# Post-print: Impacts of Urban-Rural Development on Ecosystem Productivity in the Inner Mongolia Plateau over the Past Two Decades

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## Abstract

Scientific assessment of monitoring urban and rural development and construction activities on the Inner Mongolia Plateau and their impacts on regional ecosystem productivity is of great scientific and practical significance for building the national northern ecological security barrier. Based on remote sensing imagery, land use data, meteorological observation data, and other auxiliary information, this study comprehensively applied methods such as dynamic degree analysis and neighborhood substitution to evaluate the spatial extent, expansion rate, and impacts on ecosystem productivity of urban and rural development and construction on the Inner Mongolia Plateau from 2000 to 2020. The results show: (1) In 2020, the area of urban and rural development and construction land on the Inner Mongolia Plateau was 18206.49 $km^2$, accounting for 1.46% of the total land area. (2) From 2000 to 2020, the expansion area of urban and rural construction was 7462.99 $km^2$, with 59.76% originating from the expansion of industrial and mining land. The expansion of urban and rural construction land mainly occupied natural and farmland ecosystems, with urban land and rural residential areas primarily occupying farmland, while industrial and mining land mainly occupied grassland and desert. (3) From 2000 to 2020, the loss of vegetation net primary productivity (NPP) on the Inner Mongolia Plateau due to human urban and rural development and construction activities reached 143.51$×10^{4}$ tC, with mining development causing the most losses, its proportion increasing from 60.72% in 2000–2010 to 73.91% in 2010–2020. Since 2010, NPP losses caused by urban and rural development and construction occupying farmland have been alleviated, while NPP losses from grassland have been intensifying. (4) Ecosystem NPP losses in the Mu Us Sandy Land, Hulunbuir Sandy Land, Hunshandake Sandy Land, and Horqin Sandy Land were mainly caused by mining development. Increases in urban population and GDP, as well as related policies, have caused continuous expansion of urban and rural construction, exerting a certain degree of impact on ecosystem NPP. The

research results provide important reference value for high-quality urban and rural development and construction and ecological civilization construction on the Inner Mongolia Plateau.

## Full Text

# Impacts of Urban and Rural Construction on Ecosystem Productivity in the Inner Mongolia Plateau from 2000 to 2020

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**Abstract:** Monitoring human urban and rural construction activities in the Inner Mongolia Plateau and scientifically assessing their impacts on regional ecosystem productivity holds significant scientific and practical importance for building China's northern ecological barrier. Based on remote sensing imagery, land use data, meteorological observations, and auxiliary information, this study employed dynamic analysis and neighborhood substitution methods to evaluate the spatial extent, expansion rate, and impacts on ecosystem productivity of urban and rural construction from 2000 to 2020. The results indicate that: (1) The area of urban and rural construction land in 2020 reached 18,206.49 $km^2$, accounting for 1.46% of the total land area of the Inner Mongolia Plateau. (2) Over the past 20 years, the expansion area of urban and rural construction land totaled 7,462.99 $km^2$, with 59.76% originating from industrial and mining land expansion. This expansion primarily occupied natural and cultivated ecosystems, with urban land and rural residential areas mainly encroaching on farmland, while industrial and mining land predominantly occupied grassland and desert ecosystems. (3) From 2000 to 2020, the total loss of net primary productivity (NPP) caused by human urban and rural construction activities in the Inner Mongolia Plateau reached 143.51$×10^{4}$ tC, with mining development causing the most severe losses. The proportion of NPP loss from industrial and mining land increased from 60.72% during 2000–2010 to 73.91% during 2010–2020. (4) Since 2000, NPP loss from urban and rural construction occupying farmland has been alleviated; however, grassland NPP loss has intensified. The four major sandy lands of the Inner Mongolia Plateau—Mu Us, Hulunbuir, Otindag, and Horqin—experienced significant ecosystem losses,

primarily driven by mining development. Urban population growth, GDP increase, and related policies have triggered continuous expansion of urban and rural construction, exerting considerable impacts on ecosystem NPP. These findings provide important reference value for high-quality urban and rural development, ecological civilization construction, and ecosystem protection in the Inner Mongolia Plateau.

**Keywords:** urban and rural construction; ecosystem; NPP loss; Inner Mongolia Plateau

## Introduction

Terrestrial ecosystem productivity is a critical indicator for assessing regional vegetation carbon sequestration functions and ecosystem services. With the widespread implementation of the United Nations Millennium Ecosystem Assessment program, ecological evaluation has become a frontier topic in global environmental research. Net primary productivity (NPP) refers to the biomass accumulated by green plants per unit area per unit time, and its variation profoundly influences the global carbon cycle and environmental quality upon which organisms depend. Land use/cover change affects regional ecosystem quality and stability, with urban and rural construction expansion representing a significant cause of ecosystem productivity decline.

The Inner Mongolia Plateau, located in a typical temperate arid and semi-arid climate zone, hosts desert, grassland, and forest ecosystems from southwest to northeast. As an important northern ecological barrier in China, it represents a geographically vulnerable region with fragile ecosystems. The plateau also encompasses four major sandy lands—Hulunbuir, Horqin, Otindag, and Mu Us—which are hotspots of desertification in China. Influenced by climate change and human activities such as reclamation, overgrazing, and energy extraction, the Inner Mongolia Plateau has experienced ecological degradation, desertification, vegetation disturbance, and declining ecosystem service functions. Timely monitoring of the status, speed, and scale of urban and rural construction and their impacts on ecosystem productivity can provide scientific evidence for improving regional resource management and achieving sustainable development.

Previous studies have demonstrated diverse and significant impacts of urban and rural construction on regional ecosystem productivity in the Inner Mongolia Plateau. Research indicates that the rapid increase of open-pit coal mines in Ordos has led to the loss of natural ecosystems including grasslands, forests, and sandy lands, causing severe negative impacts on vegetation productivity. Vegetation within 500 m of typical mining areas in the Inner Mongolia Plateau suffers extreme destruction. However, other studies show that urban expansion in the Hohhot-Baotou-Ordos region from 2000 to 2015 improved urban greening levels and increased regional NPP. These studies primarily focused on typical areas with small spatial scales, yielding inconsistent conclusions and providing limited guidance for resource management across the entire Inner Mongolia

Plateau. Therefore, this study addresses the entire plateau, analyzing the scale, speed, and ecosystem occupation of urban and rural construction from 2000 to 2020 based on satellite imagery, land use data, meteorological observations, and auxiliary information. It reveals the impacts of construction activities on ecosystem productivity over the past two decades, providing crucial scientific support for optimizing urban and rural development processes and coordinating emission reduction targets, ecological civilization construction, and ecosystem protection in the Inner Mongolia Plateau.

### 1.1 Study Area Overview

The Inner Mongolia Plateau (36°16 –52°99 N, 92°68 –125°83 E) is China's second-largest plateau, spanning the northeast, northwest, and north China regions, and serving as a critical northern ecological security barrier. The study area includes 12 prefecture-level cities and 91 counties in Inner Mongolia Autonomous Region, Gansu Province, Ningxia Hui Autonomous Region, and Hebei Province, covering approximately 124.70$×10^{4}$ km$^2$ with an average elevation of about 1,145.92 m. The region features predominantly plain and gentle hill landforms and experiences a temperate continental monsoon climate with precipitation increasing from west to east. The plateau's main ecosystems are grassland and desert, accounting for 40.34% and 30.24% of the land area, respectively. Based on ecosystem structure, climate zones, and geomorphological divisions, the region is categorized into eastern (forest-dominated), central (grassland and farmland-dominated), and western (desert-dominated) areas. The four major sandy lands—Hulunbuir (42,065.32 km$^2$), Horqin (9,022.04 km$^2$), Otindag (39,979.18 km$^2$), and Mu Us (33,130.64 km$^2$)—represent ecologically significant and representative areas for analyzing ecosystem function and quality changes in the Inner Mongolia Plateau.

### 1.2 Data Sources and Preprocessing

This study utilized land use/cover data, Enhanced Vegetation Index (EVI), meteorological data, and auxiliary information (Table 1). Land use/cover change data were obtained from China's Land Use/Cover Dataset (CLUD) produced by the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences. This continuous database has a spatial resolution of 30 m and was derived from Landsat TM/ETM+/OLI imagery through human-computer interactive visual interpretation, including 6 primary and 25 secondary land use types. Based on definitions of Chinese terrestrial ecosystem types and their distribution in the Inner Mongolia Plateau, we reclassified them into five ecosystem types: farmland, grassland, forest, desert, and others.

Remote sensing data included Terra MOD13Q1 EVI products with 250 m spatial resolution and 16-day temporal resolution, downloaded from NASA. After extraction, data covering the Inner Mongolia Plateau were mosaicked, projected, and clipped to obtain annual EVI datasets. Meteorological data comprised 500 m resolution monthly precipitation and temperature datasets for China from

the National Tibetan Plateau Science Data Center. Considering the vegetation growing season primarily occurs from May to September, we selected data from these months for vegetation disturbance index calculations. Grassland vegetation types, boundaries of the four major sandy lands, and administrative divisions were obtained as vector data from the Resource and Environmental Science Data Center and the Atlas of Deserts and Desertification in Northern China. DEM data were acquired from the National Geomatics Center of China.

### 1.3 Methods

**1.3.1 Extraction of Urban and Rural Construction Land** Urban and rural construction land (URCL) in this study includes urban land, industrial and mining land, and rural residential land. Urban land refers to built-up areas of large, medium, and small cities and towns above county level. Industrial and mining land includes factories, large industrial zones, oil fields, salt fields, quarries, transportation roads, airports, and special-use land. Rural residential land refers to settlements independent of urban areas. We extracted URCL expansion areas from 2000 to 2020 using overlay analysis. Urban land, rural residential land, and industrial/mining land were distinguished based on their characteristics. Industrial and mining land was further categorized into small (<1 $km^2$) and large ($ 1$km^{2}$) plots, with 500 m and 1,000 m buffer zones established respectively to assess impacts on surrounding ecosystems.

**1.3.2 Assessment of Urban and Rural Construction Impacts on Ecosystems** We used the vegetation disturbance index (VDI) to quantify ecosystem disturbance from urban and rural construction. In arid and semi-arid regions, precipitation is the primary determinant of vegetation growth. Without disturbance events, vegetation yield per unit precipitation (e.g., EVImax/PREcum) should approximate multi-year averages or remain within natural variability ranges. When negatively impacted by urban construction, mining, or other disturbances, EVImax values become significantly lower than natural variability ranges. We established buffer zones around urban land (500 m), rural residential land (500 m), and industrial/mining land (500 m for small plots, 1,000 m for large plots) to calculate VDI and assess impacts on ecosystem productivity. VDI is calculated as:

$$VDI = \frac{EVImax/PREcum}{(EVImax/PREcum)_{mean}}$$

where $EVImax$ is the annual maximum EVI, $PREcum$ is cumulative precipitation, and $(EVImax/PREcum)_{mean}$ is the multi-year average of the EVImax to precipitation ratio. When VDI $< 0.8$, the area is considered disturbed by urban and rural construction through direct occupation and reduced vegetation productivity in surrounding areas.

**1.3.3 Estimation of Urban and Rural Construction Impacts on Ecosystem Productivity** We employed the neighborhood substitution method to evaluate NPP loss from URCL expansion. Assuming similar climate and vegetation growth conditions within a certain range, the NPP of pixels occupied by URCL expansion would approximate the average NPP of the same ecosystem type in the surrounding area. Therefore, for expansion occurring between year t and t+1, we used the average NPP of the same ecosystem type within a 500 m buffer of the newly expanded URCL in year t+1 as the potential NPP (NPPpot) of occupied ecosystem pixels. The actual observed NPP (NPPu&r) in year t+1 was then subtracted from NPPpot to obtain NPP loss caused by URCL expansion (NPPloss = NPPpot - NPPu&r). Calculations were performed separately for t and t+1 years, with their means used as final estimates.

## 2 Results and Analysis

### 2.1 Spatial Extent and Distribution of Urban and Rural Construction

From 2000 to 2020, the intensity of urban and rural construction in the Inner Mongolia Plateau increased significantly, with notable differences in expansion area and speed among urban land, industrial/mining land, and rural residential land (Figure 3). By 2020, URCL area reached 18,206.49 $km^2$, increasing from 0.89% to 1.46% of the plateau's total area. Over the 20-year period, URCL expansion totaled 7,462.99 $km^2$, accounting for 67.44% of the total URCL area in 2020. Urban land expanded steadily, increasing by 854.88 $km^2$ and 872.71 $km^2$ during 2000–2010 and 2010–2020 respectively, with its proportion rising from 4.72% to 7.81%. Industrial/mining land showed the largest and fastest expansion, particularly after 2010, with an expansion rate of 222.94 $km^2$/year and a total area of 4,458.90 $km^2$, representing 59.76% of total URCL expansion. This expansion was concentrated in Ordos City, Wuhai City, and Ningxia Hui Autonomous Region's Yinchuan, Wuzhong, and Shizuishan cities. Rural residential land expanded by 5806.37 $km^2$, with the most rapid growth occurring after 2010.

Spatial distribution of URCL expansion varied significantly across the plateau, with the central region serving as the primary concentration area (Figure 2). Urban land expansion was widespread in central areas, while industrial/mining land expansion occurred extensively in both central and western regions. During 2000–2020, central region URCL accounted for 53.02% of the plateau's total, with urban and industrial/mining land comprising 24.87% and 11.92% of total expansion respectively, concentrated in Hohhot, Baotou, and Zhangjiakai (Hebei Province). Western region industrial/mining land accounted for 36.02% of the plateau's total, showing rapid growth.

### 2.2 Occupation and Disturbance of Ecosystems by Urban and Rural Construction

Analysis of ecosystem occupation by URCL expansion reveals that farmland experienced the highest proportion of loss, reaching 3,360.06 $km^2$ (45.02% of total occupied area), primarily by rural residential land and urban land (22.46% and 19.84% respectively). Grassland ecosystem occupation totaled 2,251.64 $km^2$ (30.24% of total area), with industrial/mining land accounting for 15.70% of this loss. Typical steppe comprised 21.74% of grassland occupation. Desert ecosystem occupation reached 982.21 $km^2$, with industrial/mining land responsible for 88.49% of this loss.

Beyond direct occupation, URCL expansion disturbed broader surrounding areas. From 2000 to 2020, total ecosystem disturbance area reached 11,474.07 $km^2$, with farmland and grassland experiencing the most disturbance (39.85% and 31.82% of total disturbed area respectively). Urban land and rural residential land primarily disturbed farmland ecosystems through direct occupation, with disturbance to other ecosystem types remaining below 10%. Industrial/mining land caused the largest disturbance to natural ecosystems (2,777.78 $km^2$), with typical steppe, desert, and desert steppe comprising 11.22%, 7.25%, and 9.78% respectively. This disturbance significantly reduced vegetation productivity.

### 2.3 Impacts of Urban and Rural Construction on Ecosystem Productivity

From 2000 to 2020, NPP loss caused by human urban and rural construction activities in the Inner Mongolia Plateau reached 143.51$×10^{4}$ tC. Industrial/mining land expansion was the primary driver, accounting for 67.71% of total NPP loss and increasing from 60.72% during 2000–2010 to 73.91% during 2010–2020. In contrast, NPP loss from urban land and rural residential land showed decreasing trends.

Among ecosystem types, NPP loss from grassland and farmland was most significant, though trends differed. Farmland NPP loss decreased most substantially from 2000–2010 to 2010–2020, dropping from 18.05$×10^{4}$ tC to 5.38$×10^{4}$ tC. Forest and other ecosystems also showed reductions of 1.53% and 0.96% respectively. However, grassland and desert NPP loss increased by 16.23$×10^{4}$ tC and 5.96$×10^{4}$ tC respectively. Industrial/mining land expansion was the main cause of natural ecosystem NPP loss, with its proportion increasing from 60.72% to 73.91%. Typical steppe experienced the most significant loss, with industrial/mining land-caused NPP loss increasing by 66.01% from 2000–2010 to 2010–2020.

### 2.4 Urban and Rural Construction in the Four Major Sandy Lands and Ecosystem Impacts

Since 2000, urban and rural construction in the four major sandy lands has been dominated by industrial/mining land expansion, affecting regional vegetation productivity. However, urban greening has slightly increased NPP in peri-urban ecosystems. Total URCL expansion in the sandy lands reached 389.51 $km^2$ (5.22% of plateau total), with industrial/mining land accounting for 86.26%. Vegetation disturbance area totaled 527.47 $km^2$ (4.36% of plateau total), with NPP loss reaching 6.26$×10^{4}$ tC (4.36% of plateau total). Industrial/mining expansion caused NPP loss of 5.40$×10^{4}$ tC, while urban land expansion resulted in only 0.07$×10^{4}$ tC loss, likely due to urban greening with high-biomass tree species under intensive management.

Among the four sandy lands, Mu Us showed the strongest impact, with URCL expansion of 222.50 $km^2$ (83.03% industrial/mining land). Hulunbuir and Otindag had industrial/mining expansions of 44.38 $km^2$ and 35.77 $km^2$ respectively, with NPP loss in Hulunbuir being 4.08 times that in Otindag. Horqin Sandy Land's NPP loss from artificial construction reached 0.20$×10^{4}$ tC.

## 3 Discussion

### 3.1 Continuous Intensification of Urban and Rural Construction Activities in the 21st Century

Since 2000, urban and rural construction intensity in the Inner Mongolia Plateau has continuously increased, with URCL proportion rising from 0.89% to 1.46%, dominated by industrial/mining land expansion. Resource distribution, socioeconomic factors, and related policies are decisive factors in construction layout and change. The plateau is rich in coal, rare earth, and iron ore resources, with mining development driving local economic growth. Urban population increased by 67.48% from 2000 to 2020, with large influxes of labor demanding expanded infrastructure and construction land. National strategies such as "Western Development" and "Central Region Rise," along with provincial development policies, have promoted construction expansion.

Our study found that urban and rural land mainly occupied farmland ecosystems, while industrial/mining land primarily occupied grassland and desert ecosystems, consistent with previous research. The findings further reveal that typical steppe experienced the largest disturbed area. Therefore, land use plans should be adjusted according to different construction activities to strengthen ecosystem functions of the northern ecological barrier.

### 3.2 Urban and Rural Construction Activities Have Reduced Natural Ecosystem and Farmland NPP

The temperate grasslands of the Inner Mongolia Plateau are endangered terrestrial ecosystems vulnerable to severe degradation from human activities. This

study found that urban and rural construction occupied large areas of natural and farmland ecosystems, with total NPP loss reaching 143.51$\times$10^{4}$ tC. Industrial/mining land expansion was the primary cause, particularly significant in central and western regions after 2010. While NPP loss from farmland occupation has been alleviated—likely due to the establishment of a basic farmland database and protection regulations—grassland NPP loss continues increasing. Future attention should focus on the potential impacts of construction expansion, especially industrial/mining land, on regional grain production and animal husbandry.

Since 2000, ecological conditions in the four sandy lands have improved through desertification control projects, with 2.27$\times$10^{4}$ km$^2$ showing improvement. However, socioeconomic development poses serious challenges to sandy land ecosystem stability. Stepwise regression analysis revealed that while the influence of natural factors like temperature and elevation on NPP is weakening ($P < 0.001$), precipitation effects are increasing, and human activity impacts are intensifying, particularly from urban expansion and industrial/mining development intensity ($P < 0.001$). This aligns with findings that human-natural factor interactions are strengthening in the plateau's sandy lands. Notably, NPP loss from industrial/mining expansion is substantial despite being far smaller than areas improved by ecological projects, highlighting the need for strengthened research on ecosystem responses to construction activities.

## 4 Conclusion

From 2000 to 2020, urban and rural construction expansion in the Inner Mongolia Plateau covered 7,462.99 km$^2$, representing 67.44% of total URCL area in 2020. Total URCL area increased from 0.89% to 1.46% of the plateau's total area. Industrial/mining land expansion was the dominant type, accounting for 59.76% of total expansion area. Urban land and rural residential land primarily occupied farmland ecosystems, while industrial/mining land mainly occupied grassland and desert ecosystems. Total NPP loss caused by construction activities reached 143.51$\times$10^{4}$ tC, with industrial/mining expansion contributing 67.71%. While farmland NPP loss has been alleviated, grassland NPP loss continues to intensify. In the four major sandy lands, industrial/mining expansion was the main cause of NPP loss, though urban greening slightly increased peri-urban ecosystem NPP. These results provide scientific support for coordinating urban-rural development, ecological protection, and sustainable development in the Inner Mongolia Plateau.

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