Meta-Analysis-Based Study on Desertification Dynamics in the Mu Us Sandy Land (Postprint)

Authors: Xiu Xiaomin, Wu Bo, Fei Bingqiang, Yin Jie, Zhang Lingguang, Li Jia, Pang Yingjun, Jia Xiaohong

Date: 2025-02-27T00:00:00+00:00

Abstract

Desertification is a critical global ecological and environmental issue, and the Mu Us Sandy Land represents a key region for desertification control in China. While numerous studies have examined desertification dynamics in the Mu Us Sandy Land over the past 30 years, systematic analysis of dynamic change trends over the past 70 years remains lacking. This study employs Meta-analysis to synthesize findings from 39 research cases, systematically analyzing desertification dynamic trends in the Mu Us Sandy Land since the 1950s and discussing the underlying driving factors. The results demonstrate that: (1) Over the past 70 years, the proportion of mildly desertified area in the Mu Us Sandy Land has exhibited a trend of initial decrease followed by increase; the proportion of moderately desertified area has shown a slightly increasing trend; the proportion of severely desertified area has displayed a trend of initial increase followed by decrease; and desertification has demonstrated a pronounced reversal trend. (2) During 1980–1989, desertification in the Mu Us Sandy Land experienced slight reversal; during 1990–1999, desertification exhibited an expansion trend; during 2000–2009, desertification was reversed; during 2010–2019, desertification continued to undergo stable reversal; and the year 2000 represents a critical temporal node for the reversal of desertification in the Mu Us Sandy Land. (3) Continuous drought exerts a significant promoting effect on desertification expansion, while sustained ecological engineering construction and the implementation of policies including 'grazing prohibition, rest grazing, rotational grazing, and livestock capacity determination based on forage availability' since 2000 constitute the primary reasons for the sustained reversal of desertification in the Mu Us Sandy Land. These research findings can provide valuable references for systematically understanding the development patterns of desertification in the Mu Us Sandy Land and formulating effective desertification control strategies.

Full Text

A Meta-analysis of Desertification Dynamics in the Mu Us Sandy Land

ARID LAND GEOGRAPHY Vol. 47 No. 12 Dec. 2024

Authors: XIU Xiaomin1,2, WU Bo1,2,3, FEI Bingqiang1,2, YIN Jie1,2, ZHANG Lingguang1,2, LI Jia1,2, PANG Yingjun1,2, JIA Xiaohong1,2

Affiliations: 1. Institute of Ecological Conservation and Restoration, Chinese Academy of Forestry, Beijing 100091, China 2. Key Laboratory of State Forestry and Grassland Administration on Desert Ecosystem and Global Change, Beijing 100091, China 3. Institute of Great Green Wall, Beijing 100091, China

Abstract

Desertification represents a critical global ecological and environmental challenge, with the Mu Us Sandy Land serving as a key focus area for desertification control in China. While numerous studies have examined desertification dynamics in this region over recent decades, a systematic analysis of long-term trends spanning the past 70 years has been lacking. This study employed Meta-analysis to synthesize findings from 39 research cases on the Mu Us Sandy Land since the 1950s, systematically analyzing desertification trends and discussing their driving factors. Results indicate: (1) Over the past 70 years, the proportion of lightly desertified areas initially decreased then increased, moderately desertified areas showed a slight increasing trend, and severely desertified areas first increased then decreased, demonstrating a clear reversal of desertification trends. (2) From 1980-1989, desertification exhibited slight reversal; from 1990-1999, desertification expanded; from 2000-2009, the expansion trend was reversed; and from 2010-2019, desertification continued to steadily reverse. The year 2000 marked a significant turning point in desertification reversal. (3) Continuous drought significantly promoted desertification expansion, while sustained ecological engineering construction since 2000 and implementation of policies including "grazing prohibition, rest grazing, rotational grazing, and livestock capacity determination based on forage availability" have been the primary drivers of continued desertification reversal. These findings provide valuable insights for understanding desertification development patterns and formulating effective control strategies in the Mu Us Sandy Land.

Keywords: desertification dynamics; Meta-analysis; driver factors; ecological project; Mu Us Sandy Land

1. Introduction

Desertification is among the most critical ecological and environmental problems globally, severely constraining and threatening human survival and sustainable socioeconomic development. China is one of the countries

most severely affected by desertification, with direct economic losses exceeding 6.40$\times 10^{11} yuan annually and impacting 4.00\times 10^{9} people. National desertification and sandification monitoring$
km^2, accounting for approximately 26.81% of total national territory. Desertification remains China' s most serious ecological and environmental issue.

Since the 1990s, desertification monitoring and assessment research has gained widespread academic attention to meet national desertification monitoring needs and fulfill obligations under the United Nations Convention to Combat Desertification. Desertification dynamic monitoring is crucial for land resource management and desertification control strategy formulation. Remote sensing technology provides multi-scale, multi-temporal, and long-term sequential spatial data and analytical methods, enabling regional-scale, long-term, continuous desertification dynamic monitoring. Recent advances in remote sensing have greatly promoted desertification monitoring technology development.

Meta-analysis is a quantitative statistical method that synthesizes and compares research results on the same topic, analyzing and summarizing overall patterns. As a core metric in Meta-analysis, effect size encompasses a series of indicators measuring effect magnitude, with selection depending on data type. Continuous variables typically use weighted mean difference or standardized mean difference, while categorical variables use odds ratio or relative rate/risk. Meta-analysis was first applied in medical research and later introduced to ecology. In recent years, Chinese scholars have applied Meta-analysis to grassland ecological restoration, grazing impacts on grasslands, ecosystem service value assessment, and environmental pollution, though its application to desertification research remains unreported.

The Mu Us Sandy Land is a typical and hotspot region for desertification research in China. Since the 1990s, numerous scholars have conducted extensive research on desertification dynamics and landscape patterns using remote sensing technology. While these studies have systematically analyzed nearly 30 years of desertification dynamics, they remain independent with differing results, leaving the overall patterns of desertification dynamics unclear. This study systematically integrates desertification dynamic monitoring literature on the Mu Us Sandy Land, constructing a Meta-analysis framework to analyze desertification trends over the past 70 years, identify development stages, and examine impacts of climate and socioeconomic factors in different periods. The aim is to provide decision-making support for systematic management of mountains, rivers, forests, farmlands, lakes, grasslands, and deserts, and for regional sustainable ecological, social, and economic development.

2. Study Area and Methods

2.1 Study Area Overview The Mu Us Sandy Land is located in the southern Ordos Plateau, geographically positioned between 37°28 -39°21 N and 107°23 -110°30 E, covering approximately 4.0$×$10^4 km^2. Administratively, it spans the border region of Inner Mongolia, Shaanxi, and Ningxia, including southern Ordos City in Inner Mongolia (southern Yijinhuoluo Banner, entire Wushen Banner, southeastern Etuoke Front Banner, southeastern Etuoke Banner), northern Yulin City in Shaanxi Province (parts of Shenmu, Yuyang, Hengshan, Jingbian, and Dingbian), and northeastern Yanchi County in Ningxia. The terrain slopes from northwest to southeast, with elevations ranging from 1200–1600 m. The region features a typical temperate continental semi-arid climate, with mean annual temperature of 8.5°C, mean annual precipitation of 250–440 mm (concentrated in July–September and decreasing from southeast to northwest), and mean annual wind speed of 2.1–3.3 m · s^-1, peaking in April. The landscape is characterized by interspersed fixed, semi-fixed, and mobile dunes, with aeolian sandy soil as the main soil type, loose surface material, abundant sand sources, and intense aeolian activity. Vegetation is dominated by psammophytes, with *Artemisia ordosica*, *Caragana korshinskii*, *Sabina vulgaris*, and *Salix cheilophila* as the main constructive species.

2.2 Data Collection Literature was retrieved from the China National Knowledge Infrastructure (CNKI) and Web of Science databases using keywords including "Mu Us sandy land," "desertification," "sandy land," "Mu Us sandyland," "desertification landscape," and "desertification sandyland Maowusu landscape." The search included journal articles, dissertations, and conference papers, yielding 64 initial documents. Literature screening followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Selection criteria included: (1) study area within the Mu Us Sandy Land; (2) content including desertification remote sensing monitoring or assessment; (3) provision of desertification remote sensing monitoring or assessment data. Ultimately, 39 literature sources were selected for analysis [Figure 1: see original paper].

Climate data for eight meteorological stations (Etuoke Front Banner, Wushen Banner, Yulin, Shenmu, Yanchi, Dingbian, Jingbian, and Hengshan) from 1980–2019 were obtained from the National Meteorological Science Data Center. Socioeconomic data were collected from the Inner Mongolia Statistical Yearbook, Ordos Statistical Yearbook, Etuoke Banner Gazette, and Yulin Statistical Yearbook.

2.3 Database Construction Information extracted from the 39 literature sources included basic details (title, authors), study area, time period, methods, and results. Data were extracted directly from text and tables, with image-based data extracted using PlotDigitizer Version 2.6.9 software. The compiled information was organized and entered into an Excel database for Meta-analysis.

Desertification classification systems and evaluation criteria varied across studies. Some classified land as fixed, semi-fixed, and mobile dunes representing different desertification degrees; others used 3-level (light, moderate, severe) or

4-level (adding extremely severe) systems. Primary evaluation indicators were vegetation indices (e.g., NDVI) or vegetation coverage. Despite inconsistent classification systems, the reflected desertification dynamic patterns and trends were consistent. Following the National Desertification and Sandification Monitoring Technical Regulations, original data were reclassified into three categories: light, moderate, and severe desertification, with fixed/semi-fixed/mobile dunes and severe/extremely severe categories merged accordingly.

2.4 Monitoring Period Division Based on collected cases, the earliest monitoring period traced back to the late 1950s. Cases included 7 studies with 1-3 year monitoring, 9 with 3-5 years, 8 with 5-10 years, 8 with 10-20 years, 5 with 20-30 years, and 2 with 30-40 years. Desertification processes exhibit temporal development characteristics, with evolution patterns varying across different time scales. To objectively reflect desertification dynamics in different periods over the past 70 years, six monitoring periods were established: 1950-1979, 1980-1989, 1990-1999, 2000-2009, 2010-2019, and 1950-2019.

2.5 Analysis Methods 2.5.1 Desertification Area Data Standardization Most studies covered the entire Mu Us Sandy Land, though boundaries varied. Some focused on sub-regions. To ensure comparability, area data for different desertification degrees were converted to area percentages. For studies covering only part of a monitoring period, annual average change rates were used to estimate data for the full period.

2.5.2 Desertification Area Change Metrics Drawing on the concept of land use dynamic degree, which measures change speed of a land use type during a study period, we defined desertification area percentage dynamic degree (K):

$$K = \frac{U_b - U_a}{U_a \times T} \times 100\%$$

where U_a and U_b are initial and final area percentages of a desertification degree, and T is study period length in years. Two metrics were used: annual area percentage change and dynamic degree.

2.5.3 Meta-analysis Framework Effect size quantitatively assesses the magnitude of effects. For categorical variables like desertification degree, relative rate/risk (RR) was selected as the effect size metric:

$$RR = \frac{p_2 - p_1}{p_1}$$

where p_1 and p_2 are initial and final area percentages. Standard error (SERR) and 95% confidence intervals (CIRR) were calculated:

$$SERR = \sqrt{V}$$

$$CIRR = RR \pm 1.96 \times SERR$$

where V is approximate variance. A random effects model was employed, assuming each study' s effect size varies and represents random sampling from a larger population. Weights were calculated as the inverse of within- and between-study variance sum. The pooled effect size (RR++) was the weighted average:

$$RR++ = \frac{\sum w_j \theta_j}{\sum w_j}$$

When confidence intervals overlap the null line (RR = 0), the change is non-significant ($P > 0.05$). RR++ > 0 indicates area percentage increase, RR++ < 0 indicates decrease.

3. Results

3.1 Area Changes of Different Desertification Degrees Desertification dynamic monitoring data were extracted from 39 cases. Area percentage distributions for different desertification degrees across monitoring periods are shown in [Figure 3: see original paper]. Overall, from 1950–2019, light desertification area percentage initially decreased then increased, moderate desertification showed a slight increasing trend, and severe desertification first increased then decreased.

From 1980–2019, light desertification area showed "increase-decrease-increase" pattern, moderate desertification showed "decrease-increase-increase," and severe desertification showed "decrease-increase-decrease" [Figure 4: see original paper]. Comprehensive analysis of annual change and dynamic degree revealed: 1980–1989 saw light desertification increase while moderate and severe decreased (slight reversal); 1990–1999 had light and moderate desertification decrease while severe increased (expansion); 2000–2009 showed substantial light and moderate desertification increase with severe decrease (reversal); 2010–2019 continued light desertification increase and moderate/severe decrease (sustained reversal) [Figure 4: see original paper].

3.2 Relative Rate Changes of Different Desertification Degrees Meta-analysis results show significant differences in desertification area changes across periods [Figure 5: see original paper]. From 1980–2019, light desertification area significantly increased in 1980–1989 ($P < 0.001$), 2000–2009 ($P < 0.001$), and 2010–2019 ($P < 0.001$). Moderate desertification significantly increased in 1990–1999 ($P < 0.001$) and 2000–2009 ($P < 0.001$). Severe desertification significantly decreased in 2000–2009 ($P < 0.001$) and 2010–2019 ($P < 0.001$). Changes were non-significant in some periods due to limited case numbers.

These results demonstrate that 2000 was a crucial turning point for desertification reversal. The third national desertification and sandification survey (1999–

2004) showed China' s desertified land area decreased by 37,924 km^2 during 1995-2004. Subsequent surveys (fourth, fifth, sixth) show continued reduction. Since 2000, particularly since the 18th National Congress, China' s desertification control has achieved tremendous success, with desertified areas showing "overall improvement and accelerated recovery" and desert ecosystems demonstrating "enhanced function and stable, positive conditions." Thus, 2000 marks the critical reversal point for the Mu Us Sandy Land.

4. Discussion

4.1 Desertification Dynamic Trend Analysis Individual studies show varying focus areas, periods, and methods. For example, Wu Bo [4], Wang Tao [25], and Yan Feng [26] studied the entire Mu Us Sandy Land (~3.47$×$10^4 km^2), while others examined sub-regions. These differences produced varying results: some indicated reversal during 1980-1990, others showed intensification during 1990-2000, and some documented overall reversal during 2000-2010. Integrating 39 cases revealed consistent overall patterns: light desertification proportion first decreased then increased, moderate desertification slightly increased, and severe desertification first increased then decreased [Figure 3: see original paper], showing expansion followed by reversal. This aligns with previous research [4,25,26] while providing more robust conclusions through random effects Meta-analysis that minimizes methodological differences.

4.2 Desertification Driver Factor Analysis Desertification expansion and reversal in the Mu Us Sandy Land are influenced by both climatic and socioeconomic factors. As a semi-arid region, desertification is closely related to precipitation, temperature, and wind speed.

Climate Factors: From 1980-1989, increasing precipitation, fluctuating temperature, and decreasing wind speed favored reversal. From 1990-1999, decreasing precipitation and rising temperature favored expansion, particularly during severe droughts in 1999-2001 when precipitation dropped significantly, reducing vegetation biomass and promoting desertification [61,71]. From 2000-2019, increased precipitation and stable temperature favored reversal. Overall, continuous drought significantly promotes desertification expansion, while increased precipitation promotes reversal.

Socioeconomic Factors: In the 1980s, overgrazing was severe. The early 1990s implementation of the "grassland and livestock dual responsibility system" in Inner Mongolia reduced goat numbers and alleviated grazing pressure, contributing to slight reversal when combined with increased precipitation. During the 1990s, population growth, increased livestock numbers (with primary industry employment exceeding 59.95% in Ordos City), and extensive grazing practices degraded grasslands, making them vulnerable to wind erosion. Severe drought and expanded cultivated land also promoted desertification expansion.

Since 2000, despite continued population, livestock, and cultivated land increases, desertification has gradually reversed due to optimized industrial structure and implementation of key policies and ecological projects. The "grazing prohibition, rest grazing, rotational grazing, and livestock capacity determination" policy transformed traditional livestock production toward intensification, with herders receiving subsidies for grazing bans and adopting cooperative sustainable pasture management [73]. Water-saving irrigation and mechanized cultivation increased agricultural output while conserving soil and water. Ecological projects including Natural Forest Protection, Beijing-Tianjin Sand Source Control, and Grain for Green have been crucial. From 1998-2019, cumulative afforestation in Wushen Banner, Etuoke Banner, Etuoke Front Banner, and Yuyang District reached 4.53$\times 10^4 km^2, withsustainedgrowthmaintained[Figure 8: seeoriginalpaper]. TheseprojectsinOrdosCityhavecumulativelycovered 16.26\times$10^4 km^2 since 2000, significantly increasing vegetation coverage [16,26] and enhancing regional windbreak and sand fixation capacity.

4.3 Study Limitations This Meta-analysis quantified desertification processes and revealed overall patterns over the past 70 years, but has limitations. Like many Meta-analyses, it is affected by grey literature and retrieval strategies, making incomplete data unavoidable. Some monitoring periods had limited case numbers, potentially affecting result accuracy. Future work should improve retrieval strategies to collect more literature and enhance result reliability.

5. Conclusion

Over the past 70 years, the Mu Us Sandy Land has shown: light desertification proportion first decreasing then increasing, moderate desertification proportion slightly increasing, and severe desertification proportion first increasing then decreasing, demonstrating clear reversal trends. Desertification slightly reversed during 1980-1989, expanded during 1990-1999, reversed during 2000-2009, and sustained stable reversal during 2010-2019, with 2000 as the critical turning point. Desertification dynamics are influenced by both climatic and socioeconomic factors. Continuous drought significantly promotes desertification expansion, while sustained ecological engineering construction and favorable policies since 2000 are the main drivers of continued desertification reversal.

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