Characteristics and Influencing Factors of Urban Heat Island Effect in Jining City from 1970 to 2024

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Abstract Based on the observation data of meteorological observation stations in Jining City during 1970 – 2024, MK mutation test and principal component analysis (PCA) were used to study the evolution characteristics of urban heat island intensity (UHII) and the contribution rate of various influencing factors in Jining City over the past 55 years. The results show that from 1970 to 2024, the UHII in Jining City generally rose at a rate of 0.1 ℃/10 a. On the interannual scale, the correlation between temperature and UHII was most significantly positive. On the seasonal scale, there was a strong negative correlation between wind speed and UHII. PCA reveals that temperature had a significant positive impact on the increase of UHII in Jining City.

Key words Urban heat island effect; Changing characteristics; Influencing factors; Jining City

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Urban heat island effect refers to the phenomenon that the temperature in the center of a city is higher than that in the suburbs[1]. In recent years, scholars at home and abroad have attached great importance to the study of urban heat island effect, and gradually expanded it to multiple fields such as urban architecture, planning, and urban ecology[2]. When intensifying urban energy consumption, urban heat island effect may also cause abnormal urban climate and even result in casualties[3]. China has established a high-density network of automatic weather stations, and accumulated years of continuous observation data, laying a foundation for in-depth research on the climatic characteristics of urban heat islands[4]. Research on urban heat islands mainly uses the observation data from meteorological stations to characterize urban temperature by calculating the difference in air temperature between urban and rural areas. Liu *et al.* analyzed the temperature and heat island intensity of Chongqing City using the heat island data from 1979 to 2018[5]. In view of the current research status of the influencing factors of urban thermal environment, Xiong Ying *et al.* [6] conducted a multi-angle study on urban heat island effect using the principal component analysis method[6]. Most scholars at home and abroad have adopted methods such as single correlation and regression analysis to explore the intrinsic connection between various factors and surface temperature, but ignore heat island effect in urban agglomeration areas, and have an unclear understanding of the long-term evolution law of heat islands[7].

In this study, based on the observation data of meteorological observation stations in Jining City from 1970 to 2024, MK mutation test method was adopted to study the evolution characteristics of urban heat island in Jining City over the past 55 years, and principal component analysis (PCA) was applied to explore the contribution rate of various influencing factors to the development of urban heat island, so as to provide a scientific basis for the governance of urban heat island and urban planning in Jining City.

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1 Data sources and methods

1.1 Data of the study area In this study, 11 meteorological observation stations in Jining City, including Jining Station, Yutai County, Liangshan County, Wenshang County, Yanzhou District, Jinxiang County, Qufu City, Zoucheng City, Sishui County, Jiaxiang County and Weishan County, were selected. Among them, Jining Station represents the urban area, and the remaining 10 stations stand for the suburbs. The information of these meteorological stations are shown in Table 1. All the data are sourced from the Meteorological Data Center of Shandong Meteorological Bureau, and the data quality has been strictly controlled.

Table 1 Locations and descriptions of the urban and suburban stations

Station number	Station name	Location
54907	Yutai County	Suburb
54910	Liangshan County	Suburb
54912	Wenshang County	Suburb
54915	Jining Station	Urban area
54016	Yanzhou District	Suburb
54917	Jinxiang County	Suburb
54918	Qufu City	Suburb
54919	Zoucheng City	Suburb
54920	Sishui County	Suburb
54921	Jiaxiang County	Suburb
58020	Weishan County	Suburb

1.2 Research method

1.2.1 Calculation of urban heat island intensity (UHII). UHII

is the temperature difference between the urban (T_u) and suburban (T_s) areas of a city, and can be calculated as follows:

$$UHII = T_u - T_s \quad (1)$$

$$T = (T_1 + T_2 + \cdots + T_m)/m \quad (2)$$

Where T is the average of temperature at stations in the urban and suburban areas of a city; m is the number of the stations[8].

1.2.2 Methods of analyzing variation characteristics and influencing factors of UHII. The evolution law and mutation characteristics of UHII in Jining City at the interannual scale were studied by using methods such as linear regression, moving average and MK mutation test. The principal component analysis method was used to compare the contribution rate of five influencing factors to UHII in Jining City, so as to screen out the dominant factors of UHII in Jining City.

2 Variation characteristics of urban heat island intensity

2.1 Variations of temperature The variations of temperature anomaly and 5-year moving average from 1970 to 2024 in Jining City are shown in Fig. 1. It can be seen that the temperature in Jining City generally showed a continuous fluctuating upward trend. Fig. 2 presents the annual variations and linear trends of temperature in the urban and suburban areas of Jining City during 1970 – 2024. Before 1980, the temperature in the urban and suburban areas of Jining City was similar, and the temperature in the suburbs was even slightly higher than that in the urban area. The reason is that China's economic development was relatively stable before 1980, so the temperature difference between the urban and suburban areas was not obvious, and the heat island effect was not prominent. With the implementation of the reform and opening-up policy in China after 1980, the economic growth rate has greatly increased, and urban construction has advanced rapidly. As a result, the temperature in urban areas is significantly higher than that in suburban areas, and urban heat island effect begins to emerge. From 2003 to 2008, due to the frequent influence of typhoons, the precipitation in Jining City was excessive, which alleviated the urban heat island effect. Overall, the annual average temperatures in both the urban and suburban areas of Jining City showed an upward trend, with the linear changes of 0.501 and 0.399 ℃/10 a, respectively. The temperature in the urban area was higher than that in the suburban areas, and the increase in temperature was also greater than that in the suburban areas.

2.2 Variations of UHII The annual variation of average UHII and its MK mutation curve in Jining City from 1970 to 2024 are shown in Fig. 3. Overall, UHII in Jining City still showed a wavy growth, with an increase of 0.1 ℃/10 a, and annual average UHII was 0.2 ℃. According to the change of 3-year moving average, there was a significant annual variation in UHII. From 1970 to the early 21st century, UHII in Jining City showed a fluctuating upward trend. However, it decreased significantly and even became negative because of the abnormal increase in precipitation during 2003 – 2008. After 2010, it continued to rise. The MK mutation test results of UHII reveal that before 1980, the UF line was basically in the significant range; UF statistic was greater than 0, and showed a fluctuating upward trend. It indicates that UHII in Jining City was on an upward trend before 1980. From 1980 to 2000, it continued to rise, and exceeded the critical line. That is, it showed a significant upward trend during this period. From 2000 to 2010, UF statistic declined but did not become negative. It indicates that UHII in Jining slightly decreased during this period, but it still showed an upward trend on the whole. After 2010, UF statistic continued to rise, and broke through the significant range. It can be seen that the heat island effect in Jining City was significant and increased from 2010 to 2024. However, within the confidence interval, there is no intersection point between the UF and UB curves, indicating that there was no abrupt change in UHII in Jining City during the study period.

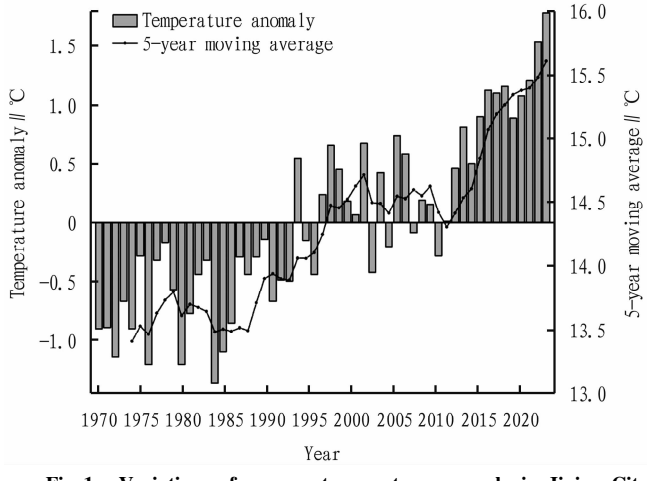

Fig. 1 Variations of average temperature anomaly in Jining City from 1970 to 2024

3 Analysis of influencing factors of urban heat island effect in Jining City

3.1 Correlation between influencing factors and UHII Five meteorological indicators that had a significant impact on the heat island effect were selected, including temperature, the highest monthly average temperature, precipitation, average wind speed and average relative humidity. The annual average and seasonal heat island intensity of Jining City were respectively taken as dependent variables, and five meteorological elements were as independent variables. Dimensionless processing was carried out on the dependent variables and independent variables. The binary correlation analysis method was used to calculate the influence of each meteorological element on the heat island effect in Jining City. The results of the correlation between UHII and various meteorological elements are shown in Table 2. Temperature had the greatest influence on annual average UHII. The correlation coefficient between annual average UHII and average temperature or the highest monthly average temperature was greater than 0.5. Annual

average UHII was negatively correlated with precipitation and humidity, but the correlation was not very strong, and there was a weak positive correlation between wind speed and annual average UHII. From a seasonal perspective, the inhibitory effect of wind speed on UHII was very obvious, especially in summer. The correlation coefficient between wind speed and summer UHII reached -0.733. It is seen that the correlation between wind speed and UHII was obvious on the seasonal scale but not significant on the annual scale. Due to the influence of the monsoon, the direction of wind changes regularly. Therefore, there was a strong negative correlation between wind speed and the heat island effect on the seasonal scale. The correlations between other factors and UHII on the seasonal scale were basically consistent with those on the interannual scale. Temperature showed a strong correlation, while the correlations of precipitation and humidity with UHII were not obvious.

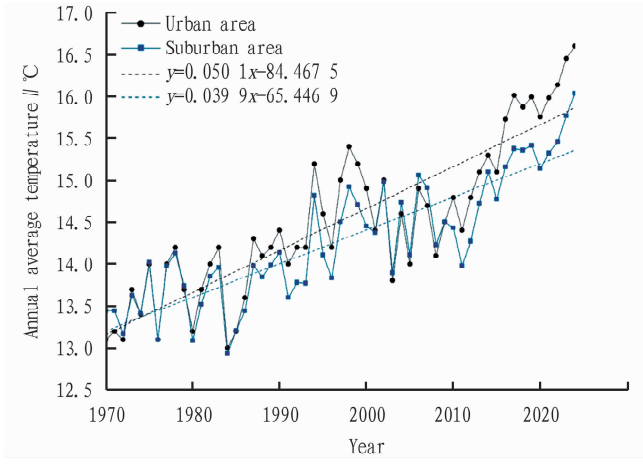

Fig. 2 Annual variations and linear trends of temperature in the urban and suburban areas of Jining City from 1970 to 2024

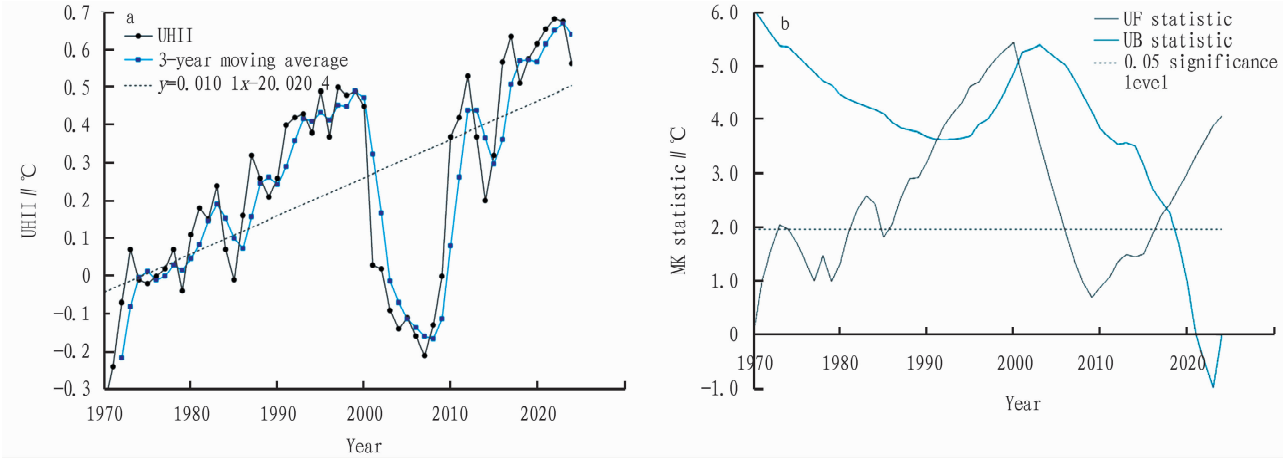

Fig. 3 Changes in annual average UHII and MK mutation test in Jining City during 1970 - 2024

Table 2 Correlation coefficient between influencing factors and UHII

UHII	Temperature	Total precipitation	Humidity	Wind speed	Highest monthly average temperature
Annual average UHII	0.574	-0.093	-0.281	0.015	0.521
Spring UHII	0.378	-0.112	-0.326	-0.733	0.323
Summer UHII	0.580	-0.212	-0.384	-0.475	0.558
Autumn UHII	0.191	-0.079	-0.208	-0.238	0.189
Winter UHII	0.414	0.047	-0.157	-0.559	0.391

3.2 Principal component analysis The principal component analysis of five meteorological elements affecting UHII in Jining City was conducted by using the z-score standardization method. The characteristic values and contribution rate of principal components are shown in Table 3. The cumulative contribution rate of the top 3 principal components was up to 88.63%, revealing that the top 3 principal components had an obvious effect on UHII in Jining City. Among them, the contribution rate of the first principal component was the largest, reaching 45.13%; the contribution rate of the second principal component was 24.42%.

For further analysis, principal component transformation was performed on the data in Table 3, and the information load conditions held by the first three principal components were obtained, as shown in Table 4. The principal component load matrix reveals the effects of various factors on UHII. The larger the value of a principal component, the greater the proportion of that component in the original variable[9]. For principal component 1, annual average

Table 3 Characteristic values and contribution rate of principal components

Principal component	Characteristic value	Contribution rate // %	Cumulative contribution rate // %
1	2.256	45.13	45.13
2	1.221	24.42	69.55
3	0.954	19.07	88.63
4	0.484	9.69	98.32
5	0.084	1.68	100.00

temperature and annual average maximum temperature were the main positive factors, while annual precipitation, annual average relative humidity and annual average wind speed were negative contributing factors. Principal component 2 mainly reflects the positive contribution of annual precipitation to UHII. In principal component 3, annual average wind speed dominated. In conclusion, temperature was the main influencing factor of UHII in Jining City.

Table 4 Load matrix of principal components

Factor	Principal component 1	Principal component 2	Principal component 3
Annual average temperature	0.609	0.286	0.049
Annual average maximum temperature	0.621	0.160	0.081
Annual precipitation	-0.069	0.834	-0.066
Annual average relative humidity	-0.450	0.426	-0.220
Annual average wind speed	-0.190	0.126	0.969

4 Conclusions

Based on meteorological observation data, methods such as MK mutation test, correlation test and PCA were adopted to study the variation law of UHII and analyze the influences of five meteorological elements on UHII in Jining City. It is concluded that from 1970 to 2024, the UHII in Jining City generally increased at a rate of 0.1 ℃/10 a. On the interannual scale, the correlation between temperature and UHII was most significantly positive. On the seasonal scale, wind speed showed a strong negative correlation with the variation of UHII. From PCA, it is found that temperature had a significant positive impact on the increase of UHII in Jining City.

References

[1] LI Y, ZHOU DC, YAN ZM. Spatiotemporal variations in atmospheric urban heat island effects and their driving factors in 84 major Chinese cities [J]. Environmental Science, 2021, 42(10): 5037 - 5045.
[2] SUN YL, WANG HF, LI G, *et al.* Study and influence factors of heat island spatio-temporal changes in Beijing from 2000 to 2019[J]. Environmental Ecology, 2020, 2(8): 43 - 50.
[3] XU R, DONG JH, WANG FL. Review on the influencing factors,methods and countermeasures of urban heat island effect[J]. Journal of Zhongkai University of Agriculture and Engineering, 2020, 33(4): 65 - 70.
[4] MENG FC, HUANG H, GUO J, *et al.* Analysis of fine-scale spatial and temporal characteristics of Tianjin urban heat island intensity[J]. Ecology and Environmental Sciences, 2020, 29(9): 1822 - 1829.
[5] TIAN L, LU J, LI Y, *et al.* Temporal characteristics of urban heat island and its response to heat waves and energy consumption in the mountainous Chongqing, China [J]. Sustainable Cities and Society, 2021, 75: 103260.
[6] XIONG Y, ZHANG F. Thermal environment effects of urban human settlements and influencing factors based on multi-source data: A case study of Changsha City[J]. Acta Geographica Sinica, 2020, 75(11): 2443 - 2458.
[7] HU NL, REN ZB, DONG YL, *et al.* Spatio-temporal evolution of heat island effect and its driving factors in urban agglomerations of China[J]. Scientia Geographica Sinica, 2022, 42(9): 1534 - 1545.
[8] ZHANG JZ, LIANG YN, WANG J, *et al.* Temporal and spatial characteristics of urban heat island effect and its influencing factors in Beijing from 1981 to 2020[J]. Transactions of Atmospheric Sciences, 2024(4): 581 - 591.
[9] FENG XG, SA LW, XU WD, *et al.* Analysis of the characteristics and causes of the evolution of the urban heat island amidist the of rapid urbanization[J]. Journal of Xi'an University of Architecture & Technology (Natural Science Edition), 2015, 47(4): 565 - 570.

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temperature ≥ 35.0 ℃ for 3 consecutive days or more occurred repeatedly in summer, which brought inconvenience to people's work and life. The average temperature was higher in 2024, with more precipitation and sunshine hours.

3 Conclusions

By constructing a climate data management program, this paper realized the efficient management of Wuzhou climate data, and provided a new idea and method for the collection, integration and utilization of climate data. At the same time, through a practical application, this paper systematically analyzed the climate overview of Wuzhou City in 2024 and its impact on the economy, revealed the specific performance and potential threat of climate change in the region, and promoted the application of climate data in decision support, disaster prevention, resource planning and other fields.

In the future, with the continuous progress of technology and the continuous accumulation of data, it will lay a solid foundation for achieving the goals of more green, low-carbon and sustainable development by deepening the application research of climate data. Finally, it is expected to stimulate more in-depth discussion on the interaction between climate change and local economic development, and jointly build a better future of harmonious coexistence between human and nature.

References

[1] China Meteorological Administration. Format of surface meteorological observation data files and record books[M]. Beijing: Meteorological Publishing House, 2005.
[2] GUAN JY. Ground meteorological information data processing system [J]. Journal of Guangxi Meteorology, 2005, 26(A02): 53 - 56.
[3] PENG JL, LI F, LU Y, *et al.* Using VB6.0 programming to extract elements from A file and generate meteorological service summary table in Excel format[J]. Desert and Oasis Meteorology, 2009,3(S1): 80 - 82.
[4] HUANG Z, QIU PZ, TAN F. Research and implementation of precipitation timesharing accounting key technologies for regional automatic station [J]. Journal of Meteorological Research and Application, 2019, 40(2): 86 - 89.
[5] JIANG LZ, FU YX, XU YH. Development and application of the regional automatic station message-handling system of municipal level[J]. Journal of Meteorological Research and Application, 2010, 31(1): 77 - 79.
[6] CHEN B, CHEN K. Design and application of meteorological data database in mesoscale encryption station[J]. Computer Knowledge and Technology, 2011, 7(31): 7572 - 7573, 7578.
[7] QUAN WJ, ZHAO Y, LIAN LM. Data processing system of the medium-scale automatic observatory[J]. Journal of Guangxi Meteorology, 2006, 27(4): 54 - 56.