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Study on the Temperature Change Trends and Influencing Factors in Changsha

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Abstract. As the capital of Hunan Province, Changsha has been rapidly urbanized in recent decades. However, increasing population density, traffic pressure, and energy consumption have a significant anthropogenic impact on the regional climate. Therefore, this paper reviews the spatial and temporal changes in Changsha's temperature, urban heat island effect, extreme high temperature and heat wave problems, and the application of multi-source data. The study noted a significant rise in Changsha's average annual temperature, an increase in the frequency and intensity of heat waves, and a significant urban heat island effect, primarily driven by urbanization and global warming. Meanwhile, urban blue-green spaces can bring localized cooling of 1 to 3°C, playing a positive role in alleviating high temperatures. To address climate challenges, academics have proposed measures such as low-carbon development, green buildings, protection of blue and green spaces, construction of ventilation corridors, and multi-source data monitoring. However, current research lacks consistency in data, mechanism simulation, and adaptation strategies. Future research recommends strengthening long-term data construction, multi-source data integration, and mechanism research to help Changsha achieve sustainable development.

Keywords: Changsha, temperature change, urban heat island, heat wave, remote sensing

1. Introduction

In recent years, the global warming trend has continued to intensify, with regional high temperatures and extreme weather events occurring frequently. As a major city in the middle reaches of the Yangtze River, Changsha has seen particularly pronounced temperature issues in the context of rapid urbanization, dense population, and increased energy consumption. Monitoring data shows that the annual average temperature in Changsha continues to rise, the number of extremely hot days in summer is increasing, and the frequency and duration of extreme heatwave events have significantly increased. This not only intensifies the urban heat island effect but also poses serious challenges to residents' health, urban operational safety, and the ecological environment.

Academic studies have some results on temperature changes in Changsha and its surrounding areas. Existing literature reveals an overall warming trend in Changsha over recent decades, indicating that the increase in the lowest nighttime temperature is greater than that of the highest daytime temperature [1]. At the same time, the urban heat island effect has significantly intensified, and the frequency and intensity of extreme high temperature events have increased [2]. Li used

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Landsat remote sensing to invert the surface temperature (LST) and station observation data and found that the temperature increase in the Changsha urban area was about 0.2-0.3℃/10 years higher than that in the suburbs during 1980-2015, and the intensity of the heat island in summer nights could reach 3-5℃ [3]. In terms of extremely high temperatures, Liu used the heat wave threshold definition and extreme value distribution model based on daily temperature data from 1961 to 2017 and found that the number of heat waves in Changsha increased from less than 10 in the 1960s to more than 30 in the 2010s, and the average duration was extended by about 2 days [2]. The research results show that urbanization, land use change, population and energy density, and blue-green spatial pattern all affect local temperature changes to varying degrees.

While these studies provide valuable insights into Changsha's temperature changes, they still have some shortcomings. These include a lack of uniformity in data sources and time series, limited depth in mechanistic research, a lack of in-depth exploration of the differentiated characteristics of urban functional zones, and a need to strengthen the systematic and practical nature of mitigation and adaptation strategies. In light of these questions, this article systematically reviews recent research on temperature change in Changsha, focusing on temperature trends, key influencing factors, and existing response measures. It also reviews relevant research methods and findings, and proposes future research directions. This research aims to provide a scientific reference for Changsha's urban planning and climate adaptation strategies.

2. Research on temperature trends in Changsha

2.1. Theoretical framework

There are numerous theoretical frameworks for studying the temperature trends in Changsha, including global climate change theories, urban heat island effect models, land use/cover change theories, and blue-green space cooling theories.

The theory of global climate change holds that the most prominent manifestation of global climate change is global warming. That is, since the Industrial Revolution, due to the increase in greenhouse gas emissions, the global average atmospheric and surface temperatures have continued to rise. Regional climate change often occurs against the backdrop of global warming, a combination of natural variability and human-driven factors. The warming in Changsha not only reflects the local climate system's response to urbanization and land use change, but also is a typical manifestation of global warming at the regional level. Therefore, studying the temperature changes in Changsha from the perspective of global climate change not only helps to understand the local climate evolution mechanism, but also provides a reference and comparison for urban climate research in the background of global warming.

The urban heat island effect model describes how the characteristics of a city's underlying surface alter its energy balance, increasing heat storage and reducing evaporation, resulting in higher urban temperatures than surrounding areas. The model states that dense populations, dense buildings, and increased energy consumption in cities lead to significant local temperature increases, particularly at night and with a decrease in the diurnal temperature difference. Meanwhile, the theory of land use and cover change helps people understand that as farmland and forest land are replaced by construction land, the energy balance and water and heat circulation on the surface of the earth will also change, thereby contributing to the increase in temperature. In Changsha, with the acceleration of urbanization and large areas of land being developed and utilized, the heat island effect has become increasingly obvious, and the temperature difference between urban and suburban areas has also widened year by year.

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The blue-green space cooling theory states that vegetation through transpiration and water through evaporation can both create localized cooling island effects. In Changsha, the temperature along the Xiangjiang River and in areas like the Yanghu wetland is typically 1-3°C lower than surrounding areas, a finding verified by satellite remote sensing and field surveys. This theory not only explains the temperature differences among various areas within a city but also provides practical and feasible references for urban planning, green space construction, and climate adaptation strategies. Incorporating blue-green spaces into climate research not only helps us better understand the causes of urban temperature changes, but also provides a direction for urban management and improving the living environment of residents.

2.2. Technical methods

The research on temperature changes in Changsha mainly relies on the combination of several methods. Firstly, ground-based meteorological stations provide the most direct temperature data, helping people understand the trend of temperature changes. Secondly, by using remote sensing technology to monitor surface temperature via satellite, we can see the temperature differences in various areas of the city, especially the impact of green spaces and buildings on cooling, although ground data is needed for correction. Further analysis of the data can make up for the shortcomings of ground observations and provide more continuous climate information, but the resolution is relatively low and needs to be adjusted.

When analyzing the trend of temperature changes, statistical methods are commonly used to determine the rate of warming and significant change points. For extreme heat events, special methods are employed to estimate the frequency and intensity of heat waves. In recent years, machine learning and various data fusion technologies have been applied, making the data more accurate and the predictions more reliable. Numerical simulation helps us simulate temperature changes under different conditions, facilitating understanding of the reasons and supporting decision-making.

Overall, these methods complement each other, capturing both overall trends and detailing differences. However, data fusion and uncertainty analysis still need improvement. Future research needs to better integrate these various methods to make the results more comprehensive and easier to understand.

3. Influencing factors

Exploring the factors influencing temperature changes in Changsha is key to understanding their causes and guiding urban development. Changsha's permanent population has grown from approximately 3.5 million in 1980 to over 10 million in 2020. This significant increase in population density has led to building expansion, electricity and energy demand, and traffic pressure. Studies have found that there is a significant positive correlation between population growth and energy consumption. The average annual growth rate of electricity consumption in Changsha exceeded 10% between 2000 and 2018. In terms of transportation, the number of motor vehicles increased from less than 100,000 in 1995 to more than 3 million in 2020. Exhaust emissions and waste heat emissions have become important factors contributing to urban warming [4,5].

Although urbanization leads to overall warming, blue-green spaces play a key role in local mitigation. By comparison, it was found that the average surface temperature along the Xiangjiang River and the Yanghu wetlands was 1–3°C lower than that in the city center, forming a clear cold island effect. Huang's research further pointed out that for every 10% increase in green space coverage, the intensity of the urban heat island can be reduced by about 0.5°C. These results show that the construction of urban ecosystems is of great significance in resisting rising temperatures [6].

Scholars have generally used a variety of methods to study the causes of rising temperatures in Changsha and have achieved relatively systematic results. Zhou et al, based on the observational data from 1961 to 2010 at the stations, used the Mann–Kendall test and Sen's slope estimation to find that the annual average temperature in Changsha increased at a rate of about 0.39–0.42°C per decade, with the lowest nighttime temperature increasing more significantly, indicating that the risk of extreme high temperatures is increasing [1]. Using daily temperature data from 1961 to 2017, combined with heat wave threshold and extreme value theoretical models, it was found that the average annual number of high-temperature days in Changsha increased from less than 10 days to more than 30 days, and the frequency and duration of heat waves increased significantly [2].

In terms of driving mechanisms, researchers employed statistical regression analysis to explore the relationship between population, energy consumption, and temperature. The results showed that the average growth rate of electricity consumption in Changsha from 2000 to 2018 exceeded 10%, which was highly correlated with the increase in urban temperature during the same period [5]. By inverting the land surface temperature (LST) using remote sensing technology and combining it with land use/cover changes, it was found that the temperature increase in urban areas was about 0.2–0.3°C/10 years higher than that in suburban areas between 1980 and 2015, and the nighttime temperature was generally 3–5°C higher than that in suburban areas. The built-up area expanded nearly five times, and the reduction in green space significantly exacerbated the urban heat island effect [3]. In terms of the regulatory role of blue-green space, Li et al.'s research indicated that the summer temperature in the Xiangjiang River and Yanghu wetlands was 1–3°C lower than that in the city center [7]. Huang Yong et al. pointed out that for every 10% increase in green space coverage, the intensity of the nighttime heat island can be reduced by about 0.5°C [6].

In addition, some studies have combined health data to reveal the social impact of high temperatures. Wang analyzed the number of heat stroke cases and meteorological data in Changsha Hospital and found that when the maximum temperature exceeded 35°C, the number of heat stroke cases increased significantly, and the hospitalization rate during heat waves was 15%–20% higher than normal [8]. These results show that global warming provides a macroscopic background for the rise in temperature in Changsha, while urbanization, population growth, energy consumption, and transportation expansion are the main driving forces, and blue-green space plays an important role in local mitigation.

These studies collectively indicate that the increase in temperature in Changsha is the result of the combined effect of multiple factors. Global warming provides the overall background for this trend, while urbanization and changes in land use are the main driving forces. Population growth, energy consumption, transportation, and industrial waste heat are the specific pressures that directly cause the temperature rise. At the same time, the blue and green spaces in cities can, to some extent, alleviate local high-temperature problems and play an important protective role.

4. Issues and improvements

4.1. Limitations and shortcomings

In recent years, although there have been significant advancements in the research on temperature changes in Changsha, some shortcomings still exist. First, there are relatively few meteorological observation stations, and some observation data are affected by station relocation and urbanization, resulting in less-than-ideal data quality and consistency [1]. Secondly, many studies mainly focus on

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the statistical aspects and do not delve deeply enough into the underlying causes and mechanisms. As a result, it is difficult to accurately distinguish whether the temperature changes are due to global warming or the impact of urbanization [3]. Furthermore, although remote sensing technology can reveal the distribution of the urban heat island effect, the surface temperature and the actual temperature are not exactly the same, and more on-site observations are needed for correction [7]. In the research on extreme heat events, the definition of heat wave indicators has not yet been unified, which makes it difficult to directly compare different studies [2]. Therefore, future research needs to be further deepened in areas such as unified dataset construction, multi-source data fusion, mechanism simulation, and strategy evaluation.

4.2. Response measures

Changsha is facing an increasingly severe rise in temperature and the risk of heat waves. Therefore, researchers and urban managers have proposed multi-level response strategies, and there are already practical cases in the city and other cities. In terms of mitigation, promoting low-carbon development and optimizing the energy structure can help reduce human-generated heat sources and greenhouse gas emissions at the source [9]. At the urban planning level, Changsha has carried out ecological restoration and blue-green space construction along the Xiangjiang River and in wetland parks. Practice has shown that local temperatures can be reduced by 1–3°C, improving the thermal environment and ecosystem services [6, 7]. Meanwhile, the nationwide "sponge city" pilot projects have also shown that permeable pavement, rain gardens, and green space expansion can enhance evapotranspiration and alleviate surface heat, and have valuable reference value for Changsha [1]. In terms of engineering measures, studies in Guangzhou and other places have shown that promoting high-reflectivity roofs can reduce urban noon temperatures by approximately 1.2°C during heat waves and significantly decrease building energy consumption, providing feasible experience for the renovation of public buildings in Changsha [10]. In addition, the monitoring and prediction system is equally indispensable. By integrating meteorological observations, remote sensing data, and numerical simulations, the ability to issue heatwave warnings can be effectively enhanced [2]. At the social adaptation level, Wang's research showed that the number of heat stroke cases in Changsha increased significantly during the period of extreme high temperatures, so it is necessary to strengthen public health protection, optimize energy scheduling, and improve community emergency response [8].

To sum up, Changsha needs to make concerted efforts in both mitigation and adaptation to cope with rising temperatures and heat wave risks, and gradually build a systematic and effective localized response system through the combination of ecological restoration, engineering transformation, and social governance.

5. Conclusion

In the past few decades, due to the dual impact of global warming and rapid urban development, the temperature has risen significantly, high temperatures and extreme heat waves in summer have occurred more frequently, and the city's heat island effect has become increasingly prominent. The study found that population growth, increased energy use, expansion of transportation, and land use change were the main causes of these changes, while urban blue and green spaces (such as parks, green areas, and water bodies) played a significant role in alleviating high temperatures and improving the urban climate.

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At present, scientists are using a variety of methods, including ground-based meteorological stations, satellite remote sensing, data analysis, and simulation, to gain a detailed understanding of the trends and causes of temperature changes in Changsha. In terms of response, it is generally believed that promoting low-carbon development, building more green spaces and water bodies, optimizing air circulation channels, improving multi-source monitoring and heat wave early warning systems, and strengthening public health adaptation measures are all very effective and feasible means.

However, the existing research also has some shortcomings. For instance, the observational data are not coherent enough, the mechanism explanations are not deep enough, the indicators for extreme climate events are not unified, and there is a lack of systematic assessment of mitigation and adaptation strategies. Future research needs to better integrate long-term, multi-channel data, deeply explore the mutual impact between urbanization and climate change, and provide more scientific support for Changsha's future urban planning and public health management by combining simulation with actual investigation. As long as all parties work together, Changsha has every opportunity to become a model for the central region in responding to climate change and building resilient cities.

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