Postprint: Physicochemical Properties and Quality Status of Surface Soil in the Gobi Desert of Hami City

Authors: Zhang Jiudan, Zhang Aiguo, Jin Jingyu, Liu Shuaiqi, Wu Han, Li Junli

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Abstract

Soil quality in the Gobi desert is of significant importance to surface vegetation cover and ecological restoration. This study collected 56 typical soil samples from the Gobi region of Hami City, analyzing soil texture, salinity, and nutrient characteristics through eight indicators including soil water content, soil bulk density, pH, total salt, organic matter, total nitrogen, total phosphorus, and total potassium, and constructed a Soil Quality Index (SQI) for comprehensive evaluation of soil quality. Results indicate that soil quality in the Gobi region of Hami City is generally poor, characterized by high gravel coverage on the Gobi surface, low soil water content, severe salinization, and deficient nutrient conditions. Spatially, the average soil quality in Yiwu County and Barkol Kazakh Autonomous County is slightly higher than that in Yizhou District, particularly in transitional zones between Gobi margins and other land-use types where soil quality is comparatively higher. Overall, soil quality across the entire Gobi region of Hami City and its various sub-regions remains at a low level (SQI ranging from 0.4 to 0.5), exhibiting a decreasing trend from north to south. The study underscores the necessity of enhancing environmental protection and sustainable development measures to mitigate the impacts of intensifying human activities on the ecological environment.

Full Text

Physicochemical characteristics and quality assessment of Gobi soils, Hami City, China

ZHANG Jiudan[12], **ZHANG Aiguo**[3], **JIN Jingyu**[124], **LIU Shuaiqi**[12], **WU Han**[12], **LI Junli**[1]

[1]State Key Laboratory of Desert and Oasis Ecology, Key Laboratory of Ecological Safety and Sustainable Development in Arid Lands, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, Xinjiang, China
[2]University of Chinese Academy of Sciences, Beijing 100049, China
[3]Nanjing Institute of Environmental Sciences, Ministry of Ecology and Environment, Nanjing 210042, Jiangsu, China
[4]Survey and Mapping Achievement Center of Xinjiang, Urumqi 830002, Xinjiang, China

Abstract

Soil quality is essential for vegetation cover and ecological recovery in Gobi zones. In this study, we analyzed 56 typical soil samples from the Hami Gobi to evaluate soil texture, salinity, and nutrient characteristics using eight indices, including soil moisture content, soil bulk density, pH, total salt content, organic matter, total nitrogen, total phosphorus, and total potassium. Based on these indices, we constructed a soil quality index (SQI) for a comprehensive soil quality assessment. The results revealed that soil quality in the Hami Gobi region was generally low, characterized by high gravel cover, low moisture content, severe salinization, and nutrient deficiency. The average soil quality in the Yiwu and Barkol regions was slightly higher than in the Yizhou zone, with better soil quality observed in areas where Gobi transitions into other land types. Overall, the SQI ranged from 0.4 to 0.5 across the Hami Gobi region and its subregions, showing a decreasing trend from north to south. This study highlights the urgent need for enhanced environmental protection and sustainable development strategies to cope with the impact of increasing human activities on the ecosystem.

Keywords: Gobi; soil nutrients; gravel cover; salinization; soil quality index; Hami City

Introduction

Gobi is a unique geographic landscape formed under arid and hyper-arid climatic conditions, characterized by gravel-covered surfaces. The gravel armor layer on Gobi surfaces effectively reduces wind erosion and sand movement, playing a critical role in soil conservation and sand control. Hami City represents a major distribution area of black Gobi in China, where the surface is covered with extensive gravel, sand, and saline-alkali patches, with sparse desert vegetation distributed along dry riverbeds and low-lying areas.

Extensive research has been conducted on soil physicochemical characteristics and quality assessment for ecosystems such as croplands, grasslands, and forests, including analyses of soil property features, soil microbial community distribution, impacts of environmental changes on soil properties, and quality assessments of different soil types. However, due to unique natural environments and geological conditions, Gobi soils differ significantly from other soil types. Current research on Gobi soils has focused on soil formation and development, surface gravel cover and sediment characteristics, physicochemical properties, soil wind erosion, and spatiotemporal vegetation distribution, yet comprehensive assessments of Gobi soil quality remain insufficient.

With increasing human activities, particularly the construction of new energy bases, mineral development, and road construction, the Gobi gravel armor layer is being crushed and destroyed, leading to a series of environmental problems including exposure of underlying soils, increased wind-blown sand, and Gobi vegetation degradation. Analyzing the physicochemical properties of Gobi soils and evaluating soil quality levels helps understand soil nutrient status and spatial differences, which is crucial for ecological restoration in Gobi regions.

Soil serves as the material basis for vegetation growth and terrestrial ecosystem maintenance, with soil quality representing a comprehensive indicator of soil fertility and ecological health. Soil quality is primarily assessed using the Soil Quality Index (SQI), a comprehensive index constructed from multiple physicochemical indicators that can be applied across different regions, scales, and ecosystem types. Key physicochemical indicators include soil moisture content, soil bulk density, pH, total salt, organic matter, total nitrogen, total phosphorus, and total potassium.

This study investigates the Gobi region of Hami City, Xinjiang, by collecting typical soil samples to obtain information on surface structure, physicochemical characteristics, and nutrient status of Gobi soils. We constructed a comprehensive quality index based on soil physicochemical properties to analyze spatial characteristics of Gobi soil quality and enhance understanding of Gobi soil properties, providing a scientific basis for improving and protecting Gobi ecosystems.

1.1 Study Area Overview

Hami City is located in the eastern part of Xinjiang, China (40°49 42 –45°08 56 N, 91°08 56 –96°24 55 E). The Gobi areas are primarily distributed across alluvial fans and plains at the northern and southern foothills of the Tianshan Mountains. The region experiences a typical continental arid climate with hot summers and cold, dry winters. The annual average temperature is approximately 9–11°C, with annual precipitation of 50–100 mm and evaporation rates reaching as high as 2000 mm.

The Gobi landforms in Hami are dominated by accumulation-type Gobi, supplemented by erosion-type Gobi. Accumulation-type Gobi is distributed in piedmont alluvial fan areas, while erosion-type Gobi occurs in rocky plains or gravel-covered plains with residual hills and island mountains. The main soil types include brown desert soil, gray-brown desert soil, brown calcic soil, and lithosol. Vegetation consists primarily of drought-tolerant desert plants such as *Ephedra przewalskii*, *Anabasis aphylla*, and camel thorn, distributed in strips along dry riverbeds and phreatic overflow zones with extremely low coverage. Due to the extremely arid climate, scarce surface water resources, and strong potential evaporation, soil salinity is high. Despite the harsh Gobi ecological environment, Hami possesses superior mineral-forming geological conditions, serving as a midstream base for coal, petroleum, and metal mineral resources in Xinjiang, with climate conditions suitable for wind and solar energy development.

1.2.1 Sample Plot Setup and Soil Sampling

This survey primarily covered accumulation-type and erosion-type Gobi at the northern and southern foothills of the eastern Tianshan Mountains within Hami. Given the extensive Gobi area, we selected typical Gobi sites for soil investigation and sampling based on high-resolution remote sensing base maps, considering natural distribution characteristics, soil types, and sampling accessibility. Approximately two soil surveys were conducted, with actual sampling points determined according to field conditions. A total of 56 soil samples were obtained, with a sampling ratio of 3:2 between accumulation-type and erosion-type Gobi.

During sampling, a scale frame (30 cm × 30 cm) was first used to define the sampling area. A digital camera was focused to capture the frame area vertically, and the actual size of surface gravel was estimated based on the ratio between the frame size and the digital image dimensions. The gravel covering the Gobi surface was then gently moved aside with a steel ruler, and soil samples were collected at depths of 10 cm, 20 cm, and 40 cm using a sampling shovel. Sampling points within each area were spaced approximately 1–20 km apart. However, due to difficulties in deep sampling in some areas, only 10 cm depth samples were collected. Therefore, all measurement indicators used for physicochemical analysis and quality assessment in this study were derived from soil samples taken at 10 cm depth. Considering the varying geological landforms and soil type distributions across different regions, the number of sampling points differed by area, with specific locations shown in Figure 1.

1.2.2 Soil Sample Pretreatment and Measurement

The physicochemical indicators measured in this study included gravel coverage, soil bulk density, soil moisture content, pH, total salt, organic matter, total nitrogen, total phosphorus, and total potassium. Due to the high gravel content in Gobi surface sediments that prevented direct grinding and pressing, collected soil samples were processed using sieving methods to remove gravel larger than 2 mm before elemental analysis.

In the laboratory, fresh soil samples were air-dried (except for bulk density samples collected by the ring knife method and moisture content samples). Soil samples were spread thinly on sulfuric acid paper and dried in a cool, ventilated area. Using the quartering method, appropriate amounts of air-dried samples were taken, and non-soil materials such as plant and animal residues and small stones were removed. The soil was then crushed to pass completely through a

2 mm test sieve. The sieved soil samples were mixed uniformly and stored in bags for analysis.

For measurements, gravel coverage was estimated using the camera photography method, which utilized vertically captured images to estimate gravel particle size. The ratio of pixels occupied by gravel larger than 2 mm to the total image pixels was calculated as the estimated gravel coverage value. Soil bulk density was determined using the ring knife method; soil moisture content was measured using the oven drying method; soil pH was measured using the potentiometric method; total salt content was determined using the electrical conductivity method; soil organic matter was measured using the potassium dichromate oxidation method; total nitrogen was determined using the combustion method; total phosphorus was measured using $HClO_4$-H_2SO_4 antimony molybdenum spectrophotometry; and total potassium was determined using flame photometry.

1.3 Soil Quality Evaluation Methods

Soil physical and chemical properties reflect soil quality and nutrient levels. In Gobi regions, the soil environment exhibits unique arid and semi-arid characteristics, with generally low moisture and nutrient contents and high salinization. Therefore, this study selected representative physical indicators (soil moisture content, soil bulk density, pH, and total salt) and chemical indicators (organic matter, total nitrogen, total phosphorus, and total potassium) to conduct a comprehensive soil quality assessment for the Hami Gobi.

Soil moisture content and bulk density are important indicators for measuring water retention capacity and structural compactness, influencing soil ecological functions and plant growth conditions. pH and total salt are key chemical indicators reflecting soil acidity/alkalinity and salinization levels, directly affecting nutrient availability and microbial activity. Organic matter, total nitrogen, total phosphorus, and total potassium serve as primary sources of soil nutrients, determining soil fertility levels and plant nutrient supply capacity, which are crucial for Gobi vegetation community development.

To standardize the dimensions of each indicator, we normalized soil physicochemical property indices using linear membership functions, including ascending distribution functions ('more is better' indicators) and descending distribution functions ('less is better' indicators) (Formulas 1 and 2). The processed data then underwent Bartlett' s sphericity test and significance test to verify the feasibility of principal component analysis. Meanwhile, by calculating each indicator' s eigenvalues and variance contribution rates, we selected principal components with eigenvalues greater than 1 that explained at least 5% of total variance. Combining the variance contribution rates, loading coefficients, and importance of each principal component in soil quality, we determined the coefficients in the comprehensive scoring model (Formula 3). Finally, the Soil Quality Index (SQI) was applied for comprehensive Gobi soil quality evaluation (Formula 4).

Formula 1: Ascending distribution function

$$Q(X_i) = \frac{X_{ij} - X_{i\min}}{X_{i\max} - X_{i\min}}$$

Formula 2: Descending distribution function

$$Q(X_i) = \frac{X_{i\max} - X_{ij}}{X_{i\max} - X_{i\min}}$$

where $Q(X_i)$ represents the membership value of each soil indicator; X_{ij} is the value of each soil indicator; and $X_{i\max}$ and $X_{i\min}$ refer to the maximum and minimum values of the ith soil indicator, respectively.

Formula 3: Weight calculation

$$W_i = \frac{C_i}{\sum_{i=1}^{n} C_i}$$

where W_i is the weight of each indicator; C_i is the common factor variance of each evaluation indicator; and n is the number of evaluation indicators.

Formula 4: Soil Quality Index calculation

$$SQI = \sum_{i=1}^{n} W_i \times S_i$$

where W_i is the weight coefficient of the ith indicator; S_i is the membership value of the ith indicator; and n is the number of evaluation indicators.

2 Results and Analysis

Analysis of the 56 soil samples is presented in Table 1. The sensitivity of each indicator is generally represented by the coefficient of variation (Cv), where larger Cv values indicate greater sensitivity of the evaluation indicator to soil quality differences. Indicators can be classified into four types: insensitive (Cv<10%), low sensitivity (10%≤Cv<40%), medium sensitivity (40%≤Cv<100%), and high sensitivity (Cv$ $100%).

As shown in Table 1, gravel coverage, soil moisture content, total salt, organic matter, and total nitrogen were high-sensitivity indicators (Cv$ 100 $Cv <$ 100 $Cv<40%), while total phosphorus was an insensitive indicator (Cv<10%).

2.1.1 Gravel Coverage and Soil Bulk Density Characteristics

Gravel coverage reflects the structural characteristics of the Gobi surface gravel layer. Higher coverage indicates better wind-sand resistance and greater stability of underlying sandy and loamy soils. Overall, soil compactness in the Hami

Gobi region is generally high, while gravel coverage shows significant spatial variation. The mean gravel coverage for 56 soil samples was 82.66%, with a coefficient of variation (Cv) of 123.69%, indicating substantial structural differences among sampling points and high variability in gravel coverage (Table 1).

Regional statistics for the three areas show that Yizhou District had a mean gravel coverage of 77.12% with a Cv of 158.04%, demonstrating extremely high variability. Barkol Kazakh Autonomous County (hereinafter referred to as Barkol County) and Yiwu County had mean gravel coverage values of 82.66% and 15.29%, respectively, with Cv values of 41.36% and 34.97%, indicating high gravel content in these two regions but relatively small spatial differences among sampling areas.

Soil bulk density primarily characterizes soil compactness, where lower values indicate better soil quality. A larger Cv indicates better soil structure with strong aeration and water permeability; conversely, it indicates compact soil structure with poor permeability. According to China' s soil property classification standards, bulk density is divided into six levels: too loose ($<1.00\ \mathrm{g \cdot cm^{-3}}$), suitable (1.00-1.25 $\mathrm{g \cdot cm^{-3}}$), slightly tight (1.25-1.35 $\mathrm{g \cdot cm^{-3}}$), compact (1.35-1.45 $\mathrm{g \cdot cm^{-3}}$), firm (1.45-1.55 $\mathrm{g \cdot cm^{-3}}$), and too firm ($>1.55\ \mathrm{g \cdot cm^{-3}}$). The mean bulk density of Gobi soils in the study area was 1.64 $\mathrm{g \cdot cm^{-3}}$, classified as firm, with a Cv of 19.06%, indicating low-sensitivity variability (Table 1). The mean bulk density in all three regions exceeded 1.55 $\mathrm{g \cdot cm^{-3}}$, with Cv values below 40%, demonstrating that soil compactness and density are generally high throughout the Hami Gobi region.

2.1.2 Soil Salinity Analysis

The combination of soil moisture content, pH, and total salt reflects the salinization level of Gobi soils. As shown in Table 1, the average soil moisture content in the study area was 1.95%, indicating extremely low water content insufficient to support vegetation survival requirements. The moisture content indicator showed extremely high variability, with obvious responses to changes in external environmental factors.

Soil pH was the lowest among all indicators at 8.62, indicating that soils in the Hami Gobi region are generally alkaline with relatively small spatial differences. The average total salt content was 66.32 $\mathrm{mg \cdot kg^{-1}}$, indicating high soil salinity, with field surveys revealing varying degrees of salinization at many sampling points.

Overall, the Hami Gobi exhibits extremely low soil moisture content, alkaline conditions, and severe soil compaction that is unfavorable for organic matter accumulation. Additionally, most areas are located at basin margins where sandification and desertification are relatively severe, resulting in weak base fertility.

2.1.3 Gobi Soil Nutrient Characteristics Analysis

According to the national second soil nutrient classification standards (Table 3), the mean organic matter content of Hami Gobi soils was 5.12 $g \cdot kg^{-1}$, classified as Level 6, indicating extremely poor conditions. The black Gobi experiences drought with little rainfall and high evaporation, resulting in extremely low soil organic matter content.

Total nitrogen content was at Level 4 with a mean of 0.48 $g \cdot kg^{-1}$, and the Cv for total nitrogen was 39.94%, classifying it as a low-sensitivity indicator. This is primarily because nitrogen moves slowly in soil, and its spatial distribution heterogeneity is difficult to improve over time, resulting in a lower Cv for total nitrogen.

Total phosphorus content was at Level 4 with a mean of 0.48 $g \cdot kg^{-1}$, and the Cv for total phosphorus was 5.61%, classifying it as an insensitive indicator. This is mainly because phosphorus moves slowly in soil, and its spatial distribution heterogeneity is difficult to improve over time, leading to a lower Cv for total phosphorus.

Total potassium had a mean of 22.43 $g \cdot kg^{-1}$, classified as Level 2, indicating relatively high potassium content. This is primarily due to the long-term accumulation of mineral components in the Gobi that readily accumulate potassium elements through weathering and decomposition.

2.2 Gobi Soil Quality Index Construction and Analysis

We selected eight indicators—soil moisture content, soil bulk density, pH, total salt, organic matter, total nitrogen, total phosphorus, and total potassium—to construct the Gobi Soil Quality Index (SQI). It should be noted that gravel coverage only characterizes surface composition features and has no direct impact on soil quality, thus it was not included in the SQI construction.

2.2.1 Correlation Analysis of Main Soil Indicators As shown in Table 4, the eight soil quality indicators demonstrate relatively high independence, providing a comprehensive representation of soil quality levels in the Hami Gobi region. Organic matter and total nitrogen showed a significant positive correlation (correlation coefficient of 0.82), while total salt and total potassium exhibited a significant negative correlation (correlation coefficient of -0.63). Other indicator pairs showed some significant correlations, but the absolute values of correlation coefficients were all less than 0.5.

2.2.2 Construction of Soil Quality Index A sphericity test was performed on the soil quality indicators (KMO=0.55>0.5), indicating that the dataset was suitable for principal component analysis. Principal components with eigenvalues greater than 1 and explaining at least 5% of total variance were selected, yielding the loading coefficients, common factor variance, and principal component weights for soil quality indicators (Table 5). Larger eigenvalues indicate greater representation of soil index system characteristics. Table 5 shows four principal components with eigenvalues greater than 1, with a cumulative contribution rate of 88.07%, capable of explaining most information in the soil quality indicators. This analysis extracted four principal components with corresponding weighted variance explanation rates (weights) of 35.74/88.07=40.58%, 14.63/88.07=16.61%, 9.38/88.07=10.65%, and 28.32/88.07=32.16%, respectively.

2.2.3 Gobi Soil Quality Analysis Using Formula 4, we calculated the Soil Quality Index for the Hami Gobi. Statistical analysis of soil quality across all sampling points is presented in Table 6. Based on study area characteristics and previous research, the calculated SQI values were relatively classified. No outliers were found in the index results, and the coefficient of variation (Cv) for the entire region' s SQI was 20.31%, indicating relatively small variability in soil quality levels among survey points and good data representation.

The mean and median SQI for the entire Hami region were both 0.45, indicating that Gobi soil quality levels were generally low in this survey. However, the maximum regional SQI was 0.69 (occurring in Yiwu County), while the minimum was 0.23 (occurring in Yizhou District), demonstrating substantial differences in soil quality between regions. According to the relative soil quality level classification in Table 7, most areas in the Hami Gobi region exhibited low soil quality levels, with fewer areas at medium levels and very few at high levels. Among the three subregions, the relative soil quality level followed the pattern Yiwu County > Barkol County > Yizhou District, though all averages fell within the 0.40-0.50 range, indicating that soil quality in all three regions remained at low levels.

In terms of spatial SQI distribution (Figure 2), soil quality levels in the Hami Gobi region showed obvious spatial heterogeneity across the three subregions. Yiwu County exhibited higher soil quality than the other two regions, with southwestern Gobi areas showing slightly better quality. These areas had relatively higher soil moisture content, with surface cover dominated by relatively moist loam and gravel combinations, and soil types primarily consisting of nutrient-rich meadow soil and chestnut soil. Samples from this region showed relatively high SQI values, raising the average quality level of Yiwu County.

Barkol County showed relatively consistent soil quality with a Cv of 11.27%, indicating stable soil quality levels across space. However, both the mean and median SQI were 0.42, suggesting that overall soil fertility in Barkol County is low, keeping soil quality at a low level despite its consistency.

In contrast, Yizhou District had the lowest soil quality, with a Cv of 25.68%, particularly in areas south of Sandao Ridge, southeast of Nanhu, and the Qijiaojing region, indicating the characteristics of poor and structurally loose Gobi soils in these areas. Within the region, areas with SQI>0.6 were distributed in transition zones between Gobi and other land types on the northwest side of

Nanhu, representing medium quality levels.

3 Discussion

3.1 Impact of Gravel Cover on Wind-Sand Movement in Hami Gobi

Due to differences in Gobi surface composition, gravel coverage, and distribution patterns, Gobi landscapes exhibit significant spatial heterogeneity, and wind-sand movement characteristics vary accordingly. Research indicates that gravel coverage is negatively correlated with wind-sand movement intensity, which decreases as gravel coverage increases. Wind-sand movement alters surface composition through wind erosion and deposition processes, while underlying surface gravel coverage also changes, presenting a coupled relationship of mutual influence. Furthermore, when gravel coverage increases to 30%-35%, it can effectively suppress wind erosion phenomena in Gobi regions, reducing wind-sand frequency and intensity.

The measurement results from 56 soil sampling points in the study area indicate that, except for the upper alluvial fan, the Gobi surface is covered by compositions of various gravel sizes, sand, and silt. Gravel coverage shows strong consistency in the east-west direction but demonstrates a clear increasing trend from north to south, particularly in Yizhou District. Under constant wind speed conditions, sediment transport rates in Gobi soils also show obvious spatial differences. Moreover, frequent mining activities in southern Gobi areas easily destroy the underlying gravel cover layer. Once gravel coverage is destroyed, the underlying soil loses its protective barrier, wind erosion resistance rapidly weakens, and the moisture retention capacity of the underlying soil without gravel cover also significantly decreases.

Based on our sampling survey, gravel coverage in the Hami Gobi region exhibits spatial heterogeneity, making certain areas more susceptible to wind-sand erosion. These vulnerable areas are mainly distributed in regions with gravel coverage <30% and surface gravel thickness <5 cm—thin or discontinuous gravel layers where fine-grained soil is easily exposed, significantly enhancing wind erosion. These areas are typically flat or gently sloping where wind can directly act on the surface, mainly distributed at the front, middle, and back edges of piedmont alluvial fans and low-lying areas with sparse vegetation. Due to water accumulation and deposition, these low-lying areas have relatively less gravel and weaker capacity to form a gravel armor barrier. Soils in these regions are more easily lifted by wind, forming dust storms, such as at sampling points A1, B1, and C1.

The second type includes areas with frequent human activities, particularly mining and road construction, mainly distributed in southern Yizhou District, such as sampling points D1, E1, and F1. The third type comprises edge transition zones where Gobi transitions to desert or other land types. Due to gradually decreasing surface gravel and changing surface types, these areas have unstable soil structures vulnerable to wind erosion, mainly distributed along the western-to-eastern Gobi edges of Barkol and Yiwu counties and near Qijiaojing in Yizhou District, such as sampling points G1 and H1.

3.2 Impact of Soil Quality on Vegetation Distribution in Hami Gobi

Soil quality in Gobi regions is closely related to vegetation growth conditions, and the poor state of soil quality significantly influences vegetation type, distribution, and diversity. This study found that soil quality in the Hami Gobi region is generally low, with an average Soil Quality Index (SQI) of 0.45 and many areas showing SQI<0.4. Soil quality limits plant growth and diversity, with vegetation dominated by drought-tolerant shrubs and perennial herbs such as *Haloxylon*, *Reaumuria*, *Zygophyllum*, and *Salsola*, which have adapted to low nutrient and water conditions in the soil.

The Hami Gobi region exhibits substantial spatial heterogeneity in soil quality, with significant differences between areas. The Yiwu County Gobi zone has relatively higher soil quality, with nutrient-rich meadow soil and chestnut soil distributed in areas with higher soil moisture content than other regions. Vegetation types are relatively abundant, forming desert forest and shrub communities dominated by *Populus euphratica* and *Tamarix*. In contrast, the Yizhou District and Barkol County Gobi zones have lower soil quality, with vegetation adapted to extremely arid and nutrient-poor environments, consisting of drought-tolerant shrubs and herbaceous plants.

The soil quality and vegetation conditions in the Hami Gobi region demonstrate that the Gobi ecosystem is extremely fragile. Under extremely arid conditions, Gobi vegetation communities have poor adaptability to external changes, and once damaged, restoration is extremely difficult. Meanwhile, due to low soil quality and water deficiency, the flora shows strong xerophytic characteristics, with few plant species and narrow ecological niches, resulting in poor ecosystem stability. Furthermore, plants in the black Gobi region represent an important plant gene pool, and protecting these genetic resources requires holistic ecosystem conservation. Energy and mineral resource development in these areas must protect the xerophytic vegetation ecosystems of Gobi regions.

Although improving soil quality can promote plant growth and diversity—for instance, artificial irrigation or soil amendment techniques can increase soil moisture and nutrient content—these measures are costly and can only be implemented under special conditions for mining area environmental restoration, with poor sustainability. Therefore, low soil quality and simple vegetation in Gobi regions are interrelated. The low soil quality in Gobi areas leads to few specialized vegetation types, creating fragile ecosystems that are difficult to restore.

3.3 Factors Influencing Spatial Variation of Soil Quality in Hami Gobi

The spatial pattern of Gobi soil quality is influenced by multiple natural and anthropogenic factors. First, natural factors are particularly significant at the regional scale. Hami region exhibits distinct geomorphological differences: most areas north of the eastern Tianshan Mountains are alluvial fan accumulation Gobi, where soils are relatively fertile due to newer parent material rich in minerals, combined with gentle terrain and good drainage, forming relatively high-quality soil conditions such as in Yiwu County and eastern Barkol County. In contrast, most areas south of the Tianshan Mountains are plain erosion-type Gobi, where long-term wind erosion has aged the soil parent material and increased soil water evaporation, resulting in relatively poor soil structure.

Climate conditions and external erosion are also important factors affecting soil quality. The overall climate in Hami region is arid with extremely low annual precipitation, particularly in Yizhou District and Barkol County where precipitation is scarce and wind speeds are high, leading to significant wind erosion and generally low soil quality in these areas. Due to topographic factors, Yiwu County has relatively higher vegetation coverage, with relatively abundant soil moisture and organic matter content that helps mitigate wind erosion impacts, resulting in relatively better soil quality. In Yizhou District and Barkol County, sparse vegetation dominated by drought-tolerant plants and low soil organic matter content further exacerbate soil impoverishment.

Additionally, human activities in southern Hami, particularly mining and road construction, not only destroy surface vegetation and soil structure but also accelerate soil erosion and degradation. In numerous mining areas and their surroundings in eastern and southern Yizhou District, the destruction of surface gravel and sand layers has made soils more fragile and significantly reduced wind erosion resistance, leading to further deterioration of soil quality. In contrast, Yiwu County Gobi experiences fewer human activities and relatively less external disturbance, resulting in higher soil quality compared to the other two subregions.

Overall, the spatial heterogeneity of Gobi soil quality in Hami region is primarily determined by natural factors, though anthropogenic influences cannot be ignored. Natural factors including topography, climate conditions, vegetation types, and external erosion play dominant roles at the regional scale, while human activities affect soil quality at local scales.

4 Conclusions

This study investigated the gravel structure and property characteristics of Gobi soils in Hami City, collecting 56 Gobi soil samples from Yizhou District, Yiwu County, and Barkol County. We examined eight physical and chemical indicators including soil moisture content, bulk density, pH, total salt, organic matter, total nitrogen, total phosphorus, and total potassium. Descriptive statistics were first used to analyze surface structure, salinization, and soil nutrient characteristics in the region. We then constructed a Soil Quality Index (SQI) using the eight soil quality indicators to assess relative soil quality levels. The findings reveal the following characteristics of soil quality in the Hami Gobi region:

(1) Gravel coverage in Gobi areas is generally high, though relatively lower at Gobi edges, with firm soil texture; soil moisture content is universally low while salinization is relatively high; soils in most areas are relatively poor with poor nutrient conditions.

(2) In terms of spatial differences, the average soil quality level in Yiwu and Barkol counties is slightly higher than in Yizhou District. Soil quality in transition zones between Gobi and other land types is higher than in pure Gobi areas, with better soil moisture and nutrient conditions.

(3) Comprehensive evaluation shows that soil quality across the entire Hami Gobi region and its subregions is at a low level (SQI=0.4-0.5). Soil quality shows a decreasing trend from north to south, with Yiwu County Gobi having the highest average soil quality level.

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