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Supply-demand Relationship of Thermal Environment Regulating Service in Xi'an from the Perspective of Functional Zones

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Abstract: In this paper, the supply of thermal environment regulation service is depicted by the InVEST urban cooling model, the demand for thermal environment regulation service is depicted by the risk assessment framework, and the relationship between supply and demand and quantity is depicted by supply-demand difference model, to explore the difference between supply and demand of thermal environment regulation service in Xi'an city from the perspective of functional areas. The main conclusions are as follows. The overall supply of thermal environment regulation services in Xi'an City is poor, showing a spatial pattern of high external and low internal, and the problem of unbalanced distribution is more prominent. The supply of water areas, agricultural areas, and park green space is strong, while the supply of commercial areas, residential areas, and industrial areas is weak. The demand for thermal environment regulation services in Xi'an is low on the whole, showing a spatial pattern of low outside and high inside, and the problem of unbalanced distribution is also prominent. The demand for commercial areas, public service areas, and urban villages is strong, while the demand for water areas, agricultural areas, and park green space is weak. Nearly half of the areas in Xi'an are in a state of oversupply or supply deficit, and the problem of quantity imbalance is quite serious, showing the pattern of external surplus and internal deficit in space. Residential areas, commercial areas, industrial areas, urban villages, and traffic stations are mainly in negative equilibrium, public service areas are mainly in positive and negative equilibrium, and parks, green areas, agricultural areas, water areas, and open spaces are mainly in positive surplus.

Keywords: Functional zoning; Green space; Cooling effect; Supply and demand matching; Xi'an City

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1. Introduction

Green space is an important material space carrier for regulating the urban thermal environment. Studies have confirmed that green space can form an "urban cold island" through transpiration, shading, and cold air advection, which can effectively reduce the ambient temperature in a certain range [1]. Furthermore, the thermal environment regulating service (TERS) of the green space belongs to the ecological function which does not require water and electricity consumption. Once completed, they can play a stable and continuous cooling effect [2]. With the increasing severity of the heat island problem and the increasing attention paid to the quality of the human settlement environment, the thermal environment regulation service of urban green space has received increasing attention. The cooling effect of green space belongs to the type of climate regulation service in the ecosystem service function, and its effective play is not only affected by its biophysical properties but also closely related to the needs of residents. Hence, identifying the supply-demand relationship of green space thermal environment regulation services has become a key breakthrough direction in urban cooling research.

At present, the supply and demand of urban thermal environment regulation services have developed in the academic field. The supply of thermal environment regulation services can be understood as the cooling effect provided by urban green space, which is mainly evaluated by calculating the temperature difference between green space and surrounding area or cooling distance by buffer zone method [3–6]. The demand for thermal environment regulation services can be understood as the expectation or preference of urban residents for the cooling effect of green space. Considering that the residents are very diverse, and the preferences or expectations of different subjects are very different, it is difficult to quantify the demand for thermal environment regulation services, and direct research results are also very few. In recent years, some scholars have discussed the impact of the thermal environment on human society from the perspective of risk or vulnerability based on the frameworks of "risk — exposure — vulnerability" and "exposure — sensitivity — adaptability", etc., which can reflect residents' demand for urban thermal environment regulation services from one side [7–10]. Despite this, few studies link the supply and demand of urban thermal environment regulation services to explore the matching relationship between the two.

Based on the above research, this paper describes the supply of thermal environment regulation services through the InVEST urban cooling model, describes the demand for thermal environment regulation services through the thermal environment risk assessment framework, and describes the relationship between supply and demand and quantity through the supply-demand difference model. This study explores the difference between the supply and demand of thermal environment regulation services in Xi'an from the perspective of the urban functional zone (UFZ).

2. Study design

2.1. Study area and data

Xi'an, located in northwest China, is the capital of Shaanxi Province, the core city of the Guanzhong City cluster, and a national-level central city. It is also an important scientific research, education, and industrial base in China. As a typical northern megacity and hot city in summer, Xi'an has multiple urban functions. In recent years, the urban thermal environment has become increasingly harsh, and a large number of residents are exposed to high-temperature environments. Xi'an is a typical case for discussing the differences between the supply and demand of thermal environment regulation services in different functional areas. In this paper, the research scope is limited to the main urban area of Xi'an, involving 52 street offices in 7 municipal districts with a total area of 791.82 km^2 (**Figure 1**).

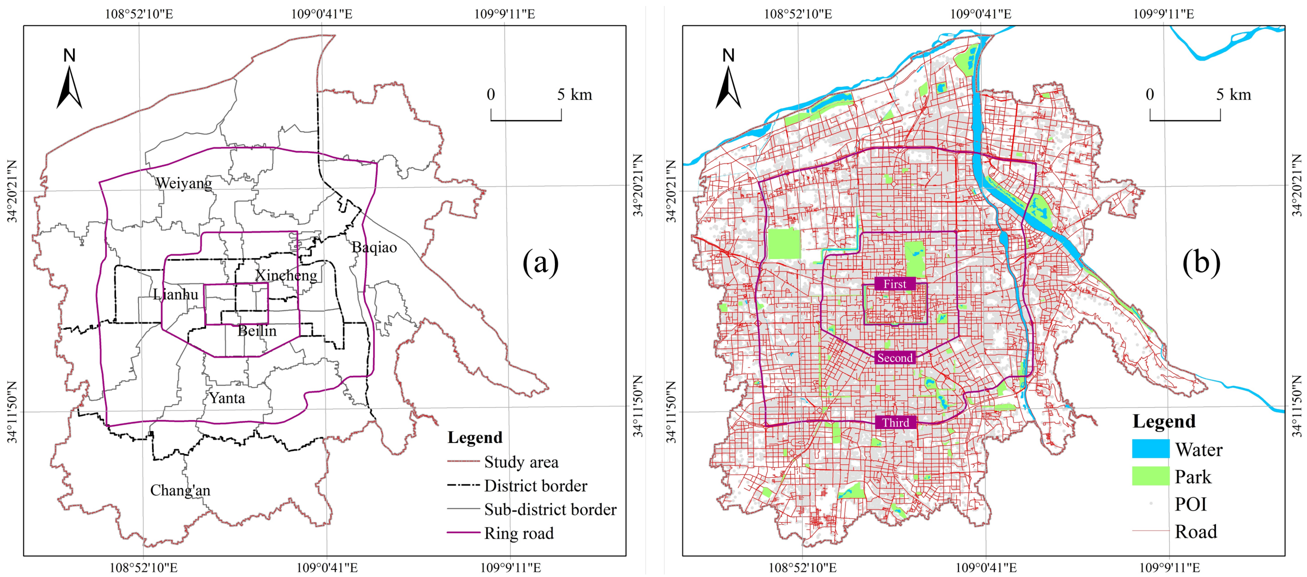

Figure 1. Study area. (a) main urban area; (b) built elements

In this paper, remote sensing images, built environments, and socio-economic data are used. The remote sensing image data are mainly Landsat-8 image and potential evapotranspiration data, the built environment data are mainly POI, AOI, park green space boundary, subway station, and road network, and the socio-economic data are mainly mobile phone signaling and housing price. These data sources are from the United States Geological Survey (USGS), Amap, Unicom Smart Footprint Company, and Fangtian.com. The study period was limited to 2020, with the current year's data given priority, and in the absence of data, data from adjacent years were used as substitutes.

2.2. Study methods

2.2.1. Supply model

This paper uses the urban cooling model built in InVEST 3.13.0 to evaluate the supply of urban thermal environment regulation services. The basic principle of the InVEST urban cooling model is that vegetation can increase cooling by providing shade, evapotranspiration, and changing thermal characteristics, thereby reducing urban heat islands. The working mode is to use land use, evapotranspiration, and other data, and combine the biophysical parameters of vegetation shade, surface evapotranspiration, and surface albedo of different land use types. The raster scale heat mitigation index (HMI) is calculated from the distance between different grids and cold islands (such as parks or large green Spaces) [11].

2.2.2. Demand model

This paper evaluates the demand for thermal environment adjustment services from hazard, exposure, and vulnerability dimensions (**Table 1**). Hazard refers to the high-temperature disaster faced by urban residents, which is reflected by the urban thermal environment. Exposure refers to the size of the population exposed to high temperatures in the city, reflected by the number of population. Vulnerability refers to the degree of vulnerability of urban residents in the face of high temperatures, which is further subdivided into sensitivity and adaptability. Sensitivity is reflected by residents' individual attributes, and adaptability is reflected by residents' ability to access resources. Among them, risk, exposure, and sensitivity have a positive promoting effect on demand, while adaptability has a negative counteracting effect [10].

Table 1. Demand indicators of urban thermal environment regulating service

Types	Indicators	Uses	Directions
Hazard	Surface temperature (C)	Used to reflect the intensity of thermal environmental stress	+
Exposure	Population density (people/km^2)	Used to reflect total population size	+
	Teen population density (people/km^2)	Used to reflect the size of the population aged 14 years and under	+
	Elderly population density (people/km^2)	Used to reflect the size of the population aged 65 years and older	+
Vulnerability	Housing price (yuan/m^2)	Used to reflect income differences among residents	-
	Number of medical facilities (per unit)	Indicates the availability of medical resources	-
	Number of cooling facilities (units)	Used to reflect the ability to obtain cooling resources	-

Note: "+" means the higher the value, the higher the demand, and "-" means the higher the value, the lower the demand.

2.2.3. Supply-demand model

This paper uses the range normalization method to normalize the supply index and demand index calculated above and then introduces the supply-demand difference of ecosystem services to calculate the quantity difference, to reflect the supply-demand quantity relationship of urban thermal environment regulation services [12–13]. The value of the difference between supply and demand is −1-1, and a value greater than 0 indicates that supply is greater than demand and is in a surplus state; Less than 0 means supply is less than demand and is in deficit. A value of zero means supply equals demand and is in balance. Based on obtaining the difference between supply and demand, taking the mean value of the positive and negative difference between supply and demand and 0 as the threshold value, the quantity relationship between supply and demand is further divided into four types: positive surplus, positive equilibrium, negative equilibrium, and negative deficit.

3. Results

3.1. Supply assessment result of TERS

The supply index of the block-scale thermal environment regulation service was obtained by the InVEST model. The natural breakpoint method was divided into five levels, and the area proportion of the supply index in different functional zones was calculated (**Figure 2**). In Xi'an, the higher-grade (high and second-high) supply areas accounted for less, and the lower-grade (low and second-low) supply areas accounted for more, and the overall supply of thermal environment regulation services was poor. In terms of space, it shows the pattern of high outside and low inside, and the problem of unbalanced supply distribution is more prominent. In the water area, agricultural area, and park green space of Xi'an city, the supply of thermal environment regulation service is strong, and the proportion of high and low high supply areas is the largest. In the commercial area, residential area, and industrial area, the supply of thermal environment regulation service is weak, and the low supply area accounts for the largest proportion.

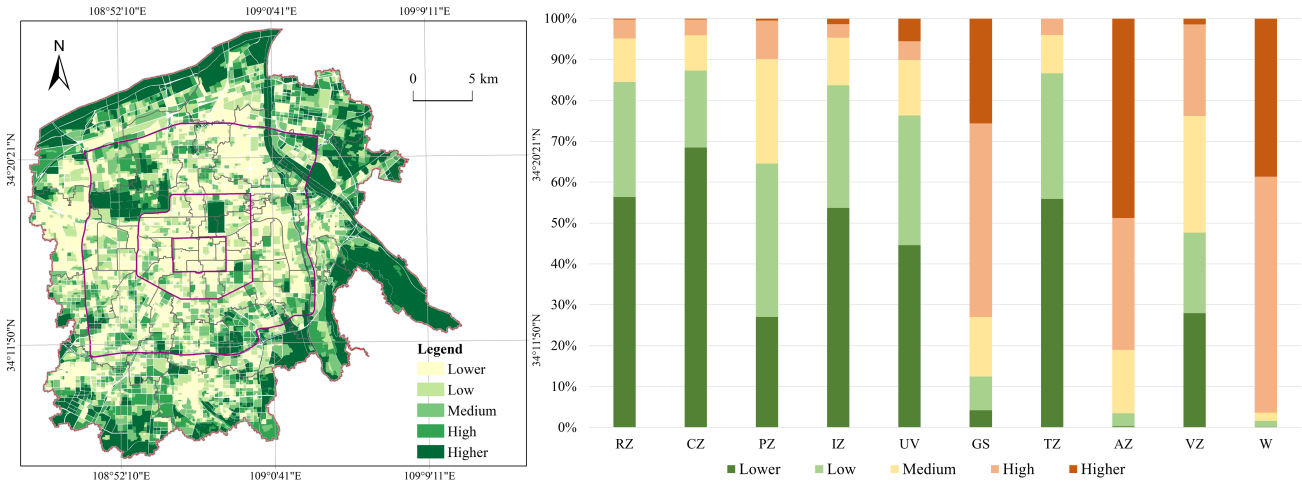

Figure 2. Spatial variation and area proportion across UFZs of supply for TERS in Xi'an. RZ: residential zone, CZ: commercial zone, PZ: public service zone, IZ: industrial zone, UV: urban village, GS: green space, TZ: traffic service zone, AZ: agricultural zone, VZ: vacant zone, W: water

3.2. Demand assessment result of TERS

The demand index of block-scale thermal environment regulation services was obtained through the risk assessment framework. The natural breakpoint method was divided into five levels, and the area proportion of the demand index in different functional areas was calculated (**Figure 3**). In Xi'an, high-grade (high and second-high) demand areas accounted for less, and lower-grade (low and second-low) demand areas accounted for more, and the overall demand for thermal environment regulation services was low. In terms of space, it shows the pattern of low outside and high inside, and the problem of unbalanced demand distribution is more prominent. In the commercial area, public service area, and urban village of Xi'an, the demand for thermal environment regulation services is strong, and the medium and low demand areas account for the largest proportion. In water area, agricultural area and park green space, the demand of thermal environment regulation service is weak, and the low demand area accounts for the largest proportion.

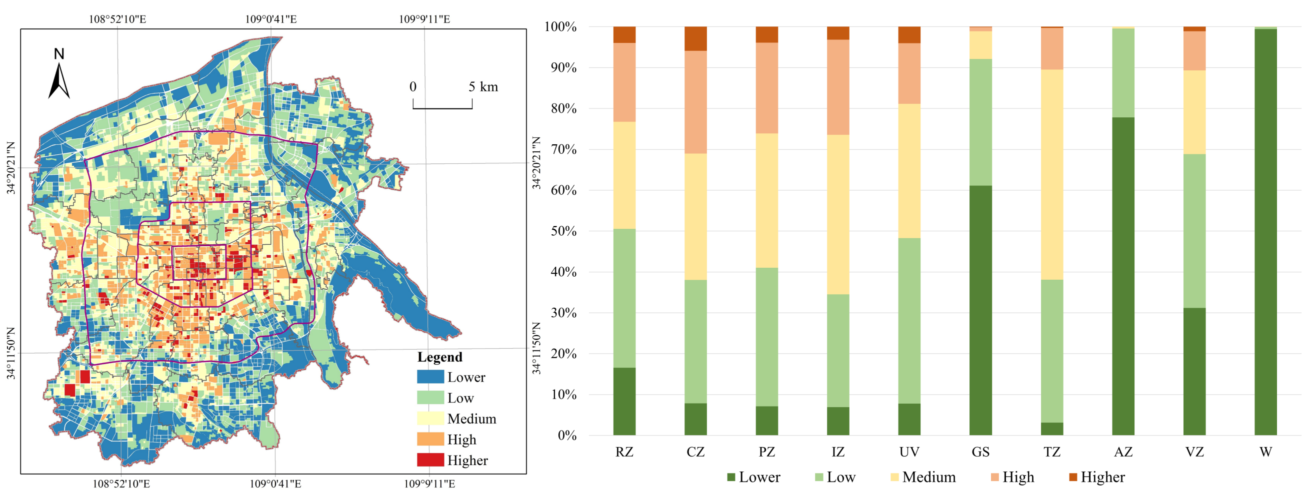

Figure 3. Spatial variation and area proportion across UFZs of demand for TERS in Xi'an

3.3. S-D relationship of TERS

The supply-demand and quantity relationship of the block-scale thermal environment regulation service was obtained through the supply-demand difference model, and the area proportion of the supply-demand and quantity relationship in different functional zones was calculated (**Figure 4**). Nearly half of the regions in the quantity relationship of thermal environment regulation services in Xi'an are in a state of oversupply or supply deficit, and the problem of quantity imbalance is quite serious. In terms of space, affected by the unbalanced distribution of supply and demand, it shows the pattern of external surplus and internal deficit, and the problem of spatial imbalance of the supply and demand relationship is also relatively serious. In residential areas, commercial areas, industrial areas, urban villages, and traffic stations of Xi'an City, the supply of thermal environment regulation services is generally less than the demand, which is dominated by negative equilibrium. In parks, green areas, agricultural areas, water areas, and open spaces, the supply of thermal environment regulation services is generally greater than the demand, and the positive surplus is mainly. In public service areas, the supply and demand of thermal environment regulation services are relatively flat, mainly in positive and negative balance.

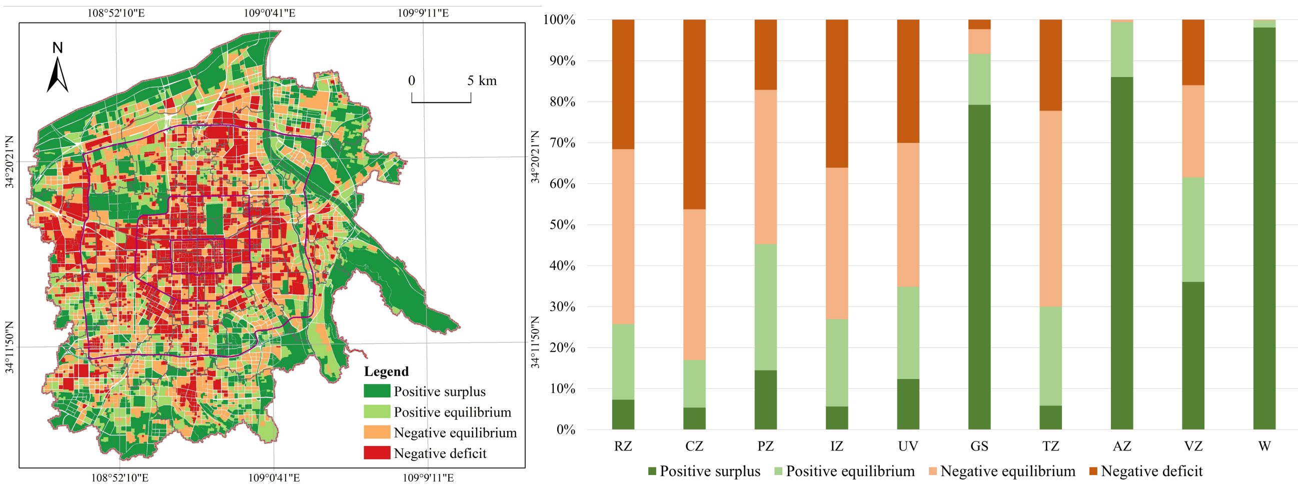

Figure 4. Spatial variation and area proportion across UFZs of supply-demand relationship for TERS in Xi'an

4. Conclusions

This paper discusses the difference between the supply and demand of thermal environment regulation services in Xi'an from the perspective of functional areas. The conclusions are as follows. The overall supply of thermal environment regulation services in Xi'an is poor, showing a spatial pattern of high external and low internal, and the problem of unbalanced supply distribution is prominent. In the water area, agricultural area, and park green space, the supply of thermal environment regulation service is strong, and the proportion of high and low supply areas is the largest. In commercial, residential, and industrial areas, the supply of thermal environment regulation services is weak, and the low supply area accounts for the largest proportion. The overall demand for thermal environment regulation services in Xi'an is low, showing a spatial pattern of low outside and high inside, and the problem of unbalanced demand distribution is prominent. In commercial areas, public service areas, and urban villages, the demand for thermal environment regulation services is strong, and the medium and sub-low-demand areas account for the largest proportion. In water areas, agricultural areas, and park green space, the demand for thermal environment regulation services is weak, and the low-demand area accounts for the largest proportion. Nearly half of the thermal environment regulation services in Xi'an are in a state of oversupply or supply deficit, which is a serious problem of quantity imbalance and space imbalance between supply and demand. Residential areas, commercial areas, industrial areas, urban villages, and traffic stations are mainly in negative equilibrium, public service areas are mainly in positive and negative equilibrium, and parks and green spaces, agricultural areas, water areas, and open spaces are mainly in positive surplus.

Disclosure statement

The author declares no conflict of interest.

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