

Analysis of NDVI Change and Influencing Factors in Daqingshan National Nature Reserve Based on GEE: Postprint

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Abstract

Studies on regional vegetation dynamics constitute one of the important approaches for assessing ecological and environmental benefits in national nature reserves. Based on the Google Earth Engine (GEE) cloud platform, this study extracted annual growing-season Normalized Difference Vegetation Index (NDVI) datasets from Landsat remote sensing imagery for the Daqingshan National Nature Reserve in Inner Mongolia during 1995–2020, and analyzed the spatiotemporal variation characteristics of NDVI and its influencing factors before and after the establishment of the reserve using methods including Pearson correlation, residual analysis, and the Lindeman-Merenda-Gold (LMG) model. The results indicate that: (1) The areal proportion of regions exhibiting declining NDVI trends from 1995 to 2008 was 69.04%, whereas the proportion of regions with increasing NDVI trends from 2008 to 2020 reached 94.98%, demonstrating significant vegetation improvement following the designation of the study area as a national nature reserve. (2) Negative human activities and the warming-drying climate trend contributed to the reduction of vegetation NDVI in the experimental zone during 1995–2008, with the warming-drying climate trend serving as the dominant factor. (3) Increased precipitation and positive human activities drove the increase of vegetation NDVI in the experimental zone during 2008–2020. Among these, positive human activities, represented by ecological environmental protection projects, constituted the primary cause of vegetation recovery during this period. The research findings can provide a scientific basis for environmental governance and ecological engineering construction in the Daqingshan National Nature Reserve.

Full Text

Analysis of NDVI Change and Influencing Factors in Daqingshan National Nature Reserve Based on GEE

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Abstract

Examining vegetation dynamics represents an important approach for assessing the ecological benefits of national nature reserves. Based on the Google Earth Engine (GEE) cloud platform, this study uses Landsat remote sensing imagery to extract annual growing-season Normalized Difference Vegetation Index (NDVI) datasets for the Daqingshan National Nature Reserve in Inner Mongolia from 1995 to 2020. The spatiotemporal variation characteristics of NDVI and their influencing factors before and after the reserve's establishment were analyzed using Pearson correlation, residual analysis, and the Lindeman-Merenda-Gold (LMG) model. The results indicate that during the 1995–2008 period, 69.04% of the study area exhibited a decreasing NDVI trend, whereas during the 2008–2020 period, 94.98% of the area showed an increasing trend, demonstrating significant vegetation improvement following the reserve's designation as a national nature reserve. During the 1995–2008 period, negative human activities combined with climatic warming and drying trends caused NDVI reductions, with climate warming identified as the dominant factor. During the 2008–2020 period, increased precipitation and positive human activities drove NDVI increases, with positive human impacts—represented by ecological and environmental protection engineering—serving as the primary cause of vegetation recovery. These findings provide scientific evidence for environmental governance and ecological engineering construction in the Daqingshan National Nature Reserve.

Keywords: Google Earth Engine; NDVI; climate change; human activities; National Nature Reserve

1. Study Area Overview

The Daqingshan National Nature Reserve in Inner Mongolia is located in Hohhot City, Baotou City, and Ulanqab City on the northern Tumochuan Plain, extending from 109°47' to 112°17' E and 40°34' to 41°14' N. The reserve covers approximately 3888.70 km², with an east-west length of 217 km and an average north-south width of 18 km. The area features medium-low mountainous terrain with elevations ranging from 1012 to 2319 m, characterized by gentle northern slopes and steep southern slopes [Figure 1: see original paper]. The region experiences a temperate semi-arid continental monsoon climate with an average annual temperature of 3–4 °C and annual precipitation of approximately 500 mm. The northern slopes are influenced by dry air currents from the Mongolian Plateau, resulting in cold, dry conditions, while the southern slopes are warmer and more humid due to orographic blocking. The reserve serves as a comprehensive mountain forest reserve primarily for water source conservation, comprising mountain forests, shrublands, mountain grasslands, and important water source areas.

2. Data and Methods

2.1 Data Sources The remote sensing data used in this study consist of Landsat-5 TM, Landsat-7 ETM+, and Landsat-8 OLI imagery. Annual growing-season images from July to August with cloud cover below 10% were selected for the period 1995–2020. The GEE platform was used for data format conversion, mosaicking, and clipping, followed by NDVI calculation using maximum value compositing. To ensure comparability across the Landsat sensors, reflectance values from Landsat-5 and Landsat-7 were adjusted using intercepts and offsets provided by Roy et al. [18] to match Landsat-8 data, yielding a spatial resolution of 30 m. Meteorological data were obtained from the China Meteorological Administration's daily gridded temperature and precipitation dataset (0.5° × 0.5°). Data from pixels covering the study area during the July–August growing season were extracted and interpolated using inverse distance weighting in Python to generate annual temperature and precipitation datasets at 1 km spatial resolution. Land use data were derived from the 30 m annual land cover dataset for China developed by Yang and Huang [20] from Landsat imagery, which was used to extract forest and grassland areas for assessing the effectiveness of ecological engineering implementation.

2.2 Methods 2.2.1 Sen's Slope and Mann-Kendall Non-parametric Test

Sen's slope estimator, a non-parametric algorithm for linear trend estimation, was used to calculate NDVI trends for two time periods. The formula is:

$$\beta = \text{Median} \left(\frac{x_j - x_i}{j - i} \right), \quad \text{for } i < j$$

where β represents the trend magnitude, and x_i and x_j are NDVI values for a given pixel in years i and j , respectively. The Mann-Kendall test was applied to assess the significance of these trends at the 95% confidence level.

2.2.2 Correlation Analysis

Pearson correlation coefficients were calculated to determine the relationship between NDVI and climatic factors (temperature and precipitation). The formula is:

$$r_{xy} = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2 \sum_{i=1}^n (y_i - \bar{y})^2}}$$

where r_{xy} is the correlation coefficient, n is the number of years, x and y are the two variables, and \bar{x} and \bar{y} are their respective means. Significance was tested at the 95% confidence level. The relative importance of different factors was quantified using the relaimpo package in R, which partitions the explained variance in multiple linear regression. Climate factors included temperature and precipitation, while human activities were represented by forest and grassland areas.

2.2.3 Residual Analysis

Assuming NDVI is influenced only by human activities and climate conditions, residual analysis was used to evaluate the impact of human activities. The calculation formula is:

$$\text{NDVI}_{\text{predicted}} = a + b \times \text{temperature} + c \times \text{precipitation}$$

$$\sigma = \text{NDVI}_{\text{actual}} - \text{NDVI}_{\text{predicted}}$$

where a , b , and c are regression coefficients, and σ represents the residual value. A positive residual trend indicates that human activities promote NDVI increase, while a negative trend indicates inhibition.

2.2.4 Lindeman-Merenda-Gold Model

While correlation and residual analysis can reflect the impacts of climate factors and human activities on NDVI, they cannot quantify the contribution rates of these factors to NDVI change. Therefore, this study used variance decomposition in multiple linear regression to quantify the relative importance of different factors through the LMG model. The model calculates the contribution of temperature, precipitation, forest area, and grassland area to NDVI change.

3. Results

3.1 NDVI Variation Characteristics 3.1.1 Interannual Variation

As shown in [Figure 3: see original paper], NDVI values exhibited a non-significant decreasing trend from 1995 to 2008 at a rate of -0.002 per year ($Z = -1$). However, from 2008 to 2020, NDVI showed a significant increasing trend at a rate of 0.011 per year ($Z = 4.98$), indicating that vegetation improved significantly after the reserve's establishment as a national nature reserve.

3.1.2 Spatial Variation

During the 1995–2008 period, decreasing NDVI trends occupied 69.04% of the total area, with significantly decreasing areas accounting for 7.78% and primarily distributed north of the east-west mountain range. Increasing NDVI trends occupied 19.90% of the area, with significantly increasing areas comprising 1.55% and mainly distributed along the southern margin of the reserve. This pattern demonstrates that before the reserve's establishment, NDVI change was dominated by non-significant decreases, exhibiting a spatial characteristic of “decrease in the north, increase in the south.” In terms of functional zones, the core, buffer, and experimental zones showed similar patterns, with non-significant decreasing areas accounting for 60.26%, 64.97%, and 60.29%, respectively, and significant decreasing areas comprising 8.14%, 6.64%, and 8.04% [FIGURE:4, TABLE:1].

During the 2008–2020 period, decreasing NDVI areas occupied only 2.26% of the total area, while increasing areas accounted for 94.98%, with significantly increasing areas comprising 38.47%. The increasing areas were mainly distributed in the eastern and western parts of the reserve, with the central zone also showing improvement. This indicates that after the reserve's establishment, vegetation NDVI exhibited an overall improving trend. The core, buffer, and experimental zones showed significantly increasing areas of 36.19%, 43.88%, and 30.35%, respectively, with the experimental zone demonstrating the highest recovery rate.

3.2 Climate Factor Variation 3.2.1 Interannual Variation of Climate Factors

From 1995 to 2008, precipitation decreased at a rate of $-4.737 \text{ mm} \cdot \text{a}^{-1}$, while temperature increased at $0.053 \text{ }^\circ\text{C} \cdot \text{a}^{-1}$, indicating a warming and drying trend that was unfavorable for vegetation growth [Figure 5: see original paper]. From 2008 to 2020, precipitation increased at $3.059 \text{ mm} \cdot \text{a}^{-1}$ while temperature increased at a slower rate of $0.019 \text{ }^\circ\text{C} \cdot \text{a}^{-1}$, suggesting that the warming-drying trend moderated. The increase in precipitation provided favorable conditions for vegetation growth and recovery.

3.2.2 Correlation Between Climate Factors and NDVI

The correlation between precipitation and NDVI differed between the two periods. During 1995–2008, positive correlations dominated, with non-significant positive correlations accounting for 79.06% and significant positive correlations comprising 18.54% of the study area, primarily in the western and northeastern regions [FIGURE:6, TABLE:2]. After the reserve's establishment, non-significant positive correlations occupied 72.08% of the area, while significant positive correlations increased to 24.57%, mainly concentrated in the western part and along the southern margin. This expansion indicates that precipitation's influence on NDVI increased.

Temperature correlations showed different patterns. During 1995–2008, negative correlations dominated, with non-significant negative correlations accounting for 41.75% and significant negative correlations comprising 56.17% of the area, distributed across the northeastern, central, and western regions [FIGURE:7, TABLE:3]. After 2008, non-significant positive correlations became dominant (84.46%), with significant positive correlations at only 1.58%, indicating that temperature's negative impact on NDVI weakened significantly.

3.3 Human Activity Impacts on NDVI According to national regulations, human activities are prohibited in the core and buffer zones. Therefore, this study assessed human activity impacts using the experimental zone as an example. During 1995–2008, residual trends indicating inhibition occupied 84.46% of the experimental zone area, primarily along the northern margin where NDVI was decreasing or significantly decreasing, indicating that unreasonable human activities caused NDVI decline [FIGURE:8, TABLE:4].

After the reserve's establishment (2008–2020), residual trends indicating inhibition accounted for only 2.79% of the experimental zone, while promotion trends occupied 94.62%, covering most of the experimental zone and overlapping substantially with areas showing NDVI increase [Figure 8: see original paper]. This demonstrates that positive human activities became the dominant influence driving vegetation recovery in the experimental zone.

3.4 Contribution Rates of Climate Factors and Human Activities to NDVI Change To further quantify the impacts and identify dominant factors before and after the reserve's establishment, the LMG model calculated contribution rates of temperature, precipitation, forest area, and grassland area to NDVI change in the experimental zone. During 1995–2008, precipitation contributed 32.00% and temperature contributed 58.42%, while forest and grassland areas contributed less than 10% combined [Figure 9: see original paper]. This confirms that the warming-drying climate trend was the primary cause of NDVI decrease.

During 2008–2020, forest area contributed 43.93% and grassland area contributed 34.28%, while precipitation and temperature contributed 19.02% and 2.78%, respectively. This indicates that after the reserve's establishment, positive human activities became the dominant factor influencing NDVI change,

demonstrating the significant benefits of ecological protection engineering implemented in the experimental zone.

4. Discussion

This study utilized Landsat imagery and the GEE platform to monitor long-term vegetation dynamics in the Daqingshan National Nature Reserve, revealing that 94.98% of the area exhibited increasing NDVI trends after the reserve's establishment, representing substantial vegetation improvement. These results align with findings from Hu Ercha et al. [21] and Wang Jiabin et al. [33]. The use of Landsat imagery and GEE's integrated computing environment enabled acquisition of long time-series vegetation monitoring data at relatively high spatial resolution, providing more accurate characterization of NDVI spatiotemporal evolution and enriching technical approaches for long-term, small-scale vegetation monitoring.

The results indicate that climate warming and drying caused NDVI decreases before the reserve's establishment, consistent with Chen Shujun et al. [7]. Rising temperatures and decreasing precipitation can lead to meteorological drought, intensifying water deficits and drought stress that inhibit vegetation growth [32]. After the reserve's establishment, positive human activities became the dominant factor influencing NDVI change in the experimental zone. According to incomplete statistics, the reserve has completed artificial afforestation on 1.32×10^6 hm² and closed forest management on 6.45×10^6 hm², substantially increasing forest coverage [33]. Previous studies often used land use transition areas (e.g., conversion from cropland to forest or grassland) to represent ecological engineering effectiveness [34]. This study directly used forest and grassland areas because cropland constitutes a small proportion of the study area [35], and cropland conversion alone cannot fully represent ecological engineering outcomes.

This research focused on the positive effects of national nature reserve establishment, demonstrating vegetation improvement following ecological project implementation. However, limitations exist due to the lack of spatiotemporal data on negative human activities such as grazing intensity and tree cutting, which prevented their inclusion in the LMG model. Additionally, without precise information on the timing and location of ecological engineering implementation, deeper investigation of human activity driving mechanisms was not possible. Furthermore, this study only considered temperature and precipitation, while vegetation responses in this semi-arid region involve complex processes influenced by additional climatic factors such as potential evapotranspiration [36]. Future research should incorporate multiple climate factors to assess their combined effects on vegetation change.

5. Conclusions

Based on the analysis of NDVI changes and influencing factors in the Daqing-shan National Nature Reserve from 1995 to 2020, the following conclusions are drawn:

Before the reserve's establishment (1995-2008), vegetation NDVI decreased at a rate of -0.002 a^{-1} , with decreasing areas occupying 69.04% of the total study area. After the reserve's establishment (2008-2020), NDVI increased at a rate of 0.011 a^{-1} , with increasing areas accounting for 94.98% of the total area, demonstrating that the reserve's establishment significantly promoted vegetation improvement.

During 1995-2008, the study area experienced a warming and drying climate trend. Areas showing significant negative correlation between NDVI and temperature accounted for 41.75% of the total area, while areas with significant positive correlation between NDVI and precipitation comprised 18.54%. During 2008-2020, NDVI was predominantly positively correlated with both precipitation and temperature, with significant positive correlation areas of 24.57% and 1.58%, respectively, indicating that precipitation's influence on NDVI increased while temperature's influence weakened significantly.

During 1995-2008, precipitation and temperature contributed 32.00% and 58.42%, respectively, to NDVI change in the experimental zone, confirming that climate factors were the primary drivers of NDVI decrease. During 2008-2020, forest area and grassland area contributed 43.93% and 34.28%, respectively, while precipitation and temperature contributed only 19.02% and 2.78%, demonstrating that positive human activities became the dominant factor driving vegetation recovery.

References

- [1] Xue Dayuan, Bao Haosheng, Li Wenhua. A valuation study on the indirect values of forest ecosystem in Changbaishan Mountain Biosphere Reserve of China[J]. China Environmental Science, 1999, 19(3): 247-252.
- [2] Cao Wei, Huang Lin, Xiao Tong, et al. Effects of human activities on the ecosystems of China's National Nature Reserves[J]. Acta Ecologica Sinica, 2019, 39(4): 1338-1350.
- [3] Wang Youbing, Zhang Shiping, Li Ziguang, et al. Study on ecosystem health change of Cangshan Erhai National Nature Reserve in Yunnan Province[J]. Ecological Science, 2022, 41(2): 131-136.
- [4] Song Chao, Yu Qiyin, Wang Ruixia, et al. Radiation effects of windbreak and sand fixation function in Baijitan National Nature Reserve, Lingwu, Ningxia of northwestern China[J]. Journal of Beijing Forestry University, 2022, 44(7): 78-89.

- [5] Militino A F, Ugarte M D, Pérez Goya U. Stochastic spatio-temporal models for analysing NDVI distribution of GIMMS NDVI3g images[J]. *Remote Sensing*, 2017, 76(9): 1-17.
- [6] Liu Y F, Guo B, Lu M, et al. Quantitative distinction of the relative actions of climate change and human activities on vegetation evolution in the Yellow River Basin of China during 1981–2019[J]. *Journal of Arid Land*, 2023, 15(1): 91-108.
- [7] Chen Shujun, Xu Guochang, Lü Zhiping, et al. Spatio-temporal variations of fractional vegetation cover and its response to climate change and urbanization in China[J]. *Arid Land Geography*, 2023, 46(5): 742-752.
- [8] Zhang Fangning, Yang Liangjie, Yang Yongchun. Change of vegetation NDVI and its response to climatic and human activities in the Loess Plateau during 1981–2016[J]. *Research of Soil and Water Conservation*, 2023, 30(2): 1-8.
- [9] Yue Xiyuan, Zuo Xiaolan, Chang Xueli, et al. NDVI of typical steppe and desert steppe in Inner Mongolia in response to meteorological factors[J]. *Journal of Desert Research*, 2019, 39(3): 25-33.
- [10] Zhang Hua, An Huimin. Analysis of NDVI variation characteristics and trend of Minqin Oasis from 1987 to 2019 based on GEE[J]. *Journal of Desert Research*, 2021, 41(1): 28-36.
- [11] Long Shuang, Guo Zhengfei, Xu Li, et al. Spatiotemporal variations of fractional vegetation coverage in China based on Google Earth Engine[J]. *Remote Sensing Technology and Application*, 2020, 35(2): 326-334.
- [12] Yang Xianbao, Zhang Wangfei, Sun Bin, et al. Recognition of vegetation types in Hulunbuir Sandy Land and its surrounding areas based on GEE cloud platform and Sentinel-2 time series data[J]. *Remote Sensing Technology and Application*, 2022, 37(4): 982-992.
- [13] Li Quanji. Comprehensive scientific examination papers of Daqing Mountain National Nature Reserve in Inner Mongolia[M]. Beijing: China Forestry Publishing House, 2014: 1-32.
- [14] Du Jiaqiang, Aheti Jiaerheng, Zhao Chenxi, et al. Dynamic changes in vegetation NDVI from 1982 to 2012 and its responses to climate change and human activities in Xinjiang, China[J]. *Chinese Journal of Applied Ecology*, 2015, 26(12): 3567-3578.
- [15] Internal Affairs (2019) No.19. Notice of the People's Government of Inner Mongolia Autonomous Region on the coordinates of control points for correcting the boundaries of the scope and functional area of Daqingshan National Nature Reserve in Inner Mongolia[S]. Hohhot, 2019.
- [16] Wang Jiabin, Bi Zherui, Wang Xiaofang. Effect of the protection project in Daqing Mountain National Nature Reserve: Taking Hohhot as an example[J]. *Grassland and Prataculture*, 2020, 32(4): 53-58.

- [17] Zhang Hua, Song Jinyue, Li Ming, et al. Eco-environmental quality assessment and cause analysis of Qilian Mountain National Park based on GEE[J]. *Chinese Journal of Ecology*, 2021, 40(6): 1883-1894.
- [18] Roy D P, Kovalsky V, Zhang H K, et al. Characterization of Landsat-7 to Landsat-8 reflective wavelength and normalized difference vegetation index continuity[J]. *Remote Sensing of Environment*, 2016, 185: 57-70.
- [19] Xu Yong, Huang Wenting, Jing Juanli, et al. Dynamic variation of vegetation cover and its relation with climate variables in Beijing-Tianjin-Hebei region[J]. *Bulletin of Soil and Water Conservation*, 2020, 40(5): 319-327.
- [20] Yang J, Huang X. The 30 m annual land cover dataset and its dynamics in China from 1990 to 2019[J]. *Earth System Science Data*, 2021, 8(13): 3907-3925.
- [21] Hu Ercha, Wang Xiaojiang, Tie Niu, et al. Spatio-temporal variation of NDVI and influencing factors in the Daqing Mountain National Nature Reserve, Inner Mongolia[J]. *Acta Ecologica Sinica*, 2022, 42(14): 5945-5955.
- [22] Sen P K. Estimates of the regression coefficient based on Kendall Tau[J]. *Journal of the American Statistical Association*, 2012, 63(324): 1379-1389.
- [23] Wang Dianlai, Liu Wenping, Huang Xinyuan. Trend analysis in vegetation cover in Beijing based on Sen+Mann-Kendall method[J]. *Computer Engineering and Applications*, 2013, 49(5): 13-17.
- [24] Zhang Zhigao, Xu Xiaoman, Guo Chaofan, et al. Spatial and temporal characteristics and influencing factors of frost date in the Yellow River Basin from 1960 to 2020[J]. *Arid Land Geography*, 2022, 45(6): 1685-1694.
- [25] Zhang Zhiqiang, Liu Huan, Zuo Qiting, et al. Spatiotemporal change of fractional vegetation cover in the Yellow River Basin during 2000–2019[J]. *Resources Science*, 2021, 43(4): 849-858.
- [26] Cai H Y. Human induced grassland degradation/restoration in the central Tibetan Plateau: The effects of ecological protection and restoration projects[J]. *Ecological Engineering*, 2015, 83: 112-119.
- [27] Zhang Leyi, Li Xia, Feng Jinghui, et al. Spatial-temporal changes of NDVI in Yellow River Basin and its dual response to climate change and human activities[J]. *Bulletin of Soil and Water Conservation*, 2021, 41(5): 1-11.
- [28] Gu Xiling, Guo Enliang, Yin Shan, et al. Influence of Yellow River Diversion Project on vegetation in the northern margin of Kubuqi Desert[J]. *Chinese Journal of Ecology*, 2021, 40(9): 2678-2688.
- [29] Grömping U. Relative importance for linear regression in R: The package relaimpo[J]. *Journal of Statistical Software*, 2006, 17(1): 1-27.
- [30] Yao Y T, Wang X H, Li Y. Spatiotemporal pattern of gross primary productivity and its covariation with climate in China over the last thirty years[J]. *Global Change Biology*, 2018, 24(1): 184-196.

- [31] Zhao Wenbo, Feng Lili, Zhao Anzhou, et al. Spatial and temporal evolution of desertification and its driving factors of climate in Hebei Province[J]. Bulletin of Soil and Water Conservation, 2021, 41(4): 252-259.
- [32] Li C J, Fu B J, Wang S, et al. Drivers and impacts of changes in China' s drylands[J]. Nature Reviews Earth and Environment, 2021, 2: 858-873.
- [33] Hohhot Forestry and Grassland Administration [2022] No.15. Work plan for comprehensive management of forest and grass ecology in Daqing Mountain of Hohhot[Z]. Hohhot: Hohhot Forestry and Grassland Administration, 2022.
- [34] Fang Z, Ding T H, Chen J Y, et al. Impacts of land use/land cover changes on ecosystem services in ecologically fragile regions[J]. Science of the Total Environment, 2022, 831: 154967, doi:10.1016/j.scitotenv.2022.154967.
- [35] Zheng Hongyu. Resource status and value analysis of Daqing Mountain National Nature Reserve, Inner Mongolia[J]. Inner Mongolia Forestry Investigation and Design, 2019, 42(3): 20-23, 26.
- [36] Jia Danyang, Xiong Zhenzhen, Gao Yan, et al. Land use/land cover change and influencing factors in the Taitema Lake area in the past 30 years[J]. Arid Land Geography, 2021, 44(4): 1022-1031.
- [37] Shao Quanqin, Fan Jiangwen, Liu Jiyuan, et al. Assessment on the effects of the first stage ecological conservation and restoration project in Sanjiangyuan region[J]. Acta Geographica Sinica, 2016, 71(1): 3-20.

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