

Postprint: Impacts of Urbanization on Fractional Vegetation Cover and Landscape Patterns in the Beijing-Tianjin-Hebei Region

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Abstract

This study quantitatively investigated the dynamic changes in vegetation coverage and landscape pattern in the Beijing-Tianjin-Hebei region from 2000 to 2010, revealing the disturbance process of urbanization on vegetation landscapes and its impact on ecological quality. The results showed that: (1) From 2000 to 2010, the urbanization process was a prominent characteristic of land change in the Beijing-Tianjin-Hebei urban agglomeration, with artificial surface area increasing from 1.79×10^4 km² in 2000 to 2.16×10^4 km², an increase of 21.16%; (2) The average vegetation coverage in Beijing-Tianjin-Hebei exhibited an increasing trend that was not statistically significant ($P=0.46$), with obvious spatiotemporal dynamic differences. A pattern dominated by low-medium and medium vegetation coverage was formed in the coverage structure; (3) In terms of landscape spatial pattern changes, vegetation landscapes in low-medium and high coverage areas became more fragmented, while vegetation area in low and medium coverage areas increased and landscape fragmentation decreased; especially in urban areas dominated by low vegetation coverage, the landscape pattern changed substantially, manifested as increased green space area, reduced landscape fragmentation, and improved ecological quality; (4) Across the entire study area, urbanization had a negative impact on regional vegetation coverage, manifested as a negative correlation between urbanization degree and regional average vegetation coverage ($P=0.08$); however, in areas with low vegetation coverage (mainly urban areas), urbanization degree was significantly positively correlated with vegetation coverage area ($P < 0.001$), indicating that vegetation coverage area in urban areas increased during the urbanization process and ecological quality improved, which is related to the increasing emphasis on urban green space construction during urbanization.

Full Text

Preamble

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Impact of Urbanization on Vegetation Coverage and Landscape Patterns in the Beijing-Tianjin-Hebei Region

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Abstract

Accelerated urbanization and socio-economic development cause a series of environmental problems, including decreased ecological quality. Accurately and efficiently quantifying the effects of urbanization on vegetation is critical for understanding regional ecological conservation and achieving sustainable development. Previous studies have primarily focused on the spatiotemporal patterns of vegetation cover and its relationship with climatic factors. Here, we quantified the spatiotemporal patterns of vegetation cover from 2000 to 2010 in the Beijing-Tianjin-Hebei megaregion and analyzed the effects of urbanization on vegetation cover dynamics using MODIS and Landsat TM data. We found that: (1) During the study period, urban land expanded rapidly in this megaregion, with built-up land area increasing from 1.79×10^4 km² in 2000 to 2.16×10^4 km² in 2010, representing a 21.16% increase. (2) Vegetation coverage exhibited a slight but statistically insignificant increasing trend from 2000 to 2010 ($p = 0.45$), and the region was dominated by low-medium and medium coverage vegetation. (3) Spatiotemporal patterns varied among vegetation types with different density levels. For vegetation with low-to-medium and high density, fragmentation increased from 2000 to 2010. In contrast, for vegetation with low and medium density, landscape patterns became more aggregated rather than fragmented. (4) The proportional cover of developed land showed negative correlations with overall vegetation coverage ($p = 0.08$). However, developed land cover exhibited a significantly positive relationship with the proportion of low-density vegetation area ($p < 0.001$), indicating that urban green space area increased during urbanization, improving ecological quality—likely due to growing emphasis on urban green space construction.

Keywords: Beijing-Tianjin-Hebei; vegetation coverage; urbanization; spatiotemporal dynamics; landscape pattern

1 Study Area Overview

The Beijing-Tianjin-Hebei region includes Beijing, Tianjin (two municipalities), and various cities under Hebei Province's jurisdiction such as Shijiazhuang. The total land area is 2.17×10^5 km², located at 36°05' -42°40' N, 113°27' -119°50' E. The region has a typical temperate semi-humid and semi-arid monsoon climate, with dry and windy springs/autumns and hot, rainy summers. The Beijing-Tianjin-Hebei region has become China's fastest-growing regional economy with the highest level of economic development. However, increasing human activity intensity has placed tremendous pressure on ecosystems, causing serious environmental degradation that threatens regional habitat quality and sustainable development.

[Figure 1: see original paper] Location of the studied area and its topography

2 Methods

2.1 Vegetation Coverage Calculation

Vegetation coverage calculation was based on MODIS data from NASA's Data and Information Services Center (MOD13Q1 product). This dataset has a spatial resolution of 250×250 m, a 16-day temporal resolution, and required pre-processing including atmospheric correction, format/projection conversion, and synthesis into monthly averages using the Maximum Value Composite (MVC) method. A linear relationship exists between vegetation coverage and NDVI, enabling conversion between the two to extract vegetation coverage information.

This study employed a remote sensing estimation method based on the pixel dichotomy model, which offers a simple technical route, strong operability, and applicability across different vegetation types [25]. The method assumes each pixel comprises vegetation and non-vegetation components. The vegetation coverage of a pixel is calculated as the percentage of vegetation cover within the pixel using the formula:

$$F_c = \frac{NDVI - NDVI_{soil}}{NDVI_{veg} - NDVI_{soil}}$$

where $NDVI$ is the actual pixel value, $NDVI_{soil}$ is the value for bare soil pixels, and $NDVI_{veg}$ is the value for full-vegetation pixels.

Following the Soil Erosion Classification and Grading Standards of the Ministry of Water Resources of China, vegetation coverage was classified into four grades: $< 30\%$ (low coverage), $30\% - 45\%$ (low-medium coverage), $45\% - 60\%$ (medium coverage), and $> 60\%$ (high coverage). We performed regression analysis between vegetation coverage and year for each pixel to quantitatively analyze temporal trends.

2.2 Land Cover Classification

Land cover classification utilized Landsat TM data at 30 m spatial resolution. An object-oriented classification method categorized land cover into woodland, grassland, water, cropland, built-up land, and bare land. The product achieved 98% accuracy with a Kappa coefficient of 0.85 after geometric and radiometric correction. This study used built-up land area (i.e., construction land) to represent urbanization process and intensity.

2.3 Landscape Index Selection

Landscape patterns can be described using landscape metrics that condense pattern information and quantitatively reflect structural composition and spatial configuration characteristics [27]. This study calculated vegetation patch type indices across different vegetation coverage grades to analyze vegetation area and fragmentation, thereby parsing regional landscape pattern changes.

Five landscape metrics were selected: Percentage of Landscape (PLAND), Mean Patch Size (MPS), Patch Density (PD), Edge Density (ED), and Landscape Shape Index (LSI). These characterize vegetation cover proportion, patch scale, and landscape heterogeneity. Higher patch density indicates greater fragmentation. Formulas for these indices are detailed in reference [27]. We vectorized different vegetation coverage grade regions for 2000 and 2010 to analyze landscape pattern changes, as these metrics effectively explain patch size, distribution, and fragmentation [28]. Fragmentation is also related to patch shape—simpler shapes have lower fragmentation for the same area.

3 Results

3.1 Land Urbanization

Urbanization progressed significantly from 2000-2010, with built-up area increasing from 1.79×10^4 km² to 2.16×10^4 km² (21.16% growth). Urban expansion converted substantial cropland to built-up land, with converted cropland accounting for 55.32% of total cropland loss. This demonstrates that rapid construction land expansion was a major characteristic of land change in the Beijing-Tianjin-Hebei urban agglomeration. Spatial variation was pronounced, with rapid expansion in large/medium cities like Beijing, Tianjin, and Shijiazhuang.

[Figure 2: see original paper] Spatial distribution of built-up lands and their changes in Beijing-Tianjin-Hebei region from 2000 to 2010

3.2 Interannual Variation and Spatiotemporal Distribution of Vegetation Coverage

Average vegetation coverage in Beijing-Tianjin-Hebei remained relatively stable with minor fluctuations (44.9%-48.8%). Coverage was relatively high in 2001

and 2006, but lower in 2000, 2004, and 2008. Overall, vegetation coverage increased insignificantly from 2000-2010 ($p = 0.46$).

Spatiotemporally, 61.84% of the region showed increasing vegetation coverage, with 14.52% showing significant increases ($p < 0.05$). Significant increases occurred primarily in areas with minimal human activity, such as the Taihang Mountains, wind-sand source control project areas, and natural forest growth zones, also reflecting the effectiveness of Beijing-Tianjin wind-sand source control, returning farmland to forest, and hillside closure policies [29-30]. Significant decreases (5.96%) occurred mainly in Zhangjiakou's Bashang area due to overgrazing and reclamation that damaged grassland ecosystems and intensified desertification. Decreases also concentrated around cities like Beijing, Tangshan, and Shijiazhuang, where rapid urbanization converted cropland and grassland to construction land.

Land cover change transition matrix and relative change rates (2000-2010) / km²

3.3 Analysis of Different Vegetation Coverage Grades

The region is dominated by medium (42.08%) and low-medium (30.32%) vegetation coverage, with high (16.25%) and low (11.35%) coverage comprising smaller proportions. From 2000-2010, different grades exhibited distinct trends. High-coverage vegetation decreased dramatically, with 42.29% (18,252.56 km²) converting to medium coverage, particularly around cities. Medium-coverage vegetation increased from 75,323.38 km² (37.22%) to 91,276.13 km², primarily from low-medium coverage conversion, reflecting the effectiveness of ecological projects like shelterbelt systems, hillside closure, and returning farmland to forest.

Low-coverage vegetation increased by 0.49% (229.81 km²), mainly due to construction land expansion in urban centers and peripheries. Low-coverage areas are distributed in large/medium cities and their fringes (Beijing, Tangshan, Shijiazhuang), as well as the Bashang area where human disturbance is strong.

[Figure 3: see original paper] Variation of annual vegetation cover in Beijing-Tianjin-Hebei region from 2000-2010

[Figure 4: see original paper] Spatial distribution of vegetation cover trends from 2000 to 2010: (a) spatial distribution of annual change rate; (b) spatial distribution of change trends

[Figure 5: see original paper] Variations of different vegetation cover levels from 2000 to 2010

[Figure 6: see original paper] Spatial distribution of different vegetation cover levels in 2000 and 2010

3.4 Vegetation Coverage Spatial Pattern Changes

Landscape patterns varied among vegetation coverage grades. In 2000, PLAND ranking from high to low was: low-medium, medium, high, and low coverage. Low-coverage areas had small, highly fragmented patches, while high-coverage areas showed the opposite pattern.

From 2000–2010, medium-coverage areas experienced substantial landscape pattern changes: MPS increased while PD and ED decreased, indicating reduced fragmentation. Low-coverage areas also showed large changes with increased green area and reduced fragmentation, likely related to urban green space construction. As awareness of urban green space ecological services grew, construction efforts intensified, improving green area and ecological quality. High-coverage landscape patterns changed inversely to medium-coverage patterns, with MPS decreasing most significantly, indicating increased fragmentation and more complex shapes.

[Figure 7: see original paper] Landscape metrics of different vegetation cover levels in 2000 and 2010

3.5 Impact of Urbanization on Vegetation Coverage

Quantifying correlations between urbanization rate and vegetation coverage revealed that as regional urbanization level increased, average vegetation coverage decreased while low-coverage vegetation proportion increased. The area proportion of low-coverage vegetation reflects urban green space area to some extent.

Due to varying urbanization levels and ecological project implementation across administrative units, average vegetation coverage, urbanization rates, and vegetation change rates differed among prefecture-level cities. From 2000–2010, all cities' urbanization rates increased, with Beijing showing the fastest growth (7.80 percentage points), followed by Tianjin (6.93 percentage points). Chengde and Zhangjiakou had the slowest urbanization growth. Average vegetation coverage increased only in Cangzhou and Hengshui, while decreasing or remaining stable elsewhere. Low-coverage vegetation area proportion increased in most cities but decreased in Shijiazhuang, Qinhuangdao, and Langfang.

Cross-city comparisons revealed negative correlations between urbanization rate and average vegetation coverage ($r = -0.476$, $p = 0.08$), but significant positive correlations between urbanization rate and low-coverage vegetation proportion ($r = 0.805$, $p < 0.001$). Higher urbanization rates corresponded to lower average vegetation coverage but higher proportions of low-coverage vegetation.

Urbanization rate and vegetation coverage of each city in Beijing-Tianjin-Hebei region in 2000 and 2010 / %

Correlation between urbanization rate and vegetation coverage in Beijing-Tianjin-Hebei region

4 Discussion

4.1 Impact of Urbanization on Vegetation Dynamics

This study examined the rapidly urbanizing, intensively human-disturbed Beijing-Tianjin-Hebei region with significant land use changes. Vegetation coverage dynamics reveal ecological quality changes and provide a scientific basis for ecological construction assessment and sustainable urbanization planning.

From 2000–2010, habitat quality showed a spatial pattern of higher quality in the north and lower quality in the southeast. High-coverage vegetation dominated the Yanshan-Taihang Mountains and Zhangjiakou's Bashang area, while low-coverage vegetation occupied urban cores of Beijing, Tangshan, and Baoding. The region was dominated by low-medium and low vegetation coverage, with an insignificant overall increasing trend.

Ecological projects and urbanization were the main drivers of vegetation coverage change. Coastal shelterbelt and returning farmland-to-forest projects improved vegetation coverage and ecological environment in areas like Hengshui. Since 2000, the Beijing-Tianjin wind-sand source control project has enhanced vegetation coverage through protection, watershed management, and ecological migration [30–31]. However, urban fringe areas experienced vegetation coverage declines as construction land expansion occupied high-quality cropland and forest land, reducing high-coverage vegetation and expanding low-coverage areas.

Numerous studies demonstrate that land use change, particularly human-driven changes, directly alters vegetation cover and affects regional ecological quality [11,13,32]. Rapid urbanization caused dramatic land use changes, converting cropland to built-up land. This study found that in low-coverage areas, vegetation patch area ratios increased while fragmentation decreased significantly, reflecting improved urban green space patterns. Urban green spaces provide essential ecosystem services (carbon sequestration, cooling, humidification, pollutant absorption) and cultural functions (recreation) that improve urban ecological quality and living environments [33–36]. The increased vegetation proportion in low-coverage areas likely reflects growing emphasis on urban green space planning and construction. While urbanization negatively correlates with regional average vegetation coverage, low-coverage areas partially characterize urban zones.

4.2 Impact on Vegetation Landscape and Ecological Quality

Rapid urbanization has dramatically altered surface landscapes and patterns. The large-scale growth of construction land is the primary factor intensifying landscape fragmentation. From 2000–2010, vegetation area increased, but rising patch density and decreasing mean patch size indicate enhanced fragmentation.

The entire region's vegetation fragmentation increased, particularly in high-coverage areas where mean patch size decreased most significantly. This shows

that urban expansion's significant landscape impact is increased fragmentation, as continuous natural and cropland landscapes were replaced by construction land. This habitat fragmentation may alter ecosystem energy flow, material cycling, and nutrient processes, affecting critical ecosystem services [37]. Habitat fragmentation directly reduces species dispersal and population establishment opportunities, decreasing biodiversity [38].

However, reduced fragmentation in low-coverage areas indicates improving urban green space landscape patterns, which has important value for enhancing urban ecological and human living environments.

6 Conclusion

- (1) From 2000-2010, built-up land in the Beijing-Tianjin-Hebei urban agglomeration expanded rapidly from 1.79×10^4 km² to 2.16×10^4 km² (21.16% increase), with rapid cropland reduction being a major characteristic.
- (2) Overall vegetation coverage showed an insignificant increasing trend ($p = 0.46$) with obvious spatiotemporal differences, dominated by low-medium and medium coverage vegetation.
- (3) Landscape pattern changes varied: high-coverage areas became more fragmented, while medium-coverage vegetation area increased with reduced fragmentation. Urban areas dominated by low-coverage vegetation showed large pattern changes, with increased green area, reduced fragmentation, and improved ecological quality.
- (4) Across the study area, urbanization negatively impacted vegetation coverage, showing negative correlation with average vegetation coverage ($p = 0.08$). However, in low-coverage areas (mainly urban), urbanization showed significant positive correlation with vegetation area ($p < 0.001$), indicating improved vegetation coverage and ecological quality during urbanization, related to increasing urban green space construction.

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