Postprint of Eco-environmental Quality Changes in the Babusha Region of Gulang County

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Abstract

The Babusha region is situated at the junction of the Qinghai-Tibet Plateau ecological barrier and the northern sand prevention belt, constituting the frontline defense against the southward encroachment of the Tengger Desert. Evaluating changes in its ecological environment quality holds guiding significance for assessing regional sand control effectiveness and advancing the "Three-North" Shelterbelt Program battle. Based on Google Earth Engine (GEE) platform data, this study examines land use pattern changes in the Babusha region from 1986 to 2021, and comprehensively assesses spatiotemporal variations in regional ecological environment quality using the Normalized Difference Vegetation Index (NDVI), Desertification Index (DI), and Remote Sensing Ecological Index (RSEI). The results indicate: (1) Temporally, desert area in the Babusha region continuously decreased, grassland area continuously increased, and vegetation coverage increased. From 1986 to 2021, NDVI and RSEI exhibited fluctuating upward trends, with NDVI rising from 0.14 to 0.31, representing an increase of more than twofold; RSEI increased from 0.22 to 0.24, with a growth rate of 9.39%; DI showed a fluctuating downward trend, decreasing from 0.79 to 0.57, with a cumulative reduction of 27.85%. (2) Spatially, high-value areas of NDVI and RSEI were concentrated in the southern and northwestern parts of the study area, dominated by forestland and cropland, while low-value areas were distributed in the northern part, dominated by extremely low-coverage vegetation and desert. (3) In the study area, NDVI and RSEI trends were characterized by non-significant/significant increases, while DI trends were characterized by non-significant decreases. Specifically, areas with non-significant and significant NDVI increases accounted for 12.12% and 61.10%, respectively; areas with non-significant and significant RSEI increases accounted for 5.06% and 38.63%, respectively. Regions with improved ecological environment quality were concentrated in the northwestern and southeastern parts with greater human activity. From 1986 to 2021, vegetation coverage in the Babusha region increased significantly, ecological environment quality continuously improved,

sand control achievements were remarkable, and a replicable Babusha model has been established.

Full Text

Changes in Ecological Environment Quality in the Babusha Region of Gulang County

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Abstract

Located at the convergence zone of the Qinghai-Xizang Plateau Ecological Barrier and the Northern Sand Control Belt, the Babusha region serves as a frontline defense against the southward encroachment of the Tengger Desert. Assessing changes in its ecological environment quality holds significant value for evaluating regional desertification control effectiveness and advancing the Three-North Shelter Forest Program. This study utilized Google Earth Engine platform data to investigate land use pattern changes in the Babusha region from 1986 to 2021, employing the Normalized Difference Vegetation Index (NDVI), Desertification Index (DI), and Remote Sensing Ecological Index (RSEI) to conduct a comprehensive assessment of spatiotemporal variations in regional ecological environment quality. The results indicate: (1) Temporally, desert area in the Babusha region has continuously decreased while grassland area has progressively increased, with vegetation coverage showing clear improvement. From 1986 to 2021, NDVI and RSEI exhibited fluctuating upward trends, with NDVI increasing from 0.14 to 0.31 (a >50% increase) and RSEI rising from 0.22 to 0.24 (a 9.39% increase). Conversely, DI showed a fluctuating downward trend, decreasing from 0.79 to 0.57 with a cumulative reduction of 27.85%. (2) Spatially, high-value areas of NDVI and RSEI were concentrated in the southern and northwestern parts of the study area, dominated by woodland and cultivated land, whereas low-value areas were distributed in the northern region characterized by extremely low vegetation coverage and desert. (3) Trend analysis revealed that NDVI and RSEI changes were primarily characterized by nonsignificant or significant increases, while DI changes were mainly nonsignificant decreases. Specifically, 12.12% and 61.10% of the study area showed nonsignificant and significant increases in NDVI, respectively, while 5.06% and 38.63% exhibited nonsignificant and significant increases in RSEI. Areas of ecological improvement were concentrated in the northwestern and southeastern regions with higher levels of human activity. From 1986 to 2021, the Babusha region demonstrated marked vegetation restoration, sustained improvement in

ecological environment quality, and significantly effective desertification control, facilitating the establishment of a replicable "Babusha Model."

Keywords: ecological environment quality; vegetation coverage; remote sensing ecological index (RSEI); spatiotemporal variation; Babusha

1 Introduction

Land desertification represents one of the most critical environmental challenges facing humanity, with China being among the most severely affected countries worldwide. Ecological restoration of desertified land is essential for ensuring regional ecological security and sustainable socioeconomic development. As a key province in northwestern inland China, Gansu faces severe land desertification that not only damages the ecological environment but also exacerbates poverty, posing a major threat to sustainable provincial development. China has consistently prioritized desertification control, with the Three-North Shelter Forest Program notably curbing the expansion of desertified areas and achieving remarkable success. On June 6, 2023, President Xi Jinping inspected Bayannur in Inner Mongolia, deploying three landmark battles for the Three-North Project and setting the goal of creating new miracles in desertification control in the new era. This strategic deployment aligns closely with ecological governance practices in the Babusha region, providing crucial direction and policy support for local desertification control efforts and holding profound significance for enhancing regional ecological environment quality and promoting sustainable development.

Remote sensing technology offers significant advantages for large-scale, long-term ecological monitoring compared to field surveys. Remote sensing data can effectively evaluate control effectiveness, and various ecological environment quality indices derived from remote sensing imagery—such as Normalized Difference Vegetation Index (NDVI), Desertification Index (DI), and Remote Sensing Ecological Index (RSEI)—provide objective metrics for assessment. NDVI serves as a key indicator for quantifying vegetation cover, reflecting vegetation greenness and coverage. DI, constructed from surface albedo and vegetation indices, effectively characterizes desertification degree. RSEI, calculated through principal component analysis of multiple ecological indices, systematically measures regional ecological quality dynamics and is suitable for large-scale, long-term monitoring needs.

The Google Earth Engine platform integrates multi-source satellite data and geographic datasets, supporting large-scale time-series analysis and demonstrating remarkable effectiveness in vegetation dynamic monitoring. Previous studies have utilized this platform to investigate vegetation coverage evolution and driving factors in the Loess Plateau and Naiman Banner. As a crucial component of China' s "Two Screens and Three Belts" ecological security pattern, the Babusha region represents a key battlefield in the Hexi Corridor-Taklamakan Desert edge blocking battle and historically the largest wind-sand passage in

Gulang County. In 1981, Gulang County implemented a "government subsidy, individual contract" policy in Babusha, establishing the Babusha Forest Farm. Through three generations of sand fixation and afforestation efforts, the farm has completed sand control and afforestation on 1.5×10^{4} hm^2 and managed 2.5×10^{4} hm^2 of enclosed sand areas for forest and grassland, effectively controlling land desertification on the northern oasis edge of Gulang and becoming a national model for desertification control. This study selects the Babusha Forest Farm and its surrounding areas as the research region, using remote sensing data to analyze vegetation dynamics and ecological environment quality changes, aiming to understand trends and patterns of sand-fixing vegetation, scientifically evaluate desertification control effectiveness, and provide guidance for the Hexi Corridor-Taklamakan Desert edge blocking battle and ecological construction projects in surrounding areas.

1.1 Study Area Overview

The study area encompasses the Babusha region in northern Gulang County (including Babusha Forest Farm and surrounding areas), located at 37°23 -37°55 N, 102°57 -103°50 E on the southern edge of the Tengger Desert. The terrain slopes from high in the south to low in the north. Geographically unique, it borders Dajing Town to the east, Tumen Town to the west, extends to the Ming Great Wall at the foot of the Qilian Mountains in the south, and reaches deep into the Tengger Desert in the north. The climate is temperate continental arid, with large daily and annual temperature variations, annual precipitation of approximately 180 mm (unevenly distributed), strong solar radiation, and high evaporation. The groundwater table depth exceeds 15 m. Soils are primarily aeolian sandy soils, with landforms including mobile dunes, semi-fixed and fixed dunes, dry riverbeds, and wind-eroded sandy lands. Zonal vegetation consists of steppe-desert communities, with main natural shrubs including *Artemisia ordosica*, *Zygophyllum xanthoxylum*, *Krascheninnikovia ceratoides*, and *Reaumuria songarica*, and major natural herbaceous plants including *Stipa breviflora*, *Allium mongolicum*, *Agriophyllum squarrosum*, *Eragrostis pilosa*, and *Bassia dasyphylla*. Artificially planted shrubs include *Corethrodendron scoparium*, *Haloxylon ammodendron*, *Caragana korshinskii*, and *Tamarix chinensis*.

1.2 Data and Methods

1.2.1 Data Acquisition This study employed NDVI, DI, and RSEI as evaluation indicators to reflect spatiotemporal changes in ecological environment quality in the Babusha region. Remote image extraction and processing were completed on the Google Earth Engine cloud platform (https://code.earthengine.google.com/). Landsat TM/ETM+/OLI remote sensing images were obtained from the United States Geological Survey (https://earthexplorer.usgs.gov/), with spatial resolution of 30 m. The platform was used to screen images with cloud cover below 10% for calculating NDVI, DI, and RSEI. Land use data adopted the annual land cover dataset

CLCD (China Land Cover Dataset) from Wuhan University, which currently contains China' s annual land cover information from 1990 to 2020 with 30 m spatial resolution. The dataset was imported into GEE, and land use information for the Babusha region was extracted according to defined boundaries.

1.2.2 Evaluation Indicator Calculation Methods (1) Normalized Difference Vegetation Index (NDVI)

NDVI is one of the most commonly used vegetation indices and an important indicator for measuring ecosystem health and vegetation coverage. It reflects surface vegetation health and density through reflectance differences in near-infrared (NIR) and red (RED) bands:

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

where NIR represents near-infrared band reflectance and RED represents red band reflectance. The value ranges from -1 to 1, with higher values indicating denser, healthier vegetation. When NDVI $>$ 0.3, an area has a high probability of being vegetated. To reflect NDVI spatiotemporal distribution patterns, values were classified into five levels: extremely low (NDVI $\leq$ 0), low (0 $<$ NDVI $\leq$ 0.3), medium (0.30 $<$ NDVI $\leq$ 0.5), high (0.5 $<$ NDVI $\leq$ 0.7), and extremely high (NDVI $>$ 0.7).

(2) Desertification Index (DI)

DI quantifies the degree or risk of land degradation to desert status, comprehensively reflecting ecosystem vulnerability and human activity impacts. This study used surface albedo (Albedo) and Soil Adjusted Vegetation Index (SAVI) to calculate DI:

$$DI = Albedo - SAVI + 0.130$$

$$Albedo = 0.356 \times BLUE + 0.130 \times RED + 0.373 \times NIR + 0.085 \times SWIR + 0.072$$

$$SAVI = \frac{NIR - RED}{NIR + RED + 0.5} \times (1 + 0.5)$$

where BLUE, RED, NIR, and SWIR represent blue, red, near-infrared, and short-wave infrared bands, respectively. Based on DI values, desertification was classified into: non-desertified (DI $\leq$ 0.1), lightly desertified (0.1 $<$ DI $\leq$ 0.3), moderately desertified (0.3 $<$ DI $\leq$ 0.5), and severely desertified (DI $\geq$ 0.5).

(3) Remote Sensing Ecological Index (RSEI)

RSEI is derived from principal component transformation of four ecological indices, systematically measuring regional ecological quality dynamics and suitable for large-scale, long-term monitoring:

$$RSEI = f(Greenness, Wetness, Dryness, Heat)$$

where Greenness, Wetness, Dryness, and Heat correspond to NDVI, Normalized Difference Water Index, Normalized Difference Soil Index, and Land Surface Temperature, respectively. RSEI values were classified into five quality levels: poor (RSEI ≤ 0.2), relatively poor ($0.2 <$ RSEI ≤ 0.4), medium ($0.4 <$ RSEI ≤ 0.6), good ($0.6 <$ RSEI ≤ 0.8), and excellent (RSEI ≥ 0.8).

(4) Slope Trend Analysis
The Slope trend analysis method uses unary linear regression to fit temporal trends in multi-year remote sensing index sequences, effectively eliminating interference from sporadic factors to more accurately reflect long-term change characteristics. The calculation formula is:

$$\theta_{Slope} = \frac{n\sum_{i=1}^{n}(i \cdot x_i) - \sum_{i=1}^{n} i \sum_{i=1}^{n} x_i}{n\sum_{i=1}^{n} i^2 - (\sum_{i=1}^{n} i)^2}$$

where n represents time series length, i represents the i-th year, and x_i represents the index value. A positive Slope indicates an upward trend over time, while a negative Slope indicates a downward trend.

2 Results

2.1 Land Use Type Changes From 1986 to 2021, the main land use types in the Babusha region were grassland and desert, with woodland and construction land occupying relatively small proportions. Desert area continuously decreased (Fig. [Figure 1226: see original paper]), dropping from 1226.16 km^2 to 637.08 km^2, while grassland and cultivated land areas continuously increased. Grassland showed the largest increase, growing by 403.97 km^2 (20.52% increase). Spatially, cultivated land was primarily distributed in the northwestern and southern parts of Babusha, with fragmentation gradually decreasing and spatial agglomeration becoming significant. Desert was mainly distributed in the central and northern regions, with its range continuously compressed. By the end of the study period, the central desert area had nearly disappeared. Desert reduction exhibited a differentiated pattern of "rapid disappearance in the center—slow contraction in the north," reflecting the effectiveness of integrated shrub-grass and engineering sand fixation measures. Over the past 35 years, the ecological environment in the Babusha region has improved significantly, with remarkable desertification control effects.

2.2 Temporal Change Characteristics of Ecological Environment Quality Indices From 1986 to 2021, NDVI in the Babusha region showed a clear fluctuating upward trend (Fig. [Figure 4: see original paper]), increasing from 0.14 to 0.31 with a growth rate of 129.45% and a dynamic degree of 8.24%. The 2000–2009 period was the most significant growth phase, with the dynamic degree exceeding 50.20% of the total, indicating accelerated control processes. Vegetation coverage increased substantially, with the most obvious growth occurring from 2010 to 2021. During 1986–1999, NDVI was in a gradual improvement stage with stable annual decline rates, coupled with steady increases in RSEI. The gradual recovery of sand-fixing vegetation during this period effectively promoted desertification improvement.

RSEI showed an overall "slow growth with fluctuations" trend (Fig. [Figure 4: see original paper]), increasing from 0.22 to 0.24 with a limited amplitude of 9.39%. Two notable decline periods occurred in 1993 and 2001, likely caused by human disturbances (such as periodic overgrazing) and drought events (e.g., the major drought in Northwest China in 2001). In contrast, DI values showed a relatively stable decreasing trend, declining from 0.79 to 0.57 with a cumulative reduction of 27.85%. This stable trend demonstrates the positive effects of ecological construction measures on environmental quality improvement. The 2010–2021 period showed a significant DI decline with a dynamic degree of -2.49%, indicating accelerated control processes.

2.3 Spatial Change Characteristics of Ecological Environment Quality Indices **NDVI Spatial Distribution:** In 1986, high-value areas were distributed in the western and southeastern parts of Babusha, with extremely low and high values accounting for 92.16% and 4.51%, respectively, indicating severe desertification and extremely low vegetation coverage. By 2021, the low-value area proportion decreased to 85.83%, medium-value areas increased from 4.27% to 7.40%, and high-value areas grew from 0.02% to 1.35%. Geographically, high-value areas gradually connected and formed patches, particularly in the southeastern artificial forest belt and western oasis periphery. Low-value areas decreased by approximately 7.84%, with some regions degrading to extremely low values due to intensified desertification, while others were transformed to medium-high values through control measures.

DI Spatial Distribution: In 1986, low-value areas (non-desertified and lightly desertified) dominated, accounting for 54.23% of the region, while severely desertified areas accounted for 1.64%. By 2021, severely desertified areas decreased to 0.03%, and lightly desertified areas rapidly increased from 5.67% to 9.51%. High-value areas (good and excellent) showed high overlap with NDVI high-value areas (high vegetation coverage), indicating a positive correlation between RSEI and vegetation coverage. The 2000–2009 period showed significant expansion of low and extremely low vegetation coverage areas, with initial control effects but no large-scale connectivity. The 2010–2021 period witnessed continuous reduction in desertified areas and rapid expansion of non-desertified and lightly desertified areas, with non-desertified patches becoming continuous.

RSEI Spatial Distribution: In 1986, low-value areas dominated with a proportion of 89.98%, while excellent areas accounted for only 0.31%. By 2021, excellent areas increased to 5.73%, good areas grew from 3.18% to 9.28%, and medium areas decreased from 6.16% to 5.05%. Geographically, high-value areas formed continuous patches within the western oasis, with significantly increased density in the southeastern forest-cultivated land overlay zone. The spatial distribution showed a significant negative correlation with DI, with severe desertification areas corresponding to low RSEI values. After 2010, excellent areas increased substantially, indicating that newly added woodland and cultivated land (human intervention) enhanced the stability of medium-high vegetation coverage.

2.4 Trends in Ecological Environment Quality Changes From 1986 to 2021, vegetation coverage in the Babusha region showed an overall increasing trend, with ecological environment quality 明显改善. NDVI trend analysis revealed that 12.12% and 61.10% of the area exhibited nonsignificant and significant increases, respectively, while basic unchanged, nonsignificant decrease, and significant decrease areas accounted for 14.94%, 11.22%, and 0.09%, respectively. Areas with significant increases were concentrated in the northwestern and southeastern regions with intensive human activities, while areas with decreasing trends were mainly located in the northeastern and southwestern regions near wind-sand passages and arid townships.

DI trend analysis showed that 5.06% and 38.63% of the area experienced nonsignificant and significant decreases, respectively, indicating desertification range contraction and overall stable and improving ecological environment. The synchronous occurrence of significant DI decrease and significant NDVI increase demonstrates that high vegetation coverage effectively suppresses desertification.

RSEI trend analysis indicated that 7.75% of the area showed significant increases, primarily distributed in cultivated land regions, with comprehensive ecological quality improvement. Nonsignificant increase areas accounted for 47.28%, where ecological quality improved only slightly, possibly due to insufficient ecological functions of low-coverage vegetation. Basic unchanged, nonsignificant decrease, and significant decrease areas accounted for 30.13%, 14.66%, and 0.19%, respectively, mainly located in the northeastern and southwestern regions, corresponding to DI trend patterns.

3 Discussion

3.1 Dynamic Changes in Ecological Environment Quality in the Babusha Region Over the past 35 years, sand-fixing vegetation in the Babusha region has continuously recovered, desertified land area has persistently decreased, while grassland and cultivated land areas have continuously increased. NDVI showed a fluctuating upward trend with an average annual growth rate of 2.40%, indicating stable and improving vegetation growth. These findings align with previous research showing that Gulang County has completed sand control afforestation on 0.62$\times10^{4}$ hm^2 since 2010, establishing a national carbon sink forest base of 133.33 hm^2. DI decreased more significantly, with desertified area substantially reduced. RSEI showed a trend of initial decrease followed by increase, then maintaining dynamic equilibrium, with overall upward trend from 2010. The overall vegetation coverage in the Babusha region from 1986 to 2021 showed a fluctuating upward trend, consistent with research by Li Jialin. In summary, the environmental quality of the Babusha region has improved markedly with significant desertification control achievements. However, attention must be paid to potential ecological risks from agricultural land expansion and excessive afforestation in this water-scarce region.

3.2 Causes of Ecological Environment Changes in the Babusha Region
The main factors influencing vegetation coverage changes are temperature and precipitation, with precipitation playing a decisive role in the growth of natural desert vegetation. Gulang County has consistently regarded desertification control as a long-term, strategic task. Relying on national key ecological function zone transfer payments, enclosed protection zone construction for desertified land, and provincial desertification control projects, sand control efforts in the Babusha region on the southern edge of the Tengger Desert have effectively controlled wind-sand passages and increased vegetation coverage. From 1986 to 2021, cumulative sand control afforestation reached 1.5$\times10^{4}$ hm^2, with enclosed sand area for forest and grassland management reaching 2.5$\times10^{4}$ hm^2. Trend analysis shows that areas with increasing vegetation coverage spatial trends correspond to key desertification control and enclosed protection zones, indicating that large-scale human intervention provided strong support for vegetation recovery and environmental improvement. The desertification control achievements in Babusha also depend on active public participation, with local residents and volunteers engaging in afforestation activities that contributed significantly to vegetation coverage increases.

4 Conclusion

Ecological environment quality plays a crucial role in evaluating desertification control effectiveness. From 1986 to 2021, land types in the Babusha region remained dominated by desert and grassland, with desert area continuously decreasing at an average annual rate of 0.76% and grassland area continuously increasing at an average annual rate of 0.59%. NDVI and RSEI showed overall upward trends with average annual growth rates of 2.40% and 0.28%, respectively, while DI decreased annually by 0.90%, indicating continuously weakening desertification and increasing vegetation coverage. Spatially, 12.12% and 61.10% of the area showed nonsignificant and significant increases in NDVI, respectively, while 5.06% and 38.63% exhibited nonsignificant and significant increases in RSEI, respectively. Areas of ecological environment quality improvement were concentrated in the northwestern and southeastern regions with intensive human activity. Evidently, from 1986 to 2021, vegetation coverage in the Babusha region increased substantially, ecological environment quality continuously improved, desertification control achieved remarkable effectiveness, and a replicable "Babusha Model" was established.

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Note: Figure translations are in progress. See original paper for figures.