Postprint: Sustainability Assessment of China' s Four Major Sandy Land Areas Based on Ecological Footprint

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Date: 2018-11-14T00:00:00+00:00

Abstract

The Four Major Sandy Lands represent the regions with the most severe desertification in China, and effective evaluation and comparison of their sustainability levels hold significant importance for regional development. Based on socio-economic statistical data, this study employs a productive ecological footprint model to assess and compare the productive ecological footprints and ecological deficit/surplus conditions of China' s Four Major Sandy Lands in 2000 and 2015, aiming to reveal regional sustainability. The results demonstrate that: from 2000 to 2015, the per capita ecological footprint in the Four Major Sandy Lands exhibited an overall increasing trend, with the Mu Us Sandy Land registering the highest average annual growth rate at 20.85%, corresponding to an increment of 79.21 $hm^2 \cdot person^{-1}$; the per capita ecological footprint was predominantly composed of fossil energy footprint and grassland footprint; the ecological deficit in the Four Major Sandy Lands continued to intensify during 2000–2015, with the Mu Us Sandy Land showing the largest change in per capita ecological deficit, reaching 79.51 $hm^2 \cdot person^{-1}$, where the primary driver of the aggravated deficit was the large-scale production of fossil energy in the region. With the improvement of living standards, the demand for resources is continuously increasing. Currently, socio-economic development in the Four Major Sandy Lands still relies to some extent on the massive production and consumption of natural resources, and the balance between economic development and environmental protection remains a challenge. It is necessary to formulate targeted management measures according to the specific conditions of each region to maintain regional sustainable development.

Full Text

Sustainability Assessment of Four Sandy Lands in China Based on the Ecological Footprint Model

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Abstract

The four mega-sandy lands are typical regions experiencing desertification in China due to the instability and vulnerability of natural conditions. With the implementation of ecological restoration projects, the area of desertified land in China' s four sandy lands has decreased since 2000. However, regional sustainable development still faces challenges due to increasing socio-economic development pressure and limited resource carrying capacity in these sandy lands. Therefore, evaluating and comparing the sustainability levels of the four sandy lands is significant for targeted management and regional sustainable development. Based on the ecological footprint model developed by Wackernagel, this paper adopts an improved productive ecological footprint model to compare the actual area of land occupied by each region from the ecosystem each year (ecological footprint) and the land that provides biological and productive materials in the same area (ecosystem capacity), and then determines the pressure of human activities on the local ecosystem in the four sandy lands to analyze their sustainability. This study calculated productive ecological footprint and analyzed the sustainability of four sandy lands of China from 2000 to 2015. The results showed that per capita ecological footprint (PCEF) had a significant increasing trend among the four sandy lands. The annual increasing rate of PCEF in Mu Us Sandy Land was 20.85%, higher than the other three sandy lands. The increasing amount of PCEF in Mu Us Sandy Land was highest (79.21 $hm^2 \cdot cap^{-1}$). The PCEF of the four main sandy lands was mainly dominated by fossil energy footprint and grassland footprint. The per capita ecological deficit (PCED), which is the difference between PCEF and per capita ecological capacity, was also growing from 2000 to 2015, with Mu Us Sandy Land having the highest value. The main reason for the increasing PCED was the mass production of fossil energy footprint. According to the correlation analysis of PCEF and other sustainability indices such as Human Development Index and Engel' s coefficient, people' s demand for resources has increased with the improvement of living standards and the development of society and economy, which was still at the expense of natural resource production and consumption. The balance between economic development and environmental protection in sandy zones remains a challenge. It is suggested that the mode of mineral resource exploita-

tion should be adjusted, and protection and utilization of grassland resources should be conducted according to the main structural types of ecological deficits in different sandy lands.

Keywords: Four sandy lands; ecological footprint; ecological deficit; sustainability assessment

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1. Study Area

The four mega-sandy lands in China include the Mu Us Sandy Land, Horqin Sandy Land, Otindag Sandy Land, and Hulunbuir Sandy Land [Figure 1: see original paper]. These regions are located in arid and semi-arid zones with fragile ecosystems, making them typical areas of desertification. Table 1 presents the general geographic, climatic, economic, and population information for these four sandy lands.

2. Methods

2.1 Data Sources This study utilized land use/cover data, socio-economic statistics, and energy consumption data from 2000 to 2015. The ecological footprint model was applied to calculate per capita ecological footprint (PCEF) and per capita ecological capacity. The Human Development Index (HDI) and Engel coefficient were used as supplementary indicators for sustainability assessment.

2.2 Ecological Footprint Model The ecological footprint model calculates the biologically productive area required to produce resources consumed and absorb waste generated by a given population. The improved productive ecological footprint model adopted in this study considers local ecosystem productivity variations. The per capita ecological deficit (PCED) was calculated as:

$$PCED = PCEF - \text{per capita ecological capacity}$$

3. Results

3.1 Temporal Changes in Ecological Footprint (2000–2015) From 2000 to 2015, the per capita ecological footprint in all four sandy lands showed significant increasing trends. The Mu Us Sandy Land exhibited the highest annual growth rate at 20.85%, with an absolute increase of 79.21 $hm^2 \cdot cap^{-1}$. The Horqin Sandy Land showed an increase of 6.81 $hm^2 \cdot cap^{-1}$, representing a 10.01% growth rate.

The PCEF of the four sandy lands was dominated by fossil energy footprint and grassland footprint, reflecting the energy-intensive economic development and pastoral land use patterns in these regions.

3.2 Ecological Deficit Trends The per capita ecological deficit increased across all four sandy lands during 2000–2015. The Mu Us Sandy Land maintained the highest PCED values throughout the study period, primarily driven by fossil energy consumption. This indicates that human demand for natural resources exceeded the regenerative capacity of local ecosystems.

4. Discussion

4.1 Correlation with Socio-Economic Indicators Correlation analysis between PCEF and sustainability indices revealed significant relationships. The Human Development Index (HDI) showed positive correlation with ecological footprint, indicating that improved living standards corresponded with increased resource consumption. The Engel coefficient analysis demonstrated that as household incomes rose (coefficient decreased), ecological footprint increased, suggesting a shift toward more resource-intensive consumption patterns .

4.2 Driving Factors of Ecological Deficit The primary driver of increasing ecological deficit was the expansion of fossil energy footprint, associated with industrial development and urbanization. Grassland degradation also contributed significantly, particularly in pastoral areas where overgrazing and land conversion occurred.

4.3 Regional Sustainability Challenges The balance between economic development and environmental protection remains critical. The four sandy lands face different challenges: - **Mu Us Sandy Land:** Highest ecological pressure from energy development - **Horqin Sandy Land:** Moderate deficit with potential for improvement - **Otindag and Hulunbuir:** Lower deficits but vulnerable to future development

5. Conclusions and Recommendations

The study demonstrates that despite desertification control achievements, the four sandy lands face growing ecological pressure from socio-economic development. Key recommendations include:

1. **Adjust mineral resource exploitation modes** to reduce fossil energy footprint
2. **Implement grassland resource management** based on ecological deficit structures
3. **Promote sustainable consumption patterns** as living standards improve
4. **Strengthen regional coordination** for balanced development

The ecological footprint model provides an effective tool for monitoring sustainability in sandy land regions, though further research should incorporate ecosystem service values and climate change impacts.

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