sustainability

MDPI

Article

Spatio-Temporal Patterns of Vegetation in the Yarlung Zangbo River, China during 1998–2014

Xiaowan Liu, Zongxue Xu * and Dingzhi Peng

College of Water Sciences, Beijing Normal University, Beijing 100875, China
* Correspondence: zongxuexu@vip.sina.com; Tel./Fax: +86-10-5880-1989

Received: 26 June 2019; Accepted: 7 August 2019; Published: 11 August 2019

check for updates

Abstract: Spatiotemporal vegetation patterns are of great importance for regional development. As one of the largest transnational rivers in China, the Yarlung Zangbo River in the Qinghai-Tibetan Plateau was selected as the study site, and the spatiotemporal patterns of vegetation during 1998–2014 were analyzed using the normalized difference vegetation index (NDVI). The results show that the NDVI increased with decreasing elevation, and the largest value was observed for the broadleaf forest. The lag time of NDVI to precipitation for most of the vegetation units was distinguished as approximately one month. In the region with an elevation of over 5000 m, the NDVI for the alpine vegetation was negatively correlated with the precipitation. Most NDVI variations were due to precipitation and temperature (approximately 75%). These results could provide a reference for ecological protection at a similar high elevation in the future.

Keywords: NDVI; precipitation; vegetation; Yarlung Zangbo River

1. Introduction

Worldwide decreases in vegetation have become increasingly severe in recent decades [1–8]. Comprehensively understanding the characteristics of each vegetation unit is vital for ecological protection, particularly under the changing environment (climate change or human activities). As an effective index for representing cover conditions and vegetation growth, the normalized difference vegetation index (NDVI) has been successfully applied worldwide [9–13]. As it affects the NDVI most directly, the relationship between precipitation and the NDVI is commonly analyzed. Numerous studies have been conducted to elucidate the patterns of the NDVI and its relationship with precipitation for different vegetation units [14–18]. In addition to precipitation (water vapor factor), heat also strongly affects vegetable growth, and temperature is the most common indicator of heat applied in relevant studies [16,19,20]. However, few studies have focused on the changes in different vegetation units at a high elevation. Therefore, it is necessary to study the characteristics of the NDVI and the influences of precipitation and temperature on it at a high elevation for effective water resources allocation and ecological protection.

As one of the largest international rivers in China, the Yarlung Zangbo River plays a vital role in supporting the economic development of the whole of Tibet [21,22]. The Yarlung Zangbo River Basin is located in the southern part of the Qinghai-Tibetan Plateau with significant variations in elevation. Few studies on the relationship between NDVI and precipitation or temperature have been conducted in this study area [23,24]. In this study, the maximum, minimum, mean, and median NDVI for each vegetation unit in the Yarlung Zangbo River Basin are calculated and the trend of the NDVI during 1998–2014 is analyzed. The results can aid ecological protection and water resource management.

2. Materials and Methods

2.1. Study Area and Data

The Yarlung Zangbo River is located in the southwest frontier of China (82°–97°7′ E and 28°–31°16′ N) (Figure 1). It flows from west to east across Tibet and then into India as the Brahmaputra River. The length of the Yarlung Zangbo River is approximately 2057 m and it covers an area of 2.42×10^5 km^2. The largest elevation decrease at mountains across the basin reaches 5435 m. Precipitation is mainly concentrated in June to September, accounting for 60–90% of the annual total. There are great differences in the water vapor conditions from upstream to downstream, and the annual precipitation increases from 50 mm to over 4000 mm. The high precipitation occurs at the humid areas from the midstream and downstream valleys where monsoonal air-masses (Indian Summer Monsoon) move in. In addition, low precipitation happens in the dry areas from the rain shadow of the Himalayas. For the temperature, the spatial pattern is opposite to the precipitation. The annual average temperature in the study area is between −7.1 and 22.2 °C (increasing from upstream to downstream).

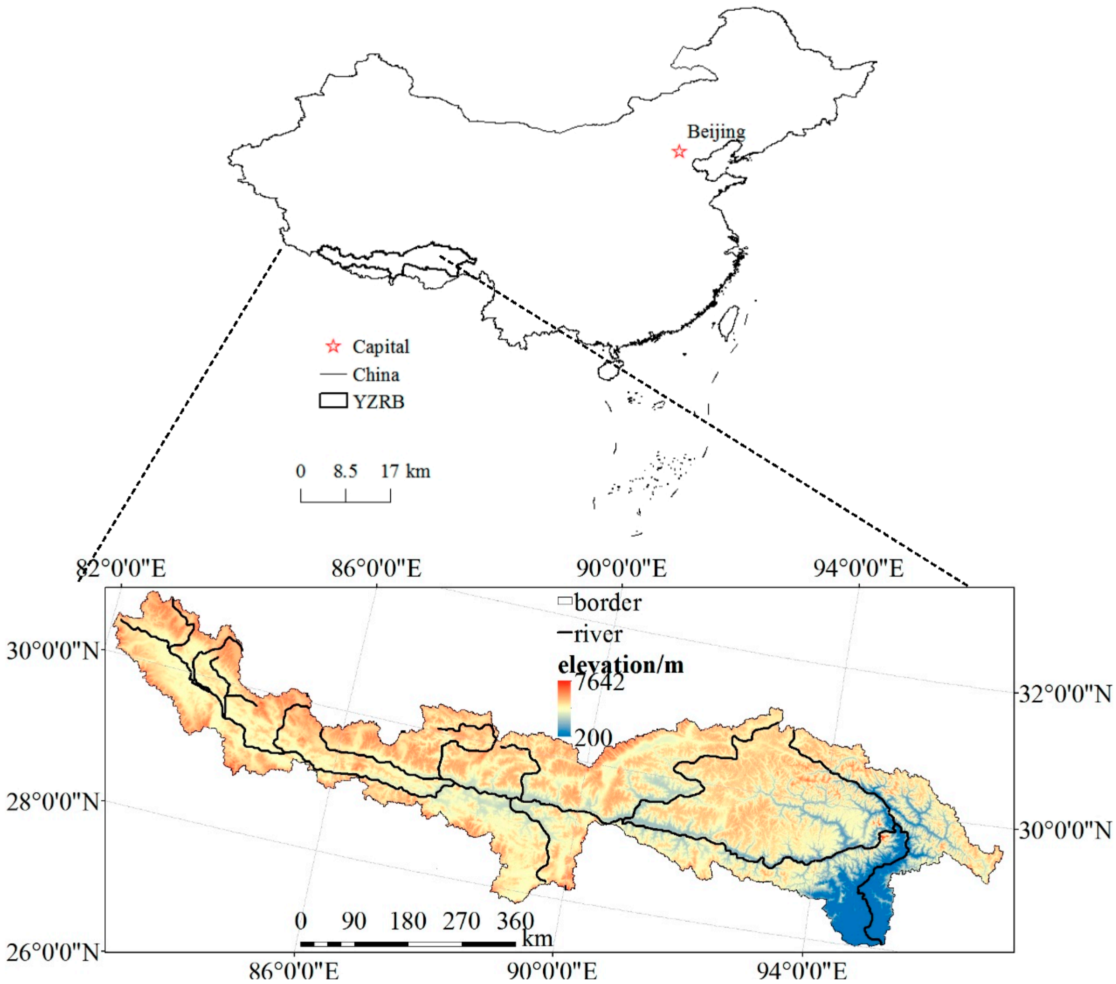

Figure 1. Map of the Yarlung Zangbo River basin. Note: YZRB in the legend refers to the Yarlung Zangbo River basin.

NDVI data was acquired from SPOT VEGETATION VGT-S10 (10 days) products (https://www.vito-eodata.be/) with the spatial resolution of 1 km (2257 grids from the original dataset have been extracted for the study area). The products were generated by using atmospheric correction and multiband composite technology. The maximum value extraction algorithm was adopted to the monthly NDVI data [13]. The data duration from 1998 to 2014 was selected as the study period. Considering the vegetation has a growing and non-growing season, the time step was selected as one year, from April to the next March. The elevation data was downloaded from SRTM (Shuttle Radar Topography Mission, launched by NASA Jet Propulsion Laboratory in California Institute of Technology) DEM (Digital Elevation Model) products at the grid of 90 m × 90 m (http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp).

In addition, the daily precipitation and temperature data with a resolution of 0.1° were obtained from the Cold and Arid Regions Science Data Center at Lanzhou, China (http://westdc.westgis.ac.cn). The precipitation and temperature dataset was validated by Gao et al. [25] and Dai et al. [26]. A vegetation cover map with a scale of 1:1,000,000 was also downloaded from the same data center. This map was achieved by the National Agricultural Commission, National Science and Technology Commission, and Chinese Academy of Sciences in 2008, and took around 30 years to complete. The types of vegetation in the Yarlung Zangbo River Basin include alpine vegetation, meadow, grassland, shrub, cultivated vegetation, coniferous forest, broadleaf forest, and others (Figure 2).

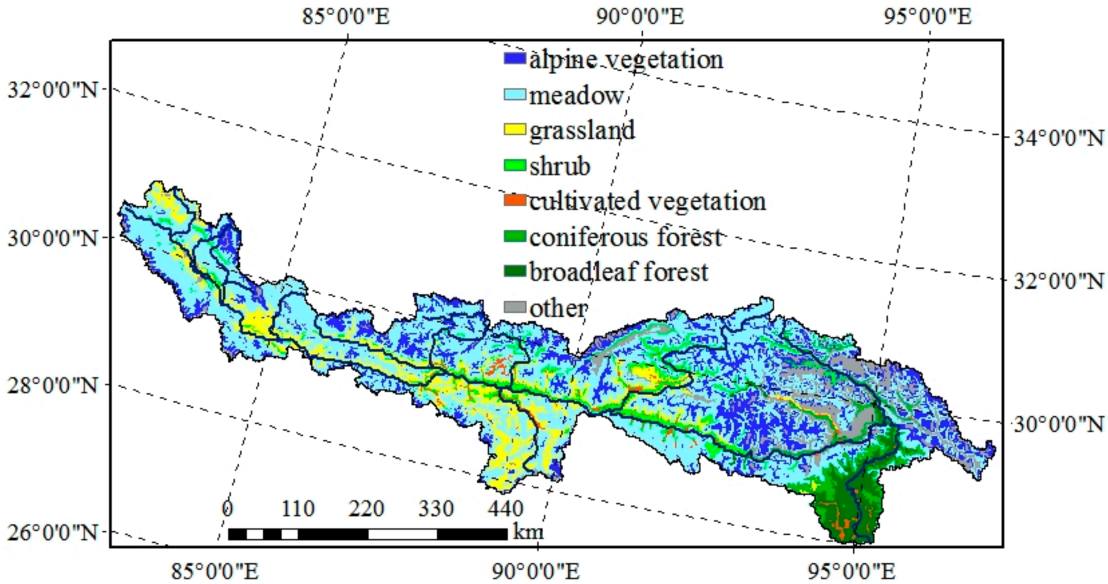

Figure 2. Distribution map of vegetation in the basin.

2.2. *Descriptive Statistics*

Some statistics were selected and used to analyze the distribution of NDVI and its linkage to elevation with a box plot, such as maximum, minimum, mean, first quartile, second quartile (median), third quartile, fifth percentile, ninety-fifth percentile, and interquartile range [27–29].

2.3. *Lag Time*

The correlation coefficient cc_t [30,31] between the two series of X (X_1, X_2, ... , X_n, where n is the length of study period) and Y (Y_{1+t}, Y_{2+t}, ... , Y_{n+t}, where t is the lag time) can be calculated. The maximum value of t is denoted by T. Then, a number of cc_t can be obtained, i.e., cc_0, cc_1, ... , cc_T. The maximum of cc_0, cc_1, ... , cc_T is the final correlation coefficient between X and Y, and the corresponding subscript is the final lag time.

2.4. *Multiple Linear Regression*

In this study, the multiple linear regression method [32–34] was applied to quantify the contributions of different independent variables (precipitation, temperature) to the dependent variable

(NDVI). To this aim, the key procedure in a multiple linear regression algorithm to derive the contributions is to solve the linear functions as below in this study.

$$NDVI_i = aP_i + bT_i + c \quad (1)$$

$$NDVI_i = a'P_i + c' \quad (2)$$

$$NDVI_i = a''T_i + c'' \quad (3)$$

where P_i, T_i, and $NDVI_i$ (i is the month rank, i = 1, 2, . . . , 192) are the mean monthly precipitation, temperature, and NDVI, respectively. In addition, a, b, a', b', a'', b'' are regression coefficients, which can be determined by using least squares fitting [35], and c, c', c'' are intercepts.

Based on the above procedures, the contribution of precipitation and temperature to the NDVI can be calculated as Equations (4) and (5), respectively.

$$c_P = \frac{\sum_{i=1}^{192}(NDVI_i - NDVI_i'')^2 - \sum_{i=1}^{192}(NDVI_i - NDVI_i')^2}{\sum_{i=1}^{192}(NDVI_{i,0} - NDVI_i'')^2} \quad (4)$$

$$c_T = \frac{\sum_{i=1}^{192}(NDVI_i - NDVI_i''')^2 - \sum_{i=1}^{192}(NDVI_i - NDVI_i')^2}{\sum_{i=1}^{192}(NDVI_{i,0} - NDVI_i''')^2} \quad (5)$$

$$c_O = 1 - c_P - c_T \quad (6)$$

where $NDVI_i'$, $NDVI_i''$, and $NDVI_i'''$ are the linear modeled value of the month i (i = 1, 2, . . . , 192) by Equations (1)–(3), respectively. c_P, c_T, and c_O are the contribution of precipitation, temperature, and other factors to change the NDVI, respectively.

3. Results

3.1. Elevation vs. Vegetation

Elevation has been found to be the most significant land factor determining the distribution of different vegetation types [36]. To elucidate the characteristics of elevation that affect the vegetation unit in this case study, the proportion of different vegetation types is listed in Table 1, and the distribution of different types of vegetation across different elevations is shown in Figure 3. The average elevation for different vegetation types decreased gradually in the following order: Alpine vegetation > meadow > other > grassland > shrub > cultivated vegetation > coniferous forest > broadleaf forest unit. Specifically, alpine vegetation was mainly observed in the area above 5000 m a.s.l., which covered 16% of the whole study area. Meadow, grassland, shrub, cultivated vegetation, and other vegetation were located in the area with an elevation of 350–5000 m. The meadow area accounted for 47% of the total area. In addition, coniferous and broadleaf forests were mainly located in the region with lower elevation, and their median elevations were below 3500 m.

Table 1. Proportion of different vegetation in the basin.

Vegetation	Percentage/%	Vegetation	Percentage/%
Meadow	47	Shrub	6
Alpine vegetation	16	Broadleaf forest	4
Other	11	Coniferous forest	3
Grassland	11	Cultivated vegetation	2

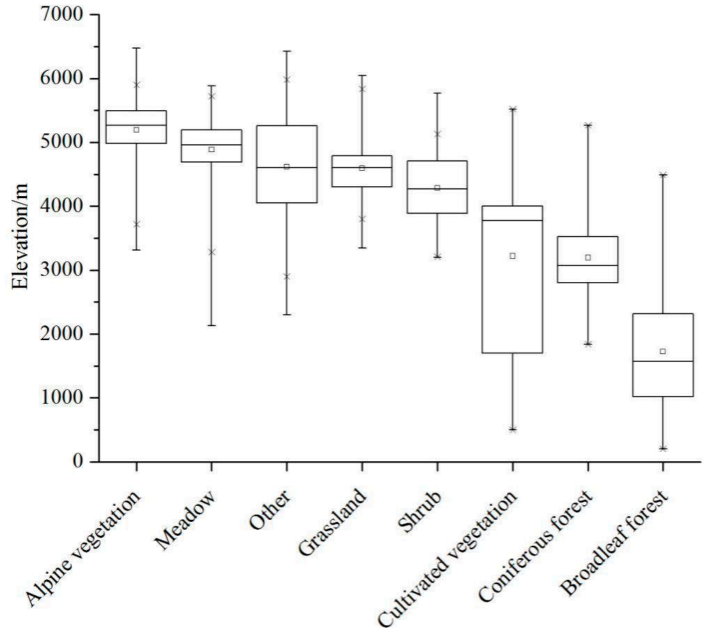

Figure 3. Distribution of elevation for different types of vegetation in the basin.

3.2. Trend of NDVI

During 1998–2014, the mean and median NDVI values were mostly distributed between 0.12 and 0.41, and 0.09 and 0.40, respectively. However, the mean and median NDVI values in the broadleaf forest were larger than those of other land covers, with values of 0.70 and 0.74, respectively. For the alpine vegetation, the mean NDVI value was quite low. The mean NDVI values and the variations for different types of vegetation are shown in Figure 4. Similar studies have been conducted in the source regions of the Yangtze and Yellow Rivers, and the results suggest that the annual mean NDVI values were within 0.19–0.25, and 0.26–0.35, respectively [37]. The NDVI in the source region of the Yangtze and the Yellow Rivers was higher than that in the source region of the study area due to the higher elevation of the latter.

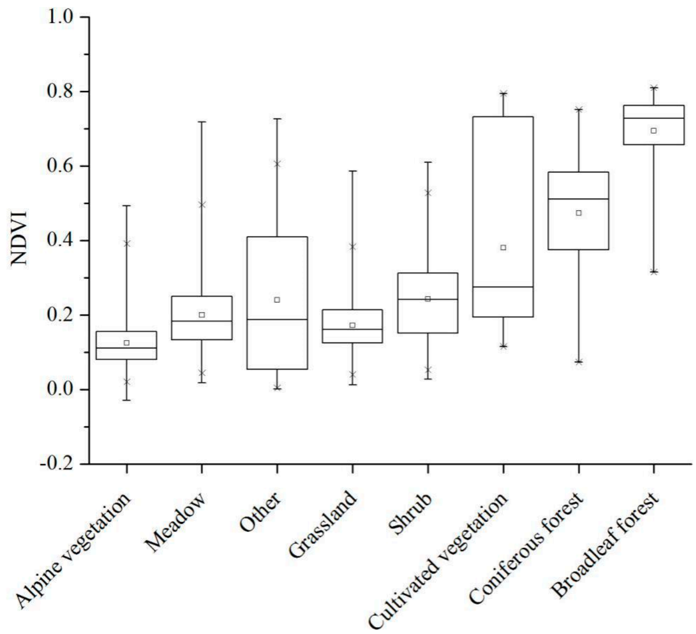

Figure 4. Mean and variation of normalized difference vegetation index (NDVI) for different types of vegetation in the basin.

The NDVI trends were analyzed by calculating the trend coefficient (Table 2) and tendency of the annual NDVI during 1999–2013 for different vegetation units, and the results are presented in Figure 5. All NDVIs exhibited an increasing trend. In addition, the significance of the trends was tested by conducting a Mann–Kendall test, and the results show that all trend coefficients are significant [30]. The trend of the NDVI for the cultivated vegetation unit was most significant, with a tendency of 0.0029/year [5,34]. The trend of the NDVI for the shrub unit was also highly significant, with a tendency of 0.0016/year. In addition, the significance of the NDVI trends for other vegetation units decreased as follows: Meadow > grassland > broadleaf forest > alpine vegetation > other > coniferous forest unit. The tendency values were linked to the NDVI values. The tendencies of the NDVI for alpine vegetation, meadow, grassland, shrub, and other unit were within an order of 10^{-3} year^{-1}, while those for cultivated vegetation, coniferous forest, and broadleaf forest unit were 2×10^{-3}, 3×10^{-3} and 4×10^{-3} year^{-1}, respectively.

Table 2. Trend coefficient of normalized difference vegetation index (NDVI) for different vegetation.

Vegetation	Trend Coefficient	Vegetation	Trend Coefficient
Alpine vegetation	0.58	Shrub	0.80 *
Meadow	0.77 *	Cultivated vegetation	**0.84** *
Other	0.52	Coniferous forest	0.51
Grassland	0.72 *	Broadleaf forest	0.64 *

Note: The trend coefficients range from 0 to 1, for which the larger value corresponds to the closer relationship between the studied two variables. The significance in trend coefficients is tested by the nonparametric Mann–Kendall (MK) test method [38–41]. Values with '*' indicate that they have passed the 0.05 significance level, and only the bold value is the largest trend coefficient.

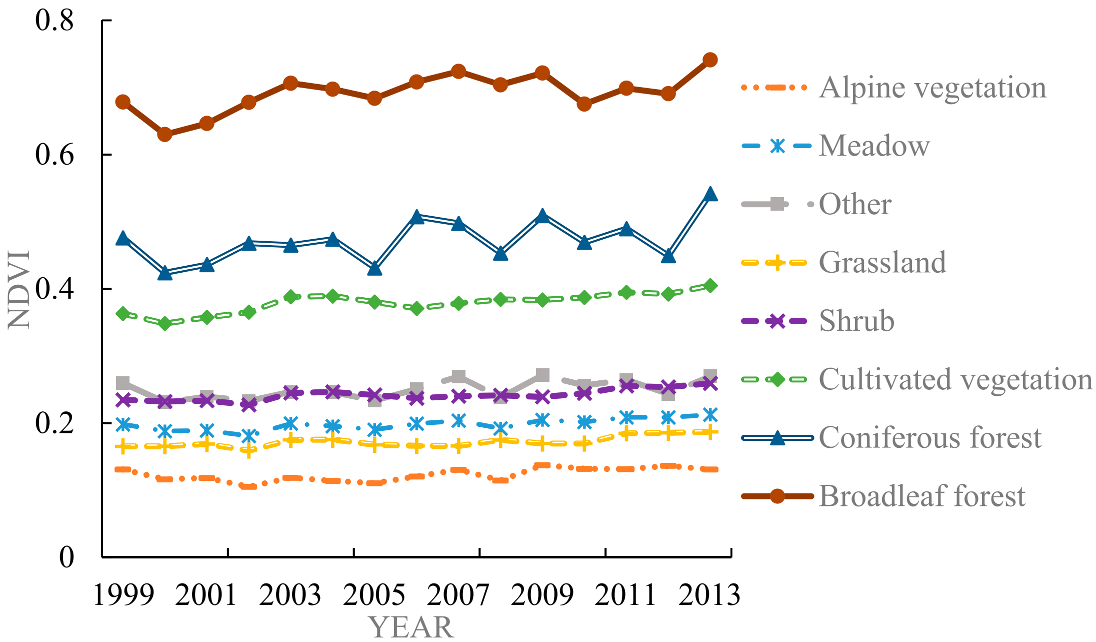

Figure 5. Trend of NDVI for different types of vegetation in the basin.

3.3. Influences of Precipitation and Temperature to Change in NDVI

The lag times of the NDVIs to precipitation in 2257 pixels were calculated, and the proportions of each specific lag time in different vegetation units are shown in Table 3. The results indicate that the lag times ranged from 0 to 10 months. As the most common vegetation type (41%, meadow), the lag time for 71% of meadow pixels was one month. For the shrub and cultivated vegetation unit, 83 and 79% of pixels exhibited a lag time between NDVI and precipitation of one month, respectively. As one of the most widely distributed vegetation types, the NDVI in 41% of the alpine vegetation pixels exhibited a lag time to precipitation of one month. For other vegetation types with lower distribution ratios, such as grassland, coniferous forest, broadleaf forest, and other units, the lag time between the NDVI and precipitation varied. Specifically, for the coniferous forest, the lag times between the NDVI and precipitation were zero and one month in 30 and 36% of the pixels. However, there was no lag between the NDVI and precipitation for most (46%) of the other vegetation units. The most common lag time between the NDVI and precipitation in the Yarlung Zangbo River Basin was one month.

Table 3. Proportions of pixels with different lag time of the NDVI to precipitation for different vegetation. (Unit: %).

Lag Time (month) Vegetation	0	1	2	3	4	5	6	7	8	9	10
Alpine vegetation	5	**41**	7	3	3	3	2	8	23	4	1
Meadow	3	**71**	5	4	0	1	0	6	8	1	1
Grassland	8	19	8	11	4	5	3	10	20	3	9
Shrub	4	**83**	6	0	0	0	0	2	5	1	0
Cultivated vegetation	10	**79**	1	1	0	1	1	3	2	2	0
Coniferous forest	30	**36**	3	6	3	3	0	3	6	3	6
Broadleaf forest	21	10	16	17	3	0	1	6	9	3	14
Other	**46**	3	3	9	4	8	3	0	0	1	21

Note: The bold values represent relatively large proportions.

The mechanisms of the responses of the NDVI to the changing environment vary greatly between areas and climatic conditions. By using the multiple correlation analysis method, the dominant factors in the changes of the NDVI were studied, and the results are shown in Figure 6. The pixels with an NDVI that was mainly influenced by precipitation accounted for 54% of the whole basin and were concentrated in the center. In addition, the NDVI in 21% of pixels was driven by air temperature, and such pixels were concentrated in high-elevation areas including the upper-most and central-northern parts of the basin. Moreover, the changes in the NDVI in the residual 25% of pixels located in the downstream areas were controlled by other factors. The influences of precipitation, air temperature, and other factors on the NDVI for different vegetation types are described in the following.

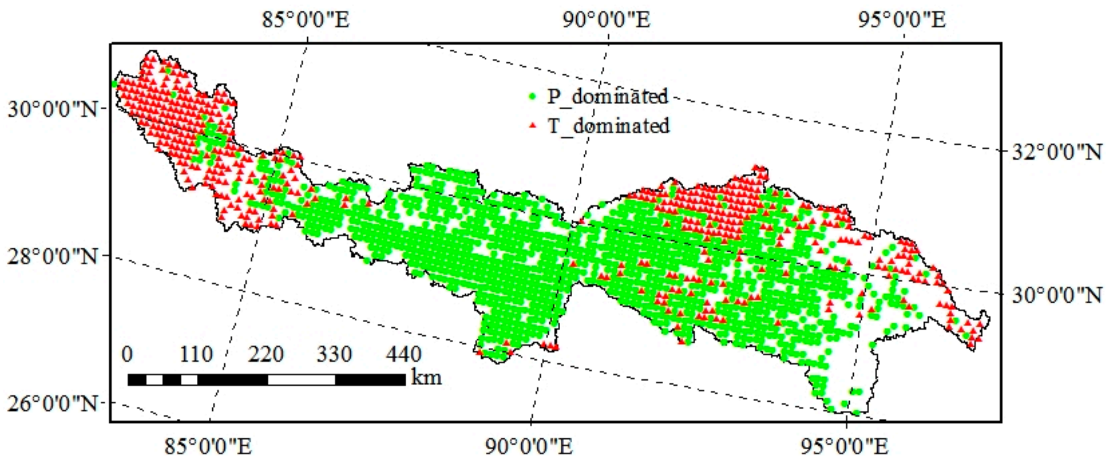

Figure 6. Dominant factors for change of NDVI in the basin.

As the essential component of water vapor, precipitation is one of the most significant factors driving the NDVI, and the influences of precipitation on the changes in the NDVI differ between vegetation units. Consistent with the above analysis, precipitation contributed to the changes in the NDVI of grassland and shrub pixels at a rate of over 0.6. In meadow, cultivated vegetation, coniferous forest, and broadleaf forest, the contributions of precipitation to the changes in the NDVI ranged from 0.4 to 0.5. In addition, for alpine vegetation and other units, averages and median values for the contributions of precipitation to changes in the NDVI below 0.4 were identified. However, unlike precipitation, the contributions of air temperature to changes in the NDVI were smaller, particularly for coniferous and broadleaf forest, where the median contributions were below 0.1. For grassland and other vegetation units, the median contributions of air temperature to changes in the NDVI were quite low, at approximately 0.1. In addition, for alpine vegetation, meadow, shrub and cultivated vegetation, the contributions of temperature to changes in the NDVI were slightly higher, but the values were still below 0.2. In terms of the contributions of other factors to changes in the NDVI, large medians and means with values of approximately 0.5 were identified for coniferous and broadleaf forest, particularly for broadleaf forest units. The contributions of other factors to changes in the NDVI for the alpine vegetation and other units were lower, with medians and means of 0.4–0.5. However, for meadow, grassland and shrub, the medians and averages of the contributions of other factors were generally below 0.3. For shrub unit, the median was below 0.2. Moreover, for cultivated vegetation, a large interquartile range of approximately 0.4 was observed in the contributions of inner pixels, and the median contribution of other factors to the changes in NDVI was low at 0.23.

4. Discussion

4.1. The Distribution of the Meadow Unit

As mentioned above, the range of NDVI values in the study area was quite broad, which corresponds to its large elevation difference. Specifically, the meadow unit has been found with a wide range of elevations and NDVI values. Similar studies have been conducted in nearby areas, for instance, Acharya and Vijayan [42] described that meadow is the dominant vegetation type in the northeastern part of the Qinghai-Tibetan Plateau, and is mainly concentrated in areas above 3000 m. Muller [43] also found that meadow is the most extensive land type at elevations above 3600 m, and the forest unit is distributed in the area below 3600 m.

4.2. Why It Is Greening in The Study Area

Liu et al. [20] also studied the trend of the NDVI for several types of vegetation in the Qinghai-Tibetan Plateau, and their results indicate that the NDVIs for the alpine vegetation and broadleaf forest unit exhibited significant increasing tendencies. Similar, a greening tendency has been widely diagnosed in this case study. The causations can be summarized with the following three aspects. First, in the high areas, most vegetation growth are limited by low temperature. In this case, temperature increase cultivates the vegetation growth. Second, for the mid-downstream valleys, increased precipitation may be the main reason for greening. Third, in several lowland areas, human interventions could be the dominant factor leading to greening.

4.3. Influences of Meteorological Factors to the Change of NDVI

Relevant studies also point out that precipitation and temperature are the main factors affecting the change of the NDVI. For example, Zhang et al. [44] found that there was a negative relationship between the NDVI and temperature in the southern Qinghai-Tibetan Plateau. Chu et al. [45] documented that the relationship between the NDVI and precipitation was stronger than that between the NDVI and temperature in the Lhasa area of Tibet. In addition, Liu et al. [46] studied the relationship between the NDVI and climate factors for different vegetation units in the Qinghai-Tibetan Plateau, and found positive relationships between the NDVI and precipitation/temperature for temperate steppe and desert unit. While for the broadleaf forest unit, both the relationships between the NDVI and precipitation/temperature were negative. In addition, a negative relationship was found between the NDVI and precipitation, while it was positive between the NDVI and temperature in the alpine vegetation unit, and the NDVI values of the grassland unit were positively correlated with temperature. In fact, aside from precipitation and temperature, other factors, such as the above-mentioned, including evapotranspiration, radiation, wind speed, etc., may also impact the changes in the NDVI values to a certain extent. In future relevant studies, they should be taken into consideration to thoroughly understand the mechanism in the changes of the NDVI.

4.4. Limitation of The Study

The biggest limitation of this study is the short data length. It affects the trend results to a certain extent. In addition, considering that the analysis results show that 25% of pixels in the study area have other factors–dominated changes of NDVI, several other meteorological factors (e.g., evapotranspiration, radiation, etc.) and non–meteorological factors including natural disturbances (e.g., rockfalls after earthquakes, wildfires, etc.) and anthropogenic disturbances should also be taken into consideration to thoroughly understand the mechanism in the change of the NDVI in future relevant studies.

5. Conclusions

Spatiotemporal patterns in the NDVI, precipitation, trends and relationships for different vegetation types in the Yarlung Zangbo River Basin at annual and growing season scales were comprehensively analyzed in combination with the trend coefficient and lag time. The conclusions can be summarized as follows:

(1) The largest mean NDVI values and precipitation at annual and growing-season scales were both observed for the broadleaf forest unit. The NDVI of all vegetation types increased, and the trend for the cultivated vegetation unit was most significant.

(2) The lag between the NDVI and precipitation is approximately one month. The weak links between the NDVI and precipitation are negative in higher-elevation areas with alpine vegetation, meadow, coniferous forest, and other units. The NDVIs are positively related to precipitation in lower-elevation areas with higher precipitation, such as grassland, shrub, cultivated vegetation and the broadleaf forest unit.

(3) Vegetation greening in precipitation-dominated areas (middle-southern and downstream areas) is led by decreases in precipitation. For such NDVIs, with higher positive relationships between NDVI and precipitation, greening in NDVIs due to the decreases in precipitation is more significant. However, in temperature-controlled areas (high-elevation and upstream areas), increasing NDVIs are due to increases in temperature.

Author Contributions: Data collection and preprocessing: X.L. and D.P.; Supervision: Z.X. and D.P.; Writing-original draft: X.L. and D.P.; Writing-review and editing: X.L., D.P., and Z.X.

Funding: This research was funded by National Natural Science of China (91647202; 51779006).

Acknowledgments: This study is financially supported by the State Key Program of National Natural Science of China (91647202) and the National Natural Science of China (51779006).

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Tutubalina, O.V.; Rees, W.G. Vegetation degradation in a permafrost region as seen from space: Norilsk (1961–1999). *Cold Reg. Sci. Technol.* **2001**, *32*, 191–203. [CrossRef]
2. Dregne, H.E. Land degradation in the drylands. *Arid Land Res. Manag.* **2002**, *16*, 99–132. [CrossRef]
3. Anna, A. Detection of vegetation degradation on Swedish Mountainous Heaths at an early stage by image interpretation. *AMBIO* **2003**, *32*, 510. [CrossRef]
4. Jeong, S.J.; Ho, C.H.; Brown, M.E.; Kug, J.S.; Piao, S.L. Browning in desert boundaries in Asia in recent decades. *J. Geophys. Res. Atmos.* **2011**, *116*, 3–25. [CrossRef]
5. Peng, S.S.; Chen, A.P.; Xu, L.; Cao, C.X.; Fang, J.Y.; Myneni, R.B.; Pinzon, J.E.; Tucker, C.J.; Piao, S.L. Recent change of vegetation growth trend in China. *Environ. Res. Lett.* **2011**, *6*, 044027. [CrossRef]
6. Higginbottom, T.; Symeonakis, E. Assessing land degradation and desertification using vegetation index data: Current frameworks and future directions. *Remote Sens.* **2014**, *6*, 9552–9575. [CrossRef]

7. Finstad, A.G.; Andersen, T.; Larsen, S.; Tominaga, K.; Blumentrath, S.; Wit, H.A.D.; Tømmervik, H.; Hessen, D.O. From greening to browning: Catchment vegetation development and reduced S-deposition promote organic carbon load on decadal time scales in Nordic lakes. *Sci. Rep.* **2016**, *6*, 31944. [CrossRef] [PubMed]
8. Xu, H.J.; Wang, X.P.; Yang, T.B. Trend shifts in satellite-derived vegetation growth in Central Eurasia, 1982–2013. *Sci. Total Environ.* **2017**, *579*, 1658–1674. [CrossRef]
9. Tucker, C.J.; Pinzon, J.E.; Brown, M.E.; Slayback, D.A.; Pak, E.W.; Mahoney, R.; Vermote, E.F.; Saleous, N.E. An extended AVHRR 8-km NDVI dataset compatible with MODIS and SPOT vegetation NDVI data. *Int. J. Remote Sens.* **2005**, *26*, 4485–4498. [CrossRef]
10. Pettorelli, N.; Vik, J.O.; Mysterud, A.; Gaillard, J.M.; Tucker, C.J.; Stenseth, N.C. Using the satellite-derived NDVI to assess ecological responses to environmental change. *Trends Ecol. Evol.* **2005**, *20*, 503–510. [CrossRef]
11. Albano, C.M.; Dettinger, M.D.; Soulard, C.E. Influence of atmospheric rivers on vegetation productivity and fire patterns in the southwestern U.S. *J. Geophys. Res. Biogeosci.* **2017**, *122*, 308–323. [CrossRef]
12. Zhang, X.; Wu, S.; Yan, X.; Chen, Z. A global classification of vegetation based on NDVI, rainfall and temperature. *Int. J. Climatol.* **2017**, *37*, 2318–2324. [CrossRef]
13. Zhao, A.; Zhang, A.; Liu, X.; Cao, S. Spatiotemporal changes of normalized difference vegetation index (NDVI) and response to climate extremes and ecological restoration in the Loess Plateau, China. *Theor. Appl. Climatol.* **2017**, *132*, 555–567. [CrossRef]
14. Carlson, T.N.; Ripley, D.A. On the relation between NDVI, fractional vegetation cover, and leaf area index. *Remote Sens. Environ.* **1997**, *62*, 241–252. [CrossRef]
15. Gómez-Mendoza, L.; Galicia, L.; Cuevas-Fernández, M.L.; Magaña, V.; Gómez, G.; Palacio-Prieto, J.L. Assessing onset and length of greening period in six vegetation types in Oaxaca, Mexico, using NDVI-precipitation relationships. *Int. J. Biometeorol.* **2008**, *52*, 511–520. [CrossRef]
16. Prasad, V.K.; Badarinath, K.V.S.; Eaturu, A. Effects of precipitation, temperature and topographic parameters on evergreen vegetation greenery in the Western Ghats, India. *Int. J. Climatol.* **2008**, *28*, 1807–1819. [CrossRef]
17. Liu, Y.; Wang, X.F.; Guo, M.; Tani, H.; Matsuoka, N.; Matsumura, S. Spatial and temporal relationships among NDVI, climate factors, and land cover changes in Northeast Asia from 1982 to 2009. *Giscience Remote Sens.* **2011**, *48*, 371–393. [CrossRef]
18. Chuai, X.W.; Huang, X.J.; Wang, W.J.; Bao, G. NDVI, temperature and precipitation changes and their relationships with different vegetation types during 1998–2007 in Inner Mongolia, China. *Int. J. Climatol.* **2013**, *33*, 1696–1706. [CrossRef]
19. Shreve, F. The role of winter temperatures in determining the distribution of plants. *Botany* **1914**, *1*, 194–202. [CrossRef]
20. Liu, S.H.; Yan, D.H.; Shi, X.L.; Wang, G.; Yuan, Z.; Yin, J. Grassland NDVI response to climate factors in different vegetation regionalizations in China. *Commun. Comput. Inf. Sci.* **2013**, *399*, 370–380. [CrossRef]
21. Qiu, L.H.; You, J.J.; Qiao, F.; Peng, D.Z. Simulation of snowmelt runoff in the ungauged basin based on MODIS: A case study in Lhasa River basin. *Stoch. Environ. Res. Risk Assess.* **2014**, *28*, 1577–1585. [CrossRef]
22. Peng, D.Z.; Chen, J.; Fang, J. Simulation of summer hourly stream flow by applying TOPMODEL and two routing algorithms to the sparsely gauged Lhasa River basin in China. *Water* **2015**, *7*, 4041–4053. [CrossRef]
23. Li, H.D.; Li, Y.K.; Shen, W.S.; Li, Y.N.; Lin, J.; Lu, X.Y.; Xu, X.; Jiang, J. Elevation-dependent vegetation greening of the Yarlung Zangbo River basin in the southern Tibetan Plateau, 1999–2013. *Remote Sens.* **2015**, *7*, 16672–16687. [CrossRef]
24. Li, H.D.; Jiang, J.; Chen, B.; Li, Y.K.; Xu, Y.Y.; Shen, W.S. Pattern of NDVI-based vegetation greening along an altitudinal gradient in the eastern Himalayas and its response to global warming. *Environ. Monit. Assess.* **2016**, *188*, 5196–5199. [CrossRef] [PubMed]
25. Gao, S.R.; Wu, Q.B.; Zhang, Z.Q.; Xu, X.M. Impact of climatic factors on permafrost of the Qinghai-Xizang Plateau in the time-frequency domain. *Quat. Int.* **2015**, *374*, 110–117. [CrossRef]
26. Dai, Y.F.; Yao, T.D.; Li, X.Y.; Ping, F. The impact of lake effects on the temporal and spatial distribution of precipitation in the Nam Co basin, Tibetan Plateau. *Quat. Int.* **2016**, *475*, 63–69. [CrossRef]
27. McGill, R.; Tukey, J.W.; Larsen, W.A. Variations of box plots. *Am. Stat.* **1978**, *32*, 12–16. [CrossRef]
28. Frigge, M.; Hoaglin, D.C.; Iglewicz, B. Some implementations of the boxplot. *Am. Stat.* **1989**, *43*, 50–54. [CrossRef]

29. Hubert, M.; Vandervieren, E. An adjusted boxplot for skewed distributions. *Comput. Stat. Data Anal.* **2008**, *52*, 5186–5201. [CrossRef]
30. Fisher, R.A. *Statistical Methods for Research Workers*, 13th ed.; Hafner Pub. Co.: New York, NY, USA, 1958; pp. 136–138.
31. Kendall, M.G.; Stuart, A. *The Advanced Theory of Statistics*, 4th ed.; C. Griffin: London, UK, 1979; pp. 99–102.
32. Haan, C.T. *Statistical Methods in Hydrology*; Iowa State University Press: Ames, IA, USA, 1977.
33. Clow, D.W. Changes in the timing of snowmelt and streamflow in Colorado: A response to recent warming. *J. Clim.* **2010**, *23*, 2293–2306. [CrossRef]
34. Judd, C.M.; McClelland, G.H. *Data Analysis: A Model Comparison Approach*, 1st ed.; Routledge: New York, NY, USA, 1989; pp. 86–89.
35. Nash, J.C. *Compact Numerical Methods for Computers: Linear Algebra and Function Minimization*, 2nd ed.; CPC Press: Bristol, UK, 1990; pp. 78–83.
36. Zolfaghari, F.; Pahlevanravi, A.; Fakhireh, A.; Jabari, M. Investigation on relationship between environmental factors and distribution of vegetation in Agh Toghe basin. *Iran. J. Range Desert Res.* **2010**, *17*, 431–444.
37. Yang, J.; Ding, Y.; Chen, R. Spatial and temporal of variations of alpine vegetation cover in the source regions of the Yangtze and Yellow Rivers of the Tibetan Plateau from 1982 to 2001. *Environ. Geol.* **2006**, *50*, 313–322. [CrossRef]
38. Mann, H.B. Nonparametric tests against trend. *Econometrica* **1945**, *13*, 245–259. [CrossRef]
39. Forthofer, R.N.; Lehnen, R.G. *Rank Correlation Methods*, 4th ed.; Springer: Boston, MA, USA, 1981; pp. 146–151.
40. Peng, D.Z.; Xu, Z.X. Simulating the impact of climate change on streamflow in the Tarim River basin by using a modified semi-distributed monthly water balance model. *Hydrol. Process.* **2010**, *24*, 209–216. [CrossRef]
41. Qiu, L.H.; Peng, D.Z.; Xu, Z.X.; Liu, W.F. Identification of the impacts of climate changes and human activities on runoff in the upper and middle reaches of the Heihe River basin, China. *J. Water Clim. Chang.* **2016**, *7*, 251–262. [CrossRef]
42. Acharya, B.K.; Vijayan, L. Vertical stratification of birds in different vegetation types along an elevation gradient in the Eastern Himalaya, India. *Ornithol. Sci.* **2017**, *16*, 131–140. [CrossRef]
43. Muller, C.H. Relations of the vegetation and climatic types in Nuevo Leon, Mexico. *Am. Midl. Nat.* **1939**, *21*, 687–729. [CrossRef]
44. Zhang, L.; Guo, H.D.; Ji, L.; Lei, L.P.; Wang, C.Z.; Yan, D.M.; Li, B.; Li, J. Vegetation greenness trend (2000 to 2009) and the climate controls in the Qinghai-Tibetan Plateau. *J. Appl. Remote Sens.* **2013**, *7*, 073572. [CrossRef]
45. Chu, D.; Lu, L.X.; Zhang, T.J. Sensitivity of normalized difference vegetation index (NDVI) to seasonal and interannual climate conditions in the Lhasa area, Tibetan Plateau, China. *Arct. Antarct. Alp. Res.* **2007**, *39*, 635–641. [CrossRef]
46. Liu, S.L.; Su, X.K.; Dong, S.K.; Cheng, F.Y.; Zhao, H.D.; Wu, X.Y.; Zhang, X.; Li, J.R. Modeling aboveground biomass of an alpine desert grassland with SPOT-VGT NDVI. *GIScience Remote Sens.* **2015**, *52*, 680–699. [CrossRef]