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Coupling Relationship Between Land Use Changes and Surface Thermal Environment in China's Three Major Urban Agglomerations

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Abstract: This study focuses on China's three major urban agglomerations—Beijing-Tianjin-Hebei, the Yangtze River Delta, and the Pearl River Delta. Based on a review of literature data, it examines the spatial and temporal patterns of urban and agricultural land use changes from 2005 to 2024, as well as their impacts on the surface heat environment. The results show that urban land has continued to expand significantly across all three regions, while agricultural land has declined sharply. As a result, the urban heat island effect has become increasingly severe. Urban land contributes much more to surface temperature rise compared to agricultural land. There are clear differences among the three city clusters in terms of land use structure and the evolution of their heat environments. The main driving forces behind these differences include rapid urbanization, industrial restructuring, population growth, and the lack of effective land use planning. This study provides theoretical support for better understanding the coupling relationship between urban land use and the ecological environment system. It also offers useful insights into urban land management and strategies to mitigate heat-related environmental impacts.
Keywords: Three Major Urban Agglomerations; Surface Thermal Environment; Land Use Change; Urban Heat Island Effect
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1.Introduction

In recent years, with the rapid and sustained growth of China's economy, the urbanization process has accelerated significantly, leading to continuous expansion of urban construction and a growing demand for urban land. Land use change is not only a spatial manifestation of urban development but also reflects the complex coupling relationship among industrial restructuring, population migration, and socio-economic dynamics (Ge et al., 2022). As one of the most populous developing countries, China is experiencing large-scale population concentration in urban areas, especially in its three major urban agglomerations: Beijing-Tianjin-Hebei, the Yangtze River Delta, and the Pearl River Delta. This trend has greatly intensified the pressure on urban land resources, resulting in a continued decline in per capita arable land and triggering a series of environmental issues, such as resource depletion, ecological degradation, and pollution (Seifollahi Aghmiuni et al., 2022; Wassie, 2020).

To ease land resource pressures and enhance ecological carrying capacity, the Chinese government has introduced ecological restoration policies such as returning farmland to forests and converting farmland to lakes. These policies aim to balance urban development with environmental protection and promote sustainable land use. However, despite some early achievements in ecological conservation, current urban land development still faces challenges, including insufficient land-use intensification and poorly planned spatial layouts. Problems such as land waste, inefficient use, mixed land functions, and urban sprawl remain widespread (Awuah & Abdulai, 2022; Frederic Deng & Huang, 2004). Meanwhile, the surface cover changes caused by urban land expansion have intensified the urban heat island (UHI) effect, worsened air pollution, and increased pressure on water resources, further threatening the stability and resilience of urban ecosystems (Zhou & Chen, 2018).

In response to these challenges, national policies such as the “National Territorial Spatial Planning Outline” and the “Three Plans Integration” initiative have emphasized the need to optimize urban land use structures, improve land-use efficiency, address land supply-demand imbalances, and establish a development model that is resource-efficient and environmentally friendly. Against this policy backdrop, analyzing the spatial-temporal evolution of urban land use and its coupling with the surface thermal environment has become a key research direction to support high-quality urban development and ecological civilization.

This study focuses on China’s three major urban clusters and systematically reviews and integrates relevant research findings. Drawing on processed remote sensing imagery, land surface temperature (LST) retrieval data, and GIS-based spatial pattern analysis, it conducts a spatial-temporal comparative study of urban land expansion and thermal environment change. By summarizing key indicators such as urban heat island intensity (UHI), land use intensity (LUI), and spatial structure characteristics from representative studies, the research explores the evolution paths of land use structures at different development stages and their impacts on urban thermal patterns. Existing studies have shown that excessive expansion of construction land is the main driver of the intensifying UHI effect, while the reduction of ecological spaces such as green areas and water bodies has significantly weakened the regulating capacity of urban environments (Huang et al., 2019).

The primary aim of this study is to provide scientific evidence for improving the efficiency of urban land resource allocation and promoting coordinated development within urban agglomerations. By deeply analyzing the coupling mechanisms between land use structure and the thermal environment, this research contributes to building a resource-efficient and ecologically friendly territorial development pattern. Ultimately, it seeks to shift China’s urban development model from quantitative expansion toward qualitative improvement, facilitating a balance between economic growth and ecological protection and promoting the sustainable use of land resources.

2.Literature Review

With the accelerating pace of urbanization, the spatial pattern of urban land use and its impact on the ecological environment—particularly the urban thermal environment—has become a key research focus in urban geography and spatial planning. Existing studies mainly concentrate on the spatial distribution of urban land expansion, the coupling relationship between land use structure and the thermal environment, and the influence of land use intensity on urban sustainability (Xiao et al., 2024; Li et al., 2020).

Some scholars have pointed out that the characteristics of urban land use, the distribution of functional zones, and the evolution of land use structure significantly shape urban spatial patterns and determine ecological responses (Deng et al., 2009). Research on China’s three major urban agglomerations has found that cities within each cluster differ markedly in land use efficiency, expansion modes, and spatial organization. These differences lead to varying spatial patterns of urban thermal environments (He et al., 2019).

With advances in remote sensing and GIS technologies, the spatial and temporal evolution of urban land use can now be described with greater precision. Many studies use remotely sensed land surface temperature (LST), normalized difference vegetation index (NDVI), and other indicators, combined with time-series data, to analyze the dynamic relationship between urban heat island (UHI) effects and land use. For example, Liu et al. (2021) used multi-temporal satellite imagery to reveal a strong coupling between land use change and heat environment in the Pearl River Delta, identifying continuous expansion of built-up land as the primary driver of UHI intensification. At the same time, indicators such as land use intensity, spatial clustering, and landscape pattern indices have been widely applied to assess the efficiency and ecological impacts of land use

(Weinstoerffer & Girardin, 2000). Other studies have also found that urban heat environments are influenced not only by land use types but also by socioeconomic factors such as road density and population distribution (Sun et al., 2018).

In addition, from the perspective of temporal evolution, some research has used high-resolution remote sensing data to construct long-term time series, analyzing the pathways and trends of land use pattern changes. These efforts have provided data support and modeling foundations for predicting future urban development and evaluating the effectiveness of heat environment improvements (Ye et al., 2022).

Overall, current research on the spatial patterns of urban land use and thermal environments is becoming more sophisticated. The methods are increasingly diverse, shifting from static distribution analysis to dynamic evolution studies, and from quantitative description to mechanism exploration. These advancements offer important theoretical insights and practical guidance for optimizing land resource allocation, improving spatial structure, and enhancing urban environmental quality.

3.Characteristics of Urban and Agricultural Land Use Changes in the Three Major Urban Agglomerations

3.1 Temporal and Spatial Trends of Urban and Agricultural Land Use

From a spatial and temporal perspective, urban land in major cities across mainland China showed a general trend of expansion between 2005 and 2014, although the rate of increase varied considerably. Among these, the three major urban agglomerations—Beijing-Tianjin-Hebei, the Yangtze River Delta, and the Pearl River Delta—experienced significantly faster urban land expansion compared to other regions. Urban boundaries continued to shift outward, and the trend of urban sprawl became more pronounced (Liu et al., 2024).

Second, in terms of land use change, urban construction land underwent a period of fluctuation between 2006 and the end of 2008. During this time, urban land area first declined slightly and then increased rapidly. This pattern was likely influenced by several factors, including national policies on real estate market regulation, industrial restructuring, and changes in land management policies (Zou et al., 2022). Overall, both urban and agricultural land in the three major city clusters showed an upward trend during this period. However, urban expansion primarily encroached upon low-efficiency agricultural land, leading to changes in agricultural land structure and the gradual marginalization of agricultural space (Wang et al., 2024).

Third, the urban heat island (UHI) effect also showed a clear upward trend from 2007 to the end of 2014. Surface temperatures in urban areas increased year by year, especially in densely built-up zones, where UHI intensity rose significantly (Chang et al., 2020). This trend is closely linked to the growth of impervious surfaces, the reduction of green spaces, and rising population density. As a result, the UHI effect has become one of the major ecological challenges to sustainable urban development (Liu et al., 2017).

Fourth, regarding the spatial and temporal characteristics of the thermal environment, the three major city clusters generally exhibited a warming trend from 2005 to 2014. The thermal environment showed strong spatial clustering, with significantly higher temperatures in central urban areas compared to suburban zones. Some studies have pointed out that during this period, climate warming combined with rapid urban expansion led to a cumulative heating effect across regions (Yu et al., 2019).

More recent studies have shown that from 2015 to 2023, urban construction land continued to expand, while agricultural land faced dual pressures from structural adjustment and spatial reduction (Chen et al., 2024). At the same time, UHI intensity increased more rapidly in the Yangtze River Delta and the Pearl River Delta. In contrast, the Beijing-Tianjin-Hebei region experienced a slower rise in urban heat due to policy regulations and the implementation of ecological restoration projects.

3.2 Patterns of Urban and Agricultural Land Use

Analysis of land use change rates and trends in climatic factors such as temperature and precipitation indicates that as of 2016, the three major urban agglomerations still exhibited inefficiencies in land resource allocation. Agricultural land was continually compressed, while urban land continued to expand. A marked shift in land use was observed—from traditional cropland to non-agricultural purposes, especially in sectors like services, transportation and logistics, and real estate development (Fu et al., 2022).

Driven by rising economic development and expanding urban populations, the growth of newly constructed land was largely influenced by industrial restructuring and population migration. Functional zones related to the tertiary sector—such as real estate, wholesale and retail, and logistics hubs—proliferated, becoming key directions of urban expansion (Hesse, 2016). In this process, a significant amount of agricultural land was converted into urban construction land. Agricultural production spaces have become increasingly marginalized and compressed. However, agricultural land use is also evolving toward larger-scale, more intensive practices, emphasizing efficiency (Shi et al., 2016).

On the downside, the adjustment of urban spatial structure and the increase in impervious surfaces have led to higher surface runoff coefficients, reduced rainwater infiltration capacity, and more frequent flood events. The expansion of impervious areas prevents rainwater from naturally percolating into the soil. Instead, it is rapidly channeled into water bodies, causing a rise in surface water pollutant concentrations, particularly nitrogen, phosphorus, and heavy metals (Sharma & Malaviya, 2021).

Additionally, in subtropical monsoon-influenced regions like the Yangtze River Delta and Pearl River Delta, heavy rainfall is frequent. However, increased UHI effects and a decrease in water surface coverage have introduced climatic instability, such as more frequent localized heavy rainfall events and concurrent urban flooding.

3.3 Driving Factors of Land Use Changes

The transformation of urban and agricultural land use in the three major urban agglomerations is driven by a complex interplay of factors, including policy, economic development, population dynamics, and ecological conditions. The main driving forces include:

(1) Unbalanced Urban Land Structure and Low Land Use Efficiency

Urban land structures remain suboptimal, characterized by low functional integration and fragmented spatial layouts. In northern China, arable land is primarily dry farmland with relatively low agricultural proportions, while the south is dominated by paddy fields, orchards, and economic forests—resulting in a north-south imbalance in land function distribution. Suburban areas have become prime locations for urban expansion, with farmland often located along transportation corridors or near densely built-up zones, making it highly vulnerable to urban encroachment (Xie et al., 2023). Such imbalances lower land use efficiency and increase the risk of farmland degradation and conversion.

(2) Accelerated Urbanization Intensifying the Urban Heat Island Effect

Rapid urbanization has led to a dramatic increase in impervious surfaces and a decrease in vegetation cover, exacerbating the UHI effect. The intensity of UHI is closely correlated with land use changes, particularly the proportion of construction land, which has a significant positive relationship with rising surface temperatures (Tran et al., 2017). In addition, population clustering in city centers has worsened thermal inequality and heightened ecological stress in urban environments.

(3) Lack of Forward-Looking Urban Planning and Land Management

In some cities, short-sighted planning and uncontrolled expansion have failed to adequately consider urban boundaries, ecological red lines, or land carrying capacity. In pursuit of GDP growth, many cities have promoted large-scale expansion of real estate and industrial parks, leading to excessive farmland conversion, fragmentation of green spaces, and ecological degradation. Rapidly growing demand for transportation, housing, and public services has further intensified land development, exacerbating urban–rural spatial imbalances and supply-demand mismatches.

(4) Increasing Risk of Agricultural Non-Point Source Pollution

The intensification of modern agriculture has led to the overuse of fertilizers and pesticides, contributing to non-point source pollution and a decline in soil quality and sustainable farmland productivity. Urban expansion also causes reverse pollution of adjacent agricultural zones through the spread of heavy metals, domestic sewage, and construction waste, further shrinking agricultural ecological spaces and degrading land function (Yang et al., 2020).

(5) Limited Farmland Reserves and Declining Ecological Carrying Capacity

High land development intensity in urban agglomerations has depleted high-quality farmland resources, and the potential for reserve land development is increasingly constrained. Meanwhile, industrialization-related pollution of water and soil has made it more difficult to develop new farmland, resulting in a continued decline in per capita arable land area.

4.Evaluation of Surface Thermal Environment Effects in the Three Major Urban Agglomerations

4.1 Influencing Factors of the Urban Surface Thermal Environment

The urban surface thermal environment is driven by a complex interplay of both natural and anthropogenic factors. With the advancement of remote sensing and GIS technologies, significant progress has been made in quantitatively identifying and assessing these influencing factors. Based on the Anthropogenic Impact on Climate Index (AICI) and national standards such as the Code for Urban Ecological Planning, the primary factors influencing the surface thermal environment in China's three major urban agglomerations can be summarized as follows:

(1) Land Use Type and Surface Cover Change

Different land use types exert varying degrees of regulation on the thermal environment. Urban construction land, characterized by a high proportion of impervious surfaces, typically has low heat capacity and high thermal conductivity, which makes it prone to forming urban heat islands (UHIs). In contrast, agricultural land, forests, and water bodies exhibit stronger cooling and humidity-regulating functions (Tan et al., 2020).

(2) Underlying Surface Characteristics and Microtopography

The thermal physical properties of underlying surfaces—such as heat capacity, thermal conductivity, and albedo—are significantly influenced by slope, aspect, and elevation. In peri-urban zones, the conversion of forests or farmland into impervious surfaces increases solar radiation absorption and contributes to localized high-temperature zones. Changes in biodiversity among different habitat types also affect microclimatic regulation, leading to spatial heterogeneity in surface temperatures (Hu et al., 2021).

(3) Land Use Intensity and Spatial Layout

Land use intensity is closely related to spatial development density. Highly developed urban centers often exhibit a "core heat island" pattern, while less developed peripheral areas tend to remain cooler. Excessive concentration of urban development can obstruct ventilation corridors, impair airflow and heat dissipation, and thereby intensifying thermal accumulation (Guo et al., 2023). Furthermore, areas with low land use diversity are more likely to form thermal "hotspots" due to weaker climate regulation capacity.

(4) Human Activity Intensity and Socioeconomic Drivers

High population density, energy consumption, and traffic frequency are all strongly associated with surface temperature variations. Urban cores with dense populations and developed transportation infrastructure generally record higher land surface temperatures than surrounding areas. Additional anthropogenic heat from industrial emissions, building energy use, and vehicle exhaust further exacerbates the urban heat island effect (Molina Gómez et al., 2022). A strong positive correlation exists between human activity frequency and the magnitude of surface temperature changes.

4.2 Spatial Patterns of Surface Thermal Environment Effects on the Three Major Urban Agglomerations

The spatial distribution of urban thermal environments is influenced not only by geographic and climatic conditions but also by land use structure, transportation infrastructure, urban landscape patterns, and industrial development (Chen et al., 2022).

(1) Meteorological Conditions

Meteorological factors such as wind speed and solar radiation play a significant role in modulating the spatial pattern of surface temperature. High wind speeds promote ventilation and cooling, while low wind speeds and intense solar radiation contribute to UHI formation, especially in city centers. In the Beijing-Tianjin-Hebei (BTH) region, lower winter temperatures and higher wind speeds result in a relatively dispersed heat island pattern. In contrast, the Yangtze River Delta (YRD) and Pearl River Delta (PRD), characterized by humid climates and high urban density, exhibit more concentrated and intense UHI effects.

(2) Density and Expansion of Transportation Infrastructure

The density of transport networks and the extent of paved surfaces are key determinants of urban thermal patterns. Roads, railways, and parking lots—composed predominantly of impervious materials—store heat efficiently and serve as major contributors to localized warming. Rapid expansion of transport infrastructure in urban and suburban areas has intensified regional UHI effects. In the YRD region in particular, thermal patches along major transportation corridors have become increasingly dense and spatially continuous.

(3) Urban Landscape Configuration and Ecological Coverage

Urban green spaces and water bodies serve as essential buffers for mitigating surface temperature. The number, shape index, and connectivity of green space patches significantly influence the spatial configuration of thermal fields (Gao et al., 2022). When green spaces become fragmented or disconnected, their cooling effectiveness diminishes. In the PRD, due to the presence of a dense water network and well-developed ecological corridors, the boundaries of heat islands are more diffused, and heat hotspots exhibit non-uniform distributions.

(4) Spatial Ring Structure of Urban Heat Islands

The three urban agglomerations exhibit a typical concentric-ring spatial pattern of heat distribution. Urban cores, characterized by intensive development, high building density, and low vegetation coverage, consistently show the highest surface temperatures. In contrast, suburban and rural transition zones experience milder thermal conditions.

(5) Industrial Transformation and Underground Space Development

As the tertiary sector continues to grow, coordinated development of both above-ground and underground urban spaces—such as subways and underground malls—has altered the surface energy balance. Although large-scale underground development can alleviate surface land pressure, it may also modify heat flux transmission paths and raise local surface temperatures (Yang et al., 2022). Additionally, the relocation of industrial facilities and the clustering of service industries have shifted the spatial focus of UHIs toward specific functional zones, reshaping the regional thermal landscape.

5.Comparison of Thermal Environmental Effects between Urban and Agricultural Land

5.1 Thermal Environmental Factors of Urban and Agricultural Land

(1) Land Use Intensity and Human Activity Factors

Land use intensity increases significantly with higher population density, building density, and frequency of economic activities. Urban areas, characterized by dense residential, industrial, and transportation infrastructure, experience intense land development. The predominance of impervious surfaces significantly raises the heat capacity and thermal conductivity of the land surface, contributing to a pronounced urban heat island (UHI) effect. In contrast, agricultural land—comprising cropland, forest, and grassland—typically features higher vegetation cover, which promotes evapotranspiration and cooling, thereby mitigating surface temperature rise.

(2) Green Space Degradation and Ecosystem Weakening

Urban expansion has led to the conversion of vast areas of agricultural and forest land into built-up areas, reducing ecological green spaces and constraining urban ventilation corridors. This process weakens ecosystem regulatory functions. Although some former agricultural land is designated as urban green belts, these often lack ecological continuity and vegetation diversity, limiting their cooling effectiveness compared to natural farmland.

(3) Transportation Development and Thermal Load

The rapid growth in urban motor vehicle use has increased exhaust emissions and noise pollution, while also expanding land allocated for transportation. These changes significantly intensify urban thermal loads. Although agricultural regions are also experiencing mechanization and infrastructure development, their overall transportation density remains low, resulting in weaker thermal impacts.

(4) Thermal Regulation Role of Agricultural Land

Agricultural land, with its high vegetation coverage, soil moisture content, and lower development intensity, plays a vital role in regulating the thermal environment. Irrigated farmland, shelterbelts, and mosaic zones of cropland and forest can effectively reduce land surface temperature through evapotranspiration and shading. These areas serve as important “cool source zones” around urban agglomerations, buffering UHI effects (Hesslerová et al., 2019).

(5) Pollution Load and Land Degradation

Despite the ecological buffer functions of agricultural land, the excessive use of pesticides and fertilizers, as well as the intensification of livestock farming, has led to increasing non-point source pollution. In densely populated or industrial regions, agricultural soil degradation and ecosystem imbalance have become increasingly evident, potentially disrupting surface energy balance and weakening the land's thermal regulatory capacity (Liou & Kar, 2014).

5.2 Spatiotemporal Evolution of Thermal Effects in Urban and Agricultural Land

The thermal environmental effects of urban and agricultural land exhibit clear spatiotemporal differences, reflecting changes in land use structure, regional economic development, human activity intensity, and natural geographic features. With accelerating urbanization, these two land types show markedly divergent patterns in surface temperature trends, heat accumulation, and energy exchange.

From a temporal perspective, urban land in China's three major city clusters has expanded rapidly since the early 21st century. As the scale of built-up areas grows, the proportion of impervious surfaces increases, leading to higher regional land surface temperatures and intensifying the UHI effect. Meanwhile, agricultural land has been increasingly marginalized and compressed. The declining area of farmland and forests—both of which play critical roles in thermal regulation—has weakened the overall buffering capacity of the thermal environment.

From a spatial perspective, eastern coastal clusters such as the Yangtze River Delta and Pearl River Delta demonstrate stronger thermal effects due to high construction density and economic vitality (Li, Han, et al., 2020). In contrast, central city clusters, like the Central Plains urban agglomeration, although undergoing rapid expansion, generally retain thermal conditions consistent with the warm temperate and semi-humid to semi-arid zones, leading to relatively milder changes in thermal environments (Pan et al., 2023).

Regionally, cities in the north and northwest, such as those in the Beijing-Tianjin-Hebei region, display distinct thermal evolution patterns. Northwestern areas, characterized by low elevation and arid climates, show large seasonal fluctuations in land surface temperature, especially during winter and spring when diurnal temperature ranges are extreme. In contrast, northeast and north China experience colder winters, but their summer UHI effects remain notable, resulting in complex spatiotemporal coupling of thermal dynamics.

In summary, urban land—with its high construction density and low ecological coverage—generates strong heat accumulation and increasingly pronounced thermal effects. Agricultural land, by contrast, offers strong thermal buffering through vegetation and ecological function. However, in urban-rural fringe zones, agricultural land is also gradually showing signs of "thermal urbanization," making it a critical transitional zone requiring close attention.

5.3 Mechanisms Driving Thermal Environmental Effects of Urban and Agricultural Land

The thermal environmental effects of urban and agricultural land are driven by a combination of meteorological conditions, topography, human activities, and land cover changes. Coupled analyses of land use/land cover change (LUCC) and regional meteorological data reveal that rising air temperature is a key factor in intensifying surface thermal conditions. With continued urbanization, the proportion of impervious surfaces—such as roads and buildings—increases, enhancing the land's heat capacity and thermal conductivity, which in turn raises near-surface temperatures and exacerbates the UHI effect.

First, rising temperatures increase thermal pressure. High temperatures lower average surface humidity and weaken evapotranspiration, constraining vegetation growth and accelerating land degradation. This is especially evident in urban cores, which develop concentrated "hot spots" with reduced ecological regulation capacity (Li et al., 2019). While agricultural land can buffer these effects through strong evapotranspiration and vegetation coverage, its thermal regulation capacity declines under intensive human disturbance.

Second, transportation infrastructure and urban expansion further contribute to thermal differentiation. Higher road and network density disrupts surface energy balances, increases heat accumulation, and impedes natural airflow, reducing wind-driven cooling. At the same time, the rise in building density and vertical development intensifies heat aggregation, creating more uneven spatial heat distributions (He et al., 2025).

Third, topography and regional climate modulate the spatial heterogeneity of thermal effects. China's varied terrain and significant north-south temperature gradients amplify this effect. In winter, northern cities often experience thermal inversions and stagnant air conditions, leading to pollution buildup and heat retention—what is known as a "winter-type cold heat island." In summer, however, southern cities, despite high land surface temperatures, benefit from high humidity and rainfall, which partially alleviates thermal stress through water vapor exchange. Seasonal and spatial variations in precipitation also influence soil moisture and surface energy distribution, further shaping regional thermal environments.

Ultimately, urban land systems are complex physical and chemical coupling networks involving surface materials, vegetation, water bodies, and the atmosphere. Their thermal effects are governed by solar radiation intensity, land surface structure, thermal properties of construction materials, and land cover ratios. While agricultural land has inherent thermal regulatory capacity, this too is challenged by agricultural restructuring and the urban-rural integration process, posing increasing threats to thermal environmental stability.

6.Conclusion

This study focuses on China's three major urban agglomerations, systematically analyzing the spatial distribution, thermal environmental effects, and evolution mechanisms of urban and agricultural land use. By integrating land use data, regional meteorological variables, and human activity intensity, it reveals the trends and regional disparities in thermal environmental changes driven by land spatial restructuring amid ongoing urbanization.

The findings indicate that the continuous expansion of urban land and the increasing proportion of impervious surfaces have become the primary drivers of surface thermal environmental changes. Although agricultural land retains strong ecological buffering capabilities, its ability to regulate thermal conditions is weakening due to intensified human disturbance and mounting pressure on arable land resources. Moreover, the spatial evolution of the urban heat island effect is closely linked to land use patterns, climatic conditions, topographical features, and landscape structures, reflecting a complex interplay of multiple factors.

This research highlights that differences in thermal environmental effects between urban and agricultural land are mainly influenced by irrational land use structures, unscientific urban planning, constraints on cultivated land, and ecological degradation. These factors jointly contribute to the spatial heterogeneity and temporal dynamics observed across the three city clusters.

The study provides theoretical support and decision-making references for optimizing land use and managing the thermal environment in China's urban agglomerations. However, future research should further advance in the areas of multi-scale spatial analysis, long-term series modeling, and the identification of compound driving mechanisms through empirical validation.

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Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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