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Study on the Relationship between Vegetation Cover and Land Surface Temperature Based on Remote Sensing - A Case Study of Changzhou, China

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Abstract:

With the acceleration of urbanization, the environmental problems caused by the urban heat island effect are becoming increasingly noticeable. Investigating the connection between land surface temperature and vegetation cover is crucial to reducing the urban heat island effect. This paper uses Landsat data from 2021 to 2024 in the main urban region of Changzhou City, Jiangsu Province, China, as the study area to evaluate the geographical and temporal evolution of vegetation cover and land surface temperature and their coupling connection. The results show that the annual average value of vegetation cover in the main urban region of Changzhou City from 2021 to 2024 is 0.6025, with an overall upward trend, and the spatial pattern is characterized by a 'ring-like' distribution with a high level in the periphery of the city and a low level in the heart of the city. In addition, the land surface temperature showed a decreasing trend in the same period, and the middle of Wujin District and the outskirts of Xinbei District were the areas with the highest temperatures, while the sub-medium-temperature region appeared in the arable land area with good vegetation cover and around the water body. Lastly, in Changzhou City's central urban region, there is a highly substantial negative correlation between vegetation cover and land surface temperature; for every 10% increase in plant cover, the land surface temperature drops by 0.20 to 0.49℃.

Keywords: vegetation cover; land surface temperature; Changzhou City.

1. Introduction

The urban heat island effect has grown to be a significant environmental issue for contemporary cities as a result of the acceleration of global climate change. The geographical distribution of land surface temperature (LST) is mainly controlled by surface thermal energy, which is one of the key indicators to characterize the changes of the urban thermal environment. In addition to being a key factor in regulating and controlling land surface temperature, natural vegetation can be used to quantitatively describe changes in the regional ecological environment, understand the dynamic change pattern and characteristics of regional vegetation cover, mitigate the heat island effect, and enhance the quality of the urban environment [1].

In studies of the relationship between vegetation and land surface temperature, the state of vegetation is often expressed as the Normalized Difference Vegetation Index (NDVI), which is an important indicator for the study of land surface temperature [2]. Goward S. N. et al. concluded that LST-NDVI correlation is an important component of urban environmental monitoring and that throughout the long-time-scale study, the LST-NDVI relationship was negative at low latitudes [3]. BENOUMELDJADJ M et al. used Landsat 8 and Landsat 9 satellite images to derive a negative correlation between NDVI and LST in Constantine [4]. Zhanhai Jia et al. concluded that there is a negative correlation between NDVI and land surface temperature in summer in Beijing [5].

Accordingly, an increase in vegetation cover can be considered an effective means of mitigating the urban heat island effect. However, this relationship is not a single linear one but is influenced by many factors, including climatic conditions, geographic environment, and land use. Therefore, an in-depth exploration of the variability between vegetation cover and land surface temperature in different types of urban areas is important for the formulation of effective urban greening and environmental management policies.

Changzhou, China, has seen a sharp rise in urbanization in recent years as it has relied on new energy industries to support sustainable social and economic development. However, the heat island effect brought by rapid urban expansion is becoming more and more prominent, and ecological environmental protection needs to be emphasized urgently. As a result, this study uses Changzhou City as its study region and uses Landsat 8-9 C2 L2SP remote sensing data from the summer of 2021 to 2024 to extract the land surface temperature and compute the vegetation index. In order to give Changzhou City a theoretical foundation and scientific basis for urban planning, ecological construction, and environmental protection, the relationship between vegetation cover and land surface temperature is examined, as well as the potential efficacy of vegetation in reducing the urban heat island effect.

2. Research Data and Methods

2.1 Overview of the Research Area

Changzhou City is located at latitude 31°09′~32°04′N, longitude 119°08′~120°12′E, in the southern portion of Jiangsu Province, in the hinterland of the Yangtze River Delta, and on the northwestern shore of Lake Taihu. Fig. 1 shows the administrative division map of Changzhou City, revealing that the main urban region includes Xinbei District, Zhonglou District, Tianning District, and Wujin District. Changzhou City is located in the lower Yangtze River plains, which include high sandy plains, hills, and lake dikes. The plain area accounts for 38.22%; the hilly and mountainous area accounts for 24.86%; and the water area of the Yangtze River and its lakes and dikes accounts for 5.83% (with the addition of reservoirs, ponds, inland rivers, etc., the total water area accounts for about 16%). The district is located in the North Asian hot north belt to the north of the temperature south belt transition climate region, with a significant monsoon influence. It has four distinct seasons, rain and heat synchronization, adequate light, an average annual temperature of 15.6°C, and an average annual precipitation of 1086.0 mm. The vegetation cover is high, and the main vegetation types include forests, grasslands, and wetlands, with a good ecological environment.

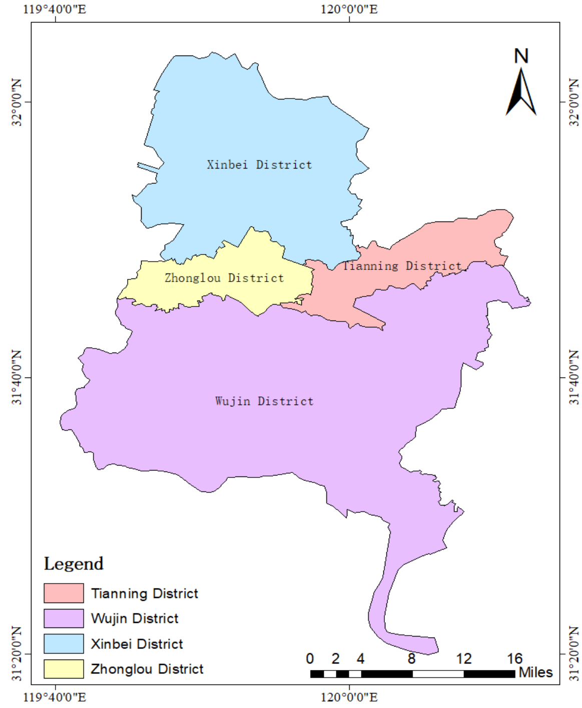

Fig. 1 the administrative division map of Changzhou City

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2.2 Data Sources and Preprocessing

The data utilized in this investigation consist of Landsat 8–9 Collection 2 Level 2 Science Products (C2 L2SP) remote sensing imagery, obtained from the United States Geological Survey (USGS). The satellite overpass dates are September 27, 2021; October 16, 2022; October 9, 2023; and October 29, 2024, respectively. This level of data has undergone systematic radiometric calibration, atmospheric correction, and geometric rectification, ensuring high geometric and radiometric accuracy. The satellite is equipped with the Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS), which provide multispectral and thermal infrared band data, respectively. After clipping the imagery to the study area, the relevant bands were selected for vegetation cover estimation and land surface temperature retrieval. The imagery has a spatial resolution of 30 meters and a temporal resolution of 16 days, offering advantages such as broad spatial coverage, long time span, and good data continuity, making it suitable for multi-temporal comparisons and spatiotemporal analyses at the regional scale.

2.3 Research Methods

2.3.1 Normalized Difference Vegetation Index

The Normalized Difference Vegetation Index (NDVI) can reflect the growth of regional vegetation as well as the density of vegetation distribution, which is calculated using the following formula:

$$NDVI = \frac{Bn - Br}{Bn + Br}. \quad (1)$$

where *Bn* denotes the near-infrared band, and *Br* denotes the red band.

The NDVI calculation range is from -1 to 1, where negative values mainly represent water bodies, snow, or thick cloud-covered areas. These pixels exhibit strong reflective characteristics in the visible light band. Zero values correspond to bare soil or rock surfaces without vegetation cover, where the reflectance in the red band is roughly equal to that in the near-infrared band. Positive values indicate the presence of vegetation cover, and an increase in value reflects an improvement in vegetation coverage and canopy density.

2.3.2 Fractional Vegetation Cover

Fractional Vegetation Cover (FVC) refers to the percentage of the vertical projection area of the vegetation canopy relative to the total area of the statistical region. It serves as an important quantitative indicator for expressing the extent of surface vegetation communities and is also a key parameter for indicating changes in the ecological environment [6]. The FVC is calculated using the following formula:

$$FVC = \frac{NDVI - NDVI_{soil}}{NDVI_{veg} - NDVI_{soil}}. \quad (2)$$

Where *NDVI* represents the normalized difference vegetation index, barren or sparsely vegetated areas' NDVI value is represented by $NDVI_{soil}$, whereas areas with complete vegetation coverage are represented by $NDVI_{veg}$.

In this study, the 5%–95% confidence interval of annual NDVI images was used for statistical analysis. The maximum value within this interval was taken as $NDVI_{veg}$, and the minimum value as $NDVI_{soil}$. Based on the *Standards for Classification and Gradation of Soil Erosion* [7], the vegetation cover in Changzhou's main urban region was classified into five levels (Table 1).

Table 1. Vegetation Cover Classification

Level	Vegetation cover class	FVC
I	Low vegetation cover	0-0.1
II	Low-medium vegetation cover	0.1-0.3
III	Moderate vegetation cover	0.3-0.5
IV	Medium-high vegetation cover	0.5-0.7
V	High vegetation cover	0.7-1

2.3.3 Land Surface Temperature

The land surface temperature band is the STB10 band of the product in Kelvin, which is contained in the Landsat 8-9 C2 L2SP data. To facilitate the analysis, the units were converted to degrees Celsius using band operations in the ENVI software. This paper classified land surface temperature in the study area into five classes based on μ (mean) and std (standard deviation) [8] (see Table 2).

Table 2. Land Surface Temperature Classification

Temperature Level	Value Range
High-temperature region	LST > μ+std
Sub-high-temperature region	μ+0.5std < LST ≤ μ+std
Medium-temperature region	μ−0.5std ≤ LST ≤ μ+0.5std
Sub-medium-temperature region	μ−std ≤ LST < μ−0.5std
Low-temperature region	LST < μ − std

3. Results and discussion

3.1 Vegetation Cover Analysis

In this study, images of the study area taken on September 27, 2021, October 16, 2022, October 9, 2023, and October 29, 2024, were processed with ENVI software to obtain the vegetation cover in Changzhou City's main urban region. The results were graded using ArcGIS software to provide a graded distribution of vegetation cover in Changzhou City's main urban area from 2021 to 2024 (Fig. 2).

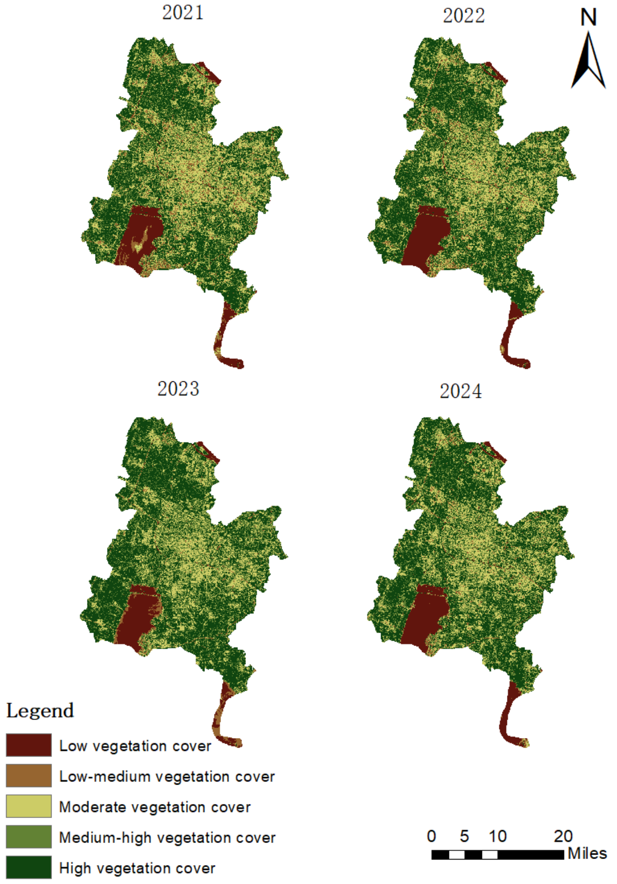

Fig. 2 Vegetation Cover Classification Distribution

From the perspective of spatial distribution, the vegetation cover in the main urban region of Changzhou City shows the distribution characteristics of high in the outskirts of the city and low in the central urban area, and overall the vegetation cover level is in the middle-upper state, showing a good ecological foundation. Multi-period image analysis during the four years shows that the average annual FVC of the region is 0.6025, reflecting that the city still retains green space relatively well in the process of rapid development. The areas with annual average FVC values of medium-high or above are mainly concentrated in Xinbei District, the eastern part of Tianning District, the western part of Zhonglou District, and the western and southern parts of Wujin District. These areas are rich in green space resources and generally have high vegetation cover, constituting an important support for urban green ecological space. After eliminating the area of water bodies, the area with low vegetation cover accounts for a very tiny part of the district's total area and has a scattered and discontinuous geographical distribution. These areas are mostly located near high-density built-up areas or transportation hubs and are limited by the intensity of land development and infrastructure construction, which has a certain inhibiting effect on vegetation growth.

Fig. 3 demonstrates the average value of vegetation cover from 2021 to 2024. Analyzed from the perspective of time series change, the slope of the trend line of FVC change is positive, reflecting the overall growth of vegetation cover and the continuous improvement of ecological quality in this period. In terms of sub-years, the mean value of FVC was 0.58 in 2021, rose to 0.59 in 2022, and further increased to 0.63 in 2023, with a significant increase in the overall trend. Especially from 2022 to 2023, the FVC increased the most, which indicated that the vegetation recovered the fastest in this period, and the greening construction was effective. However, the mean value of FVC decreased slightly to 0.61 in 2024, a slight decline from 2023, reflecting that the urban vegetation cover faces certain pressure in the process of continuous growth.

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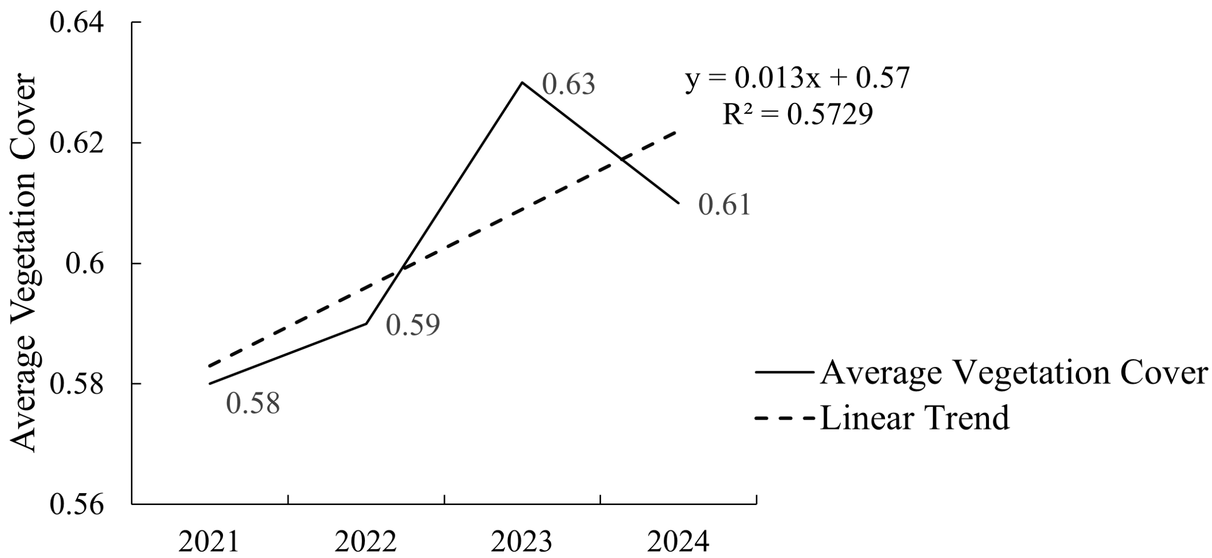

Fig. 3 Average vegetation coverage

3.2 Land Surface Temperature Analysis

A four-year distribution map of the land surface temperature in Changzhou City's main urban area was created by grading the land surface temperature for each of the four years (Fig. 4).

According to the spatial distribution map, the high-temperature region is consistently concentrated in the center of Wujin District and the outskirts of Xinbei District for four years, with a minor amount of dispersed distribution in the Wujin District's periphery. As the main industrial concentration area of Changzhou City, a large number of factories concentrated in the fringe area produce waste heat and pollution emissions in the production process, which will strengthen the local heat island effect. The center of Wujin District, on the other hand, is a densely populated area with high building density and a lack of large areas of green space and open space, leading to heat accumulation that is not easy to emit, which is also an important cause of higher land surface temperatures. On the other hand, the Xinbei District's center and the districts' outskirts, as well as the area around the water body, are primarily located in the sub-medium-temperature region. These zones are mostly cultivated land distribution areas, and the ground cover is dominated by vegetation, which has a strong cooling and buffering effect and helps to inhibit excessive increases in land surface temperatures.

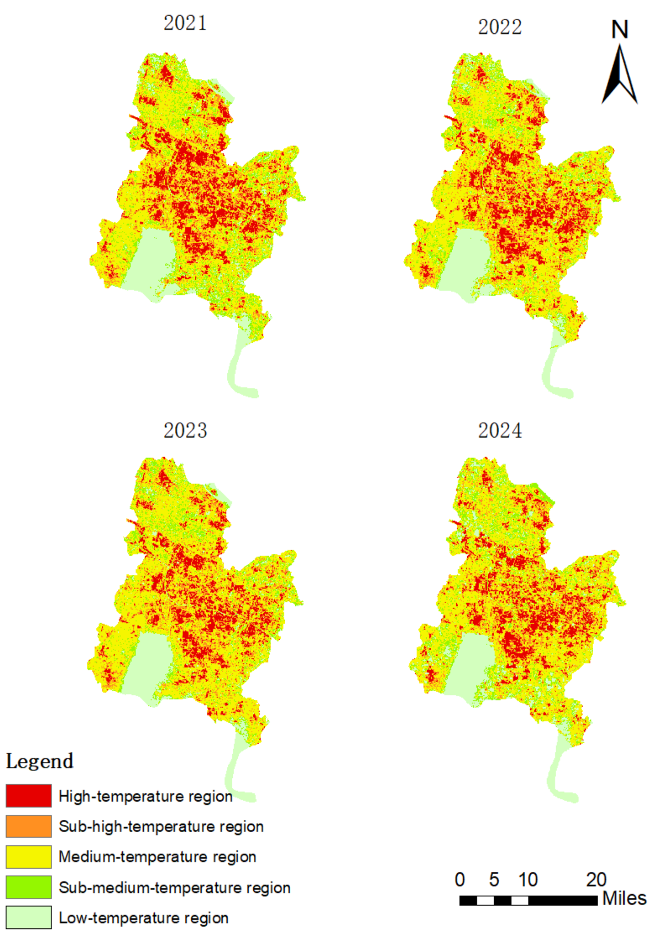

Fig. 4 Land Surface Temperature Classification Distribution

In terms of temporal changes (Fig. 5), the average land surface temperature showed an overall decreasing trend between 2021 and 2024, with the highest average temperature of 37.62°C in 2021, which was much higher than that of other years. The surface temperatures in 2022 and 2024 decreased to 27.73°C and 22.94°C, respectively, with a larger decrease, reflecting the fact that these years may have been affected by vegetation restoration and combined effects of factors such as climate regulation or human intervention. Although the average temperature in 2023 increased slightly (to 30.79°C) compared with the previous year, the moderate vegetation cover in that year was the highest among the four years, indicating that the changes in land surface temperature were not only related to the condition of vegetation but also might have been affected by changes in the distribution of other features on the ground surface in the process of urban construction, such as changes in the area of bare ground, hardened ground, or water bodies. Regression analysis revealed that the land surface temperature change trend fit the linear descent model, and the model's goodness-of-fit R^2 value of 0.74 demonstrated how well it explained the real data.

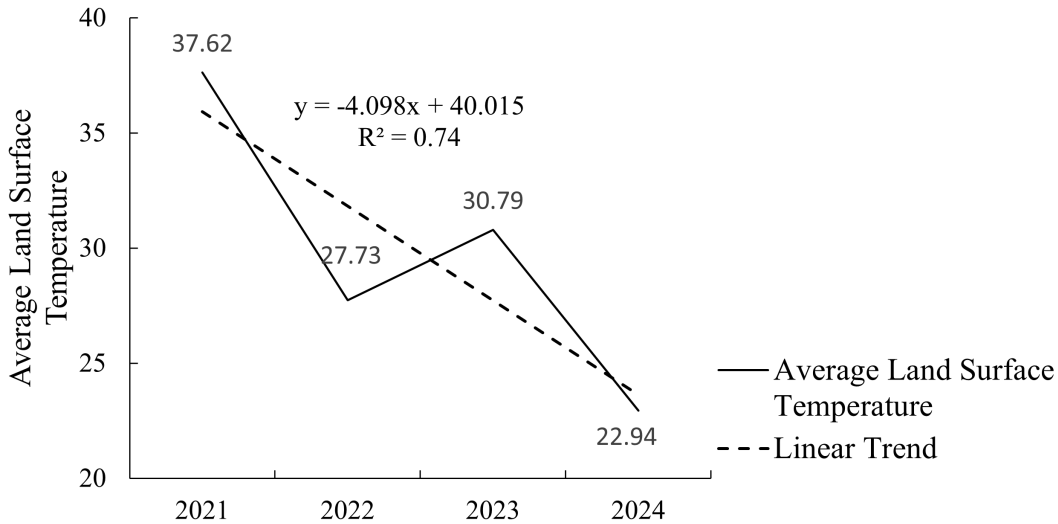

Fig. 5 Average Land Surface Temperature

3.3 LST-NDVI Correlation Analysis

Moderate vegetation cover images and land surface temperature images from 2021 to 2024 were first resampled in ArcMap, and the processed images were subsequently divided into 1800 × 1800 m grids. Finally, the study area was divided into 582 grid cells. The average vegetation cover and land surface temperature of each grid were vectorized and exported for regression analysis through grid turning points.

In this paper, sample points with large deviations from the linear relationship in the preliminary regression results were analyzed, and it was found that some sample points had lower land surface temperature but also lower moderate vegetation cover. These spots were mostly found close to bodies of water, according to a closer look at their geographic locations, which suggests that water bodies may significantly moderate land surface temperature. This is due to the fact that water bodies absorb heat through evaporation, known as the water cooling island effect [9].

Therefore, a linear regression analysis of land surface temperature versus vegetation cover was carried out after the sites with significant deviations were eliminated. Vegetation cover and land surface temperature were negatively correlated, and the slope of the linear regression analysis's findings showed that for every unit increase in vegetation cover, land surface temperature decreased (Fig. 6). The regression equation for 2021–2024 shows that the land surface temperature in Changzhou City's central urban area can drop by 0.20–0.49°C for every 10% increase in plant cover.

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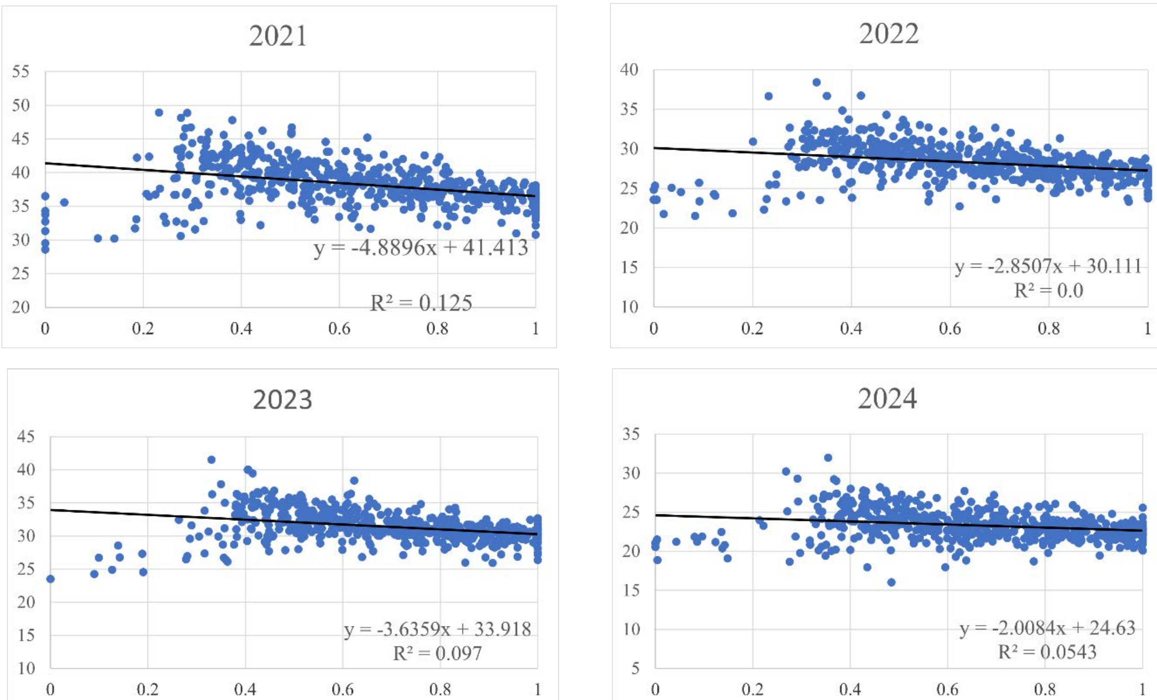

Fig. 6 Linear Regression Between Vegetation Coverage and Land Surface Temperature

3.4 Discussion

This study focuses on the relationship between vegetation coverage and land surface temperature in the main urban region of Changzhou. The findings show a negative correlation between vegetation coverage and land surface temperature during the period from 2021 to 2024. This result is in line with earlier research, including that of Wenhao Wu [10], which indicates that vegetation may help lower land surface temperatures.

From 2021 to 2023, abundant precipitation and suitable temperature in Changzhou provided favorable water and heat conditions for vegetation growth, which further promoted the expansion and quality improvement of the urban green space, and thus the vegetation cover was increasing. However, the average value of FVC slightly decreases to 0.61 in 2024, showing a slight decline compared with 2023 because, on the one hand, the process of urbanization continues to accelerate, and some of the newly built residential areas, transportation facilities, or infrastructure projects may occupy the original green space resources, resulting in the replacement of vegetation with hardened construction land; on the other hand, some of the built green spaces have problems such as inadequate maintenance and plant degradation, which may also cause a localized decline in vegetation cover. Although the overall land surface temperature in Changzhou City showed a decreasing trend from 2021 to 2024, there was a slight rebound in 2023. The reason for this change may be due to some differences in the acquisition time of remote sensing images. Although the selected images in each year are concentrated between September and October, the specific transit dates are not exactly the same, which may lead to seasonal bias in the land surface thermal condition, thus affecting the interannual comparison results of land surface temperature.

With Changzhou City as the primary urban area, this study still has certain shortcomings. The correlation analysis only looked at the impact of vegetation cover on land surface temperature, ignoring the role of other land cover types such as bare land, buildings, and water bodies, as well as anthropogenic factors such as population density and transportation activities. The data selected were from the years 2021-2024, which is a relatively short time series, and the time series of the study should be extended in the future to make the study more convincing.

4. Conclusion

This study uses NDVI to calculate the vegetation cover based on remote sensing image data of Changzhou City's main urban area taken between September and October of 2021–2024. It then systematically analyzes the relationship between the vegetation cover and land surface temperature and changes over the study area's four years, coming to the following conclusions:

(1) Between 2021 and 2024, the vegetation cover in the main urban area of Changzhou City showed an overall

upward trend, and the four-year average vegetation cover was 0.6025, which was at a medium-high level. Among them, the vegetation cover reached the highest value in 2023, indicating that the urban greening condition was relatively good in that year. During the same period, the land surface temperature showed an overall decreasing trend, especially the most significant decrease in 2022 and 2024, but the surface temperature in 2023 showed a slight recovery compared with the previous year.

(2) 'High vegetation cover and low land surface temperature in the periphery, and low vegetation cover and high land surface temperature in the central urban area' are the spatial characteristics of Changzhou's main urban area from 2021 to 2024. Among these, the city center has a large population density, a lot of buildings, and little open space, all of which contribute to heat accumulation and a much greater land surface temperature than the surrounding areas.

(3) Land surface temperature and plant cover are negatively correlated. The surface temperature in Changzhou City's central urban area can drop by 0.20 to 0.49°C for every 10% increase in moderate plant cover. In 2024, the surface temperature is at its lowest, and moderate vegetation cover has the least impact on surface cooling. This suggests that urban construction places a greater emphasis on environmental conservation and lessens the heat island effect.

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