Postprint: Study on the Status of Xinjiang' s Desert Industry and Water Resources Carrying Capacity

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Abstract

Using four periods of land use/land cover remote sensing interpretation data from 2000, 2005, 2010, and 2015, as well as data from the Xinjiang Water Resources Bulletin and statistical yearbooks, this study aims to evaluate the status of the sand industry and water resources carrying capacity in Xinjiang. By calculating the amount of unused land converted into farmland, forestland, and grassland, the development status of Xinjiang' s sand industry over the past 16 years is analyzed. Combined with the water footprint model and regional water resources carrying capacity evaluation indicators, the water footprint of Xinjiang from 2000 to 2015 is calculated, and the regional water resources carrying capacity is evaluated. The results show that: (1) During 2000-2015, with the population growth and economic development in Xinjiang, the sand industry developed rapidly, and some unused land such as sandy land and Gobi, as well as grassland, were developed into farmland, forestland, industrial and mining areas, and urban and rural residential land. (2) The overall water footprint in Xinjiang shows an upward trend, with the water footprint of agricultural products dominating and increasing rapidly. The main reason is that Xinjiang vigorously develops the sand industry, utilizing unused land and grassland for planting crops and desert medicinal herbs. (3) The per capita water footprint, water resources pressure index, and water footprint benefit indicators in Xinjiang show an increasing trend, but the values are significantly lower than the national average. The overall trend of social and economic development in Xinjiang is positive, but the water resources utilization pattern remains relatively extensive, and water resources have not been rationally developed. Therefore, Xinjiang should optimize its industrial structure, adjust crop planting ratios and water use patterns to increase the scale of sand industry development supported by water resources. This study can provide a basis for adjusting regional industrial structure and consumption patterns.

Full Text

Study of Current Status of Sand Industry and Water Resources Carrying Capacity in Xinjiang

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Abstract

Using land use/land cover remote sensing interpretation data from multiple periods together with Xinjiang Water Resources Bulletin and Statistical Yearbook data, this study evaluates the status of Xinjiang' s sand industry and water resources carrying capacity. By calculating the conversion of unused land to farmland, forest land, and grassland, we analyze the development of Xinjiang' s sand industry over the past 16 years. Combining the water footprint model with regional water resources carrying capacity evaluation indicators, we calculate Xinjiang' s water footprint from 2000–2015 and assess regional water resources carrying capacity. The results show that: (1) During 2000–2015, with population growth and economic development in Xinjiang, the sand industry developed rapidly, with portions of unused land (including sandy land and Gobi) and grassland being converted into farmland, forest land, mining/industrial land, and urban/rural residential land. (2) Xinjiang' s overall water footprint shows an upward trend, dominated by the water footprint of consumed agricultural products, which increased rapidly. This increase is primarily attributed to Xinjiang' s vigorous development of the sand industry, which utilizes unused land and grassland for planting crops and desert medicinal herbs. (3) Xinjiang' s per capita water footprint, water resources pressure index, and water footprint benefit index all show increasing trends, but their values are significantly lower than China' s national averages. While Xinjiang' s socioeconomic development trend is positive overall, water resource utilization remains relatively extensive and water resources have not been reasonably developed. Therefore, Xinjiang should optimize its industrial structure and adjust crop planting proportions and water use patterns to increase the scale of sand industry development supported by water resources. This study provides a basis for adjusting regional industrial structure and consumption patterns.

Keywords: sand industry; water resources; water footprint; carrying capacity

Introduction

The concept of "sand industry" was first proposed by Professor Qian Xuesen in 1984 as a subsystem of knowledge-intensive agricultural systems. It employs high and new technology to develop knowledge-intensive industries characterized by "more sunlight, less water, high efficiency, and new technology." Developing the sand industry represents an inevitable choice for ecological civilization construction, western China development, and poverty alleviation. However, sand industry development increases water demand, making water resources a critical constraint, particularly in arid regions. Water resources carrying capacity has become a key issue for sustainable water resource development.

The water footprint concept was first introduced by Hoekstra in 2002 at the International Expert Meeting on Virtual Water Trade in Delft. As an accounting indicator of humanity' s actual water consumption, it links human consumption to water resources, providing an important basis for maintaining regional water security and improving water use efficiency. Water resources carrying capacity refers to the maximum capacity of water resources to support production, living, and ecological water use under the premise of regional social, economic, and ecological sustainable development. This capacity depends on local natural environment, water resource quantity, and socioeconomic conditions.

Current international research primarily incorporates water resources carrying capacity into sustainable development theory, while domestic scholars mainly focus on regional and urban water resources carrying capacity using methods such as fuzzy matter-element models, neural networks, principal component analysis, and comprehensive evaluation. However, few studies consider socioeconomic factors. Water footprint theory addresses this gap by considering human water consumption from a consumption perspective, expanding water resources carrying capacity research into the socioeconomic domain.

To evaluate the status of Xinjiang' s sand industry and water resources carrying capacity, this study analyzes land use/land cover changes in Xinjiang from 2000–2015, calculates water footprint using the water footprint model, proposes water resources carrying capacity evaluation indicators, quantitatively measures regional water resources carrying capacity, and provides countermeasures for coordinated development of the sand industry and ecology in the region.

1. Study Area Overview

Xinjiang is located in inland China with an extremely arid climate and scarce precipitation, with an average annual precipitation of approximately 150 mm—only about one-third of the national average. According to the *National Water Resources Comprehensive Planning*, Xinjiang' s total water resources amount to 5.36×10^9 m^3, including 8.73×10^9 m^3 of surface water resources and 9.18×10^9 m^3 of groundwater resources. In 2015, Xinjiang' s total water consumption reached 5.77×10^9 m^3, with agricultural water use accounting for 94.7% of the total. Water resource shortages are prominent, making water resources one of the limiting factors for Xinjiang' s socioeconomic development.

Xinjiang has the largest area of desertified land and the most severe wind-sand hazards in China. The region is rich in light and heat resources and possesses unique and diverse species resources. In recent years, Xinjiang has fully utilized these abundant resources in sandy areas, combining sand prevention and control with sand industry development to promote farmer income. A distinctive sand area industry has initially formed, focusing on characteristic forestry and fruit industry, Uyghur medicinal materials, and facility agriculture, with an annual output value of billions of yuan. However, most desert areas in Xinjiang are constrained by water shortages. The current sand industry primarily focuses on plant cultivation and desert medicinal herb development, which consume large amounts of water. Consequently, water resources carrying capacity has gradually become a restrictive factor for socioeconomic development and ecosystem stability in Xinjiang. Rational water resource utilization and improving water resources carrying capacity are crucial issues for coordinated economic and ecological development in the region.

2. Methods

2.1 Sand Industry Status and Change Characteristics

According to the definition by Zhou Yicai et al., the sand industry refers to agriculture, industry, and services in desert and desertified areas that are based on ecological environment construction, employ high-tech means, leverage sufficient sunlight, break through water limitations, and promote sustainable economic, social, and ecological development. Currently, Xinjiang' s sand industry focuses mainly on plant cultivation, timber forest base construction, desert medicinal herb development, and biomass energy utilization. Based on this definition and current development conditions, the status and changes of Xinjiang' s sand industry can be expressed through the conversion of unused land (including sand, Gobi, saline land, swamp, bare land, bare rock, and other categories) into farmland, forest land, and grassland. This study analyzes sand industry status and change characteristics by monitoring land use/land cover transitions in Xinjiang.

2.2 Water Footprint Calculation

The water footprint refers to the water required to produce products and services consumed by the population within a region under certain socioeconomic development levels. Therefore, water footprint calculation includes both actual and virtual water consumption. From a consumer perspective, this study adopts a bottom-up approach for water footprint calculation using the formula:

$$WF = \sum_{i=1}^{n} (p_i \times VWC_i) + EU + LU$$

where WF is the water footprint (in m^3), EU is ecological water use (in m^3), LU is living water use (in m^3), p_i is the consumption quantity of product i (in kg), and VWC_i is the virtual water content per unit mass of product i (in $m^3 \cdot kg^{-1}$). The virtual water content per unit mass for major products in Xinjiang is shown in , with data sourced from literature [?, ?].

Ecological water use and living water use data were obtained from the *Xinjiang Uygur Autonomous Region Water Resources Bulletin* and *Xinjiang Uygur Autonomous Region Statistical Yearbook*. Agricultural product consumption was calculated based on resident consumption levels. Virtual water consumption of industrial products was estimated using industrial water consumption data from the *Xinjiang Uygur Autonomous Region Statistical Yearbook*.

2.3 Water Resources Carrying Capacity Calculation

Water resources carrying capacity refers to the scale of socioeconomic development that can be supported by reasonably developed water resources within a region while ensuring sustainable development. This study selected water resources pressure index and water footprint economic benefit indicators to characterize water resources carrying capacity in Xinjiang. The indicators and calculation methods are shown in .

The water resources pressure index (WP) represents the ratio of water footprint (WF) to total water resources (WA), reflecting the pressure of people' s living and production consumption on regional water resources: $WP = WF/WA$. The water footprint economic benefit (WFP) is the ratio of regional GDP to water footprint (WF). A larger ratio indicates greater economic benefit generated per unit of water footprint: $WFP = GDP/WF$.

These indicators assess water resources carrying capacity status and trends from consumption and socioeconomic development perspectives. The study obtained land use/land cover remote sensing interpretation results for Xinjiang from 2000, 2005, 2010, and 2015 (data from http://www.resdc.cn) to analyze spatiotemporal changes in Xinjiang' s sand industry. For analysis convenience, land use/land cover types were categorized into first-level classes: farmland, grassland, forest land, urban/industrial/residential land, water bodies, and unused land. Land use/land cover maps for each period are shown in [Figure 1: see original paper], and area statistics are presented in .

3. Results

3.1 Sand Industry Status and Change Characteristics

According to research by Zhou Yicai et al. [?], current sand industry development in Xinjiang' s desert and desertified areas focuses primarily on planting crops, desert medicinal herbs, and timber forest base construction. Therefore, sand industry development can be expressed through the conversion of unused land (including sand, Gobi, saline land, swamp, bare land, bare rock, and other categories) into farmland, forest land, and grassland.

Xinjiang' s land use/land cover is dominated by unused land and grassland, with unused land accounting for over 50% and grassland over 28.9% during the study period. Overall, farmland and mining/residential land areas increased significantly, while grassland and unused land areas decreased markedly. From 2000–2015, unused land area decreased by 8,341 km^2, grassland area decreased by 10,725 km^2, farmland area increased by 17,706 km^2 (a 29.8% increase), and mining/residential land area increased by 2,345 km^2.

The land use/land cover transition matrix () reveals that due to vigorous sand industry development, 6,247 km^2 of unused land (including sand and Gobi) was reclaimed as farmland, 220 km^2 converted to forest land, 879 km^2 converted to grassland, and 1,115 km^2 converted to mining/residential land. Simultaneously, 11,414 km^2 of grassland was reclaimed as farmland and 541 km^2 converted to mining/residential land. These changes indicate that with population growth and economic development in Xinjiang, sand industry development has driven significant increases in farmland and urban/rural residential land.

3.2 Water Footprint Change Characteristics in Xinjiang (2000-2015)

Based on water footprint calculation methods, regional total water footprint and component values were obtained as shown in , with component changes illustrated in [Figure 2: see original paper]. The water footprint of consumed agricultural products dominates, increasing from 82.7×10^8 m^3 to 121.34×10^8 m^3 during the study period, accounting for over 46.7% of total water footprint and reaching 79.96% in 2015. The rapid increase in agricultural product water footprint is primarily caused by Xinjiang' s vigorous sand industry development, which utilizes unused land and grassland for planting crops and desert medicinal herbs.

The water footprint of consumed industrial products remained below 0.25×10^8 m^3 throughout the study period, accounting for a small proportion due to the relatively small total area of mining/residential land despite its large increase. Living water use proportion decreased significantly after 2005 to approximately 5.79%, benefiting from comprehensive water-saving measures. Ecological water use first increased then decreased, showing an overall declining trend.

Xinjiang' s per capita water footprint increased during 2000–2015 but remained at 697 m^3, significantly lower than China' s national average of 1,093 m^3, indicating relatively backward production and living standards in Xinjiang. The increasing water footprint trend suggests positive regional economic development, though water resource utilization remains extensive.

3.3 Water Resources Carrying Capacity Analysis

Based on Xinjiang' s water footprint and considering current water resources status and economic development demands, changes in water resources carrying capacity indicators during 2000–2015 were analyzed ().

Water Resources Pressure Index: The water resources pressure index shows an increasing trend but remains low, increasing from 0.25 to 0.46. This indicates that overall water resources pressure in Xinjiang is low, though the pressure is increasing.

Water Footprint Economic Benefit Index: Xinjiang' s water footprint economic benefit exhibited exponential growth during 2000–2015, increasing 35.93 times with an average annual growth rate of 35.93%. This demonstrates that social wealth created per unit water footprint is continuously improving. However, Xinjiang' s water resource utilization intensity remains lower than developed coastal regions, indicating that while socioeconomic development is improving, water use patterns remain relatively extensive.

4. Discussion

During 2000–2015, the water footprint of consumed agricultural products in Xinjiang increased significantly, dominating total water footprint and accounting for over 46.7% throughout the period, reaching 79.96% in 2015. This increase stems from sand industry development that reclaimed unused land and grassland for cultivation. The per capita water footprint and water resources pressure index show slight increases but remain below national averages. Although water footprint economic benefit is improving, Xinjiang' s water resource utilization remains extensive and not reasonably developed, with overall production and living standards still relatively backward.

According to the *National Water Resources Comprehensive Planning*, Xinjiang' s total water use in 2015 was 5.77×10^9 m^3, approaching the planned limit, with agricultural water use accounting for 94.7%. Agriculture contributes only 16.6% of Xinjiang' s GDP while consuming the vast majority of water resources. Research shows that while Xinjiang produces large quantities of grain and cotton, these crops are water-intensive with low economic benefit and are oversupplied regionally. Therefore, while ensuring regional food and ecological security, Xinjiang should appropriately adjust its industrial structure and crop planting patterns to match supply with demand, increase the economic added value of agricultural raw materials, and expand the scale of sand industry development supported by water resources to ensure ecological security.

5. Conclusions

From 2000–2015, Xinjiang' s sand industry developed rapidly alongside population growth and economic development, with portions of sandy land, Gobi, and other unused land being exploited. During this period, 6,247 km^2 of unused land was converted to farmland, 220 km^2 to forest land, 879 km^2 to grassland, and 1,115 km^2 to mining/residential land. Simultaneously, 11,414 km^2 of grassland was reclaimed as farmland and 541 km^2 converted to mining/residential land.

Xinjiang' s water footprint during 2000–2015 was dominated by the water footprint of consumed agricultural products, which increased rapidly due to sand industry development that utilized unused land and grassland for planting crops and desert medicinal herbs. Xinjiang' s per capita water footprint, water footprint benefit index, and water resources pressure index all increased during this period but remained significantly below national averages. This indicates that while Xinjiang' s socioeconomic development trend is positive and living standards are steadily improving, water resource utilization remains relatively extensive and water resources have not been reasonably developed.

Agricultural water use accounts for nearly 95% of Xinjiang' s total water consumption, with agriculture occupying a disproportionately large share of the industrial structure while generating low economic benefit. Xinjiang should appropriately adjust its industrial structure, crop planting proportions, and water use patterns to increase the scale of sand industry development supported by water resources and ensure ecological security.

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