Spatial Differentiation and Equity of Urban Heat Health Risks from the Perspective of 15-Minute Life Circle

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Abstract. Intensified climate change-induced urban heat threatens urban residents' health and triggers climate equity gaps, with people over 65 and under 18 as core high-risk groups. This paper adopts the Vulnerability-Sensitivity-Adaptability (VSD) assessment framework to quantify urban heat health risks. It retrieves high-resolution land surface temperature data and constructs indicators incorporating vulnerable age populations and urban green resources. Using Geographic Information System (GIS) network analysis, the study delineates 15-minute life circles and analyze spatial differentiation of heat health risks, while applying the Gini index to measure intergroup climate equity. The study found that the old urban area of Nanjing has a high exposure rate, high vulnerability, and low adaptability, which belongs to the high-risk and low-adaptation area, while the new urban area is on the contrary. The elderly and underage population bear a higher proportion of climate risks, but they have a lower level of preventive measures, and group climate equity needs to be improved urgently. This study helps to identify risk-adaptation mismatch areas, understand the hot risk adaptability of vulnerable groups, and provide insights and a theoretical basis for coping with global warming, accelerating high temperature adaptability, ensuring the needs of vulnerable groups, and improving urban climate equity.

Keywords: Urban heat health risk; VSD framework; 15-minute life circle; climate equity;

1. Introduction

With the intensification of climate change, the risk of high temperatures has become a significant challenge to the urban environment and social equity. As densely populated social ecosystems, cities are at the center of many of the effects of global warming on the climate. Affected by existing socioeconomic and living space inequality, different groups of people have different levels of heat exposure [1]. In addition, due to differences in individual health and income levels, different groups of people have different sensitivity and adaptability to climate change, which leads to different levels of vulnerability to heat exposure [2]. Residents aged over 65 and minors under 18 constitute the population subgroups most vulnerable to heat-related mortality [3]. The 15-minute living circle is the main place for such groups to move in urban space, an important area to prevent thermal risks, and an area where planners and the government need to invest most in fine planning and shading facilities.

Heat stress in cities continues to worsen as a result of climate change. Due to the differentiation between the rich and the poor, the difference between urban infrastructure and physiological status, it has caused sustained inequality in climate impact in heat exposure risks and cooling facilities, resulting in differences in the temporal and spatial distribution of high temperature health risks [4]. Some old residential areas and their surroundings are the core areas of urban heat islands, with low greening rate and backward infrastructure, but they are the main activity space for vulnerable groups such as the elderly and children, with high risk of heat exposure. Current research shows that the 15-minute living circle is mainly the activity space with walking behavior as the main mode of travel, which can reduce the aggravating effect of motor vehicle use on climate change in terms of climate change response benefits. In terms of social benefits, it can speed up the equalization of public resource distribution. For heat health risks, green infrastructure within 15-minute life circles mitigates heat exposure, alleviates thermal inequity in communities accommodating heat-sensitive populations including the elderly, and facilitates urban climate adaptation [5]. In the complex urban environment, the use of the VSD index system can integrate the ability level of cities in heat exposure, sensitivity, and adaptability, and comprehensively indicate the high-risk areas of heat stress in cities [6]. Prior

research has constructed exposure-sensitivity-adaptability indicator frameworks under the 15-minute city framework to analyze spatial differentiation of heat stress risks, yet these frameworks fail to directly evaluate heat hazards borne by vulnerable populations including seniors and minors, leading to insufficient consideration of spatial climate equity [7]. Moreover, instead of directly analyzing the 15-minute life circle through the network, the approximate zoning is based on transportation stations such as subways. Presently, the GIS network analysis method is the main means to divide the 15-minute life circle, because it can set the mode of action as the walking speed, and solve the 15-minute activity range according to the road network [8]. Similar indicator models have also been used to assess the future risk of heat stress in residential areas. A study in Sweden considered the sensitivity of groups such as the elderly and children to climate change, predicting the risk of thermal disasters, population exposure, and socioeconomic and building environmental vulnerability [9]. Nevertheless, the research evaluates heat stress risks only at the national scale and fails to account for intricate intra-urban environmental heterogeneity.

To characterize intra-urban heat risks and regional climate equity, this research evaluates primary activity ranges of urban residents, particularly vulnerable subgroups, based on the 15-minute life circle framework. VSD index system was adopted to evaluate the high-temperature health risk of Nanjing, as a typical city with hot summer and cold winter, and to measure its contribution to urban climate equity.

2. Research design and data sources

Nanjing is a typical city with hot summers and cold winters in subtropical China. There are great differences in building age, greening, and infrastructure between old and new urban areas. As shown in Table 1, this paper uses a VSD index system to construct the evaluation system of urban high-temperature health risk, and selects corresponding indicators from three aspects of exposure, sensitivity, and adaptability to construct the index system. Land Surface Temperature (LST) was calculated using Landsat 8-9 OLI/TIRS C2 L2 surface temperature data and weighted according to population distribution to assess the thermal exposure of the population. At the sensitivity level, population structure is used to analyze, mainly focusing on the spatial distribution of the elderly and underage population, and the distribution areas of climate-sensitive population are obtained to assess the thermal vulnerability of climate-sensitive population. At the adaptability level, the normalized vegetation index was used to understand the ability of residents to obtain green resources in the 15-minute living circle.

Table 1. VSD index system.

	Indices	Explanation
Exposure	LST, population distribution	Calculate population-weighted LST to assess population exposure
Sensitivity	Distribution of population over 65 years old and under 18 years old	Assessing health vulnerability through the distribution of climate-sensitive populations
Adaptability	Normalized Difference Vegetation Index (NDVI)	Population's ability to get green resources under the threat of climate change

Residential committees are China's main grass-roots organizations, representing the centers of residential neighborhoods [10]. According to the Point of Interest (POI) distribution of residential committees in the main urban area of Nanjing obtained by Baidu map, the 15-minute walking range along the main road is calculated by GIS network analysis as the 15-minute living circle of Nanjing. Based on the VSD evaluation results. The high temperature risk level of each living circle unit is calculated. Calculating the Gini coefficient can measure the differentiation of high temperature risk groups and quantify the degree of climate equity.

The surface temperature data in this paper are from the high-resolution Surface Temperature Band 10 band of USGS Landsat 8-9 OLI/TIRS C2 L2. The time is July 3, 2025, and the cloud cover on the

land surface is 0.73. The random forest method is used to fill the gap in the remote sensing image. The data on total population distribution, minors under the age of 18, and the elderly over the age of 65 are from Worldpop. NDVI data is from the Google Earth Engine platform. The transportation network data is from OpenStreetMap, and the POI data of the residential committees is from Baidu Map. The coordinates are converted to the WGS84 coordinate system, and the above data are all in 2025.

3. Empirical results and analysis

3.1. Spatial differentiation characteristics

By measuring the overall spatial pattern of high-temperature health risk in the main urban area of Nanjing, this paper found that the high-temperature health risk showed significant core-edge spatial aggregation characteristics. The high-risk areas were highly concentrated in the old urban areas such as Drum Tower, Xuanwu, Qinhuai, and the north of Jianye, while the low-risk areas were distributed in the peripheral suburbs and new urban areas. As shown in Fig. 1, both exposure and sensitivity are characterized by high core and low edge. Central urban zones not only suffer urban heat island effects induced by dense constructions and aging residential blocks but also serve as agglomeration areas for climate-sensitive populations, which further elevates heat exposure hazards.

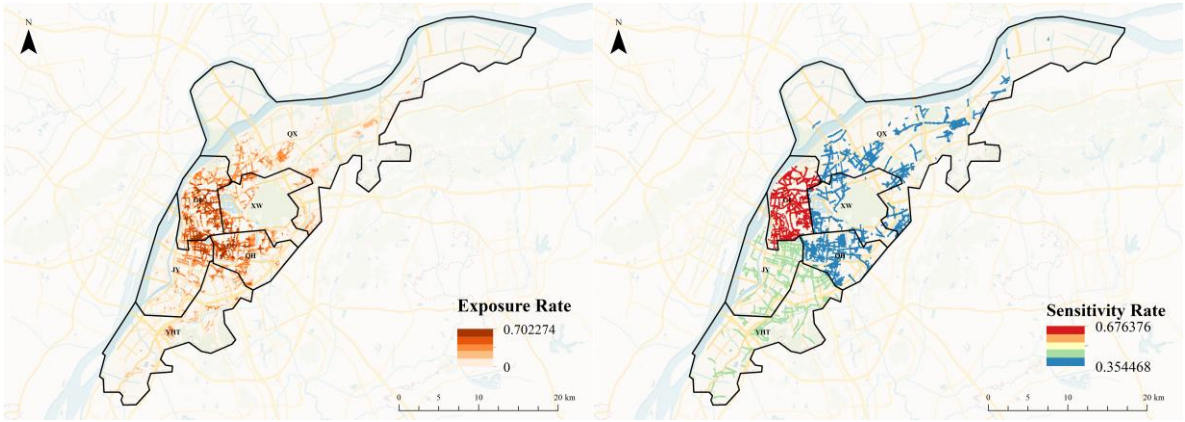


Fig 1. Spatial distribution characteristics of exposure and sensitivity (Picture credit: Original).

As shown in Fig. 2, the high-temperature adaptability based on the availability of greening shows a spatial pattern of low core - high surrounding area, which is due to the high impervious surface ratio and building density in the old urban area and the slow progress of urban renewal, resulting in the greening rate being unable to meet the basic needs.

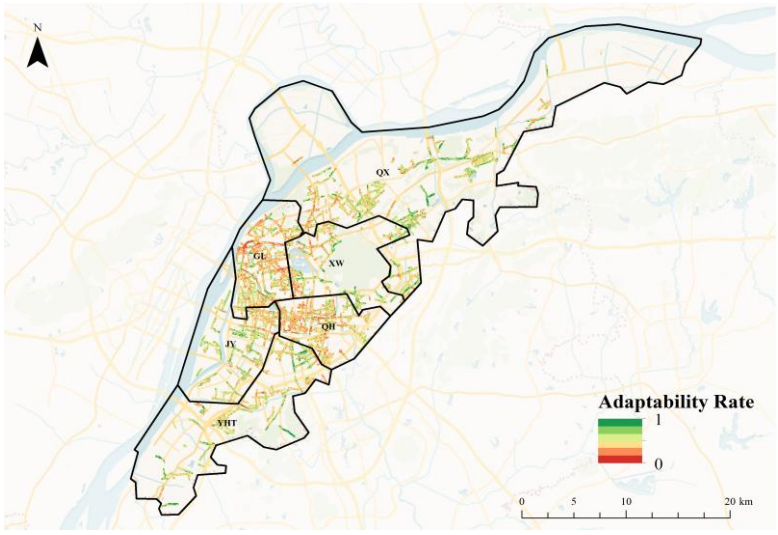


Fig 2. Spatial distribution characteristics of adaptability (Picture credit: Original).

As shown in Fig. 3, this paper also built a risk adaptation assessment system to understand the spatial equity of risk adaptation in the main urban area of Nanjing by assessing the spatial coupling relationship between high temperature health risk and adaptation. The assessment results show that the old urban area is still a high-risk, low-adaptation, and low-equity area, and the spatial mismatch between the high heat exposure level and the vulnerability and greening level leads to the high-risk population continuing to be at a high level of high-temperature health risk. This paper also shows that the construction strategy of low-density and high greening in Jianye, Qixia, and Yuhuatai districts is conducive to the prevention and control of high-temperature health risks.

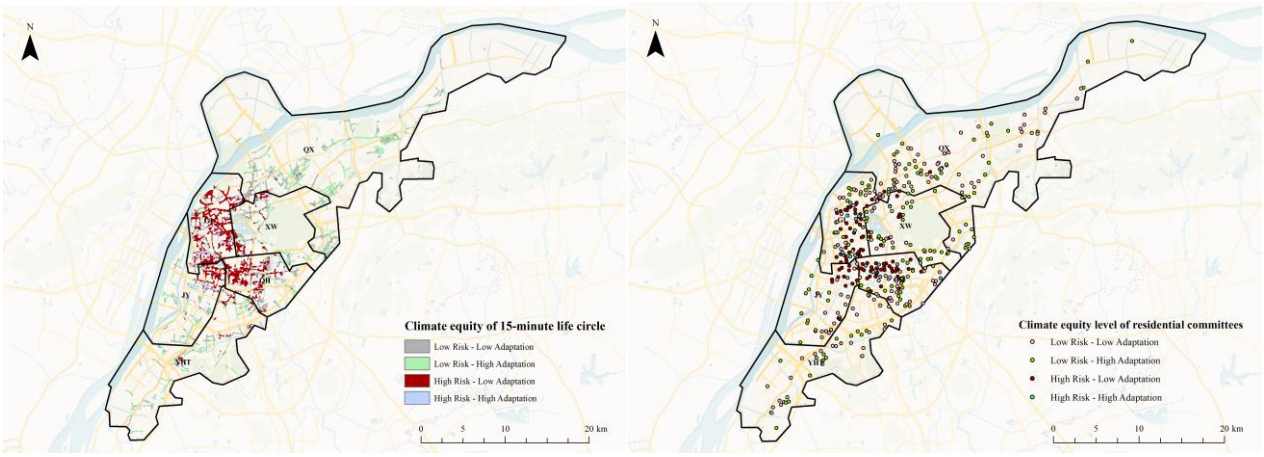


Fig 3. Spatial distribution of climate equity (Picture credit: Original).

3.2. Group equity differences

In the measurement of specific groups, the study found that the risk level of vulnerable groups by age was significantly higher than the urban average. Physiological deterioration renders seniors and minors highly susceptible to extreme heat conditions. In addition, they are mainly left behind in old communities, and they face the most serious comprehensive risk. In order to quantify this phenomenon, the Gini coefficient was used to measure the difference in high-temperature health risk among the main population. As shown in Fig. 4, the Gini coefficient of the study area is 0.4423. After decomposing the fair contribution within and between groups, it shows that vulnerable groups bear a higher proportion of climate risk. The unfairness of high temperature risk at the urban spatial scale and population level shows that the current urban planning and public service allocation fail to effectively favor vulnerable groups, and there is serious spatial unfairness in the distribution of climate resources.

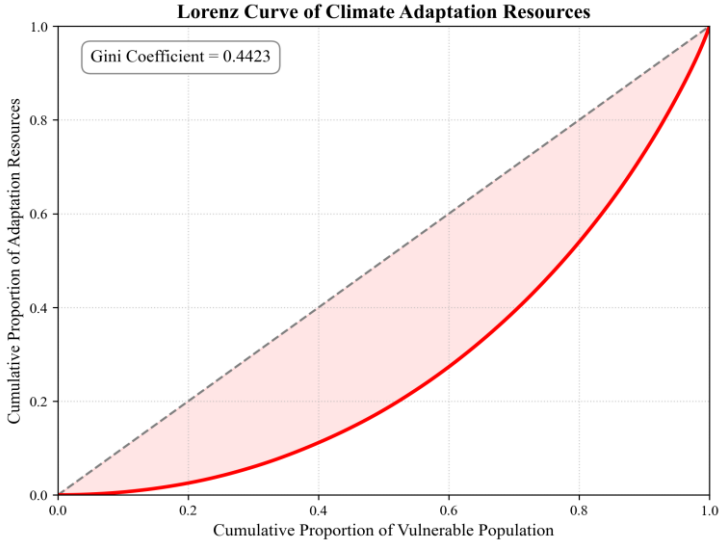


Fig 4. The decomposition of Gini coefficient (Picture credit: Original).

4. Discussion and optimization strategy

Facing the current situation of spatial differentiation and resource mismatch, urban planning departments should implement differentiation policies for different regions. For the old urban areas where the risk level and adaptability are mismatched, micro renewal should be taken as the guidance, through the construction of pocket parks, the optimization of street ventilation corridors, and the establishment of indoor summer cooling centers relying on community neighborhood committees to enhance local adaptability. For new urban areas with strong adaptability, attention should be paid to bottom-line control, and the building density and plot ratio should be strictly controlled in the subsequent development to prevent the expansion of urban heat islands to the suburbs. In addition, for "high risk - high adaptation" areas, it is necessary to regularly assess the carrying capacity of existing adaptation facilities to ensure the robustness of resource supply and response during extreme heat waves.

In order to mitigate the urban climate risk challenge intensified by climate change, urban managers must establish a fair, oriented public service allocation mechanism. The planning and allocation of disaster prevention and mitigation resources should be guided by people with highly sensitive needs, and priority should be given to make up for the infrastructure and greening shortcomings of highly vulnerable people and old communities. In the index assessment system to promote the construction of the 15-minute living circle, it should avoid the one-size-fits-all policy and add public resources such as greening and shading facilities according to the current situation of regional heat exposure and vulnerability, so as to ensure the high-temperature health of relevant people. At the level of government departments, it should build a dynamic monitoring system to assess the equalization process of climate resource allocation in real time, ensure environmental equity from the institutional level, and improve the climate risk awareness and high-temperature self-help ability of vulnerable groups, especially the elderly living alone, through popular science education and community exercises.

5. Conclusion

Based on the perspective of the 15-minute life circle, this paper quantitatively measures the spatial differentiation characteristics of high-temperature health risk and the fairness of climate resource allocation in the main urban area of Nanjing. The results show that the high temperature health risk in the study area presents a significant core-edge agglomeration pattern, and the high exposure and sensitivity of the old urban area are superimposed, while the fragmented adaptability fails to form an effective mitigation function. At the level of spatial justice, there is a serious spatial inequality in the distribution of urban climate adaptation resources. Vulnerable urban populations accounting for 60% of the total hold merely 20% of climate adaptation resources. Most aging residential blocks inhabited by these populations fall into the "high risk–low adaptation" heat exposure predicament and have lower adaptive ability than the newly developed communities. The high-density old community environment and low greening rate in the old urban area ignore the distribution of sensitive groups and the demand for heat reduction. Future urban renewal should take demand orientation as the core logic and focus on complementing the adaptability weakness of core high-risk areas.

The main contribution of this paper is to assess the risk of high temperature in the 15-minute life circle scale. This method is conducive to breaking through the statistical limitations of traditional administrative divisions and makes up for the research gap in quantitative evaluation of urban climate justice at the micro spatial scale. In addition, this paper uses the risk adaptation assessment system to assess the climate risk equity of vulnerable populations from the perspective of climate justice. However, the current research has its limitations, mainly relying on the static census and remote sensing cross-sectional data, which cannot fully capture the dynamic commute trajectory of people during the day, night, or working day. In future research, mobile signaling, Location-Based Service, and other dynamic spatio-temporal big data can be introduced to further improve the accuracy of dynamic exposure measurement.

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