Simulation and Analysis on the Urban Thermal Environment Network Pattern Based on MSPA and Circuit Theory in Lanzhou City, China

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Abstract. Based on MSPA and circuit theory, the hot and cold sources, hot and cold corridors, pinch points and obstacle points in the main urban area of Lanzhou City are identified, and then the thermal environment pattern of the main urban area of Lanzhou City is analyzed.1) The heat sources of Lanzhou City are centrally located in Xigu District and Anning District, and are sporadically distributed in other areas, with the total area of 4112.29 hectares. Cold islands are mainly distributed in the riverfront area and some urban parks, with a total area of 1,582.9 ha.2) There are 72 hot corridors in Lanzhou city, and the corridors with the highest connectivity occur in corridors less than 1 km; there are 99 cold corridors, with 50% of the corridors being less than 1 km and having good connectivity.3) Clip points are present in 75% of the corridors and are distributed in the starting end of the heat source sites; the obstacle points are present in the cold corridors that are larger than 1 km. The optimization strategy is proposed based on the above pattern. Based on the above patterns, optimization strategies are proposed: 1) add green space in the area where heat sources are concentrated and prevent adhesion to protect the existing cold sources; 2) accurately isolate the hot corridors according to the distribution of pinch points and reduce their connectivity; optimize the cold corridors according to the distribution of obstacle points, and cut down the large-area obstacle points according to the characteristics of the sub-surface, remove the small-area obstacle points, and increase the connectivity.

Keywords: lanzhou city; MSPA; circuit theory; optimized protection

1 Introduction

With the warming of the climate and the acceleration of urbanization rate, the heat island effect becomes more and more serious. Due to the rapid development of social form and economy, the urban population grows dramatically, and the urban construction land expands dramatically, which causes the change of the subsurface, coupled with the combined influence of artificial buildings and heat accumulators such as highways, which makes the heat exhaust of the whole city increase, and the heat island problem becomes more and more serious day by day [1]. Thermal pollution caused by the urban thermal environment has seriously affected people's quality of life and health

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[2], international research on the urban thermal environment and governance has become a hot issue [3]. Blue-green space can form a "cold island", the "cold island" effect is an effective means of regulating urban climate and mitigating the heat island effect, good blue-green space layout can regulate the urban climate, effectively mitigate the urban heat island effect, how to carry out reasonable design and planning to improve the health and comfort of the city, and how to make reasonable design and planning to improve the health and comfort of the city. planning to improve the health and comfort of the city is a worthy research topic.

Scholars at home and abroad have carried out a series of thermal environment network planning studies using the MSPA model combined with the circuit theory in the downtown area of Chengdu City [4], Nan'an District of Chongqing City [5], Fuzhou City [6], and Xi'an City [7], which has made the research theory of this model in the construction of thermal environment network more complete. The introduction of this series of methods makes the simulation in the thermal environment network more scientific. From the current study, the research area is mostly selected for plain-type cities, with less research and application to cities with special terrain, such as: valley-type cities, Lanzhou City, Xining City, Urumqi City, etc. The development of this type of city is very different from that of plain-type cities, and it promotes the city's outward expansion and development through the establishment of high-tech development zones or economic and technological development zones at different scales; meanwhile, most of these cities are located in the northwestern region, deep inland of China. At the same time, most of these cities are located in the northwestern region deep inland of China, with complex topography and complex climate environment, which makes it difficult to use remote sensing images to conduct thermal environment and climate research under the influence of grassland, elevation and climate.

2 Research Area and Data Sources

2.1 Overview of the Study Area

Located in the Loess Plateau in northwest China, Lanzhou is a city with a long east-west and narrow north-south banded river valley basin. Lanzhou is expanding along the river valley, and the properties and morphology of its subsurface have changed significantly. The surface heat input caused by human activities, and the resulting changes in the water-heat balance have profoundly affected the spatial distribution of the urban thermal environment. In this paper, the main urban area of Lanzhou City is firstly selected as the research object, and in the actual research process, after the surface temperature inversion, it is found that most of the heat island patches in the main urban area of Lanzhou City are located in the suburbs, which makes it difficult to express the status quo that the central urban area is densely populated with construction land and has outstanding thermal environment problems. Therefore, this study further reduces the scope of the study, the heat island network research in the central city valley development area and to be developed area, the choice of the study area at the same time can be removed from the impact of elevation on the thermal environment, as Figure 1. the central city valley basin area heat island effect is significant.

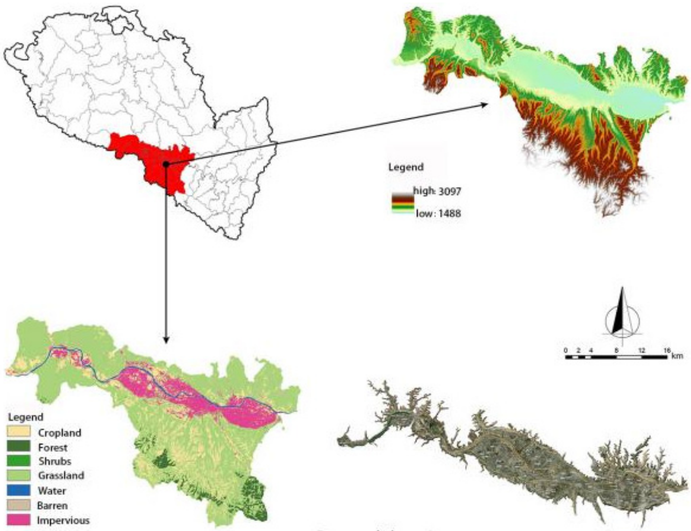

Fig. 1. Overview of the study area

2.2 Data Sources

The Landsat 8-9 C2 L2 remote sensing image of June-September was selected to invert the surface temperature, with the strip number 129-39, and the imaging time was 3:43 a.m. Beijing time on July 18, 2023.Other data include: the 2024 vector map of county-level administrative divisions in Gansu Province, which was derived from the National Geographic Information Public Service Platform; the 2022 land-use raster data of the study area, with a resolution of 10 m, which was obtained in ArcGIS, with a resolution of 10 m, and a resolution of 10 m. The data were used in the ArcGIS data analysis. 10m, reclassified in ArcGIS 10.8, and divided into 7 categories: cropland, forest land, shrubs, grassland, construction land, bare land, and water bodies; the number of population in the study area in 2022; and the nighttime lighting index as well as rainfall and temperature data from the Lanzhou Municipal Statistical Yearbook 2022.

2.3 Research Methods

The remote sensing images were processed in ENVI, and in the secondary data, the surface temperature band is the STB10 band in the ST product (2nd dataset) in Kelvin, on which band operations were performed to obtain the desired surface temperature [8]. According to the natural breakpoint method, the inverse performance surface temperature is divided into five levels, through the remote sensing image and temperature control, can be found in the high-temperature zone for a large number of bare ground heat absorption caused by a certain impact on the thermal environment analysis, so the data screening and analysis, select the sub-high-temperature zone will be the region is defined as a heat island patches, due to the Yellow River through the city, low-temperature zone for the river, select the sub-low-temperature zone position cold island patches. In the MSPA module of Guidos Toolbox, cold and hot island patches were used as foreground and other areas as background. Based on the default 8-neighborhood rule, the study area was divided into seven network structure elements: core, bridge, island, ring, edge, perforation and branch. The core area is crucial in the thermal environment pattern, which can significantly represent cold and hot islands and has higher connectivity for energy propagation and diffusion.

The resistance surface is a spatial morphological characterization of electrical resistance, indicating the distribution of the degree of resistance to heat diffusion among the source sites of thermal environments and reflecting the accessibility and trend of surface heat transfer. The spatial and temporal differentiation characteristics of urban landscape pattern largely determine the intensity of heat island effect in different cities. The calculation of surface cover resistance values is mainly based on the cooling rate characteristics of various types of sites. The heat generated by energy consumption and the heat released by human body itself are collectively referred to as anthropogenic heat fluxes, which have an enhancing effect on the urban heat island. In this paper, population size and nighttime lighting data are considered as a class of socioeconomic factors that affect the urban heat island. River valley type cities, with large urban height difference, occluded topography and almost closed urban basins, have a great influence on the thermal environment due to their special topographic and meteorological conditions, and two major factors, temperature and rainfall, are selected as climatic factors affecting the urban heat island. After determining the weights of the above influencing factors through the entropy value method, they are superimposed to get the integrated resistance surface of the heat and cold island.

Table 1. Indicators of factors affecting the urban thermal environment

Primary Indicator	Secondary Indicator	Assignment		Weights		Direction	
		Thermal resistance	Cold resistance	Thermal resistance	Cold resistance	Thermal resistance	Cold resistance
Type of land use	Cropland	52	157	0.51	0.13	+	+
	Forest	1	2				
	Grassland	76	1000				
	Water	1000	26				
	Impervious	1	559				
	Barren	106	260				
climactic	Temperatures			0.16	0.33	+	-
	Rainfall			0.16	0.33	+	+
economics	Population			0.07	0.13	-	-
	Night Lights			0.1	0.19	-	-

The circuit theory model [9] treats the surface as an electrically conductive surface, and assigns a lower resistance to surface areas that promote surface heat flow, and a high resistance to areas that impede surface heat flow [10]. In this study, spatial visualization of circuit theory is achieved by using Circuitscape software. As show in table 2.

Table 2. Circuit Theory Elements Explained

Elements of circuit theory	Elements of the urban thermal environment	sense
Voltage	heat source	Patches with high hot field ratings attract random wandering probability
Resistance	thermal resistance	Difficulty of passing through the area, the larger the value, the more difficult it is to pass through the area
Current	Convergence Path	Possibility of random wandering between boards

3 Results and Analysis

3.1 Heat Island Network Construction in Urban Areas

3.1.1 Heat Island Source Identification and Resistance Surface Construction

In the scope of the study area, the sub-high-temperature area was taken as the foreground and the rest as the background, and the core area was identified using the MSPA model, and through the size of the core area, 436 core patches with an area larger than 1 ha were selected as the alternative heat island source sites, and 44 heat island source sites were screened out, as shown in Figure. 2(a), with a total area of 41.12km^2, and the land use type was dominated by construction land and bare land.

Based on the results of the correlation analysis between the landscape pattern index and the temperature of the land cover type, AREA_MN, FRAC_MN, PLADJ, and AI were selected as the influence factors of the landscape characteristic resistance to heat island diffusion, and the weights of the landscape characteristic resistance and the resistance to land cover were calculated as 0.24 and 0.75, respectively, to get the cost resistance to heat island diffusion of each land type. Through the entropy value method superimposed on other influencing factors, the thermal environment impact shadow index table is obtained, as shown in Table 1, so as to obtain the total resistance surface, as shown in Figure.2(b).

3.1.2 Construction of Thermal Environment Network

A total of 72 heat island corridors with a total length of 131.6m were identified in the core area of the central city, which were distributed in a network shape, as shown in Figure 2(c). The connectivity between sources can be reflected by the ratio of Cost-Weighted Distances (CWD) to Least Cost Path Length (LCPL), the larger the ratio, the greater the relative resistance of the path, i.e., the lower the connectivity between the two sources. By dividing the connectivity of the corridors into 5 levels through the natural breakpoint method, the corridors of level 1 and 2 are less and distributed in the heat island concentration area, which can prioritize the measures to interrupt the connection and reduce the adhesion of the heat island source places. Seeing the heat island concentration area in the center of Lanzhou city, the Yellow River greatly hinders the connectivity of the urban heat island, and the connectivity of the corridor across the Yellow River is generally low. Corridors below 1km are concentrated in Anning and Xigu districts, totaling 37, accounting for half of the total. In Qilihe and Chengguan districts corridors are greater than 1km in length, most of which cross the Yellow River, connecting fragmented and isolated source sites.

3.1.3 Heat Island Pinchpoint Identification

Pinchpoint areas were identified using the Pinchpoint module in pairwise mode, which consists of selecting two perches as a pair at a time, grounding one and inputting 1A current to the other, and calculating the current between them on the resistance surface. Thus, the final current map is formed by superimposing the current operations between all pairs of perches. The current maps were divided into five classes using the natural breakpoint method to classify the results, and the highest class, i.e., the area of high current values, was used as the first class pinch point for this study area, and the next highest class was the second class pinch point, based on which the pinch point area could be determined as the bottleneck site to maintain the regional connectivity within the study area. From Figure. 2(d), it can be concluded that there are 35 primary pinch points with an area of 4.14 ha and 70 secondary pinch points with an area of 42.12 ha, and most of the primary pinch points are located at the beginning of the source area and completely overlap with the corridor. Secondary pinch points were more widely distributed, mainly along corridors longer than one kilometer, with two to five pinch points. Only 25 corridors do not have pinch points on them, proving that most corridors can be used to accurately implement blocking measures to reduce heat island connectivity by removing pinch points.

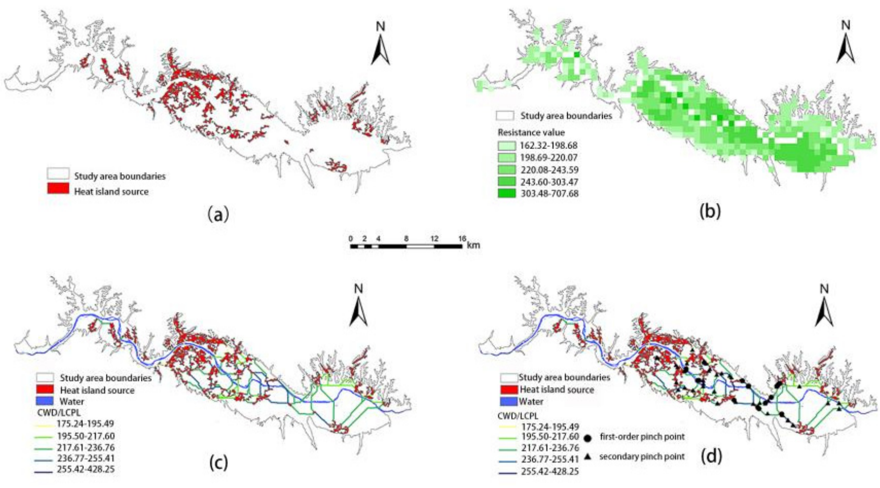

Fig. 2. Thermal environment network of Lanzhou main urban area

3.2 Cold Island Network Construction in Urban Areas

3.2.1 Cold Island Source Identification and Resistance Surface Construction

At the scale of the central city, MSPA analysis shows that the core type occupies a major proportion of the area of cold island patches. From them, core type patches with an area larger than 1 hectare were selected as alternative patches for cold island source sites, totaling 212. According to the analysis results, the wetland along the Yellow River and the urban park green space type patches have very strong connectivity, compared with the other types of land patches, which have weak connectivity, are numerous and scattered, and contribute less to heat dissipation. Finally, 48 patches were screened out as cold island source sites with a total area of 15.829 km2 , as shown in Figure. 3(a).

Based on the results of the temperature correlation analysis between the landscape pattern index and the surface cover type, CA, PLAND, NA, PD, and LSI were selected as the landscape characteristic resistance influencing factors for cold island spreading. By calculating the weights of these factors, the weight of landscape characteristic resistance was 0.28, and the weight of surface cover resistance was 0.71. These weights were applied to each site type, and the cost resistance of cold island diffusion for each site type was expressed by the values from 1 to 1001.Use the entropy value method to determine the weights of other influencing factors, as shown in Table 1, and superimpose them to obtain the integrated resistance surface of the cold island, as shown in Figure. 3(b).

3.2.2 Spatial Distribution of Cold Island Corridors and Networks

A total of 99 corridors with a length of 167.2 km were identified within the central city, and the cold island corridors were widely distributed, with at least one corridor connecting the sources without duplication except for two isolated sources, as in Figure. 3(c). By calculating the CWD/LCPL, it is found that the areas with better cold corridor connectivity are distributed in the Yellow River channel as well as the Yantan area. On both sides of the Yellow River, the source of cold islands is densely distributed, and the land use type is water body, the resistance value is small, and the connectivity of the corridor is strong; although most of the surface cover type in Yantan Area is construction land, the Yellow River faces the east, west and north, and the conditions of rainfall and temperature are excellent, and at the same time, there is no heat island appearing in the area, and the resistance value is small, so the corridor connectivity is excellent.

3.2.3 Spatial Distribution of Obstacle Points in Cold Island Network

Comparing the results of obstacle point identification under different search radii, 120m is the best. Using the natural breakpoint method to divide the results into 5 levels, the highest level area as the obstacle area, and calculate the size of the area of the obstacle area, transformed into the corresponding first-level obstacle points for expression, the results are shown in Figure 3 (d), of which 116 first-level obstacle points, with an area of 1,546.83 hectares, first-level obstacle points of the subsurface is mainly construction land and arable land, most of them are overlapped with corridors with a length of more than 1km, there are 21 locations with an area of more than 10 ha, which are the main obstacle points and difficult to remove.

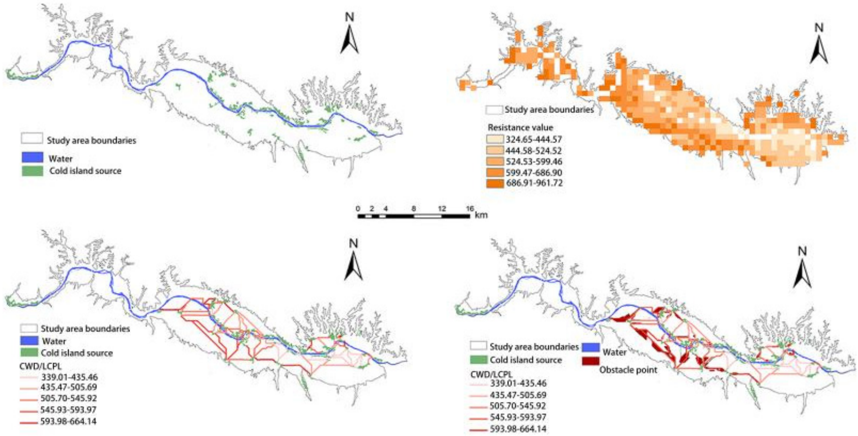

Fig. 3. Cold environment network in the main city of Lanzhou

4 Conclusion and Prospect

In this study, based on the landscape pattern index, MSPA and circuit theory, we identified the hot islands, cold islands, hot corridors, cold corridors, as well as pinch points and obstacle points in the main city of Lanzhou, and constructed a network pattern of the thermal environment in Lanzhou. The results stated: The heat islands in Lanzhou city are concentrated in parts of Xigu and Anning districts, and scattered in other areas, with a total area of 4112.29 hectares. There are 72 hot corridors, 99 cold corridors, and the cold islands are mainly distributed in the riverfront area and part of the city park, with a total area of 1582.9 ha.

The following optimization strategies are proposed according to the simulated status quo of the thermal environment network in the central city of Lanzhou, the fourth edition of the Lanzhou City Plan, and the Lanzhou City Sponge City Special Plan (2021-2035):

(1) Xigu District, increase the source of green islands to enhance the connectivity of cooling corridors while reducing the connectivity of thermal corridors. Prevent connecting with the heat island of Shajingyi Street in Anning Area to form a larger range of heat source areas. Reduce the adhesion of the heat island in the small-scale space by inserting green spaces such as shelter belts and pocket parks between the construction sites to solve the small obstacle points, while gradually reducing the large obstacle points in the regional scope to increase the connectivity of the cooling corridor. Increase the greening effect of three green parks in the regional scope to form green groups and increase the source of cold island.

(2) The distribution of cold island source sites in Anning and Honggu Districts is concentrated, and the connectivity of thermal corridors is low, focusing on the protection of existing cold island patches. There are pinch points at the beginning of the thermal corridor, and the study of its subsurface reveals that most of the pinch points are located on railroads and highways, so the greening of roads can be strengthened to accurately block the connectivity of the thermal corridor.

(3) In Qilihe District and Chengguan District, the heat islands are scattered and the thermal environment is relatively good, so we can clean up the heat source directly and connect the cold island source to form a large cooling source to create a suitable living environment.

The combination of the two methods can accurately locate the corridors and key points of cooling, and combine the current situation of the heat island effect with urban climate adaptation planning, but there are still some problems that remain to be solved, such as mainly exploring the pattern of the urban thermal environment on a two-dimensional level, and not considering the influence of three-dimensional factors such as building heights, wind direction, wind speed, and so on on the diffusion of heat, the future research should build a more complete resistance surface, and utilize the dynamic, multidimensional approach to strengthen the in-depth analysis of environmental elements.

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