

# Spatial Evolution of the Effects of Urban Heat Island on Residents' Health

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**Abstract:** Rising summer temperatures caused by the urban heat island (UHI) has considerable effects on the physical and mental health of urban residents globally. To categorize residents' health risk areas and evaluate the characteristics of urban spatial evolution, based on data analysis methods, such as ArcGIS, ENVI software, and geostatistical analysis, data from meteorological stations, satellite images, and electronic maps were used to investigate spatial evolution and the process by which UHI affects the respiratory, circulatory, and cardiovascular systems and emotional health of the residents of Tianjin. Results show the UHI significantly increases respiratory, circulatory, and cardiovascular diseases. The emotional health of residents is also significantly affected with the affected level moving from level 1 to level 2-4. Highly concentrated areas in the urban center and patches with high health risks are found to be scattered and fragmented, as indicated by the phased pattern of spatially deteriorating hotspots. Hotspots expansion occurs unidirectionally to the south, surrounding the city center, while shrinking from the inside to the outside. The study identifies urban health space risks and provides theoretical guidance for urban space optimization and healthy urban planning.

**Keywords:** health effects; spatial evolution; Tianjin; urban heat island

## 1 INTRODUCTION

The frequency of extreme weather events has increased along with global warming, causing a series of serious effects on human health, especially on urban residents [1, 2]. By 2050, 6.252 billion people will be living in cities around the world. As the size and data volume of cities increase, so will the intensity of the urban heat island (UHI). Rising temperatures caused by the superposition of climate change and UHI can affect the incidence of various diseases and seriously endanger human health and life [3, 4]. Therefore, the planning and construction of healthy cities, villages, and towns should be implemented; areas of high risk should be delineated in terms of environmental health; and the impact of the thermal environment on human health should be evaluated to explore the establishment of health risk assessment standards for key projects in high-risk areas.

The spatial differentiations of UHI intensity and the evolution of landscape patterns, which are caused by the different underlying surface structure of cities, affect the function of urban ecological services, including residents' health [5]. UHI in megacities has typical spatial evolution characteristics [6, 7]. However, most studies focused on the evolution of UHI in different urban spaces rather than on the spatiotemporal response mechanism of UHI on urban residents' health. Only a few studies examined the effects of UHI in megacities on the typical spatial and temporal patterns of human comfort [8] and respiratory diseases [9]. Given that these studies focused on single factors, such as physiological comfort or respiratory diseases, they lack representative space research on diseases or the comprehensive health hazards of UHI on physical and psychological aspects and cannot assess the health risks of different spatial locations in cities. Therefore, the effects of UHI on the health of residents in different urban spaces should be evaluated, and the evolutionary characteristics of urban internal space in health risk assessment during urbanization should be explored as important theoretical and practical issues.

To evaluate scientifically the health risk of UHI, multiple factors of physical and mental health were used to analyse the spatial evolution of the effects of UHI on

residents' health. The conclusions provide preliminary findings for improving urban green space system planning.

## 2 STATE OF THE ART

With global urbanization, the intensity and areas of UHI have been expanding rapidly, leading to a continuous rise in summer temperatures [10] and the frequency and duration of high-temperature heat waves in cities, thereby affecting the psychological and physical health of residents [11]. With the development of the economy and society, the limitations of passive cooling through air conditioning are becoming increasingly prominent. The growing number of outdoor public activities in cities has also increased the risk of exposure to high temperatures. Summer UHI in megacities, such as Tianjin, Beijing and Chongqing in China, is extremely severe [12, 13]. Data from the Chinese Center for Disease Control and Prevention show an increase in health problems caused by high temperatures [14], which seriously affects residents' comfort, respiratory and circulatory systems, and mental state. The attributable risks of death from cardiovascular and respiratory diseases caused by air temperature are 17.48% and 10.57%, respectively, and temperatures above 21 °C will increase negative emotions, affecting residents' decision-making and behaviours [15, 16].

Urban microclimate is a special climatic phenomenon produced by the urban agglomeration effect, and the UHI is its most typical thermal environment characteristic. UHI effect and global climate change together result in the deterioration of the urban thermal environment [17]. Since the concept of "UHI" was proposed more than 200 years ago, extensive research has been conducted worldwide on the topic, with a focus on its harm in terms of different spaces, times, levels, and scales [18]. Studying the effects and spatial distribution of UHI is important because of the highly spatially heterogeneous [19] nature of this phenomenon. Zhao used the landscape pattern index to analyse the spatial distribution of the UHI landscape pattern in Tianjin [20], finding that the total areas of UHI landscape patches is increasing, and the UHI landscapes of all levels are distributed in clusters. Huang used a multiple linear regression model to reveal the spatial distribution

pattern of the UHI and found that the main urban areas of Wuhan present a "double U-shaped" UHI distribution pattern from the inside out [21]. These studies focused on the spatial distribution characteristics, evolution trends, and internal driving mechanisms of UHI as well as the structure and evolution pattern of UHI landscapes.

According to the World Health Organization, a healthy environment, planning, and evaluation are important components of any healthy city. The high-density characteristic of China's megacities causes high temperatures in summer, which is not only harmful to health but also lowers the potential for further adaptability because of the constant and regular use of air conditioning [22]. Therefore, the health effects of increased heat exposure due to UHI on urban residents and the changes in urban spatial distribution are key research issues in urban health planning. In extreme cases, heat exposure causes death and various diseases of the respiratory, urinary, circulatory, and nervous systems [23]. The characteristics of the spatial pattern of UHI on human physiology and comfort [8] and the mechanism of the UHI on respiratory diseases [9] on the basis of the human body's physiological response to high temperatures were explored by Huang. However, these studies focused only on single factors, such as physiological comfort or respiratory diseases, and rarely involved a comprehensive study of the physical and mental health hazards caused by UHI and the risk characteristics of their spatial patterns.

Therefore, using data from meteorological stations, satellite images, and electronic maps, the effects of UHI on respiratory diseases, cardiovascular diseases, and emotional health were analysed through GIS, remote sensing, and spatial hotspot exploration technology. The health risk assessment of UHI and the division of affected areas were also studied.

The remainder of this study is organized as follows: Section 3 presents the evaluation criteria of the UHI effect on health and the method of detecting such effect on urban space. Section 4 discusses the single-factor impact assessment of cardiovascular diseases, respiratory diseases, and emotional health affected by the UHI as well as the AHP method for conducting a comprehensive health impact assessment, dividing health atmospheric impact zones, and analyzing hotspots where health impacts deteriorate. Section 5 presents the conclusions.

### 3 METHODOLOGY

#### 3.1 Data Collection and Processing

The accuracy of raw data was ensured through data collection, testing, and cleaning. Satellite images from 1992, 2001, 2011, and 2018 in Landsat 5 and 8 were selected. The average wind speed was less than 2.3 m/s on the two days before the image was captured, and no precipitation occurred on any day. At the time of imaging, the study areas were not covered by clouds, visibility was excellent, and imaging conditions were good. The meteorological data were obtained from 370 meteorological observation stations in Beijing and Tianjin at the same latitude, and the data quality is in line with the international meteorological testing standard.

First, registration and geometric correction of remote sensing images and thematic maps of urban planning were

conducted to control errors within one pixel. Next, data were uniformly projected into the WGS\_1984\_UTM\_50N coordinate system to maintain consistency. Finally, ArcGIS software was used to build a database to perform spatial superposition and extraction analysis on data from different periods.

#### 3.2 Health Impact Assessment Methods

To investigate the effects of the urban microclimate on residents' physical and mental health, respiratory and cardiovascular diseases were set as indicators of physical health, while emotional health of the general population was set as the indicator of mental health. The effects of UHI on physical health were analysed using the data from the Chinese Center for Disease Control and Prevention, and the grading standards of human physiological significance were employed to ensure accuracy. At the mean minimum temperature of 28.6 °C (mean temperature of 30.2 °C) from July 7 to August 7 in summer for many years, UHI temperature rises in different locations were superimposed to eliminate the occasional rainy weather temperature fluctuations. Therefore, the minimum effects of UHI on residents' health could be effectively evaluated to assess the effects of temperature on their health.

##### 3.2.1 Grading the Effects of UHI on Respiratory Diseases

External temperature change can cause temporary obstacles to thermoregulatory mechanism and increase heat accumulation in the human body, potentially causing respiratory diseases. The vitality of viruses is strengthened under extreme temperatures, which further increases the incidence or mortality due to respiratory diseases. The daily average temperature threshold of the UHI on respiratory diseases mortality is 31 °C. Respiratory diseases mortality increases by 25.3% with every 1 °C rise in air temperature [24]. The effects of UHI on respiratory mortality are divided into 10 levels (Tab. 1).

**Table 1** Grading the effects of UHI on respiratory diseases

Level	Temperature / °C	Growth of mortality / %	Physiological reaction of the human body
Level 1	20-30	-	Little impact
Level 2	30-31	-	Effect slight
Level 3	31-32	0-25.3	Discomfort begins
Level 4	32-33	25.3-50.6	Slight discomfort
Level 5	33-34.5	50.6-88.55	Highly uncomfortable
Level 6	34.5-35	88.55-126.5	Increased incidence
Level 7	35-35.5	126.5-164.45	Incidence of mortality significantly increases
Level 8	35.5-36	164.45-177.1	Increased mortality
Level 9	36-36.5	177.1-189.75	Mortality rate significantly increases
Level 10	> 36.5	> 189.75	Mortality rate significantly increases

##### 3.2.2 Grading the Effects of UHI on Cardiovascular Diseases

High temperatures increase cardiovascular diseases mortality by affecting cardiopulmonary functions, including blood pressure, blood viscosity, serum cholesterol and heart rate [25]. Elevated air temperatures increase the heart rate and myocardial oxygen consumption

in the human body. The transport of blood from organs to the skin surface becomes faster, thus creating high pressure on the heart and lungs and further increasing the incidence of cardiovascular diseases [26]. The analysis of data from Jinan, a large city at the same latitude as Tianjin, shows that the average daily temperature of 28 °C is the threshold

temperature for the effects of UHI on cardiovascular diseases mortality [24]. Cardiovascular diseases mortality increases by 7.2% with every 1 °C rise in air temperature. Therefore, the effects of UHI on cardiovascular diseases are divided into 10 levels (Tab. 2).

**Table 2** Grading the effects of UHI on cardiovascular diseases

Level	Temperature / °C	Growth of mortality / %	Physiological reaction of the human body
Level 1	0-28	-	Slight effect
Level 2	28-29	0-7.2	Slight discomfort
Level 3	29-30	7.2-14.4	Discomfort and the physical manifestation of sweating easily
Level 4	30-31	14.4-21.6	Highly uncomfortable with common physical manifestations of heavy sweating
Level 5	31-32	21.6-28.8	Increased incidence
Level 6	32-33	28.8-36	Significant increase in incidence
Level 7	33-34	36-43.2	Faster heartbeat and higher mortality
Level 8	34-35	43.2-50.4	Significant increase in mortality
Level 9	35-36	50.4-57.6	Significant increase in mortality
Level 10	36-37	57.6-64.8	Significant increase in mortality

### 3.2.3 Grading the Effects of UHI on Emotional Health

With the increase in intensity of UHI, high temperature extremes heat wave events become frequent, directly or indirectly harming residents' mental health [27]. According to relevant literature [28] and the team's analysis results of 386 valid questionnaires from 08:00-12:00 and 14:00-17:00 during 28 July to 27 August 2019 in Nanjing of China, and based on the critical temperature threshold and the correlation curve between summer high temperatures and negative emotional factors, the temperature boundary of the effects of UHI on emotional health is determined. Therefore, the average daily temperature of 28 °C is the threshold temperature for the effects of UHI on emotional health, and the effects are divided into 10 levels (Tab. 3).

**Table 3** Grading the effects of UHI on emotional health

Level	Temperature / °C	Emotional state
Level 1	< 30	Comfortable and stable
Level 2	30-31	Emotions start to fluctuate
Level 3	31-32	Mood swings
Level 4	32-33	Mood swings
Level 5	33-34.5	Restlessness, irritability, etc.
Level 6	34.5-35	Restlessness, irritability, etc.
Level 7	35-35.5	Restlessness, irritability, etc.
Level 8	35.5-36	State of "irritability"
Level 9	36-36.5	Significant increase in restlessness, yelling, and breaking things
Level 10	> 36.5	Increased frequency of fighting, suicide, and other incidents

### 3.3 Air Temperature Retrieval

The relationship model between land surface temperature (LST) and the data from meteorological stations were employed to inverse and calculate the urban air temperature field data. The LST was retrieved from satellite images, while the air temperature data were acquired from 370 meteorological stations. Atmospheric calibration was applied. First, radiometric calibration was performed according to the NASA manual (landsat.usgs.gov/documents). Next, the normalized difference vegetation index (NDVI), vegetation coverage, and land surface emissivity [29] were calculated. Finally, LST was calculated using the following ( $T_L$ ) formula:

$$T_L = 273.15 \cdot \frac{T}{1 + (\lambda T / \rho) \ln \varepsilon} \tag{1}$$

where  $\lambda$  is the central wavelength of the TM6 band (11.5  $\mu\text{m}$ ), and  $\varepsilon$  is land surface emissivity,  $\rho = h \cdot (c/\sigma) = 1.438 \cdot 10^{-2}$  K (where Stefan-Boltzmann's constant  $\sigma = 1.38 \cdot 10^{-23}$  J/K, Planck's constant  $h = 6.626 \cdot 10^{-34}$  Js and speed of light  $c = 2.998 \cdot 10^8$  m/s). LST and the atmospheric temperature at a certain distance above have a synergistic change rule, and LST is also closely related to the atmospheric temperature of 1.5 meters near the ground. Using MATLAB's curve fitting toolbox (CFTool), a good linear relationship was found among land surface temperature, NDVI, and daily average temperature. The regression formula was as follows:

$$T_A = 4.31 + 0.1678 T - 0.1747 y \tag{2}$$

where  $T_A$  is the daily average temperature,  $T_L$  is the LST, and  $y$  is the NDVI. The coefficient of determination ( $R^2$ ) is 0.95, and the root-mean-square error is 0.13.

### 3.4 Spatial Autocorrelation Analysis

Spatial autocorrelation analysis is an effective method to study changes in spatial patterns. It focuses on analyzing the correlation between spatial data, discovering singular observations, and then revealing the spatial connection of objects and changes in heterogeneous spatial patterns. The driving factors that cause spatial pattern change can be revealed by studying the temporal change of the spatial pattern. The Getis-Ord ( $G_i^*$ ) index was used to identify the spatial hotspots of the UHI effect on health during urban growth and understand the pattern characteristics of its spatial evolution.

$$G_i^* = \frac{\sum_{j=1}^n w_{ij} x_j - \frac{\sum_{j=1}^n x_j}{n} \sum_{j=1}^n w_{ij}}{\sqrt{\frac{\sum_{j=1}^n x_j^2 - (\bar{x})^2}{n} \frac{\sum_{j=1}^n w_{ij}^2 - (\sum_{j=1}^n w_{ij})}{n-1}}} \tag{3}$$

where  $x_j$  is the attribute value of element  $j$ ,  $w_{ij}$  is the spatial weight between elements  $i$  and  $j$ , and  $n$  is the total number of elements. Getis-Ord ( $G_i^*$ ) used statistical significance testing criteria, such as  $|z| > 1.96$ , significance level  $\rho < 0.05$ , and 95% confidence, to determine whether spatial clusters and structures occurred.

### 3.5 Overview of the Study Areas

Tianjin urban areas (117°13'45"-117°18'50", 39°4'25"-39°10'4") have a typical semi-humid continental monsoon climate, which are mainly dominated by monsoon circulation and are an area where the East Asian monsoon prevails (Fig. 1). The areas are dominated by southerly winds with high temperatures and precipitation. During July, August at 10:00-18:00, from 2008 to 2017

(China standard time), the lowest temperature in Tianjin was 28.6 °C, and the average temperature was 30.2 °C.

Tianjin is a major global center in the Asia Pacific region. It is one of China's four municipalities and is a major city in the Beijing-Tianjin-Hebei urban agglomeration among the three major urban agglomerations in China. Tianjin's urban space expansion is typical with the rapid advance of urbanization. In the past 20 years, the areas of urban morphology have expanded from 280 km<sup>2</sup> in 1992 to 936 km<sup>2</sup> in 2013. The study areas have a high population density and industrial concentration. Urban buildings have also been updated in the past 25 years, with many multi-story and high-rise buildings replacing the original low-rise high-density buildings (1-2 floors). Therefore, Tianjin's UHI effect and spatial evolution of effect of UHI on health are typically representative.

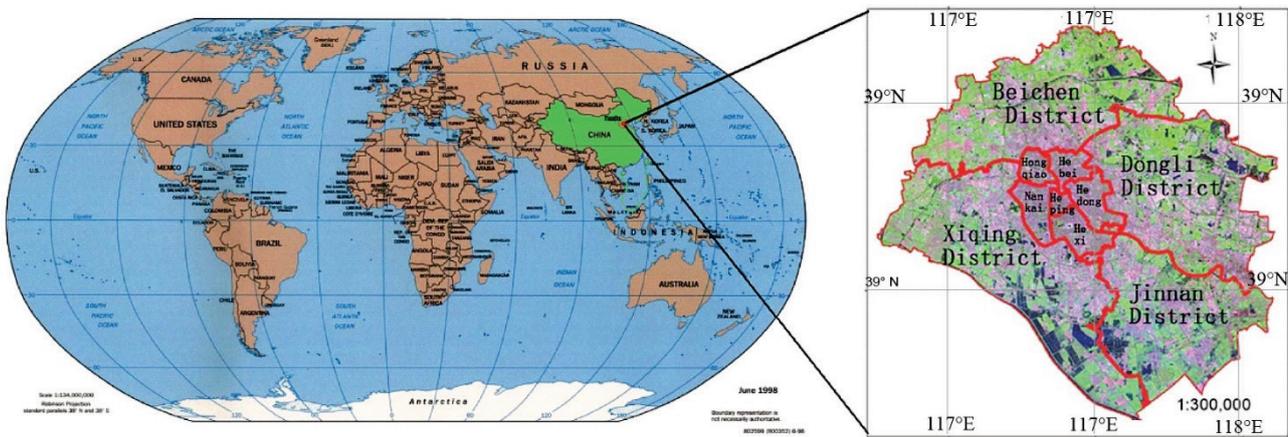


Figure 1 Study areas

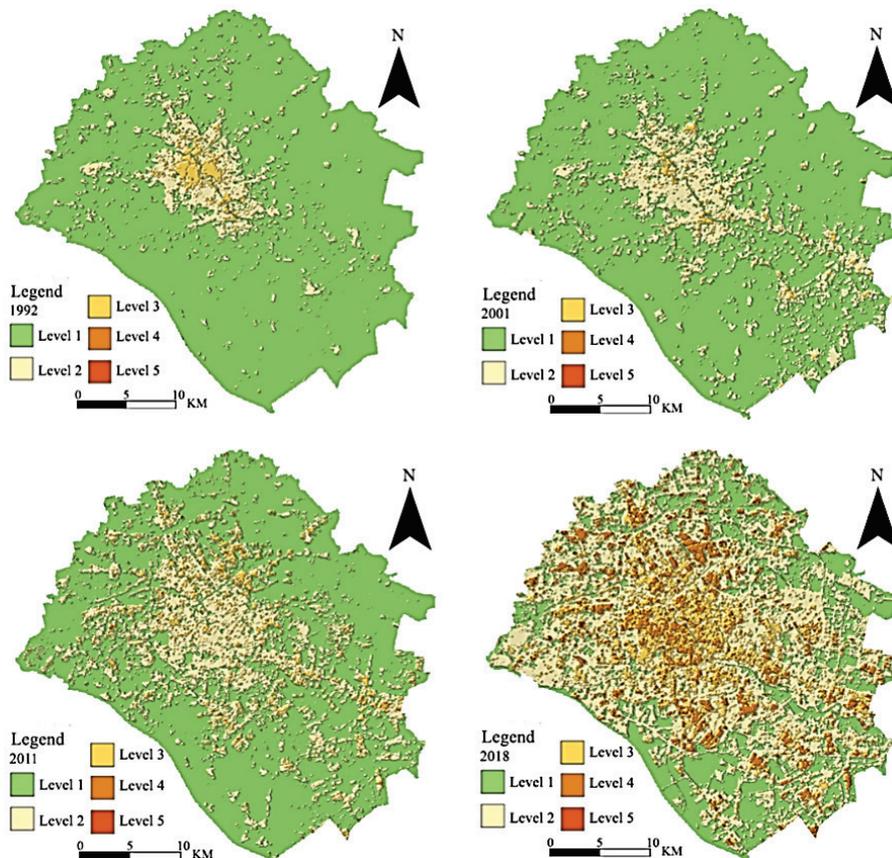


Figure 2 Distribution of the effects of UHI on respiratory diseases

**4 RESULTS AND DISCUSSION**

**4.1 Analysis of the Hazards of UHI on Health**

**4.1.1 Effects of UHI on Respiratory Diseases**

Based on the classification criteria of the effects of UHI on respiratory diseases, the affected areas in Tianjin over the four periods from 1992 to 2018 were evaluated (Fig. 2, Tab. 4). The results show that the areas where UHI affected respiratory diseases were rapidly expanding, with

the affected levels rising, and the high-level affected areas continuously expanding. The affected levels from 1992 to 2011 were mainly at level 1. From 2011 to 2018, the affected levels increased to levels 2-4 and gradually expanded from the urban center areas to the periphery. The spatial characteristics of the central city areas were concentrated, and the periphery was distributed in groups.

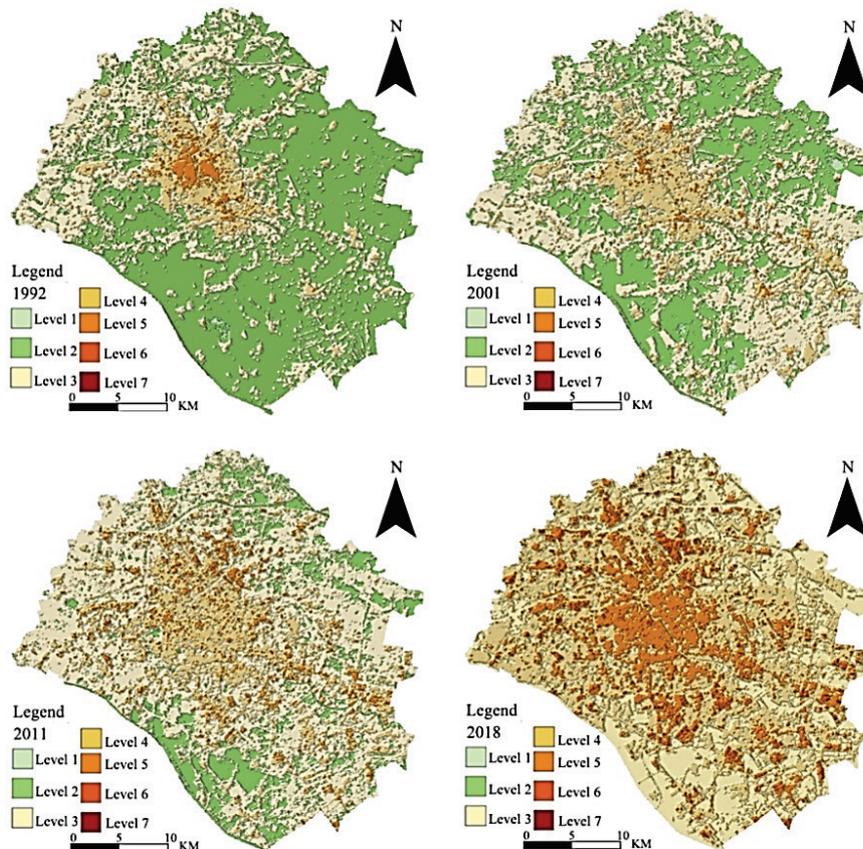
**Table 4** Areas of the effects of UHI on respiratory diseases

	Level	1	2	3	4	5
1992	Area / km <sup>2</sup>	1822.19	216.9765	41.3199	0.0774	-
	Rate / %	87.58	10.43	1.99	0.00	-
2001	Area / km <sup>2</sup>	1708.821	341.7165	29.646	0.3753	0.0054
	Rate / %	82.14	16.42	1.42	0.02	0.00
2011	Area / km <sup>2</sup>	1471.626	504.549	100.782	3.492	0.1152
	Rate / %	70.73	24.25	4.84	0.17	0.01
2018	Area / km <sup>2</sup>	606.5307	986.2344	435.4218	50.5476	1.8297
	Rate / %	29.15	47.40	20.93	2.43	0.09

**4.1.2 Effects of UHI on Cardiovascular Diseases**

According to the classification criteria of the effects of UHI on cardiovascular diseases, the affected areas in Tianjin during the four periods from 1992 to 2018 were evaluated (Fig. 3, Tab.5). The results show that the areas where UHI affected cardiovascular health were rapidly expanding, and the main affected levels increased significantly. Affected areas gradually expanded from the

city's central areas to the periphery, high-level affected areas were mainly concentrated in the central urban areas, and large-area patches were concentrated on the periphery. The effect levels of UHI on cardiovascular diseases in 1992-2001 were mainly at levels 2-3 and were mainly distributed in urban central areas. From 2001 to 2018, the affected levels increased slightly to levels 4-5, and the affected areas expanded to the suburbs.



**Figure 3** Distribution of the effects of UHI on cardiovascular diseases

**4.1.3 Effects of UHI on Emotional Health**

According to the classification standard of the effects of temperature on emotional health, the evolution

characteristics of the effects in Tianjin in the four periods from 1992 to 2018 were evaluated (Fig. 4, Tab.6). The results show that the effects of UHI on emotional health deteriorated with increasing effect levels and increasing

areas of high-level effect. Moreover, the affected levels from 1992 to 2011 were mainly at level 1 and were mainly distributed in urban peripheral areas, with less concentration in the central areas. From 2011 to 2018, the affected levels mainly increased from level 1 to levels 2-4,

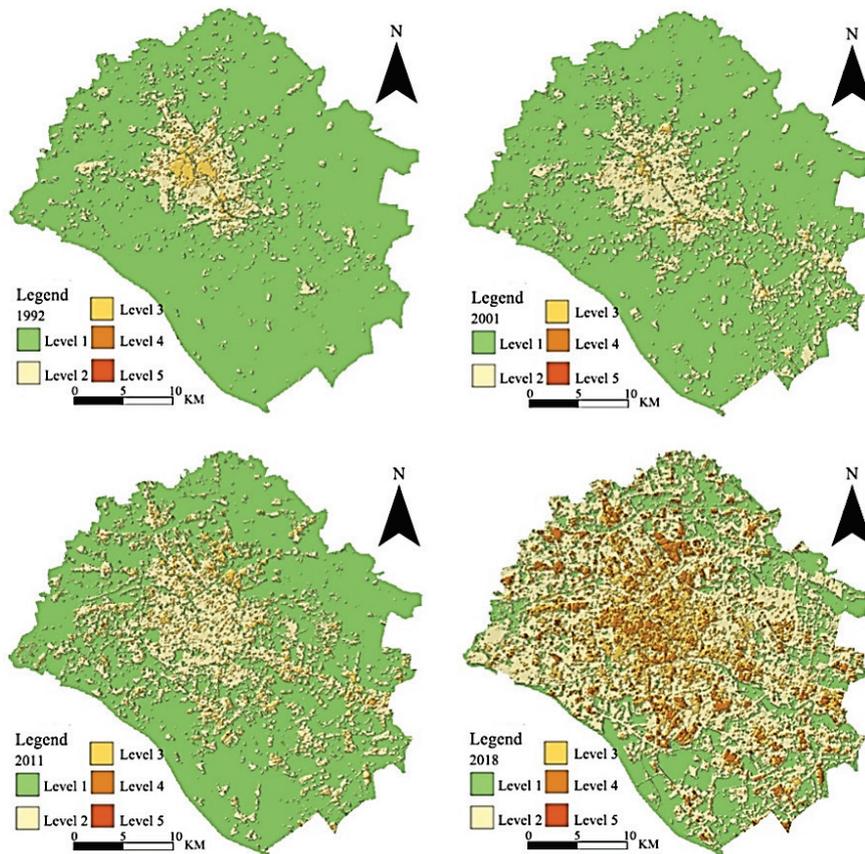
and the affected areas gradually expanded from the city centers to the periphery. The central city areas had a large area of patches concentration, while the periphery showed a high density of small patches distributed.

**Table 5** Areas of the effects of UHI on cardiovascular diseases

	Level	1	2	3	4	5	6	7	8
1992	Area / km <sup>2</sup>	3.3669	1191.815	627.0084	216.9765	41.3199	0.0774	-	-
	Rate / %	0.16	57.29	30.14	10.43	1.99	0.00	-	-
2001	Area / km <sup>2</sup>	7.8777	765.6426	935.3007	341.7165	29.646	0.3753	0.0054	-
	Rate / %	0.38	36.80	44.96	16.42	1.42	0.02	0.00	-
2011	Area / km <sup>2</sup>	0.1584	339.3666	1132.101	504.549	100.782	3.492	0.1152	-
	Rate / %	0.01	16.31	54.41	24.25	4.84	0.17	0.01	-
2018	Area / km <sup>2</sup>	0.0288	0.3177	606.1842	986.2344	435.4218	50.5476	1.8189	0.0108
	Rate / %	0.00	0.02	29.14	47.40	20.93	2.43	0.09	0.00

**Table 6** Areas of the effects of UHI on emotional health

	Level	1	2	3	4	5
1992	Area / km <sup>2</sup>	1822.19	216.9765	41.3199	0.0774	-
	Rate / %	87.58	10.43	1.99	0.00	-
2001	Area / km <sup>2</sup>	1708.821	341.7165	29.646	0.3753	0.0054
	Rate / %	82.14	16.42	1.42	0.02	0.00
2011	Area / km <sup>2</sup>	1471.626	504.549	100.782	3.492	0.1152
	Rate / %	70.73	24.25	4.84	0.17	0.01
2018	Area / km <sup>2</sup>	606.5307	935.5518	364.8744	171.7776	1.8297
	Rate / %	29.15	44.97	17.54	8.26	0.09



**Figure 4** Distribution of the effects of UHI on emotional health

**4.1.4 Comprehensive Effects of Climate on Health**

To generate a comprehensive map of UHI on health from 1992 to 2018 (Fig. 5), the influencing factors of UHI on respiratory diseases (0.18), cardiovascular diseases (0.12), and emotional health (0.70) were superimposed. The comprehensive effect areas of UHI on health expanded outward from the city center and were divided into large

patches along rivers and green belts. In the low-risk areas, the spatial pattern was in a circular expansion mode, which was mainly affected by the rapid expansion of urban morphology. In the middle-risk areas, the spatial pattern changed from large scale and centralized in the central urban areas to decentralized and fragmented areas from 1992 to 2011. During 2011-2018, large-area concentration in the central urban areas occurred again, and the suburbs

showed cluster distribution. In addition, high-risk and extremely high-risk areas were scattered around the city periphery in an island shape and were mainly concentrated on industrial land, large areas of impervious and hardened ground, high-density building areas, and commercial centers. The main reasons are the presence of many hardened floors in the industrial areas and glass curtain walls in the building factories, structures which increased

the heat absorption and temperature rise. The emission of industrial heat sources increased summer temperatures, the greening of the plant areas was relatively small, and the effects of reducing UHI was very limited. The urban thermal environment was significantly affected by different types of underlays in the urban areas, directly leading to significant differences in the temperature field, which in turn affected the health of urban residents.

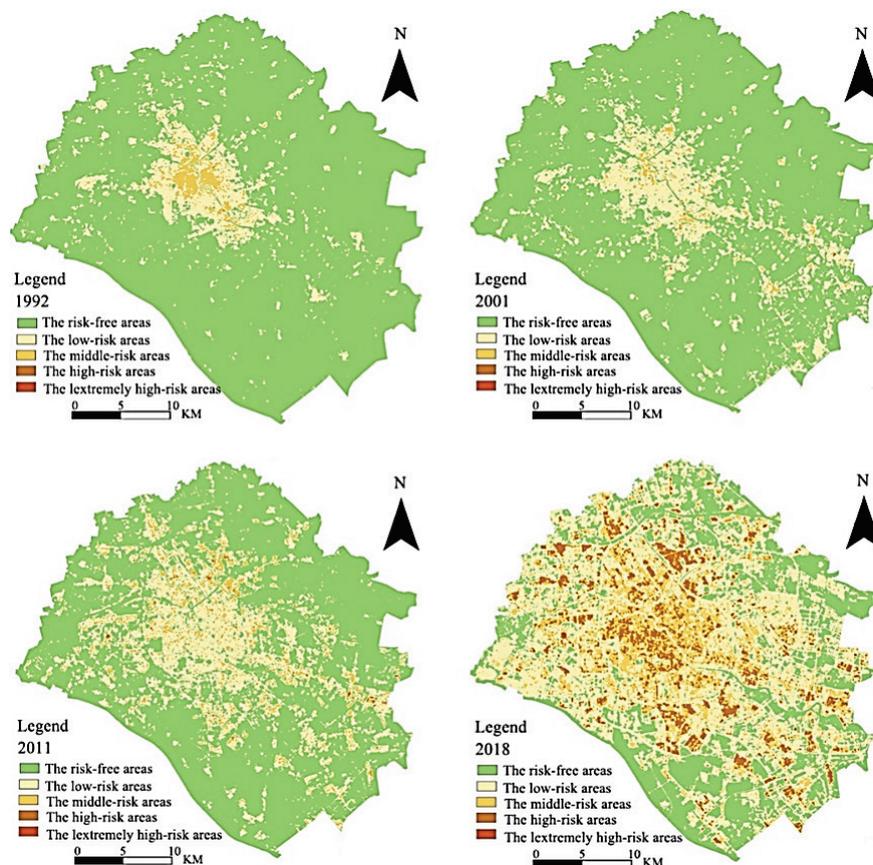


Figure 5 Comprehensive effects of UHI on health

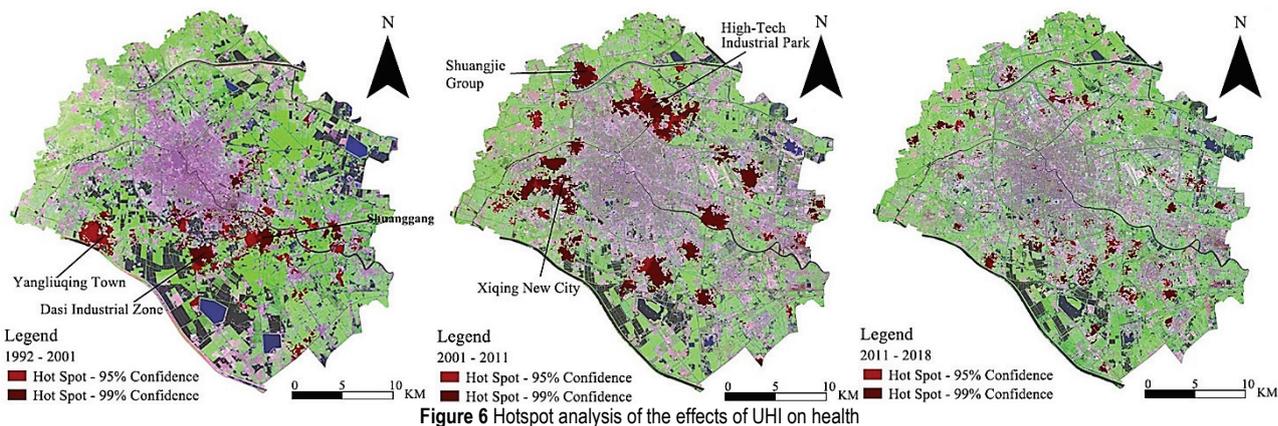


Figure 6 Hotspot analysis of the effects of UHI on health

#### 4.1.5 Comprehensive Hotspot Analysis of Climate Health Impact

The hotspots of spatial deterioration of the UHI effect on residents' health from 1992 to 2018 were explored by using ArcGIS (Fig. 6). From 1992 to 2001, the affected areas of the UHI on residents' health were mainly concentrated in the southern regions, including Shuanggang, Dasi Industrial Zone, and Yangliuqing Town.

From 2001 to 2011, the deteriorated hotspot showed a large-area patch spreading to the suburbs and was mainly concentrated in Xiqing new city, Shuangjie, and high-tech parks. These findings were mainly related to the sequence of urban construction and development, urban planning guidance, and strategic policies for urban spatial development. From 2011 to 2018, the deteriorating agglomeration hotspots expanded to the outskirts of the city, in the form of a small area of patches distribution.

In general, the evolution direction of the UHI effect on health during the three typical periods differed across Tianjin's urban areas. The expansion of the affected areas followed a phased pattern, where hotspots from four districts of the city center expanded to four districts surrounding the city center, and the patches expanded from large to small areas. The main reasons are rapid urbanization, which caused the city to expand rapidly over the past 20 years, and city construction, which was dominated by large-scale development. In addition, with the continuous improvement of the functions of the economic center and city services in the central urban areas, production functions were reduced and large-scale industrial enterprises gradually moved out and weakened the intensity of UHI in the central city, increasing it instead in the marginal of the city. This outcome has caused a serious health impact on the edges of urban center. From the adjustment of the urban master plan (1995 and 2006) to urban space, higher affected levels were showed by the planned concentrated development areas, especially in the industrial concentrated areas.

## 5 CONCLUSION

To scientifically evaluate the health risks of the effects of UHI on residents' health, based on multi-source data such as meteorological stations and satellite images, the spatial pattern and process of effects of UHI on respiratory, circulatory system diseases and emotional health was analysed, and also the spatial hotspot changes in climate health in Tianjin were studied. The conclusions are as follows:

(1) UHI has detrimental effects on residents' physical and mental health, but the intensity of effects varies. In terms of physical health, cardiovascular diseases increase greatly. The emotional health of the general population is affected significantly, but the affected levels do not increase significantly.

(2) The comprehensive harm degree and areas of the effects of UHI on residents' health increase. Severely affected areas are concentrated in the central areas of the city, and patches of distribution are fragmented.

(3) The changes in hotspots of spatial deterioration of health hazards have a phased pattern. The expansion hotspots turn unidirectionally to the south, surrounding the city center and expand from the inside out. The expansion patches change from a large area to a small area.

Three indicators are chosen to construct the evaluation criteria for the effect of UHI on health. It can more accurately reflect the effects of UHI on comprehensive health. Furthermore, this study offers a certain basis for analysing the spatial differentiation and evolutionary characteristics of the effects of UHI on the health of residents in megacities. Therefore, this study shows strong theoretical and practical feasibility.

However, the lack of a refined spatial scale limited the health effects of UHI from being deeply connected with the urban landscape. Therefore, in the future, the landscape index will be further applied to healthy urban planning to carry out high-resolution spatial-temporal data verification analysis, which further evaluates the health effects of the internal landscape of the UHI on a more refined spatial scale for effectively guiding the exploration of urban

planning and construction. Given that the study was based on the minimum temperature benchmarks for peak hours of people's activities during the day, the effects of UHI on health during other periods was underestimated. Different time periods for further refinement will be also planned for future study.

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