remote sensing

Editorial

Editorial: Special Issue on Geographical Analysis and Modeling of Urban Heat Island Formation

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Abstract: This Special Issue focuses on the data, methods, techniques, and empirical outcomes of urban heat island studies from a time and space perspective. We showcase research papers, empirical studies, conceptual or analytic reviews, and policy-related tasks to help achieve urban sustainability. We are interested in target methodologies and datasets capturing urban heat island phenomena, including novel techniques for urban heat island monitoring and forecasting with the integration of remote sensing and GIS, the spatial relationship between urban heat island intensity and land use/cover distribution in metropolitan areas, the geographical patterns and processes of urban heat island phenomena in large cities, spatial differences in urban heat island intensity between developing and developed countries, urban heat island disaster mitigation and adaptation for future urban sustainability, and prediction and scenario analysis of urban heat island formation for policy and planning purposes.

Keywords: urban remote sensing; land surface temperature; urbanization; sustainable cities; impervious surface; spatial analysis

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1. Introduction

The urban heat island (UHI) phenomenon, which is related to rapid urbanization, has attracted considerable attention from academic scholars and governmental policymakers because of its profound influence on citizens' daily lives [1]. The UHI effect has negative human impacts, including indirect economic loss, poor air quality, reduced comfort, imbalanced public health, and increased mortality rates [2,3]. The temperature difference between the center and the periphery is expanding, especially in large cities, which may result from land use/cover composition changes and increasing anthropogenic heat sources [4]. According to a United Nations estimate, nearly 54% of the world's population currently resides in urban regions, and by 2050, that number is expected to rise to 66% [5]. Urbanization is expected to add another 2.5 billion people to the global population by 2050, with Asia and Africa accounting for more than 90% of the growth. If traditional city planning continues without considering environmental factors, living conditions may be seriously degraded.

Therefore, the monitoring and modeling of urban heat island formation is important for management and sustainable development, especially in developing countries. This Special Issue focuses on the data, methods, techniques, and empirical outcomes of urban heat island studies from a geographical perspective, i.e., a time and space viewpoint. A total of 14 articles and 1 review paper are included in this Special Issue, all contributing to the field of sustainable urban development. The included studies highlight four points of importance:

(1) The spatial relationship between urban heat island intensity and land use/cover distribution in metropolitan areas;

(2) Geographical patterns and processes of urban heat island formation in large cities based on empirical studies;

(3) Spatial differences in urban heat island intensity between developing and developed counties;

(4) Useful methodologies and datasets for capturing urban heat island phenomena.

This Special Issue discusses the latest developments in these subjects, providing a review of recent geographical research on UHI effects. In the editorial, we first examine current UHI trends and discuss the impact factors of the land surface temperature (LST) in various case studies. The selected papers highlight the regional climatic parameters, topography, size, and population of each city, as well as urban materials and the distribution of green spaces, all of which affect changes in UHI intensity. Finally, we emphasize the significance and contribution of urban environmental studies and discuss sustainable development prospects for future UHI studies.

2. Current Trends in UHI Formation

With the rapid pace of industrialization and urbanization in recent decades, the UHI effect has gradually harmed our daily lives. Therefore, scientists and planning authorities have increasingly focused on mitigating the impact of UHIs by allocating land use/cover distribution and considering air ventilation in urban center planning. As a result, a growing number of UHI studies have been conducted.

Most UHI mitigation research concentrates on urban landscapes and building design in an effort to avoid intensive development that causes the loss of green spaces and an increase in impervious surfaces, which cause overheating in urban centers [6,7]. Considering that spatial structure and urban growth are not consistent across cities, long-term spatiotemporal monitoring should be carried out for various types of cities [8].

Twenty-one cities from four nations were targeted as case studies in this Special Issue. All included studies have one thing in common: population growth and urban expansion exacerbated UHI phenomena. However, water and green spaces were found to lessen the effects, especially in the central area.

Each study examined the spatial influence on UHIs by employing a different methodology. For example, Wang et al. created 12 functional construction land zones based on various social and economic indicators to examine how they contributed to the changes in the urban thermal environment [9]. We can deepen our understanding of urban thermal warming mechanisms by exploring diverse functional land zones. Another study proposed new macro-perspectives for reducing UHI phenomena by redistributing land use/cover. Zheng et al. attempted to detect cooling effects and scales using Landsat 8 Operational Land Imager/Thermal Infrared Sensor (OLI/TIRS) and Sentinel-2 data [10]. They demonstrated the application of a distance–LST scatter diagram and a multiple linear regression method, taking two inner city lakes as study objects. According to their findings, a high density of green spaces, combined with dispersed, modest structures, may aid in extending the cooling effect of inner lakes.

Shi et al. compared daytime and nighttime LSTs to explore the general spatial distribution of urban thermal environments [11]. They provided a valuable method to characterize the UHI effect more effectively and illustrate its evolution during the day. Moreover, Zhou et al. investigated the driving factors based on the temporal and spatial variation in LSTs in Zhengzhou [12]. Their findings showed a positive correlation between human activity and LSTs, accelerating the UHI effect. Although the cooling effect of vegetation and water was superior to that of topography, the role of albedo on LSTs confirmed the geographical variation.

Investigations into how the design and layout of the landscape may impact the LST on the city scale are vital. Sarif et al. examined the influence of land indices on the dynamics of LSTs from the city center to the periphery to debate the directional profiling of LSTs [13]. In Prayagraj City, the LST distribution was lower in the forested regions than in the built-up areas, bare soils, and sands. Meng et al. highlighted that various land cover patterns are considerably influenced by the spatial distribution of LST [14]. Karunaratne et al. conducted a study on the temperate mountain valley metropolis of Kathmandu, Nepal [15]. Similar to other studies, where the mean LST tended to shift in an east–south–north–west pattern, consistent with urban growth, the mean LST tended to be higher in the city's core. In Kathmandu, the LST pattern is influenced by both valley wind and urban heat island circulation. The valley wind is affected by the heat island circulation in a specific way, demonstrating that during the daytime, the valley wind speed slows down, and the LST difference reduces between the metropolitan region and the mountain slopes. On the other hand, mountain wind speeds rise at night, and the LST differential between them tends to increase.

Derdouri et al. examined the relationship between land use/cover changes and surface UHI in large cities [4]. In a systematic review, the authors attempted to synthesize, contrast, and critically evaluate numerous empirical studies conducted between 2001 and 2020, including regional characteristics, data sources, techniques for classifying land use/cover and quantifying surface UHI, and mechanisms of interaction between surface UHI intensity and land use/cover. Finally, by discussing spatial and temporal changes in land use/cover, they suggested concrete alleviation actions. Such a study can support decision-making and pave the way for future academic research, particularly in vulnerable cities that have not received considerable attention to date.

3. Prospects of UHI Formation

We can identify two directions for future UHI research: mitigating the impact of UHI formation and adapting to UHI effects on sustainability.

Over the past two decades, UHI-related studies have shown remarkable progress [4]. However, case studies of UHIs are more than just a distinction between developed and developing cities because architecture and urban design vary among cities. Many researchers have discovered that urban patches with varying densities of vegetation significantly impact LST formation, although this phenomenon has not been investigated scientifically in detail.

Zhang et al. discussed the relationship between urban vegetation components and LST distribution in Xuzhou City, China [16]. Their findings demonstrate that essential aspects in controlling the thermal environment include spatial distribution features such as patch proportion, natural connection degree, predominance degree, shape complexity, and aggregation degree of areas with a high vegetation density. The distribution, scale, and heat-reducing properties of different landscapes should be analyzed to capture the future trends in UHI patterns. In addition to water and wetlands, surface and roof materials should be re-investigated for their cooling effects.

One of the primary concerns with UHIs in geographical studies is that climate change adaptation may be more costly in urban compared to non-urban locations, owing to the increase in UHI intensity. Therefore, future UHI research is expected to evaluate the urban thermal security pattern and suggest future planning strategies that provide a favorable layout based on sustainable development goals to mitigate the consequences of UHIs.

Sismanidis et al. explored the differences in the seasonal hysteresis of surface urban heat island intensity (SUHII) between climates [17]. They offer a thorough typology of the daytime and nighttime SUHII hysteresis loops. The analysis results reveal that the seasonal hysteresis of the SUHII exhibits twisted, flat, and triangle-like patterns, in addition to concave up and down forms. Furthermore, Hu et al. proposed a regional heat island network based on circuit theory simulation [18]. They discussed the locational characteristics of UHI patches and the spatial patterns of collaborative optimization in Wuhan City, China.

With the acceleration in urbanization, urban areas continue to spread out, with a decreasing distance between urban core areas. As a result, urban agglomeration or conurbation has developed with accompanying UHI formation. An integrated research framework to assess the spatial effects of multiple environmental circumstances on habitat quality was developed by Liu et al. [19]. By highlighting the connections and interactions between various environmental challenges in urban agglomerations and ecosystems, the authors discussed the importance of the designed multidimensional sustainability and co-benefits. Liu et al. also investigated urban agglomeration, taking the Pearl River Delta, China, as the study area [20]. Compared with cities with low urbanization rates, the authors showed that the effect of land cover and socioeconomic determinants on the daytime LST was more significant in highly urbanized cities.

Integrating machine learning algorithms with remote sensing data is an important topic that has received considerable attention. Applying regression analysis and machine learning algorithms, Garzón et al. evaluated modeling techniques to assess the impact of various elements on surface UHIs [21]. In this paper, an attempt was made to illustrate the applicability of machine learning algorithms in the surface mapping of UHI intensities by quantifying surface UHIs using different contributing parameters.

4. Contributions to Future UHI Studies

To summarize this editorial, we chart the progress in related UHI studies. The UHI phenomenon is prevalent in various cities. An effective urban design reduces UHI formation while simultaneously achieving the objectives of sustainable development. As is customary, remote sensing serves as the primary data source for the analysis of the correlation between UHI intensity and urban dispersion. However, a considerable debate continues about whether the data sources are reliable enough to accurately reflect the features of cities (e.g., 2D or 3D building data). Do we need to focus on gathering actual big datasets for each building (such as building type and building height), or does the suitable size of the urban area suffice? These and other concerns are addressed, in part, in this editorial (Section 3), although they remain challenges to be solved in the future.

For researchers and city planners, we hope that this Special Issue will inspire novel concepts and methods that can lead to theoretical comprehension and practical application with respect to UHI formation and effects.

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