Analysis of Atmospheric Environmental Carrying Capacity in Shaanxi Province (Postprint)

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Abstract

This study investigates the atmospheric environmental carrying capacity in Shaanxi Province, using SO2 and PM10 in the atmospheric environment as assessment objects. The plume footprint analysis method was employed to calculate the environmental capacity coefficient A-value and the spatiotemporal distribution of SO2 and PM10 environmental carrying capacity in Shaanxi Province from 2010 to 2013. The results indicate that the A-value of the environmental capacity coefficient in Shaanxi Province exhibited a considerable variation range, with the province-wide annual average A-value ranging from 1 to 5 during 2010–2013. The A-value was highest in Northern Shaanxi, followed by Guanzhong, and lowest in Southern Shaanxi. From 2010 to 2013, Xi' an, Baoji, and Weinan in the Guanzhong region demonstrated a year-by-year declining trend. The SO2 environmental carrying capacity for the entire province ranged from -148,578.04 km2 to -189,149.59 km2 during 2010–2013, with no surplus in any of the four years. Specifically, Weinan and Xi' an experienced severe SO2 carrying capacity deficits with a declining trend. The PM10 environmental carrying capacity for the entire province ranged from 12,701.47 km2 to 44,511.02 km2 during 2010–2013, with a surplus in all four years. All prefecture-level cities in the province, except Weinan and Tongchuan, maintained a surplus throughout the four-year period, though the overall trend was declining.

Full Text

Preamble

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Mathematical Formulations:

The plume footprint analysis employs the following key equations:

The footprint function is defined as:

$$Fi = \sqrt{S/(Ai \times Cs, i)}$$

The environmental capacity coefficient is calculated as:

$$A = 3.1536 \times 10^{-3} \times \sqrt{\pi \times U \times H} + 3.1536 \times 2$$

Where: - S represents the emission source strength - Ai is the area - Cs, i denotes the concentration standard - U is the wind speed - H is the mixing layer height

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Abstract

In recent years, atmospheric environmental pollution in Shaanxi Province, China has become increasingly serious due to its complex terrain and rapid urbanization. Therefore, it is meaningful to improve air quality and promote coordinated development between economy and environment through comprehensively understanding the bearing capacity of atmospheric environment in Shaanxi Province. Based on observed meteorological data from 98 meteorological stations, this study took the annual average emissions of SO and PM as evaluation objectives from 2010 to 2013 in Shaanxi Province. The study also analyzed the spatial and temporal distributions of the environmental capacity coefficient (A) and bearing capacities of atmospheric environment for SO and PM through plume footprint analysis approach based on the analysis of ecological footprint.

The results were shown as follows:
(1) The varied magnitude of environmental capacity coefficient (A) was large, and the average value of environmental capacity coefficient (A) in the whole Shaanxi Province was ranged from 1 to 5. The largest value of environmental capacity coefficient (A) occurred in Yulin City which is located in the north of Shaanxi Province, and its corresponding values were ranged from 4 to 5. The second largest value of environmental capacity coefficient (A) appeared in Tongchuan City which is located in central Shaanxi Province, and the varied range of its corresponding values was from 3 to 4. The lowest value of environmental capacity coefficient (A) was in Hanzhong City which is located in the south of Shaanxi Province, and the corresponding values were from 1 to 1.5. In particular, the environmental capacity coefficients (A) of Xi' an, Baoji, and Weinan cities were gradually decreased from 2010 to 2013.

(2) The bearing capacities of SO across Shaanxi Province were larger than critical values during 2010–2013, and the values of bearing capacities of SO were negative and ranged from -148578.04 km² to -189149.59 km² which indicated that there was not enough space for bearing SO in these

four years. Moreover, the bearing capacities of SO in Weinan and Xi' an cities were severely larger than critical values and were obviously in descendant trend from 2010 to 2013. Compared with Weinan and Xi' an cities, the bearing capacities of SO in Yan' an, Yulin, Ankang, and Shangluo cities were better whose annual average values were positive during these four years.

(3) The bearing capacities of PM across Shaanxi Province were less than critical values from 2010 to 2013, and the values of bearing capacities of PM were positive and ranged from 12701.47 km^2 to 44511.02 km^2 which suggested that there was still space for bearing PM in these four years. The environmental capacity coefficient (A) in Weinan City was low and the emitted amount of PM was significantly increased in 2013 which revealed that plume footprint was over than bearing area. Particularly, the bearing capacities of PM in all cities were lower than critical values from 2010 to 2013 except Weinan and Tongchuan cities, and the bearing capacities of PM across Shaanxi Province was in descendant trends.

Keywords: environmental capacity coefficient; bearing capacity of atmospheric environment; plume footprint analysis; Shaanxi Province

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1. Data and Methods

1.1 Data Collection and Processing

This study utilized meteorological observation data from 98 meteorological stations across Shaanxi Province. The annual average emissions of SO and PM from 2010 to 2013 were selected as the primary evaluation objectives. The plume footprint analysis method, derived from ecological footprint analysis theory, was applied to assess the atmospheric environmental bearing capacity. Meteorological parameters including wind speed, mixing layer height, and precipitation were incorporated into the model calculations.

The emission data were obtained from environmental monitoring records, while meteorological data were sourced from the Shaanxi Provincial Climate Center archives. All data underwent quality control procedures to ensure consistency and reliability for spatial-temporal analysis.

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2. Results and Analysis

2.1 Spatial and Temporal Distribution of Environmental Capacity Coefficient (A)

The environmental capacity coefficient (A) exhibited substantial variation across Shaanxi Province, with values ranging from 1 to 5. The spatial distribution pattern revealed distinct regional characteristics:

Northern Region: Yulin City demonstrated the highest environmental capacity coefficient values, ranging from 4 to 5. This elevated capacity is attributed to favorable meteorological conditions for pollutant dispersion, including higher wind speeds and greater mixing layer heights.

Central Region: Tongchuan City showed the second-highest values, with the coefficient ranging from 3 to 4. The central region' s moderate capacity reflects its basin topography and intermediate meteorological conditions.

Southern Region: Hanzhong City exhibited the lowest environmental capacity coefficient values, ranging merely from 1 to 1.5. The low capacity in this region is associated with mountainous terrain and frequent atmospheric inversion conditions that limit pollutant dispersion.

Temporal Trends: Notably, the environmental capacity coefficients for Xi' an, Baoji, and Weinan cities demonstrated a consistent decreasing trend from 2010 to 2013, indicating deteriorating atmospheric dispersion conditions in these urban areas.

2.2 Analysis of SO Bearing Capacity

The SO bearing capacities across Shaanxi Province consistently exceeded critical thresholds during the 2010-2013 period. The calculated bearing capacity values were negative, ranging from -148578.04 km^2 to -189149.59 km^2, which unequivocally indicates insufficient atmospheric space for SO assimilation.

Critical Areas: Weinan and Xi' an cities exhibited particularly severe conditions, with bearing capacities substantially exceeding critical values and showing a marked declining trend. This suggests that these metropolitan areas experienced the most significant atmospheric environmental stress.

Comparative Assessment: In contrast, Yan'an, Yulin, Ankang, and Shangluo cities demonstrated relatively better conditions, maintaining positive annual average bearing capacity values throughout the four-year study period. This regional disparity highlights the influence of local emission intensity and topographical factors.

2.3 Analysis of PM Bearing Capacity

Unlike SO , the PM bearing capacities across Shaanxi Province remained below critical values from 2010 to 2013. The positive values, ranging from 12701.47 km^2 to 44511.02 km^2, indicate that residual atmospheric space existed for PM bearing during this period.

Regional Variations: The environmental capacity coefficient in Weinan City was notably low, yet the PM emission amount increased significantly in 2013, resulting in plume footprint exceeding the bearing area. This anomaly warrants attention for urban planning and emission control strategies.

Provincial Trends: With the exception of Weinan and Tongchuan cities, all other cities maintained PM bearing capacities below critical values. However, the overall provincial trend showed a descendant pattern, suggesting gradually diminishing atmospheric environmental space for particulate matter.

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3. Footprint Function Analysis

3.1 SO Footprint Function

[Figure 1: see original paper] shows the spatial distribution of SO emissions across Shaanxi Province from 2010 to 2013. The footprint function values, presented in , reveal significant inter-city variations. The calculation follows the formula:

$$Fi = \sqrt{S/(Ai \times Cs, i)}$$

The analysis demonstrates that cities with higher emission intensities and lower environmental capacity coefficients exhibit larger footprint functions, indicating greater pressure on atmospheric environmental resources.

3.2 PM Footprint Function

[Figure 2: see original paper] illustrates the PM emissions distribution for the same period. The footprint function analysis for PM follows the same methodological framework as SO , with appropriate adjustments for particulate matter dispersion characteristics and deposition velocities.

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4. Discussion

The substantial variation in environmental capacity coefficient (A) across Shaanxi Province reflects the complex interplay between meteorological conditions, topographical features, and emission patterns. The negative bearing capacities for SO province-wide underscore the urgent need for stringent emission reduction measures, particularly in high-impact cities like Weinan and Xi' an.

Conversely, the positive yet declining bearing capacities for PM suggest that while current conditions remain within manageable limits, proactive policies are essential to prevent future exceedances. The decreasing trend in environmental capacity coefficients in major cities (Xi' an, Baoji, Weinan) may be associated with urbanization-induced changes in local climate and atmospheric boundary layer dynamics.

The plume footprint analysis approach provides a robust framework for quantifying atmospheric environmental bearing capacity, offering valuable insights for regional air quality management and sustainable development planning.

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