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PAPER

LONG-TERM NDVI TRENDS AND TERRAIN CHARACTERISTICS IN THE NATURAL ECOSYSTEM OF THE NURATAU NATURE RESERVE

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Abstract

The aim of this study is to investigate the topographic characteristics of the Nuratau State Nature Reserve and the dynamics of vegetation cover (NDVI) over the period 2005–2025. Using MODIS remote sensing data, 20-year NDVI changes were analyzed through the Mann–Kendall t test, Sen's slope estimator, and Z-score statistics. The spatial distribution of vegetation trends was mapped and evaluated with statistical confidence levels. In addition, the topographic characteristics of the study area (elevation, slope, and aspect) were examined by classifying DEM-derived data into statistical groups. The results of the research provide an important scientific basis for assessing ecological changes in mountainous regions, improving vegetation monitoring, and developing biodiversity conservation strategies.

Key words: NDVI; vegetation dynamics; topographic factors; DEM; slope; aspect; Nuratau State Nature Reserve; remote sensing; MODIS; Mann–Kendall trend; Sen's slope estimator.

1.Introduction

Climate change has a significant impact on terrestrial ecosystems; however, its effects do not manifest uniformly across all regions [1]. Therefore, the use of remote sensing (RS) and geographic information systems (GIS) technologies is considered one of the most effective approaches for monitoring and assessing ongoing ecological changes. GIS technologies play an important role in monitoring environmental processes, detecting degradation in vegetation cover, and generating spatial databases based on satellite imagery. One of the most widely used indicators for assessing vegetation cover is the Normalized Difference Vegetation Index (NDVI). This index, based on

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reflectance in the red and near-infrared spectral bands, is commonly applied to determine vegetation biomass, its density and spatial distribution, as well as to produce vegetation maps. NDVI is calculated as the ratio of the difference between near-infrared and red reflectance to their sum [2].

A number of studies have demonstrated that topographic factors—including elevation, aspect (slope orientation), and slope steepness—exert a considerable influence on the distribution and growth of vegetation [3]. Walsh et al. (2001) conducted a multiscale correlation analysis of NDVI and topographic characteristics, revealing that the relationship between NDVI and factors such as slope and elevation varies depending on spatial scale [4]. Topographic factors play diverse roles in the formation of vegetation cover. For instance, steep slopes typically possess thin soil layers with low moisture retention capacity, resulting in reduced biomass. South-facing slopes that receive more direct solar radiation tend to support more active vegetation growth, whereas shaded slopes exhibit lower growth rates [5].

The obtained results serve as an important scientific basis for long-term monitoring of the ecological condition of vegetation cover in the Nuratau State Nature Reserve, detecting anthropogenic impacts, and developing strategies for sustainable landscape management.

2. Materials and Methods

2.1. Study Area

The Nuratau State Nature Reserve is located in the central part of the Nuratau mountain range, between 40.468487°–40.562476° N latitude and 66.65931°–66.927651° E longitude (Figure 1) [6]. The reserve covers an area of 177.52 km^2, of which 2.3 km^2 is forested. Elevation within the territory ranges from 530 m to 2169 m above sea level [6,7].

Geologically, the Nuratau mountain range comprises formations dating from the Late Proterozoic to the Early Paleozoic and was mainly shaped by the Baikal and Caledonian orogenic processes. The lithological composition of the area includes shale, limestone, sandstone, dolomite, granite, granodiorite, and diorite rocks [8]. The climate of the region is moderately continental and semi-arid, with a mean annual temperature of 10–12 °C and annual precipitation ranging from 300 to 400 mm [9].

2.2. Data Collection and Processing

In this study, multi-source remote sensing and geospatial data were used to assess land cover and vegetation dynamics within the Nuratau State Nature Reserve and its buffer zone.

NDVI (Normalized Difference Vegetation Index) values were calculated on the Google Earth Engine (GEE) platform using the MOD13Q1.061 product for the main vegetation period (April–October) over the years 2005–2025, represented as annual mean composites. The MOD13Q1.061 product provides 16-day composite images with a spatial resolution of 250 m [22]. To identify NDVI trends, the Mann–Kendall statistical test, Sen's slope estimator, and the Z-score indicator were applied.

To evaluate the topographic characteristics of the study area, a 30 m spatial resolution SRTM Digital Elevation Model (DEM) was used. Based on the DEM, elevation, slope, and aspect maps were generated in the ArcGIS 10.8 environment. All layers were clipped to the boundary of the Nuratau State Nature Reserve. Spatial datasets were standardized by harmonizing coordinate systems and pixel resolutions. As a result, elevation, slope, and aspect layers representing the relief structure of the reserve were prepared for subsequent analysis.

In this study, three statistical methods were employed to assess vegetation dynamics over the period 2005–2025 using MOD13Q1.061 satellite data: the Mann–Kendall (MK) trend test, Z-score statistics, and Sen's slope estimator. These methods are essential for determining the direction, magnitude, and statistical significance of temporal changes in NDVI values. The Mann–Kendall test is a non-parametric statistical method used to determine the presence of a trend and to identify the direction of increase or decrease in a time series.

Sen's slope estimator calculates the rate of change (slope coefficient) of the trend and provides a quantitative measure of its magnitude. The Z-score statistic is used to assess the significance level of the trend, indicating whether the observed changes are non-random. The results revealed spatial variations in NDVI values over the 20-year period: some zones exhibited positive trends, while others showed declining tendencies. The mean values indicated an overall decreasing trend.

2.2.1. Mann–Kendall Trend Test

The Mann–Kendall (MK) test is a widely used non-parametric statistical method for detecting long-term changes in climatic and ecological processes. A key advantage of this test is that it can be applied to datasets that do not follow a normal distribution [10,11,12]. The MK statistical indicator is calculated according to the following formula:

$$\tau = \frac{2}{n(n-1)} \sum_{i<j} \mathrm{sign}(x_j - x_i)$$

Here:

n — the number of years in the time interval;
x_i and x_j — NDVI values at different time points;
$Sign(x_j - x_i)$ — the sign (signum) function.

$$x_i) = \begin{cases} +1, \ if\, x_j > x_i \\ -1, \ if x_j < x_i \\ 0, \ if\, x_j = x_i \end{cases}$$

When interpreting the results:

$\tau > 0$ — greening (strengthening of vegetation);

$\tau < 0$ — decline (weakening of vegetation);

$\tau \approx 0$ — no change or no significant trend.

This test is effectively applied for analyzing meteorological, ecological, and remote sensing data within time-series frameworks.

2.2.2. Mann–Kendall Z-score

In the Mann–Kendall test, the Z-score value is used to determine the statistical significance level of the trend [10,11,13]. The calculation is expressed by the following formula:

$$Z = \frac{3\tau\sqrt{n(n-1)}}{2\sqrt{2n+5}}$$

Here: n — the number of years in the time series;
t — the Mann–Kendall statistical parameter.
When interpreting the results:
$|Z| > 1.96$ — the trend is statistically significant at the 95 percent confidence level;
$|Z| \leq 1.96$ — the trend is not statistically significant.

2.2.3. Sen's Slope Estimator

The Sen's slope method is used to determine the rate of change in observed values within a time series and evaluates the annual increase or decrease in NDVI values [14,15,16]. The method is calculated using the following formula:

$$\text{Sen's Slope } (Q) = \text{Median}\left(\frac{x_j - x_i}{j - i}\right) \quad i<j$$

x_i, x_j — NDVI values,
$j - i$ — time interval (years).

For interpretation: $Q > 0$ — vegetation increase (greening), $Q < 0$ — vegetation decrease (browning).

3. Results and Discussion

Analysis of NDVI Trends: Statistical Approaches and Findings

Based on MODIS MOD13Q1.061 NDVI data for the years 2005–2025, the trend analyses revealed that the Nuratau Reserve ecosystem has undergone clearly detectable spatial and statistical dynamics over the past 20 years. The results of the Mann–Kendall (t), Z-score, and Sen's slope estimators confirmed that vegetation conditions are not uniform across the area, and that degradation processes are particularly dominant in the buffer zone of the reserve (Figure1).

Table 1 presents the minimum (min), maximum (max), mean, and standard deviation (std) values for the Mann–Kendall t, Z-score, and Sen's slope indicators.

Table 1. Statistical summary of Mann–Kendall tau, Z-score, and Sen's slope indicators for NDVI trend analysis in the Nurata State Nature Reserve.

Indikator	Minimum	Maksimum	Mean	Standard Deviation (STD)
Tau (τ)	-0.638	0.495	-0.040	- 0.129
Z-score	-2.781	2.15	-0.176	0.564
Sen's Slope	-0.025	0.023	-0.001	0.0006

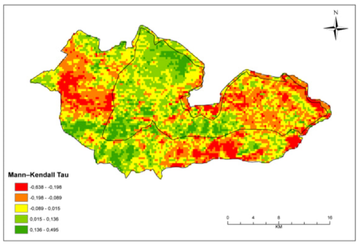

Figure 1. Mann-Kendall tau (τ) trend map of NDVI-based vegetation dynamics in the Nuratau Nature Reserve (2000–2025)

The Mann–Kendall t coefficient was used as the primary indicator for evaluating the direction of NDVI trends. The fluctuation of t values from −0.638 to 0.495 indicates the simultaneous presence of areas with both positive and negative trends across the region. However, the mean value of t = −0.040 shows that the overall vegetation condition is shifting in a negative direction, meaning that NDVI has been gradually declining over the past 20 years. The standard deviation (STD = 0.129) reflects strong spatial heterogeneity in the trends, indicating the sensitivity of the ecosystem to relief, microclimatic, and anthropogenic factors. The spatial MK map also shows that negative t values are predominantly concentrated in the buffer zone, with extensive areas along the perimeter highlighted in red. This decline in NDVI within these areas is closely associated with climate change and grazing pressure.

The Z-score statistic assessed the significance of the trends, showing a range from −2.781 to 2.15. The mean Z-score of −0.176 also indicates that the general statistical direction of NDVI is negative. Moreover, the standard deviation (STD = 0.564) confirms strong spatial variability in the trends. In particular, in the buffer zone where t is negative, Z-score values falling below −1.96 indicate that the NDVI decline is statistically significant. The Sen's slope estimator characterized the actual quantitative rate of vegetation change. The fluctuation of slope values from −0.025 to 0.023 demonstrates that the overall rate of NDVI change is very low. The mean Sen's slope value of −0.001 indicates that NDVI has been moving in a slow but consistent downward trend over the 20-year period. The standard deviation (STD = 0.0006) confirms that the rate of change is stable yet predominantly negative.

Overall, the statistical and spatial analyses for the period 2005–2025 show that the general dynamics of vegetation in the Nuratau State Nature Reserve are directed not toward stable recovery, but toward a consistent degradation process. Although positive or neutral tendencies were observed in the inner core zones, their spatial extent is limited and insufficient to compensate for the widespread negative trends across the reserve. Strong negative t values, negative Z-scores, and low Sen's slope values in the buffer zone identify this territory as the most vulnerable part of the ecosystem. These results indicate the presence of ecological stress factors such as high grazing pressure, soil compaction, moisture deficiency, and disruption of vegetation regeneration cycles. Consequently, the statistical and spatial characteristics of NDVI trends over the past 20 years scientifically demonstrate an intensification of anthropogenic pressure in the Nuratau Reserve ecosystem, a decline in vegetation stability due to climate change–related factors such as increased drought frequency and reduced precipitation, and the predominance of degradation processes particularly within the buffer zones.

Topographic Characteristics of the Nuratau State Nature Reserve

The elevation map generated from the 30 m SRTM DEM shows that the relief of the Nuratau Reserve is characterized by pronounced altitudinal variation. Elevation within the area starts from 460 meters and reaches up to 2169 meters at the highest points. The vertical zonation of the relief determines the formation of geomorphological units such as foothills, lower mountain belts, mid-mountain belts, and upper mountain ridge systems. The highest point of the range - Hayotboshi (2169 m) is located in the central part of the reserve (Figure 2).

The slope map indicates that most of the relief within the Nuratau State Nature Reserve consists of moderately steep and steep mountain slopes. Slope values range from 0° to 78.8°. The mean slope across the area is 23.94°, which reflects the

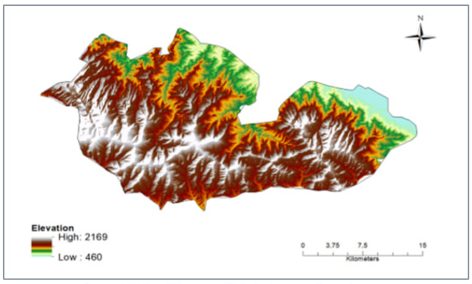

Figure 2. Elevation map of the Nuratau Nature Reserve

overall steepness of the reserve's terrain. Steep slopes (greater than 30°) account for approximately 35 percent of the area, moderately sloping terrains (15°–30°) comprise about 50 percent, gentle slopes (up to 15°) make up around 12 percent, while river valleys and mountain terraces constitute roughly 3 percent of the reserve's total area (Figure 3).

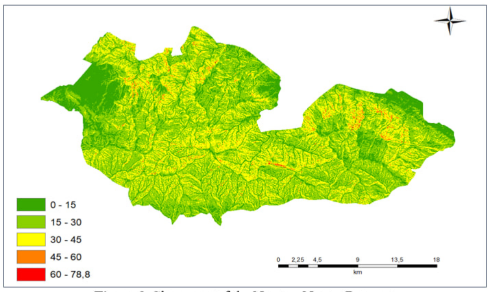

Figure 3. Slope map of the Nuratau Nature Reserve.

Aspect - a key topographic indicator describing the orientation of a terrain surface - directly influences the ecological conditions of the relief, landscape formation, and biological processes. Aspect determines the angle of solar radiation, soil temperature, moisture regime, evaporation, the rate of organic matter decomposition, and the ecological strategies of plant species. In mountainous areas such as the Nuratau Reserve, variation in aspect leads to the division of habitats into fine-scale microclimatic zones, which in turn results in pronounced landscape heterogeneity (Figure 4).

Discussion

The development of remote sensing technologies has significantly improved the efficiency of monitoring changes in vegetation cover. One of the most widely used indicators in this field is the NDVI (Normalized Difference Vegetation Index), which shows a high correlation with vegetation biomass, productivity, and leaf area index [17].

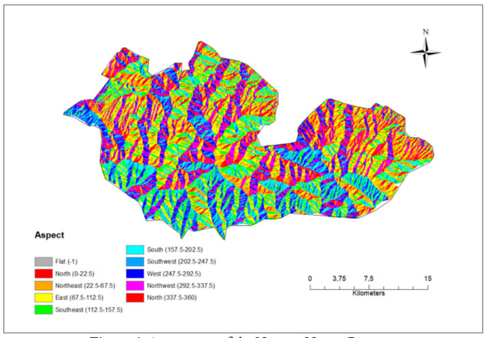

Figure 4. Aspect map of the Nuratau Nature Reserve.

NDVI enables accurate assessment of vegetation condition and greenness and is successfully applied in forests, grasslands, semi-desert and desert landscapes, particularly in arid and semi-arid regions [18,19,20,21].

The analysis conducted for the Nuratau State Nature Reserve over the period 2005–2025 showed that the overall NDVI trend exhibits a weak declining tendency (Sen's slope = −0.001). This finding is consistent with the low NDVI values (< 0.27) reported for Central and Western Asia by Fan et al. (2020) and Yang et al. (2020). Such tendencies are typically associated with anthropogenic pressure, climate change, and limited hydrological resources. The spatial analysis of NDVI trends revealed that although some localized areas exhibited vegetation improvement, the overall decline remained dominant. This observation aligns with findings by Buitenwerf et al. (2015) and Xu et al. (2019), who concluded that precipitation is the primary water source for vegetation, and that NDVI tends to decrease sharply under drought conditions. The results also indicate that the Nuratau Reserve features a complex and highly differentiated topographic structure. The sharp variation in elevation from 460 to 2169 meters forms a clear pattern of vertical zonation and determines the mosaic configuration of geomorphological units in the area. The analysis of slope gradients confirmed that most of the terrain consists of moderately steep and steep slopes, while flat areas are limited. These characteristics clearly distinguish the natural morphological differences among foothill, low-mountain, and mid-mountain zones.

Variation in aspect further demonstrates that differences in exposure to solar radiation and slope orientation create diverse microenvironmental conditions. The distribution of slopes facing north, south, east, and west reaffirms the overall geomorphological complexity of the Nuratau range. Overall, the topographic findings derived from elevation, slope, and aspect confirm that the reserve exhibits a structurally complex relief with a highly mosaic vertical and horizontal configuration.

Conclusion

In this study, the topographic characteristics and vegetation (NDVI) dynamics of the Nuratau State Nature Reserve for the period 2005–2025 were comprehensively analyzed using remote sensing (MODIS NDVI) and DEM data. Elevation, slope, and aspect maps generated from the 30 m SRTM DEM demonstrated that the reserve's relief exhibits sharp altitudinal variation between 460 and 2169 meters, a high proportion of steep slopes, and a strongly mosaic topographic structure. This confirms a distinct vertical and horizontal differentiation of geomorphological conditions.

Annual NDVI time series for 2005–2025, derived from the MOD13Q1.061 product, were analyzed using the Mann–Kendall t test, Sen's slope estimator, and Z-score statistics. The statistical results showed substantial spatial heterogeneity in NDVI trends, while the mean values indicated a generally weak negative tendency in vegetation condition ($t = -0.040$; Sen's slope $= -0.001$; Z-score $= -0.176$). Spatial analysis revealed that although positive or neutral trends occurred primarily within the inner core zones, negative and statistically significant regression tendencies were dominant in the buffer zone. This zone stands out as the most vulnerable part of the reserve, characterized by NDVI decline, grazing pressure, and higher anthropogenic load. Overall, the findings indicate that long-term vegetation stability in the Nuratau Reserve has weakened under the influence of complex topographic conditions and climatic factors. The results provide an important scientific basis for improving vegetation monitoring in mountainous protected areas, managing grazing pressure within buffer zones, and developing strategies for sustainable landscape management.

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References

1. Rousta I., Mansourmoghaddam M., Olafsson H., Krzyszczak J., Baranowski P., Zhang H., Tkaczyk P. Analysis of the recent trends in vegetation dynamics and its relationship with climatological factors using remote sensing data for Caspian Sea watersheds in Iran // International Agrophysics. – 2022. – Vol. 36, No. 3. – P. 139–153. – DOI: https://doi.org/10.31545/intagr/150020

2. Hassan, H. M., and Dakheel, H. S. (2023). Using the Normalized Difference Vegetation Index (NDVI) to study the change of vegetation cover in Thi-Qar Governorate, southern Iraq for the period from 1990–2022. Texas Journal of Agriculture and Biological Sciences, 13, 72–85.

3. Zhan, Z.-Z., Liu, H.-B., Li, H.-M., and Zhong, B. (2012). The relationship between NDVI and terrain factors: A case study of Chongqing. Procedia Environmental Sciences, 12, 765–771. https://doi.org/10.1016/j.proenv.2012.01.347

4. Walsh, S. J., Crawford, T. W., Welsh, W. F., and Crews, K. (2001). A multiscale analysis of LULC and NDVI variation in Nang Rong district, northeast Thailand. Agriculture, Ecosystems and Environment, 85(1), 47–64. https://doi.org/10.1016/S0167-8809(01)00202-X

5. Lau, C.-C. (2009, January 9). Geomorphologic distribution of normalized difference vegetation index. Geospatial World

6. Mustafayev, I. M., Beshko, N. Y., and Iminova, M. M. (2019). Checklist of ascomycetous microfungi of the Nuratau Nature Reserve (Uzbekistan). Novosti sistematiki nizshikh rastenii, 53(2), 315–324. https://doi.org/10.31111/nsnr/2019.53.2.315

7. Beshko N.Yu. (2020) Flora of Central Asia: the Nuratau Mountains. Korea National Arboretum, Pocheon. 20 p.

8. Volis, S., and Beshko, N. Yu. (2023). How to preserve narrow endemics in view of climate

change? The Nuratau Mountains as the case. Plant Diversity of Central Asia, 2(2), 83–102. https://doi.org/10.54981/PDCA/vol2$_i$ss2/a3

8. Kh.Sh. Abulfayzov, K.O. Fayziev, J.A. Isomov, B.Sh. Khabibullaev, Kh.F. Shomurodov, N.Yu. Beshko.DYNAMICS OF LONG-TERM CLIMATIC DATA IN CENTRAL UZBEKISTAN BASED ON THE EXAMPLE OF THE NURATA STATE NATURE RESERVE.In: Материалы Международной научно-практической конференции на тему: «Проблемы современной биологии в устойчивом развитии, вопросы борьбы с изменением климата и пути их решения» (17–18 октября 2025 года). Низомий номидаги Ўзбекистон миллий педагогика университети.Тошкент, 2025.

9. Mann, H. B. (1945). Nonparametric tests against trend. Econometrica, 13(3), 245–259. https://doi.org/10.2307/1907187 11. Kendall, M. G. (1975). Rank Correlation Methods (4th ed.). London: Charles Griffin.

10. Jiang, W., Yuan, L., Wang, W., Cao, R., Zhang, Y., and Shen, W. (2015). Spatio-temporal analysis of vegetation variation in the Yellow River Basin. Ecological Indicators, 51, 117–126. https://doi.org/10.1016/j.ecolind.2014.07.031

11. Helsel, D.R. Hirsch, R.M. (2002). Statistical Methods in Water Resources. U.S. Geological Survey.

12. Sen, P. K. (1968). Estimates of the regression coefficient based on Kendall's tau. Journal of the American Statistical Association, 63(324), 1379–1389. https://doi.org/10.1080/01621459.1968.10480934

13. Wang, K., Xu, M., Wang, S., Wang, L., Tian, H., Boonprong, S., Gao, X., Yang, X., Guo, H., Li, J., Yang, Y., Hu, R., Zhang, Y., Cao, C. (2025). Spatiotemporal patterns and driving factors of NDVI changes in the central and Western Asia economic corridor over the past decade. Frontiers in Environmental Science, 13, Article 1546190. https://doi.org/10.3389/fenvs.2025.1546190

14. Cai, B., and Yu, R. (2009). Advance and evaluation in the long time series vegetation trends research based on remote sensing. Journal of Remote Sensing, 13(6), 1170–1186.

15. Cao, C. (2013). Diagnosis of environmental health by remote sensing. Science Press.

16. Bashir, B., Cao, C., Naeem, S., Joharestani, M. Z., Bo, X., Afzal, H., Jamal, K., and Mumtaz, F. (2020). Spatio-Temporal Vegetation Dynamic and Persistence under Climatic and Anthropogenic Factors. Remote Sensing, 12(16), 2612. https://doi.org/10.3390/rs12162612

17. Xie, B., Cao, C., Xu, M., Duerler, R. S., Yang, X., Bashir, B., Chen, Y., and Wang, K. (2021). Analysis of Regional Distribution of Tree Species Using Multi-Seasonal Sentinel-1and2 Imagery within Google Earth Engine. Forests, 12(5), 565. https://doi.org/10.3390/f12050565

18. Wang, K., Cao, C., Xie, B., Xu, M., Yang, X., Guo, H., and Duerler, R. S. (2022). Analysis of the Spatial and Temporal Evolution Patterns of Grassland Health and Its Driving Factors in Xilingol. Remote Sensing, 14(20), 5179. https://doi.org/10.3390/rs14205179

19. Gao, X., Cao, C., Xu, M., Yang, X., Li, J., Duerler, R. S., Wang, K., Guo, H., and Yang, Y. (2023). Ecological risk assessment of grassland vegetation change based on Bayesian model in Xilin Gol League, China. Ecological Indicators, 111199. https://doi.org/10.1016/j.ecolind.2023.111199

20. Didan, K. (2021). MODIS/Terra Vegetation Indices 16-Day L3 Global 250m SIN Grid V061 [Data set]. NASA Land Processes Distributed Active Archive Center. https://doi.org/10.5067/MODIS/MOD13Q1.061 Date Accessed: 2025-11-24