

Original Research

Dynamics of Vegetation Coverage and its Climate Change Responsiveness: A Spatio-Temporal Analysis in Chongqing, Southwest China

Junxi Lin^{1#}, Qiaoxue Peng^{2,3#}, Shisi Feng¹, Xuchenyu Liu¹, Juping Huang⁴,
Chengcheng Xia¹ ^{o*}, Jie Wei¹ ^{**}

¹Chongqing Key Laboratory of Surface Process and Ecological Restoration in the Three Gorges Reservoir Area, School of Geography and Tourism, Chongqing Normal University, Chongqing 401331, China

²Key Laboratory of Water Cycle and Related Land Surface Processes, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, China

³University of Chinese Academy of Sciences, Beijing, China

⁴Chongqing Institute of Green and Intelligence Technology, Chinese Academy of Sciences, Chongqing 400714, China

Received: 21 September 2025

Accepted: 05 January 2026

Abstract

To provide a robust theoretical framework for ecological restoration, the present paper reports the spatio-temporal transformations of vegetation coverage and its responsiveness to climatic factors in Chongqing spanning the years 2000 to 2022. The results show a significant overall increase in the normalized difference vegetation index (NDVI), indicating improved vegetation coverage, and that NDVI variability was greater at lower elevations. The Hurst index showed that the majority of the city (96.3%) was experiencing protracted and enduring transformations, with 89.2% anticipated to manifest a persistent amelioration trend and 7.1% projected to demonstrate a sustained degradation trajectory in the future. The partial correlation coefficients between NDVI and annual mean temperature and precipitation were $-0.78\sim-1$ and $-0.76\sim-0.88$, respectively. Generally, the NDVI presented a positive correlation with these two factors, with precipitation imposing a greater influence on vegetation growth. The findings of this study could provide information and serve as a point of reference for the prevention of ecological risks.

Keywords: vegetation coverage, Mann-Kendall test, partial correlation analysis, Hurst index

Introduction

As a vital component of the global terrestrial ecosystem, the variations in vegetation coverage show how plant communities are expanding in the natural conditions of the regional ecological environment [1-3]. Climate factors like temperature and precipitation have a direct impact on the growth of vegetation [4-7].

#equal contribution

*e-mail: cugxcc@163.com

**e-mail wei_jie@mailsucas.ac.cn

^oORCID iD: 0000-0003-0394-2928

Previous studies ascertained that the precipitation during the growing season constitutes a pivotal determinant governing the enduring dynamics of highland vegetation [8, 9]. To investigate the response mechanisms between vegetation coverage and climate factors, numerous studies were conducted to scrutinize the temporal and spatial fluctuations in NDVI, grounded in the analysis of comprehensive NDVI datasets [10-13]. Nevertheless, studies examining the persistence of regional vegetation changes and the systematic elimination of impacts between variables from correlation analyses are scarce.

Situated in the southwest karst landscape region, Chongqing exhibits a proclivity for recurrent occurrences of natural disasters and possesses a fragile ecological milieu. As the principal economic hub in Southwest China and the uppermost part of the Yangtze River, Chongqing confronts substantial challenges in relation to vegetation growth and ecological environment, stemming from rapid urban expansion, socio-economic progress, population surge, and accelerated urbanization. Therefore, a thorough investigation of the temporal and spatial variations in the vegetation coverage of Chongqing, as well as the exploration of the relationship between those variations and climate factors, is crucial for formulating pertinent protective measures and fostering sustainable development that encompasses both human and environmental dimensions. Based on the collection and analyses of the NDVI data from 2000 to 2022, the Theil-Sen slope and Mann-Kendall test were employed to scrutinize the spatial and temporal changes of vegetation coverage. Analysis was also conducted to evaluate the persistence of regional vegetation coverage alterations and projected future trends through the application of the Hurst index. Partial correlation analysis was used to establish the relationship between changes in vegetation coverage and variations in temperature and precipitation.

Materials and Methods

Study Area

Chongqing is situated in the southwestern part of China, spanning the geographical coordinates of 105°17'~110°11'E longitude and 28°10'~32°13'N latitude. As shown in Fig. 1, approximately 76% of the topography in Chongqing comprises mountainous terrain; the terrain gradually decreases in elevation as it approaches the Yangtze River valley. The annual average temperature is between 16 and 18°C, and the annual precipitation in most areas of the region is between 1,000 and 1,350 mm. Most of the precipitation occurs from May to September, accounting for about 70% of the total annual precipitation.

Data Sources

The monthly NDVI data from the MODIS/Terra MOD13A3 Version 6.1 product (2000-2022, 1 km spatial resolution), obtained from the NASA Earthdata Search, were processed primarily in Google Earth Engine (GEE) and ArcMap 10.8. The datasets were reprojected to the WGS 1984 geographic coordinate system, subjected to Maximum Value Compositing (MVC) to minimize cloud and aerosol contamination, and clipped to the administrative boundaries of Chongqing Municipality. Annual mean NDVI was subsequently calculated by averaging the quality-assured monthly composites.

Monthly mean near-surface air temperature data (1 km resolution) from the National Tibetan Plateau Data Center were reprojected to WGS 1984, clipped to the Chongqing study area, corrected for outliers and extreme values, and aggregated to annual means. Annual precipitation data (1 km resolution) from the National Earth System Science Data Center were similarly reprojected to WGS 1984, spatially extracted using the Chongqing administrative mask, and subjected to rigorous quality control. Urban pixels were intentionally retained without masking to accurately capture the influence of urbanization on vegetation dynamics.

Analytical and Statistical Methods

Theil-Sen slope and Mann-Kendall test

Theil-Sen estimation [14, 15] and the Mann-Kendall trend test [16, 17] are non-parametric statistical methods that are robust to outliers. These methods are commonly used to analyse long time-series processes and are highly suitable for studying the evolution of vegetation coverage over a long period [18-20]. In this study, raster pixel-by-pixel computation is utilised and Theil-Sen estimation and Mann-Kendall test are employed as trend diagnosis methods. NDVI was systematically categorized based on the β values from Theil-Sen estimation and Z values from the Mann-Kendall trend test: when $\beta > 0$, it is divided into three trends by $|Z|$: NDVI shows a Strongly Significant Improvement (SSI) trend if $|Z| \geq 2.58$; a Significant Improvement (SI) trend if $1.96 \leq |Z| < 2.58$; a Weakly Significant Improvement (WSI) trend if $1.64 \leq |Z| < 1.96$. When $\beta = 0$, it only corresponds to $|Z| < 1.64$, with NDVI showing No Significant Change (NSC). When $\beta < 0$, NDVI shows a Weakly Significant Deterioration (WSD) trend if $1.64 \leq |Z| < 1.96$; a Significant Deterioration (SD) trend if $1.96 \leq |Z| < 2.58$; a Strongly Significant Deterioration (SSD) trend if $|Z| \geq 2.58$.

Hurst Index

The Hurst index [21], as a pivotal exponent utilised for prognosticating long time-series alterations, plays a vital role in predicting the future spatial and temporal evolution of vegetation and sustainability. The Hurst index value can be categorized into three ranges:

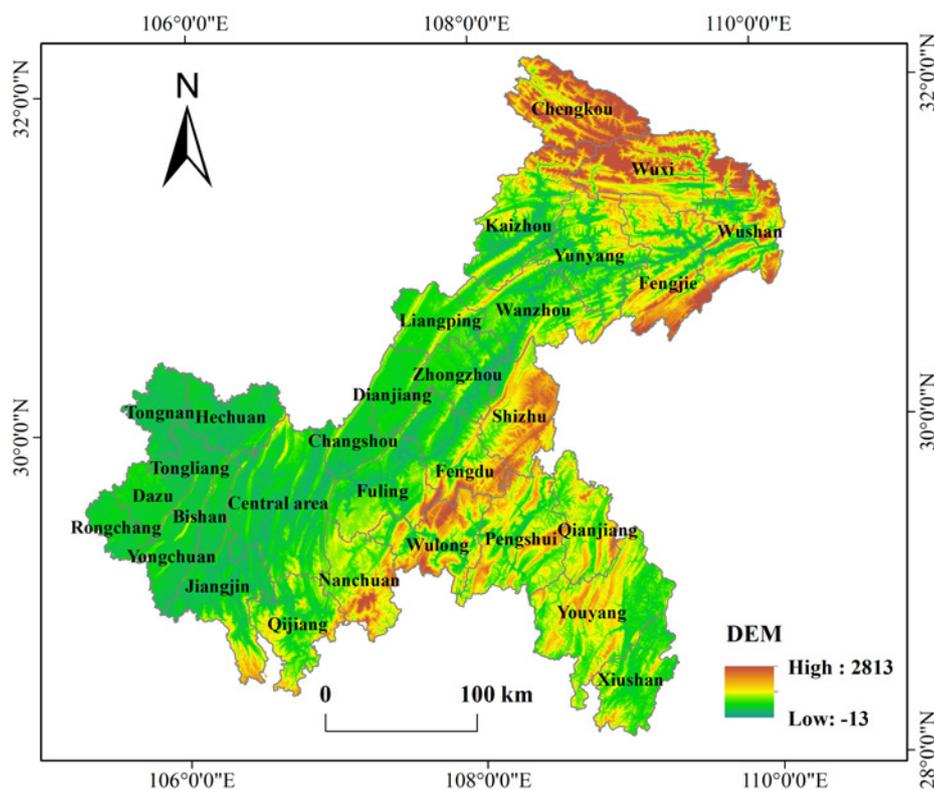


Fig. 1. Topographic characteristics and distribution of districts and counties in Chongqing.

$0.5 < H \leq 1$ signifies a positive correlation, indicating that the future change trend resembles the past change pattern. The degree of consistency strengthens as the H value approaches 1. $H = 0.5$ suggests that the future change trend is random and has a limited correlation with the past change pattern. $0 < H < 0.5$ denotes a negative correlation, indicating that the future change trend diverges from the past one. The slope (β), serving as an index delineating the trend rate, was amalgamated with the Hurst index to forecast the future trend of NDVI. When the Hurst index falls within the range of $0.5 < H \leq 1$, a positive β value indicates that the future trend of NDVI will continue to improve (CI), while a negative β value suggests that the future trend of NDVI will continue to degrade (CD). Conversely, when the Hurst index falls within the range of $0 < H < 0.5$, a positive β value indicates a transition from improvement to degradation (FITD) in the future trend of NDVI, whereas a negative β value indicates a transition from degradation to improvement (FDTI). When the Hurst index attains a value of 0.5, it becomes impossible to predict (Unpre) the future trend of NDVI.

Partial Correlation

In order to understand the examination of the relationship between the variables, the partial correlation analysis was employed to assess the relationship between annual mean precipitation, annual mean temperature, and annual mean NDVI. The predictive significance was

assessed through a t-test, and the correlation between variables was found to be significant when the P value was less than 0.05.

Results and Discussion

Spatial and Temporal Variations of NDVI in Chongqing

As shown in Fig. 2, the average NDVI value in Chongqing varied from 0.13 to 0.91 during the study period from 2000 to 2022, and the areas with vegetation coverage exceeding 0.7 accounted for 92.86%. However, there are notable geographical disparities between regions, with the overall NDVI exhibiting higher values in the northeast and southeast, while lower values are observed in the northwest.

During the period from 2000 to 2022, the fluctuations in the annual mean NDVI values (Fig. 2) indicate that the vegetation coverage in Chongqing experienced significant changes. The annual mean NDVI exhibited a range from 0.73 to 0.81, indicative of the fluctuating magnitude of vegetation coverage throughout the study period. The overall vegetation coverage of Chongqing exhibited a fluctuating growth trend. This is consistent with previous research in southwestern China [22, 23]. It is noteworthy that the lowest average NDVI value occurred in 2001, which can be attributed to the severe drought that affected the southwest region during that

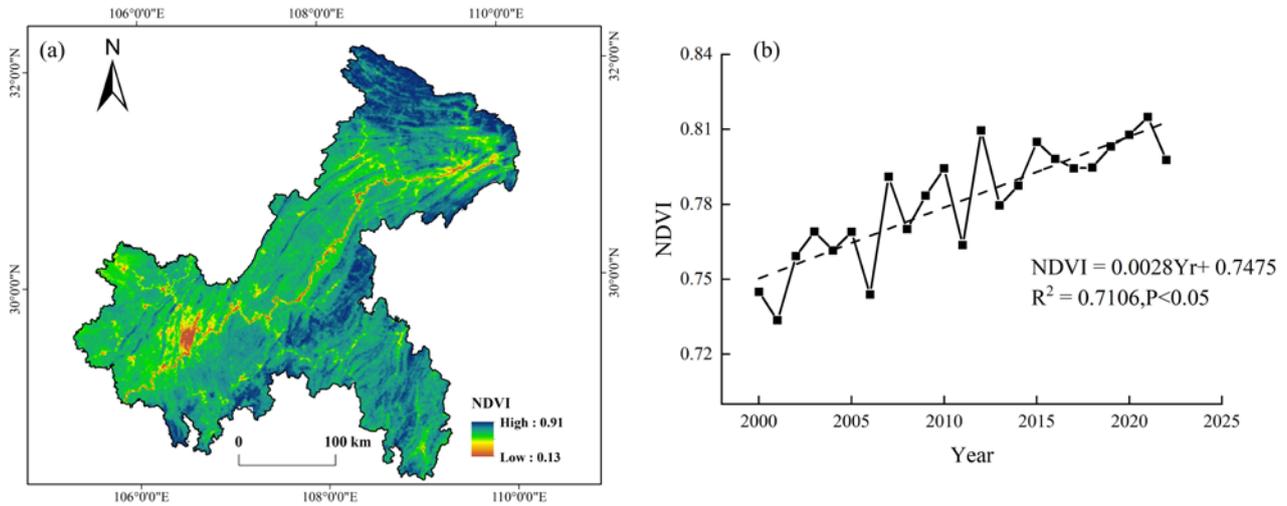


Fig. 2. a) Spatial distribution and b) annual variation of mean NDVI value from 2000 to 2022 in Chongqing.

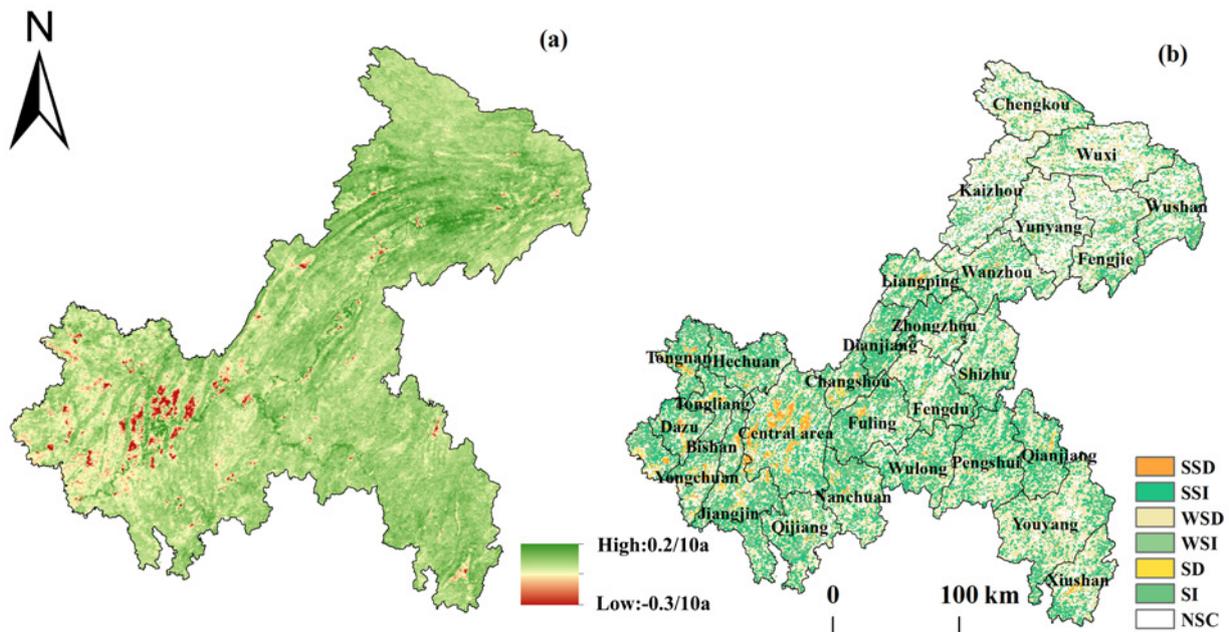


Fig. 3. a) Spatial variations in Sen slope and b) trend characteristics of NDVI in Chongqing.

year. Conversely, the highest average NDVI value was recorded in 2021, coinciding with the continuous increase in the area of newly afforested land, as reported by the Chongqing Municipal Forestry Bureau.

The analysis of the Mann-Kendall test and Theil-Sen estimation of NDVI trends in Chongqing, as depicted in Fig. 3, revealed that the majority of vegetation in Chongqing exhibited a consistent pattern from 2000 to 2022, with trends ranging from $-0.3/10a$ to $0.2/10a$. Approximately 92.1% of the regions exhibiting positive Sen slopes indicated a recovery and improvement in vegetation coverage. However, there were also localized areas with very significant vegetation degradation. Densely populated urban areas like Shapingba and Jiulongpo exhibited a decrease in vegetation coverage

and a highly significant trend of degradation, which is spatially in line with and likely attributable to intensified human activities associated with rapid urbanization [24, 25].

Elevational Differences in the Trends of Vegetation Coverage Change

According to the topographical features of Chongqing, the city was divided into six elevation groups: <500 m, 500-1000 m, 1000-1500 m, 1500-2000 m, 2000-2500 m, 2500-3000 m, with respective areas of 34,152.35 km² (40.11%), 31128.38 km² (36.56%), 13,680.96 km² (16.07%), 4,848.09 km² (5.69%), 1,306.29 km² (1.53%), and 32.42 km² (0.04%). The delineation of

Table 1. Historical trends and future persistence of NDVI across elevation groups in Chongqing.

Height/ km	Slope/10a	Historical Trend (%) (2000–2022)							Future Persistence (%)				
		SSD	SD	WSD	NSC	WSI	SI	SSI	CI	CD	FITD	FDTI	Unpre
<0.5	0.060	1.19	1.19	0.51	18.35	4.37	10.83	63.99	79.92	15.16	2.88	0.78	1.26
[0.5-1]	0.070	0.09	0.09	0.07	6.34	2.65	8.28	82.48	94.45	2.27	1.73	0.18	1.36
[1-1.5]	0.065	0.05	0.04	0.03	7.31	3.55	10.53	78.48	97.07	1.04	0.34	0.03	1.51
[1.5-2]	0.054	0.08	0.13	0.08	15.50	5.72	14.51	63.99	96.33	1.33	0.43	0.04	1.87
[2-2.5]	0.041	0.02	0.08	0.09	22.45	7.79	17.23	52.34	96.23	0.72	1.28	0.08	1.68
[2.5-3]	0.032	0.00	0.00	0.00	31.40	8.72	17.15	42.73	86.21	0.00	10.34	0.00	3.45

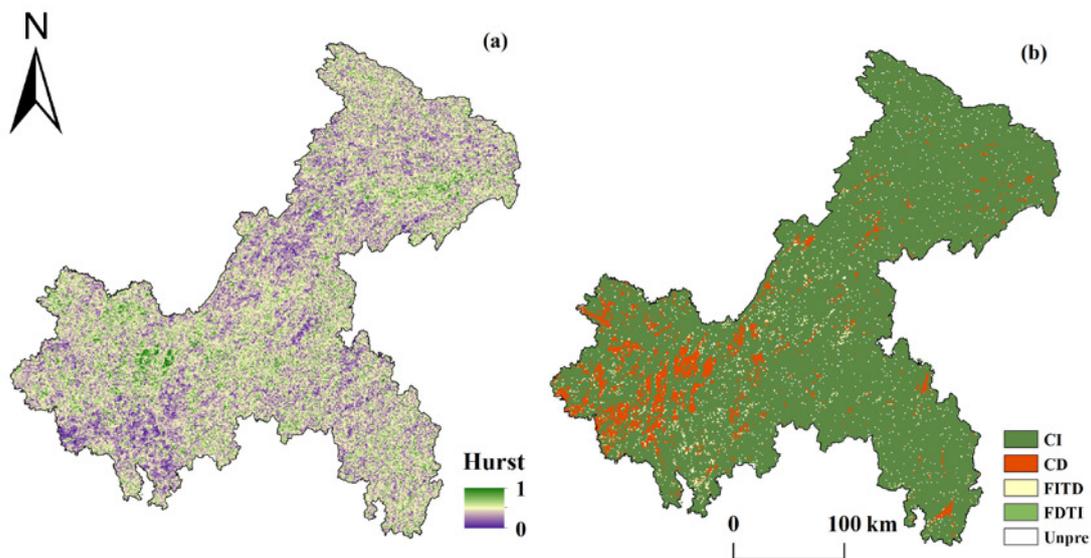


Fig. 4. a) Spatial distribution of Hurst index and b) the predicted future evolution of NDVI.

elevation gradients into six discrete bins was informed by a synthesis of established methodologies from prior research on vegetation dynamics in southwest China, while being specifically adapted to the topographic heterogeneity of Chongqing [22, 26-28]. Theil-Sen estimation was applied to analyse trends across different elevation groups. The comparison of the Sen slope of annual mean NDVI at different elevation groups (Table 1) indicated that, overall, the magnitude of vegetation coverage gradually diminished with higher elevations. The maximum magnitude of NDVI change occurred in the elevation group of 500-1000 m, reaching 0.070/10a. Within this group, the proportion of areas with degraded vegetation coverage was less than 0.3%. The proportion of areas with improved vegetation coverage reached 93.41%, among which the areas with strongly significant improvement (82.48%) > those with significantly improved areas (8.28%) > the areas with weakly significantly improved areas (2.65%). The minimum magnitude in NDVI change occurred in the elevation group of 2500-3000 m, with a value of 0.032/10a. The proportion of areas with improved vegetation coverage was 68.6% in this group, among which the areas with

strongly significant improvement (42.73%) > those with significantly improved areas (17.15%) > the areas with weakly significantly improved areas (8.72%).

The magnitude of vegetation coverage increase, and the proportion of strongly significant increase were higher in low-altitude areas compared to those in high-altitude areas. On one hand, such a difference may be attributed to the intensification of soil erosion and a reduction in soil thickness with increasing altitude [29, 30]. As altitude rises, temperature decreases, humidity increases, and the microbial decomposition capacity weakens, leading to the formation of acidic soils that are less conducive to plant growth [31, 32]. On the other hand, soil and water conservation measures are more easily implemented in low-altitude areas, whereas greater challenges exist for the implementation of soil and water management in higher-altitude areas. Current studies predominantly focus on soil erosion in local small watersheds [33-37], with limited attention given to the enhancement of soil conservation measures in high-altitude mountainous areas. Therefore, for the future practices of soil and water conservation in the Three Gorges Reservoir Area, it is advisable to

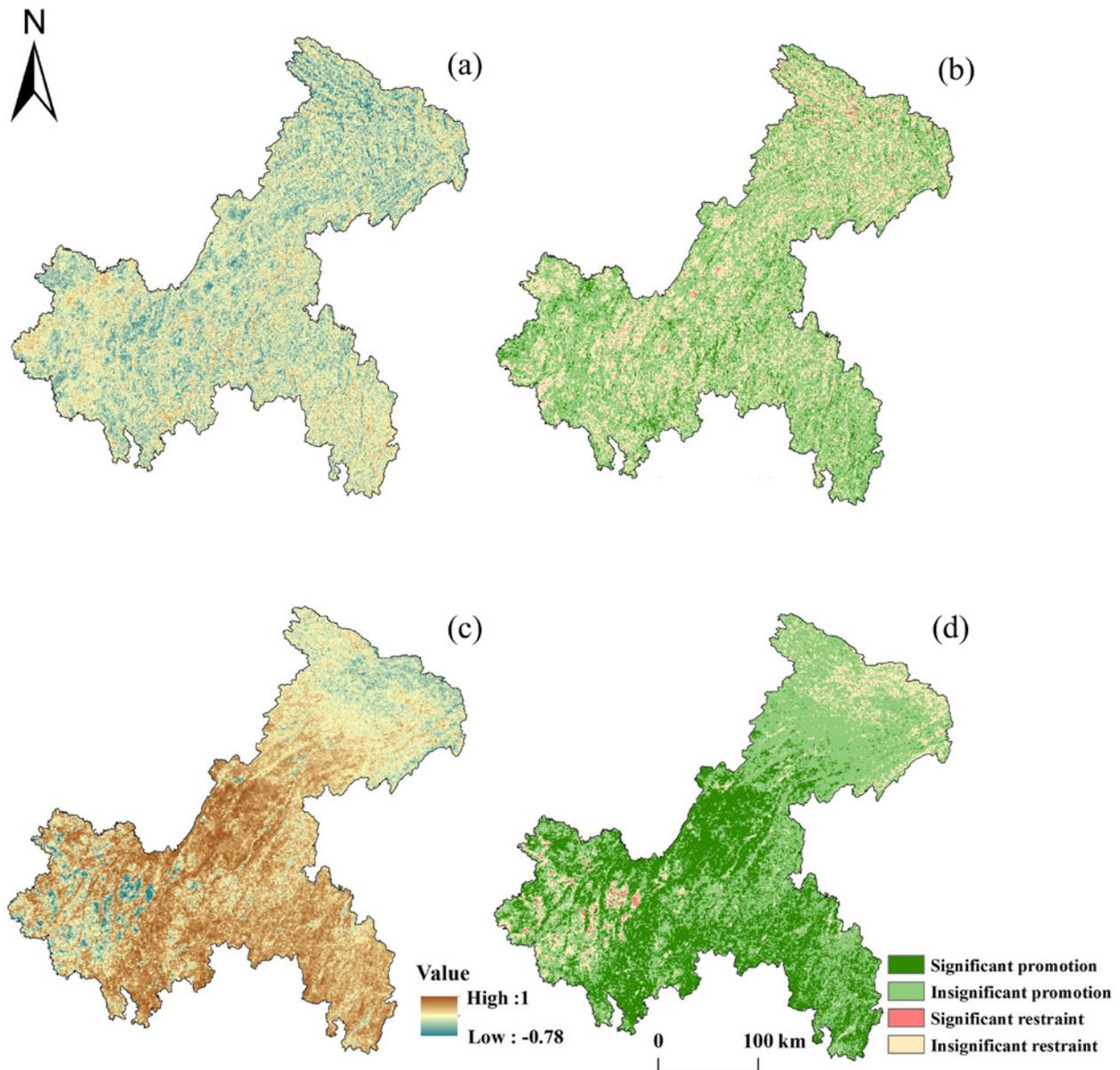


Fig. 5. (a, c) Coefficient and (b, d) significance of partial correlation between NDVI and air temperature (a, b) vs. precipitation (c, d).

establish dedicated monitoring stations in high-altitude mountainous areas to monitor the dynamic changes in soil erosion.

Persistence Analysis of Vegetation Coverage Changes in Chongqing

The Hurst index can be used to predict future changes in long time-series variables. The index is calculated for NDVI and the slope trend is superimposed to calculate the persistence of future NDVI changes in Chongqing; numerous studies have demonstrated the efficacy of this method [23, 38-40]. The outcomes (Fig. 4) reveal that a substantial majority of the area of Chongqing (96.3%) is presently experiencing sustained and consistent transformations. Among these, 89.2% of the vegetated region is expected to exhibit a continuous improvement

trend in the future, while 7.1% will undergo continuous degradation. Overall, the future changes in NDVI in Chongqing align more closely with its existing trend.

The calculation of future trends in vegetation coverage using the Hurst index (Table 1) indicated an overall trend of continuous improvement with slight variations between groups. Elevation groups spanning 500 to 1000 m, 1000 to 1500 m, 1500 to 2000 m, and 2000 to 2500 m exhibited continuous improvements, with proportions of total area exceeding 90%. The elevation group of < 500 m is characterized by the lowest proportion of continuous increase (79.92%) among all elevation groups, while it stood as the only group exhibiting a continuous degradation proportion exceeding 3% (reached as high as 15.16%). This could be partly explained by the conversion of low-altitude natural vegetation land into urban land, a process

that often leads to a decrease in plant cover and a deterioration of soil quality.

In the elevation group of 2500-3000 m, the proportion of areas transitioning from improvement to degradation is 10.34%. The soil environment in high-altitude areas is comparably less fertile compared to that in low-altitude areas, while the limited precipitation and low temperature in these areas also create unfavorable hydrothermal conditions for the synthesis of organic matter in plants. Meanwhile, the lack of dedicated soil and water conservation measures also greatly increases the risk of local vegetation degradation.

Response Pattern of NDVI to Climatic Changes in Chongqing

Both the temperature and precipitation demonstrated an increasing trend in Chongqing from 2000 to 2022, with growth rates of 0.17°C/10a and 77.46 mm/10a, respectively. Temperature and precipitation, serving as independent variables, and NDVI as the dependent variable, were subjected to partial correlation analysis at the pixel scale. As depicted in Fig. 5, the partial correlation coefficients between vegetation NDVI in Chongqing and the annual average temperature and precipitation range from -0.78 to 1 and from -0.76 to 0.88, respectively. Notably, both independent variables exhibit an overall positive correlation with NDVI. Specifically, NDVI exhibits a positive correlation with temperature in 63.7% of the city's area, with 7.0% of these correlations being significantly positive. Similarly, NDVI displays a positive correlation with precipitation in 88.5% of the city, with 37.2% of these correlations being significantly positive. From a spatial perspective, NDVI is primarily positively correlated with air temperature and precipitation in the southeastern and western parts of Chongqing. Notably, the positive correlation between NDVI and precipitation is more pronounced in the southeast, while a negative correlation is observed in the majority of the northeast area. This suggests that both temperature and precipitation contribute to fostering vegetation growth in most areas, with precipitation exerting a greater influence. This is consistent with previous research findings that precipitation has a greater impact on vegetation cover than temperature at elevations below 3000 m [41, 42].

Limitations and Recommendations for Future Study

Despite its comprehensive assessment of climatic influences on vegetation dynamics in Chongqing from 2000 to 2022, this study has several limitations that warrant acknowledgment. Primarily, the analysis focused on temperature and precipitation as dominant drivers while treating human activities (e.g., rapid urbanization, large-scale afforestation programs, and agricultural intensification) as contextual factors rather than quantified variables. Consequently, conclusions regarding the role of urbanization in exacerbating

vegetation degradation in low-elevation zones (<500 m) and the beneficial effects of ecological restoration projects on regional greening remain inferential, derived principally from ancillary land-use change patterns and socioeconomic statistics rather than mechanistic attribution.

To address these gaps, future investigations should integrate multi-source anthropogenic datasets, including land-use/land-cover transfer matrices, nighttime light intensity, population density, and gross domestic product (GDP) at fine spatial resolutions. Employing established attribution frameworks (e.g., geographical detector models or structural equation modeling) would enable robust separation and quantification of the relative contributions of climatic variability versus human interventions to observed NDVI trends. Such enhancements would refine understanding of the underlying driving mechanisms in this ecologically fragile and rapidly urbanizing region.

Conclusions

From 2000 to 2022, the vegetation coverage in Chongqing showed a clear improving trend, with overall NDVI increasing and larger magnitude changes in low-elevation than in high-elevation areas. Seasonal analyses reveal that the NDVI increases were greatest in winter (0.064/10a) and smallest in summer (0.020/10a). The Hurst index suggests that current trends will persist across 96.3% of the study area, with 89.2% showing sustained improvement and 7.1% at risk of continued degradation, with the <500 m zone having the highest degradation risk (15.16%). NDVI displayed predominantly positive partial correlations with both annual mean temperature (coefficients ranging from -0.78 to 1) and precipitation (-0.76 to 0.88), although precipitation exerted the dominant influence, manifesting positive correlations across 88.5% of the area. In high-elevation zones, elevated degradation risks arise primarily from infertile soils, unfavorable hydrothermal conditions, and inadequate soil-water conservation measures.

The combined application of Theil–Sen slope estimation, Mann–Kendall trend analysis, and the Hurst index proved effective for evaluating long-term vegetation dynamics and trend persistence in the complex terrain of Chongqing under intense anthropogenic pressure. To mitigate identified risks, strict ecological conservation measures should be prioritized in low-elevation urbanized areas, targeted soil and water conservation practices implemented in high-elevation vulnerable zones, and climate-adaptive vegetation management strategies developed with particular emphasis on precipitation variability. These findings offer a replicable analytical and policy framework for ecologically fragile landscapes, thereby supporting sustainable ecosystem management and ecological risk prevention.

Acknowledgements

This study was supported by the Chongqing Social Science Planning Project (Grant No. 2023BS058), Research Program of Humanities and Social Science of the Ministry of Education (Grant No. 21YJAZH093), the Science and Technology Research Program of Chongqing Municipal Education Commission (Grant No. KJQN202300541), and the National Natural Science Foundation of China (Grant No. 42507131 & 52209101).

Conflict of Interest

The authors declare no conflict of interest.

References

- WANG M., SUN Q., MENG H., HUANG L., LI H., ZHANG H., SHEN C. Holocene Vegetation Dynamics Revealed by a High-Resolution Pollen Record from Lake Yangzonghai in Central Yunnan, SW China. *Land*, **13** (6), 782, 2024.
- PRĂVĂLIE R., SÎRODOEV I., NITA I.-A., PATRICHE C., DUMITRAȘCU M., ROȘCA B., TIȘCOVSCHI A., BANDOC G., SĂVULESCU I., MĂNOIU V., BIRSAN M.-V. NDVI-based ecological dynamics of forest vegetation and its relationship to climate change in Romania during 1987–2018. *Ecological Indicators*, **136**, 108629, 2022.
- LI P., WANG J., LIU M., XUE Z., BAGHERZADEH A., LIU M. Spatio-temporal variation characteristics of NDVI and its response to climate on the Loess Plateau from 1985 to 2015. *CATENA*, **203**, 105331, 2021.
- AFUYE G.A., KALUMBA A.M., ORIMOLOYE I.R. Characterisation of Vegetation Response to Climate Change: A Review. *Sustainability*, **13** (13), 7265, 2021.
- CHEN M., XUE Y., XUE Y., PENG J., GUO J., LIANG H. Assessing the effects of climate and human activity on vegetation change in Northern China. *Environmental Research*, **247**, 118233, 2024.
- CHEN Y., MA L., LIU T., HUANG X., SUN G. The Synergistic Effect between Precipitation and Temperature for the NDVI in Northern China from 2000 to 2018. *Applied Sciences*, **13** (14), 8425, 2023.
- HUIYAN L., XIANGYU L., BAONI X., TIANCAI Z., JIAN S. Patterns and climate drivers of NDVI in the Yarlung Zangbo Basin, 2001–2020. *Ecological Frontiers*, **45** (5), 1226, 2025.
- LU Q., KANG H., ZHANG F., XIA Y., YAN B. Impact of climate and human activity on NDVI of various vegetation types in the Three-River Source Region, China. *Journal of Arid Land*, **16** (8), 1080, 2024.
- QI L., ZENG H., LIU P., DEGEN A.A., WANG W., HUANG M., LUO B., QI T., PENG Z., ZHAO J., SHANG Z. Asynchronous changes in precipitation and soil water content decelerate vegetation greening on the Qinghai-Tibetan Plateau. *Journal of Environmental Management*, **392**, 126847, 2025.
- LI Z., QU H., LI L., ZHENG J., WEI D., WANG F. Effects of climate change on vegetation dynamics of the Qinghai-Tibet Plateau, a causality analysis using empirical dynamic modeling. *Heliyon*, **9** (5), 2023.
- ZHAN C., LIANG C., ZHAO L., JIANG S., NIU K., ZHANG Y., CHENG L. Vegetation Dynamics and its Response to Climate Change in the Yellow River Basin, China. *Frontiers in Environmental Science*, **10**, 2022.
- REN Y., ZHANG F., ZHAO C., CHENG Z. Attribution of climate change and human activities to vegetation NDVI in Jilin Province, China during 1998-2020. *Ecological Indicators*, **153**, 110415, 2023.
- MEHMOOD K., ANEES S.A., REHMAN A., PAN S.A., TARIQ A., ZUBAIR M., LIU Q., RABBI F., KHAN K.A., LUO M. Exploring spatiotemporal dynamics of NDVI and climate-driven responses in ecosystems: Insights for sustainable management and climate resilience. *Ecological Informatics*, **80**, 102532, 2024.
- SEN P.K. Estimates of the Regression Coefficient Based on Kendall's Tau. *Journal of the American Statistical Association*, **63** (324), 1379, 1968.
- THEIL H. A Rank-Invariant Method of Linear and Polynomial Regression Analysis. Springer Netherlands, Dordrecht, 1992.
- MANN H.B. Non-parametric tests against trend. *Econometrica*, **13**, 245, 1945.
- KENDALL M.G. Rank Correlation Methods. *British Journal of Psychology*, **25** (1), 86, 1990.
- KUMAR R., NATH A.J., NATH A., SAHU N., PANDEY R. Landsat-based multi-decadal spatio-temporal assessment of the vegetation greening and browning trend in the Eastern Indian Himalayan Region. *Remote Sensing Applications-Society and Environment*, **25**, 2022.
- XIANG Y., HOU G.R., LI J.J., ZHANG Y.D., LU J., YU Z.X., NIU F.B., YANG H.Q. Exploring NDVI Responses to Regional Climate Change by Leveraging Interpretable Machine Learning: A Case Study of Chengdu City in Southwest China. *Atmosphere*, **16** (8), 2025.
- XU Y., DAI Q.Y., LU Y.G., ZHAO C., HUANG W.T., XU M., FENG Y.X. Identification of ecologically sensitive zones affected by climate change and anthropogenic activities in Southwest China through a NDVI-based spatial-temporal model. *Ecological Indicators*, **158**, 2024.
- HURST H.E. Long-Term Storage Capacity of Reservoirs. *Transactions of the American Society of Civil Engineers*, **116** (1), 770, 1951.
- PU M.X., ZHAO Y.B., NI Z.Y., HUANG Z.L., PENG W.L., ZHOU Y., LIU J.J., GONG Y.R. Spatial-Temporal Evolution and Driving Forces of NDVI in China's Giant Panda National Park. *International Journal of Environmental Research and Public Health*, **19** (11), 2022.
- ZHONG X.Z., LI J., WANG J.L., ZHANG J.P., LIU L.F., MA J. Linear and Nonlinear Characteristics of Long-Term NDVI Using Trend Analysis: A Case Study of Lancang-Mekong River Basin. *Remote Sensing*, **14** (24), 2022.
- CHEN X.F., LIU C., YU X.H. Urbanization, Economic Development, and Ecological Environment: Evidence from Provincial Panel Data in China. *Sustainability*, **14** (3), 2022.
- LUO Y., SUN W.Z., YANG K., ZHAO L. China urbanization process induced vegetation degradation and improvement in recent 20 years. *Cities*, **114**, 2021.
- ZHAO Y., LI X., ZHANG Y. Technology and Application of Mountainous Area Divisions in Qian-Gui Karst Areas. *Journal of Geo-information Science*, **19** (7), 934, 2017.
- GONG H.D., CHENG Q.P., JIN H.Y., REN Y.T. Effects of temporal, spatial, and elevational variation in bioclimatic indices on the NDVI of different vegetation types in Southwest China. *Ecological Indicators*, **154**, 2023.

28. JIANG S.S., CHEN X., SMETTEM K., WANG T.J. Climate and land use influences on changing spatiotemporal patterns of mountain vegetation cover in southwest China. *Ecological Indicators*, **121**, 2021.
29. FENG J., DONG B., QIN T., LIU S., ZHANG J., GONG X. Temporal and Spatial Variation Characteristics of NDVI and Its Relationship with Environmental Factors in Huangshui River Basin from 2000 to 2018. *Polish Journal of Environmental Studies*, **30** (4), 3043, 2021.
30. HAN X., LIU J., WU P., YU Z., QIAO X., YANG H. Predicting the thickness of alpine meadow soil on headwater hillslopes of the Qinghai-Tibet Plateau. *Geoderma*, **456**, 117271, 2025.
31. MPANDA M., MAJULE A., MARCHANT R., SINCLAIR F., AYNEKULU E., MWAKALUKWA E. Soil Fertility Dynamics Across Varied Land Use Types and Cropping Systems on Mount Kilimanjaro, Tanzania: Implications for Sustainable Soil Management. *Applied and Environmental Soil Science*, **2025** (1), 3057259, 2025.
32. WU Y., PEÑUELAS J., DENG M., PAN S., ZHANG X., ZHANG Z., LIU L. Elevational changes in vegetation and soil geochemistry drive thresholds in bulk soil carbon and its key fractions. *Journal of Ecology*, **113** (8), 1985, 2025.
33. CHEN W., NGUYEN K.A., HUANG Y.-C. Soil Erosion in Taiwan. *Agriculture*, **13** (10), 1945, 2023.
34. TAMENE L., ABERA W., DEMISSIE B., DESTA G., WOLDEAREGAY K., MEKONNEN K. Soil erosion assessment in Ethiopia: A review. *Journal of Soil and Water Conservation*, **77** (2), 144, 2022.
35. YAO Z., ZHANG Y., XIAO P., ZHANG L., WANG B., YANG J. Soil Erosion Process Simulation and Factor Analysis of Jihe Basin. *Sustainability*, **14** (13), 8114, 2022.
36. PATHAN S.A., SIL B.S. Prioritization of soil erosion prone areas in upper Brahmaputra River Basin up to Majuli River Island. *Geocarto International*, **37** (7), 1999, 2022.
37. MARKO O., GJOKA K., SHKODRANI N., GJIPALAJ J. Climate Change Effect on Soil Erosion in Vjosa River Basin. *Journal of Ecological Engineering*, **24** (2), 92, 2023.
38. CHAO Y., ZHU Y. H., WANG X.H., LI J.M., LIANG L.E. Dynamic evolution of the NDVI and driving factors in the Mu Us Sandy Land of China from 2002 to 2021. *Journal of Arid Land*, **17** (5), 605, 2025.
39. DAI Q., CUI C.F., WANG S. Spatiotemporal variation and sustainability of NDVI in the Yellow River basin. *Irrigation and Drainage*, **71** (5), 1304, 2022.
40. WANG J., ZHAO J.S., ZHOU P., LI K.N., CAO Z.X., ZHANG H.R., HAN Y., LUO Y.Y., YUAN X.R. Study on the Spatial and Temporal Evolution of NDVI and Its Driving Mechanism Based on Geodetector and Hurst Indexes: A Case Study of the Tibet Autonomous Region. *Sustainability*, **15** (7), 2023.
41. WANG Y., PENG D.L., SHEN M.G., XU X.Y., YANG X.H., HUANG W.J., YU L., LIU L.Y., LI C.J., LI X.W., ZHENG S.J., ZHANG H.L. Contrasting Effects of Temperature and Precipitation on Vegetation Greenness along Elevation Gradients of the Tibetan Plateau. *Remote Sensing*, **12** (17), 2020.
42. TAI X.L., EPSTEIN H.E., LI B. Elevation and Climate Effects on Vegetation Greenness in an Arid Mountain-Basin System of Central Asia. *Remote Sensing*, **12** (10), 2020.