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An Analysis of Feasibility of Measures to Deal with Urban Heat Island Effect Conducted by Beijing from 2000 to 2013

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Abstract. Urban Heat Island Effect (UHI Effect) is a menace to the development, which can cause Heat-Related Illness (HRI), deterioration of air quality, financial damage and loss of biodiversity etc. Many countries and regions have conducted measurements to deal with UHI Effect, but how to estimate the feasibility of the measures is still a problem. Hence, the research includes the following steps: retrieving data from MODIS products (MOD11A1, MOD11A2) and Landsat satellite, using MCKT in envi 5.3 to perform land surface inversion, extracting the data of Land Surface Temperature (LST) by utilizing Arcgis, analyzing changes in highest value of LST and Normalized Difference Vegetation Index (NDVI) to evaluate whether UHI Effect in Beijing was alleviated.After 2008, the top value of LST in Beijing decreased by around 3℃, meanwhile, it remained within a range of 1.5℃ without soaring, which provided evidence that the measurements were effective. This study can be helpful for both evaluation of feasibility of the measures to deal with UHI Effect and Urban Development.

Keywords: Urban Heat Island, Remote Sensing, LST, NDVI.

1. Introduction

Urban Heat Island Effect (UHI Effect) is a phenomenon demonstrating that the temperature of the urban area is higher than that of suburban area surrounding it [1]. The main reasons causing it were changes in underlying surface during urbanization processes (e.g. reduction in vegetation area, increase in building density), anthropogenic heat emission (e.g. industry, traffic), atmospheric pollution and other significant factors [2]. The effect can lead to aggravating energy consumption and air pollution, which results in the risk of heat-related illnesses going up [3]. As the city with rapid urbanization speed, Beijing experienced large-scale expansion from 2000, area of construction land in central city soared to over 60%, population density increased from 8,000 people/km² to 12,000 people/km², hence, UHI Effect became more apparent [4]. For instance, the data from 2005 to 2011 showed that the temperature of observation times in central urban Beijing (8:00, 14:00, 20:00) is higher than that in both satellite town and suburban area, which can reach 4.5℃ in UHI Intensity with dramatic fluctuations, which showed urgency of investigation the spatiotemporal variation patterns of the UHI Effect in Beijing [4]. In the past several years, multi-source remote

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sensing has provided efficient means for remote sensing monitoring. Current studies have revealed the relationship between UHI Effect and urban development by utilizing data from satellites (e.g. Landsat and MODIS), meteorological station observation and NDVI [5]. For instance, research have shown that accelerating urbanization is the main reason, meanwhile, it has proved that enlarging vegetation area is a key to alleviate UHI Effect. Based on multi-source data (satellite remote sensing, meteorological station observation, vegetation cover map and weather map), this research analyzed spatiotemporal evolution of the UHI Effect in Beijing comprehensively. By proceeding LST Retrieval to obtain the data provided by Landsat and combining data from MODIS products (MOD11A1 and MOD11A2) and NDVI from Sentimental-2, quantifying UHI Intensity by using Urban- Rural Temperature Difference Method (ΔT = Turban - Trural). Furthermore, making evaluation of mitigating effect of green spaces.

The purpose of this research is uncovering dynamic variation mechanism of UHI Effect in Beijing and providing scientific basis for urban planning. This research discusses the relevance of UHI Effect to urbanization and NDVI with assessing measurements (e.g. ventilation corridor). The meaning of the research is to promote climate-resilient urban development and give references to global urban heat management.

2. Study area and data

2.1. Study area

This study focuses on the administrative area of Beijing, primarily covering the central urban districts and nearby suburban regions (within the Sixth Ring Road). The climate is characterized as a temperate monsoon type, with distinct seasonal variations featuring hot and humid summers. Winters are typically cold and dry, with frequent northerly winds influencing local meteorological conditions. The topography of Beijing includes a basin surrounded by mountains to the north and west, which significantly affects air circulation and environmental patterns. These geographic and climatic characteristics provide an ideal setting for studying urban environmental dynamics and spatial heterogeneity.

2.2. Data sources and processing

This research analyzes multi-source remote sensing and auxiliary observation data acquired between 2000 and 2013, which comprises LST extracted from MODIS products and Landsat satellite imagery [6]. To ensure high-timeliness monitoring of daily surface temperature variations during the period of 2000–2010, the MOD11A1 daily product (1 km spatial resolution) was employed, and MOD11A2 eight-day composite product (1 km resolution) was utilized to obtain the data for the period of 2011-2013. Additionally, observations from meteorological station were integrated to validate and calibrate inversion results, meanwhile, Beijing's Land Use/Land Cover (LULC) data was incorporated to facilitate comprehensive analyses considering surface environmental characteristics. These multi-source datasets provide a robust data foundation and scientific support for dynamic monitoring of urban surface temperatures, spatial variation investigations, and environmental factor correlation analysis.

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3. Methods

3.1. Land Surface Temperature (LST) inversion and processing

MODIS HDF format data was performed by using the MODIS Conversion Toolkit (MCTK) in ENVI 5.3. This process encompassed data acquisition, projection parameter configuration, radiometric calibration, and geometric correction to ensure the spatial accuracy and usability of the LST product. Regarding data extraction, the MOD11A1 daily LST product (1 km resolution) was selected for the period of 2000–2010 to gain intervals of daily land surface temperature. To supplement and refine the later observation results (2011–2013), the MOD11A2 eight-day composite product (1 km resolution) was used. All the data underwent standardized coordinate projection conversion prior to put into ArcGIS. Subsequently, precise clipping, mosaicking, and visualization processing were conducted within the study area (Beijing's administrative region, encompassing the central urban district and adjacent suburban zones) [7]. An extreme high-temperature index sequence was then constructed by extracting the annual maximum value of LST on a pixel-by-pixel basis, which enabled analysis of interannual trends in urban surface temperatures and the characteristics of extreme thermal environments between 2000 and 2013. The workflow also established a complete analytical chain from data preprocessing and spatio-temporal sequence construction to statistical index extraction, providing support of high-quality remote sensing data for investigating the evolution patterns of thermal environments within the study area.

3.2. Vegetation Coverage (NDVI) calculation and reconstruction

Data of spatiotemporal distribution for the Normalised Difference Vegetation Index (NDVI) within the study area from 2000 to 2013 were generated by using ENVI 5.3. Processing involved the application of missing value interpolation and temporal reconstruction methods to multi-source remote sensing data. NDVI was calculated based on multispectral reflectance data from Landsat satellites, which ensured data integrity and consistency, providing reliable indicator support for subsequent thermal environment research [8].

To calculate urban heat island (UHI) intensity, representative central urban and suburban areas were selected. Annual average extreme UHI intensity values were yielded through comparative analysis of surface temperatures in different functional zones, thereby, quantitatively characterising spatial variations and intensity traits of the urban heat island effect can be implemented.

To investigate the relationship between vegetation cover and thermal environments, Pearson correlation analysis was employed to examine the statistical relationship between LST and NDVI, which was supplemented by linear regression modelling for fitting analysis. Results indicate that NDVI is negatively correlated with LST and demonstrate that increased vegetation cover effectively mitigates urban surface thermal conditions. This study achieved a systematic quantitative investigation into the evolution patterns of the urban thermal environment and the regulatory role of vegetation through a combined approach of remote sensing inversion, time-series reconstruction, and statistical modelling.

4. Results

From 2000 to 2007, Beijing's summer land surface temperature (LST) extremes exhibited a year-on-year upward trend, with urban heat island (UHI) intensity peaking at approximately 4.5°C. Since 2008, summer LST extremes have decreased by around 3°C compared to previous years, remaining

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within a relatively stable range (with interannual fluctuations of approximately ±1.5°C). Between 2008 and 2013, Beijing's Normalised Difference Vegetation Index (NDVI) showed a marked increase, with an average rise of approximately 0.07–0.12, indicating a significant improvement in the greening rate of the central urban area. Correlation analysis revealed a significant negative relationship between LST and NDVI ($R^2 = 0.65$, $p < 0.01$), suggesting that increased vegetation cover has been the primary driver behind the recent decline in LST [9].

5. Discussion

Since implementing its “Green Olympics” policy in 2008, Beijing has witnessed a significant increase in area of urban green space, restoration and development of wetland systems and strengthened planning for ventilation corridors. These measures have effectively reduced maximum value of LST. Roof greening and vertical greening have also demonstrated pronounced localised cooling effects within high-density urban areas. Compared to cities like Seoul and Tokyo, Beijing's policy-driven spatial planning has shown more obvious effectiveness in mitigating the UHI effect. However, there remains scope for improvement in long-term governance and sustained management. Methodologically, the integration of data from multi-source remote sensing has markedly enhanced the spatio-temporal monitoring accuracy of LST. Nevertheless, constrained by the spatial resolution of MODIS data, capturing micro-scale UHI variations remains challenging. Concurrently, cloud cover interference may lead to underestimation of extreme high-temperature events. These findings indicate that Beijing has achieved significant success in thermal environment governance through policy guidance and urban design, but future efforts should integrate high-precision data with sustained planning to realise more comprehensive thermal environment optimization [10].

6. Conclusion

Between 2000 and 2013, the intensity of Beijing's UHI exhibited a trend of initial increase followed by decline, with a marked easing after 2008. This shift is closely linked to large-scale ecological initiatives such as afforestation, wetland restoration, and new wetland construction, meanwhile, Beijing's NDVI showed a marked increase, exhibiting a strong negative correlation with LST, which further underscores the pivotal role of enhanced vegetation coverage in mitigating the UHI effect. The findings indicate that rational urban planning and ecological development are crucial strategies for improving the urban thermal environment. Future urban planning should continue expanding the scale of urban green spaces and wetland areas to fully leverage their cooling and ecological regulation functions, simultaneously, scientific optimising ventilation corridor layouts to improve urban airflow exchange and promote heat dispersion; additionally, vigorously promoting rooftop greening and vertical greening technologies to upgrade local cooling capacity in high-density built-up areas. The sustained implementation of these integrated measures will further alleviate urban thermal stress, promote healthy urban ecosystems, and foster the development of liveable environments for residents.

Authors contribution

All the authors contributed equally and their names were listed in alphabetical order.

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