference value increases with distance, rising from 0.094 at 2 km to 0.282 at 20 km. This indicates that the ecological wave of Kumbum Monastery has an increasingly positive effect on the vegetation coverage within the built-up area of Xining as it extends outward from the attraction's center. The density of vegetation coverage around the attraction is noticeably higher than that around the surrounding built-up area of Xining. As evident from Figure 8b–d, at 5 km, 10 km, and 15 km, the ecological wave of Kumbum Monastery has a radiating impact on the vegetation coverage within the built-up area of Xining.

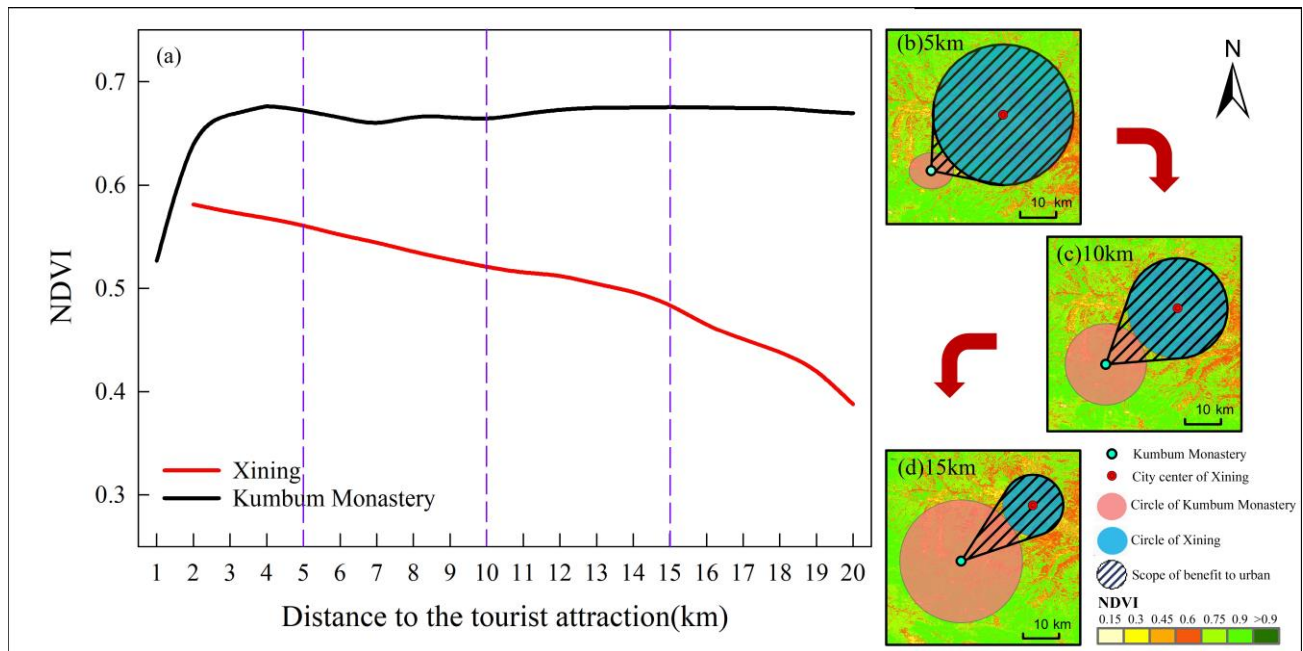


Figure 8. Application results of ripple effect model between Kumbum Temple and the city center of Xining (a); spatial map of ripple effect between Kumbum Temple and the city center of Xining at 5 km (b), 10 km (c), and 15 km (d), corresponding to the vertical dash lines in the figure.

Single Intersection Type refers to two ripple curves having only one intersection point. In this study, results for attractions such as Country Farming Ecological Park, Potala Palace, Jokhang Temple, and Yak Museum (Figure 7b,f,h,j) fall under this category. The ripple curves of these four attractions were initially located below the corresponding city center's ripple curves before the intersection point and subsequently appeared above the city center curve after the intersection, with the only difference being the distance from the intersection point. Taking Country Farming Ecological Park as an example for analysis (Figure 9), the NDVI values around the park gradually increased as the buffer area expanded, similar to Kumbum Monastery, showing the greatest increase within 1–2 km. A comparison of the two ripple curves (Figure 9a) showed that they intersected at approximately 2 km, after which the attraction's ripple curve consistently remained above the ripple curve of the Xining city center, fluctuating between 0.000 and 0.200. Further examination (Figure 9b–d) indicated that with increasing distance, the ripple range of the attraction gradually encompassed the ripple range of the city center. According to the ripple effect principle, the ecological wave of this attraction had a significant positive effect on the NDVI values of the urban build-up area beyond 2 km from the attraction, thus justifying the notion that the presence of the attraction promoted the vegetation environment within the built-up area.

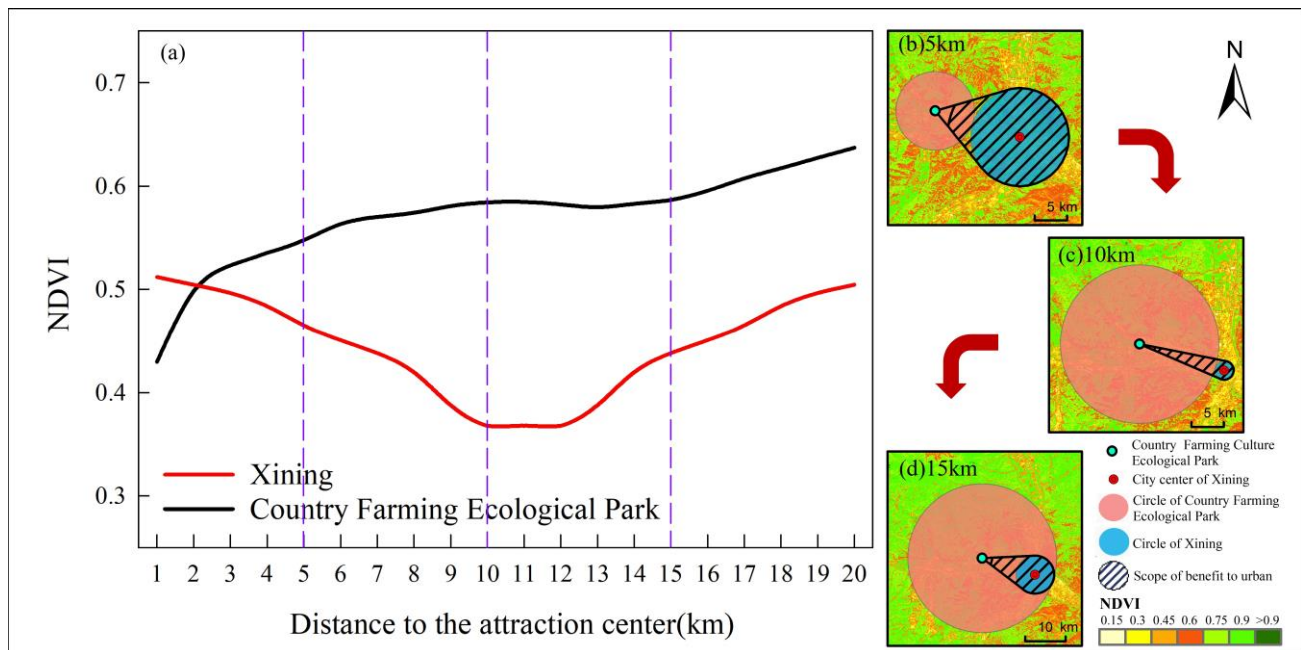


Figure 9. Application results of ripple effect model between Country Farming Ecological Park and the city center of Xining (a); spatial map of ripple effect between Country Farming Ecological Park and the city center of Xining at 5 km (b), 10 km (c), and 15 km (d), corresponding to the vertical dash lines in the figure.

Multiple Intersection Type refers to two ripple curves having two or more intersection points. In this study, Drepung Monastery (Figure 7g) and Luobulinka (Figure 7i) had multiple intersection points between the attraction center and the city center, with these curves often being complex due to the multiple interactions between the two curves leading to corresponding variable ripple effects. Taking Drepung Monastery as an example for analysis (Figure 10), the two ripple curves intersected at approximately 5 km and 10 km (Figure 10a), with the first intersection occurring at nearly 5 km, at which point the buffer zone of the city center had not yet been encompassed within the buffer zone of the attraction. Within the 0–5 km range, the NDVI around Drepung Monastery was greater than the NDVI of the city center, with a maximum NDVI difference of 0.050. The second intersection was at 10 km, and within the 5–10 km range, the buffer zone of the city center had been encompassed within the buffer zone of the attraction. At this point, the NDVI around Drepung Monastery was smaller than the NDVI of the city center, showing that the ecological wave of the attraction had no impact on the vegetation environment within the built-up area. Within the 10–20 km range, the attraction's ripple curve remained above the city center's ripple curve, with an NDVI difference of approximately 0.020, indicating that the ecological wave of the attraction still had a positive impact on the environment within the built-up area. In summary, Drepung Monastery only had a positive ecological effect on the vegetation environment within the 1–5 km and 10–20 km ranges, illustrating the existence of a distance threshold for its ecological effect. This distance threshold is reflected spatially as the restricted impact range, as depicted in Figure 10d (shaded area), showing the positive impact range of the ecological wave of Drepung Monastery on the vegetation environment within the built-up area extends to approximately 15 km.

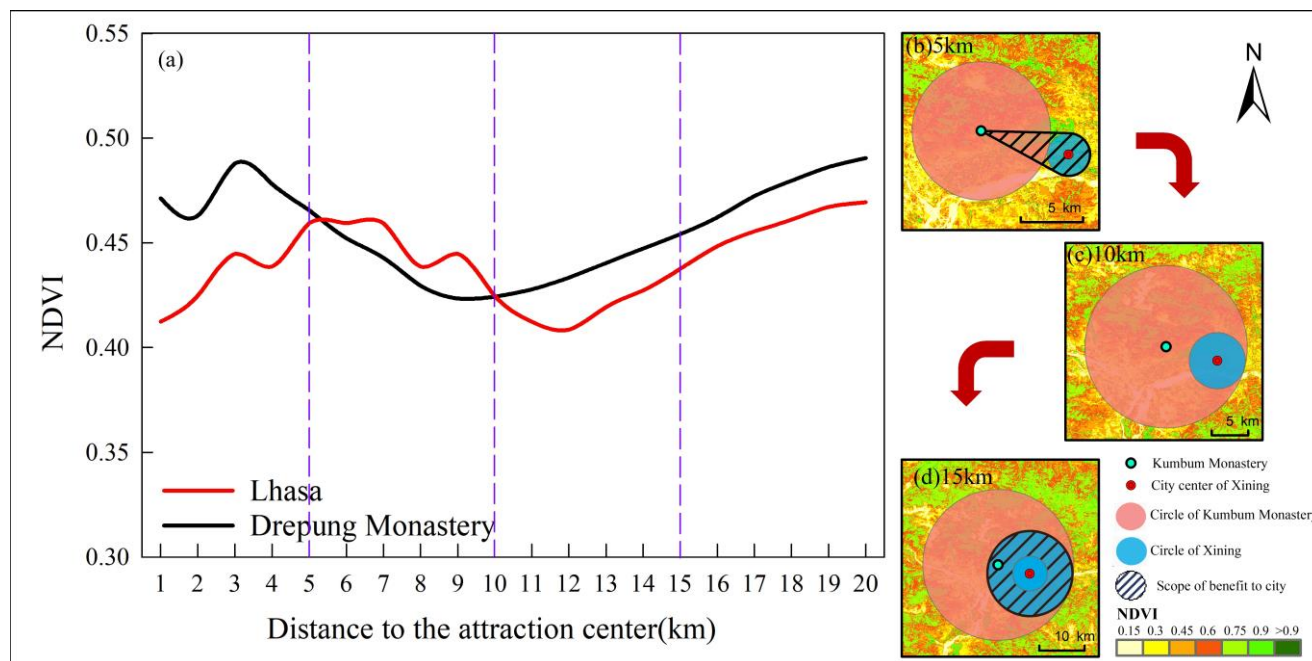


Figure 10. Application results of ripple effect model between Drepung Monastery and the city center of Lhasa (a), spatial map of ripple effect between Drepung Monastery and the city center of Lhasa at 5 km (b), at 10 km (c), and 15 km (d), corresponding to the vertical dash lines in the figure.

4. Discussion

4.1. Analysis of the Ecological Effects of Tourist Attractions on the Qinghai-Tibet Plateau

Tourist attractions in the QTP have a low NDVI within the range of 1–4 km, while a slow increase in NDVI is observed in areas > 4 km, primarily influenced by two factors. Firstly, the strength of the positive ecological effect of the tourist attraction weakens, and the construction of tourism infrastructure around the attractions contributes to the destruction of vegetation cover. Secondly, despite the positive ecological effect of the tourist attraction and the negative ecological effect of tourism, the NDVI value continues to show an increasing trend due to the superior ecological foundation in the region. In contrast, tourist attractions in the QTP show a significant increase in NDVI within the range of 1–3 km, attributed to the influence of the central buildings and human activities within the attractions. However, within the range of 3–14 km, a decrease in NDVI is observed, indicating a gradual weakening of the positive ecological effect of the attractions, possibly due to the impact of tourism infrastructure development. Additionally, within the range of 14–20 km, the NDVI of vegetation gradually increases, supporting the proposed conjecture. Despite the fragile ecological status of the Qinghai-Tibet Plateau, its impacts from human activities are relatively limited compared to other regions where tourism activities have significantly deteriorated habitat quality. For example, the tourism development in the Indian Red Sea has led to extensive degradation of coral reefs in its northern areas [38]. However, this phenomenon is closely tied to regional tourism policies and development concepts. In contrast, sustainable tourism development in places like Hainan Island has had a minimal impact on the health of the local ecosystem [39]. Therefore, the unique geographical characteristics of the Qinghai-Tibet Plateau serve as both advantages and disadvantages for ecological tourism. The key lies in whether the tourism concepts and management practices are healthy and sustainable.

4.2. Major Findings and Contributions to Existing Research

Our study of the changes in NDVI values around tourist attractions has revealed a significant impact of building construction within the attractions on nearby vegetation cover, similar to the impact of urban expansion [40]. However, in areas without construction, the ecological wave effect of tourist attractions effectively promotes the vegetation around them. Research has shown that Qinghai has a superior ecological foundation compared to Tibet [41], and our study further confirms this, demonstrating the more significant ecological effect of tourist attractions in Qinghai. This highlights the potential for the development of ecotourism in Qinghai [42].

To elucidate the impact of tourist attractions on the built-up area vegetation, we differentiated between urban and suburban attractions using Xining and Lhasa as boundaries. We found that suburban attractions, due to their distance from built-up areas, exhibit varied ecological effects on vegetation cover. Aside from the impact of infrastructure within the attractions, suburban attractions generally show a positive ecological effect on the growth of surrounding vegetation. NDVI has been proven to be a dominant factor influencing the development of tourist attractions [43], and our study demonstrates the influence of attractions on the changes in NDVI surrounding them, indicating a positive feedback relationship where the presence of attractions improves nearby vegetation cover, and excellent vegetation cover increases the popularity of attractions [44].

Urban attractions demonstrate more complex ecological effects, with different manifestations in Xining and Lhasa. We found that the vegetation cover surrounding urban attractions in Xining is better than that in the city center. This can be attributed to the influence of topography. Xining's city center exhibits a "+" layout [45], with dense central buildings, narrow roads, and limited urban green spaces, resulting in a lower NDVI value within the built-up area. In contrast, urban attractions in Xining are situated at a distance from the city center, with ample green spaces and few densely populated buildings around them, leading to a relatively higher NDVI value for the attractions. The vegetation cover within and around urban attractions in Lhasa is similar to that near the city center. Due to Lhasa's overall lower ecological foundation [46], characterized by dense central buildings and limited green spaces [47], the NDVI values of urban attractions and the city center do not differ significantly.

Analysis of the ripple effect model's results revealed varying ecological wave intensities and effects among different attractions. Furthermore, interactions between the ecological waves of attractions and those of the city center exist, with some attractions displaying multiple interactions. There are two potential reasons for this: the surrounding environment of the built-up area may be relatively uniform, resulting in little variation in vegetation quality as distance increases, or the close proximity of the city center to the attractions. These interactions reflect changes in the range of influence of the ecological effect of attractions. The tourist attractions themselves do not inherently possess the properties of ecological waves, but they are influenced by human civilization, potentially leading to impacts on the surrounding environment that exhibit characteristics of ecological waves [48]. Essentially, it represents a collision between human cultural awareness and nature. For example, religious beliefs associated with certain churches and temples can evoke pro-environmental behaviors in visitors, thereby generating positive impacts on the surrounding environment [49]. Our study also confirms this and reveals a distance limitation to these ecological waves. For example, the ripple effect at the Country Farming Ecological Park (A) and the Xining city center (B) exhibits a distance threshold (2–20 km). This corresponds to our conception of the ecological wave effect of urban attractions, indicating a distance limitation for the positive ecological effect of the attractions on urban

vegetation. Overcoming this threshold can further maximize the positive influence of the ecological wave effect of attractions on urban environments.

4.3. Limitations and Future Work of the Study

The climate and environmental conditions of the selected region for this study are unique, with highly sensitive and fragile vegetation. Therefore, the NDVI can be used to reflect the quality of the vegetation environment. However, in other regions with rich biodiversity, such as tropical rainforests, the characterization indicators of the ecological environment need to be comprehensively considered. Furthermore, this study introduces for the first time the principles of ripple effects and the concept of “ecological waves” into the field of ecology, representing a highly challenging endeavor. Similar to human “magnetic field waves”, ecological waves may impact the surrounding environment, but these effects could be so weak that they are difficult to detect on a macro scale. Moreover, influenced by unpredictable factors such as social events, extreme weather, and natural disasters, the ecological effects of tourist attractions may be masked and challenging to uncover. This can result in some tourist attractions exhibiting unclear or even non-existent ecological effects, thereby limiting our understanding of their ecological functions. When conducting comparative analyses between dual centers using the ripple effect, this study establishes a research scope of 20 km around each tourist attraction or city center. The specific range may vary across different regions to ensure that urban attractions can influence the urban environment effectively. Under this premise, we assume that other factors (terrain, climate, population, etc.) in the scenic spots and city centers remain consistent, meeting the prerequisite for the ripple effect to occur in the same environment. In addition, the analysis of the ripple effect in the study of dual centers is relatively simple, but in the case of multiple centers, the interactions between each center become more complex and require further exploration in the future. Furthermore, this study places particular emphasis on spatial changes by selecting a singular time cross-section for analysis, thus lacking an examination of time series data regarding the ecological effects of tourist attractions. This is particularly important given the significant vegetation changes occurring on the Qinghai-Tibet Plateau due to intensified global climate change. Therefore, future research directions should consider exploring the ecological effects of tourist attractions through a spatiotemporal series analysis.

5. Conclusions

In this study, we investigated the ecological wave effects of different types of tourist attractions on local vegetation environments in the Qinghai-Tibet Plateau based on changes in NDVI. The results indicate that 4A and 5A tourist attractions on the Qinghai-Tibet Plateau exhibit a positive ecological effect on surrounding vegetation cover. The ecological waves of the attractions effectively promote the greenness of surrounding vegetation but with limitations. When classified by type, suburban attractions show a negative ecological effect within the range of 1–6 km, while exhibiting a positive ecological effect within the range of 6–14 km. The strength of the ecological effect gradually diminishes, disappearing beyond the 14 km range. Among the five urban attractions in Xining, the Xining, Kumbum Monastery, Qinghai Tibetan Culture Center, and Country Farming Ecological Park show a significant positive ecological effect on the built-up area vegetation environment. However, the ecological effect of the Country Farming Ecological Park exhibits a distance limitation (2–20 km). In contrast, the ecological waves of the five urban attractions in Lhasa do not show a significant positive ecological effect on the built-up area vegetation environment, and different attractions have different distance thresholds. Furthermore, we found that Qinghai has a better ecological foundation compared to Tibet, providing more favorable

conditions for the development of ecotourism. Our study reveals the positive and negative ecological effects of the ecological waves of 4A and 5A tourist attractions on surrounding vegetation environments in the Qinghai-Tibet Plateau. We have clarified the impact of the ecological waves of urban attractions in Xining and Lhasa on the built-up area vegetation environment. These findings contribute to the development of ecotourism and ecological environment protection in the Qinghai-Tibet region, providing a scientific reference for local tourism planning and management. In addition, this study introduces for the first time the concepts of “ecological waves” and “ripple effects” applied in the field of ecological environments. By focusing on multiple tourist attractions as the subject of research, it explores the spatial ecological spillover effects, pioneering a new perspective in ecological tourism research. This study provides a novel analytical approach to the development of tourism in regions with similar case studies. This study focused on spatially exploring the ecological effects of attractions and lacked time-series exploration, which would be a more comprehensive direction for future research on the ecological effects of attractions to explore.

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Appendix A. List of 4A and 5A Tourist Attractions in the Qinghai-Tibet Plateau

Province	Located City	5A Attractions	4A Attractions
Tibet	Lasha	Potala Palace, Jokhang Temple	Luobulinka, Drepung Monastery, Yak Museum
	Rikaze	Zashilunbu Temple	Everest National Park, Sakya Ancient City, Sakya Monastery
	Linzhi	Balsongtso	Lulang Forest Sea, Yarlung Tsangpo Grand Canyon, NanYi ditch
	Shannan		Sangye Monastery
	Ali		Shenshan Sacred Lake
	Chamdo		Mangkang Salt Wells
Qinghai	Xining	Kumbum Monastery	Huangyuan Dangar Ancient City, Country Farming Ecological Park, Qinghai Province Museum, Qinghai Tibetan Culture Center, Qinghai-Tibetan Plateau Safari Park, Datong Laoya Mountain
	Haidong	Mutual Assistance Tujia Hometown Garden	Cambra, Methodist Salar Green Home
	Hainan Tibetan Autonomous Prefecture	Qinghai Lake	Qinghai Tibetan Medicine Culture Museum, Guide Highland
	Haibei Tibetan Autonomous Prefecture	Qinghai Treasure Beach	Menyuan Hundred Mile Rape Flower Sea, Qilian Scenic Spot
	Yushu Tibetan Autonomous Prefecture		Yushu Jindolabu Folk Village
	Huangnan Tibetan Autonomous Prefecture		Rengong National Historical and Cultural City
	Golog Tibetan Autonomous Prefecture		Jiuzhi County Nianbao Yuzhe, Mado Yellow River Source
	Haixi Mongol and Tibetan Autonomous Prefecture		Chaka Salt Lake, Geermu Kunlun

Appendix B. Categorized Results for Urban vs. Suburban Attractions

Province	Located City	Urban Attractions	Suburban Attractions
Tibet	Lasha	Potala Palace, Jokhang Temple, Luobulinka, Drepung Monastery, Yak Museum	
	Rikaze		Zashilunbu Temple, Everest National Park, Sakya Ancient City, Sakya Monastery
	Linzhi		Balsongtso, Lulang Forest Sea, Yarlung Tsangpo Grand Canyon, NanYi ditch
	Shannan		Sangye Monastery
	Ali		Shenshan Sacred Lake
	Chamdo		Mangkang Salt Wells
Qinghai	Xining	Kumbum Monastery, Country Farming Ecological Park, Qinghai Province Museum, Qinghai Tibetan Culture Center, Qinghai-Tibetan Plateau Safari Park	Datong Laoya Mountain
	Haidong		Cambra, Methodist Salar Green Home, Mutual Assistance Tujia Hometown Garden
	Hainan Tibetan Autonomous Prefecture		Qinghai Tibetan Medicine Culture Museum, Qinghai Lake, Guide Highland
	Haibei Tibetan Autonomous Prefecture		Menyuan Hundred Mile Rape Flower Sea, Qinghai Treasure Beach, Qilian Scenic Spot
	Yushu Tibetan Autonomous Prefecture		Yushu Jindolabu Folk Village
	Huangnan Tibetan Autonomous Prefecture		Rengong National Historical and Cultural City
	Golog Tibetan Autonomous Prefecture		Jiuzhi County Nianbao Yuzhe, Mado
	Haixi Mongol and Tibetan Autonomous Prefecture		Yellow River Source
			Chaka Salt Lake, Geermu Kunlun

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