# Study on the Impact of MODIS-derived NDVI and NDBI on Land Surface Temperature

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**Abstract.** With the development and expansion of cities, the increase in built-up area and the drop in vegetation coverage have significant influences on the climatic environment of urban areas. This study processed Moderate Resolution Imaging Spectroradiometer (MODIS) data from four months in 2001 to investigate the Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-Up Index (NDBI), and Land Surface Temperature (LST) in the Chengdu region. This paper explored the correlation between NDVI and LST, as well as the correlation between NDBI and LST. The findings revealed that areas with higher NDBI, indicating a greater extent of urban built-up areas, exhibited higher daytime and nighttime LST, indicating a more pronounced urban heat island effect. Conversely, an increase in vegetation cover was found to lead to a decrease in surface temperature and a certain degree of mitigation of the urban heat island effect. Furthermore, a good linear relationship was observed between NDBI and LST, with a stronger correlation during the daytime compared to the nighttime.

**Keywords:** NDVI, NDBI, LST, MODIS.

## 1. Introduction

Land Surface Temperature (LST) is a crucial factor in understanding surface heat behavior and its impact on the environment. It plays a crucial role in urban planning, climate change assessment, and ecosystem monitoring. Remote sensing technology has become an effective way for monitoring LST at the scale of regions and the globe [1]. In recent years, satellite-derived indices such as the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Built-Up Index (NDBI) have gained significant attention in the field of LST estimation.

NDVI is widely used to assess vegetation abundance and health as it measures the differences in reflectance within the near-infrared (NIR) and red spectrum. On the other hand, NDBI quantifies the presence of built-up areas by comparing the differences in reflectance within the shortwave infrared (SWIR) and NIR spectrum [2]. These two indices provide valuable information about surface characteristics and can be used to estimate LST.

MODIS is a mature satellite sensor that provides high-quality data for various Earth observation applications. MODIS offers a unique combination of spatial, spectral, and temporal resolutions, making it suitable for monitoring large-scale environmental processes. The availability of MODIS-derived NDVI and NDBI products enables researchers to explore the correlation between these indices and LST. Understanding the influence of NDVI and NDBI on LST is crucial. Firstly, vegetation cover has a significant influence on LST as it affects energy balance and surface humidity. Vegetation can provide shade and evapotranspiration, resulting in lower surface temperatures [3]. On the other hand, built-up areas characterized by high NDBI values tend to have higher surface temperatures due to impervious surfaces and reduced vegetation cover. Therefore, the correlation between NDVI, NDBI, and LST can provide insights into the urban heat island effect and the thermal characteristics of various surface types [4].

Furthermore, integrating NDVI with LST and NDBI with LST can improve the accuracy of surface temperature estimation. By incorporating information about surface features such as vegetation and built-up areas into the LST estimation process, spatial heterogeneity and variability of surface temperature can be considered [5-8]. This can lead to more accurate assessments of surface temperature patterns, which are crucial for urban planning, climate change research, and ecosystem management.

This study aims to study the influence of NDVI and NDBI, obtained from MODIS data, on LST. By analyzing the relationship between these indices and LST, this paper aim to gain deeper insights into the thermal behavior of different surface types. Additionally, this paper will explore the potential of integrating NDVI and NDBI with LST to improve the accuracy of ground temperature estimation. The findings of this paper can contribute to a better understanding of the urban heat island effect, the influence of climate change, and the dynamics of ground temperature, ultimately aiding in sustainable land management and environmental planning.

## 2. Study Area and Data Collection Methodology

### 2.1. Study Area

Chengdu is the administrative center of Sichuan Province in China, which is situated in the southwestern region of the country. It is situated in the central part of the Sichuan Basin, bordered by Jiangyou to the east, Yibin to the south, Ya'an to the west, and Mianyang to the north. The topography of Chengdu is predominantly plain, with other areas characterized by mountains. The highest peak in the region is Qingcheng Mountain, reaching an elevation of 2160 meters. Chengdu has a subtropical humid climate, with well-defined seasons. Spring is characterized by warm temperatures and high humidity, summer is known for hot temperatures and frequent rainfall, autumn brings cooler temperatures and drier conditions. And during winter, the weather is typically cold with low temperatures and dry conditions. As one of the biggest cities in southwestern China, Chengdu has a population exceeding 16 million. The city is economically developed and ranks as the fourth-largest city in mainland China.

### 2.2. Instrumentation Description

Moderate Resolution Imaging Spectroradiometer (MODIS) is a widely adopted remote sensing instrument for Earth observation, developed collaboratively by National Aeronautics and Space Administration (NASA) and United States Geological Survey (USGS), jointly created by NASA and USGS, a joint effort between NASA and USGS, a partnership between NASA and USGS, a combined initiative of NASA and USGS. It is mounted on two satellites, Terra and Aqua. MODIS can obtain high-resolution aerial imagery of the Earth's surface, including data from various fields such as land, ocean, and atmosphere. Its data features high resolution, multiple spectral bands, global coverage, and long time series [9-11].

### 2.3. Data Source and Preprocessing

The data employed in this study was sourced from MODIS series data provided by NASA. The NDVI and NDBI were obtained from the MOD09A1 data product, with a spatial resolution of 500m and an 8-day composite. The LST was obtained from the MOD11A2 data product, with a spatial resolution of 1km and an 8-day composite. Four different months, namely January, April, July, and October of the year 2001, were selected to represent different seasonal characteristics. A total of 16 images, one per month, were preprocessed. The MOD09A1 and MOD11A2 data were reprojected using QGIS, and spatial-temporal matching was performed using Python to ensure that the target data had the same resolution for subsequent analysis. The study area was defined as the Chengdu city region, ranging from 102°E to 104°E and from 30°N to 31°N, using QGIS. Finally, NDVI, NDBI, and LST images were obtained using QGIS, and scatter plots and regression equations were generated using MATLAB.

### 2.4. Calculation and Extraction of NDVI

The MOD09A1 data product was used in this study to derive the NDVI, which serves as a reliable indicator of vegetation growth and coverage. The corresponding relationships between the MOD09A1 data bands are shown in the Table 1.

**Table 1.** MOD09A1 data bands

| Band | Wavelength Range (nm) |
|---|---|
| Band 1 | 620 - 670 |
| Band 2 | 841 - 876 |
| Band 3 | 459 - 479 |
| Band 4 | 545 - 565 |
| Band 5 | 1230 - 1250 |
| Band 6 | 1628 - 1652 |
| Band 7 | 2105 - 2155 |

The NDVI was calculated using the equation (1). In equation (1), NIR and RED stand for the reflectance values in the near-infrared and red bands, respectively. Corresponding to the MOD09A1 bands, the NDVI is determined as NDVI = (band2 - band1) / (band2 + band1). And the NDVI values span from negative one to positive one. Negative NDVI values are observed when the land surface is covered by clouds, water, or snow. A value of 0 is obtained when the land surface consists of rocks or bare soil. Positive NDVI values indicate the presence of green vegetation, and the absolute value of the NDVI measurement. is directly proportional to the extent of vegetation coverage. Higher NDVI values indicate greater vegetation coverage.

$$NDVI = (NIR – RED) / (NIR + RED) \quad (1)$$

### 2.5. Computation and Retrieval of NDBI

The normalized difference built-up index (NDBI) was derived from the MOD09A1 data product in the present study. Urban buildings primarily consist of concrete and brick materials, which exhibit increased reflectance in the NIR and SWIR bands, whereas the reflectance in water and grassland areas is reduced. Hence, the NDBI expression is shown in equation (2).

$$NDBI = (SWIR - NIR) / (SWIR + NIR) \quad (2)$$

Here, SWIR represents the reflectance value within the bounds of shortwave infrared band, and NIR represents the reflectance value within the bounds of near-infrared band. For MODIS data, the NDBI equation is given by NDBI = (b6 - b2) / (b6 + b2), where b2 and b6 correspond to the reflectance values of the second band (0.841μm~0.876μm) and the sixth band (1.628μm~1.652μm) of the MODIS data, respectively. It is evident that the NDBI values should fall within the range of greater than -1 and less than 1. Therefore, it can be inferred that NDBI values greater than 0 indicate urban built-up areas, while values less than 0 indicate non-urban built-up areas.

### 2.6. Calculation and Extraction of Land Surface Temperature

The calculation of LST can be conducted using the band algebra function provided in the QGIS software. The specific formula is defined as follows: $T = DN \times 0.02$ (unit: Kelvin), where DN represents the grayscale value of the pixel. In the case of the Chengdu region, the DN values of the MOD11 product are influenced by cloud cover and often yield a value of 0. Consequently, performing band algebra calculations without incorporating appropriate cloud masking procedures can lead to significantly divergent land surface temperature values in comparison to other regions. Therefore, it is imperative to generate region-specific sea masks and cloud masks using the QGIS software to effectively mask out the areas affected by clouds and eliminate outliers. This approach ensures the derivation of accurate land surface temperature values specifically for the urban area of Chengdu.

# 3. Results and Discussion

## 3.1. LST Analysis

The MOD11A2 dataset was processed to remove missing and outlier values, resulting in the extraction of LST for four months in 2001: January, April, July, and October.

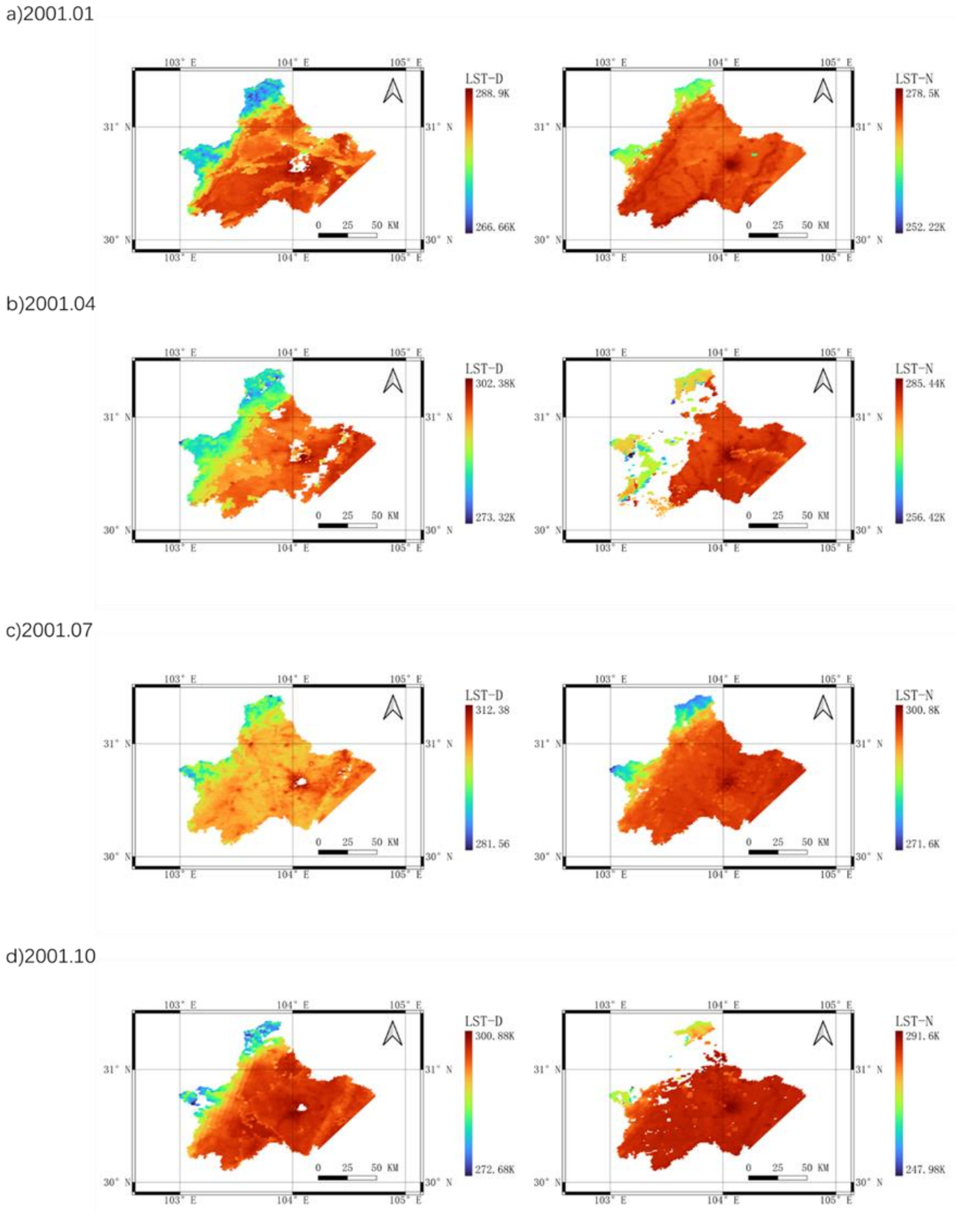


**Figure 1.** Diurnal and Nocturnal Land Surface Temperature (LST) for Four Months in 2001. (Photo credit: Original)

The LST patterns in the Chengdu region during the four months of 2001 are depicted in Fig. 1. Analysis of the LST variations reveals that the diurnal LST ranges from approximately 300K to 270K, while the nocturnal LST ranges from approximately 295K to 265K. Notably, the diurnal LST exhibits an average increase of approximately 15K compared to the nocturnal LST. Moreover, the densely urbanized areas, including the five urban districts and the High-Tech Zone, exhibit significantly higher land surface temperatures than the low-density urban areas in the northwest of Chengdu. Temporal analysis indicates a consistent upward trend in both diurnal and nocturnal temperatures from the beginning to the end of the year. This trend can be attributed to the rapid urbanization and subsequent increase in urban building density that occurred in Chengdu during the study period. The resulting urban heat island effect has led to elevated land surface temperatures. However, it is noteworthy that the land surface temperature in July exhibits a relatively lower value compared to other months. This anomaly can be attributed to the peak maturity of the major urban vegetation during this season, leading to increased vegetation coverage and a higher urban NDVI. Consequently, the mitigating effect of vegetation on the urban heat island effect results in a decrease in land surface temperature during this period.

### 3.2. NDVI Analysis

The MOD09A1 dataset was processed to remove missing and outlier values, resulting in the extraction of NDVI for four specific months in 2001: January, April, July, and October.

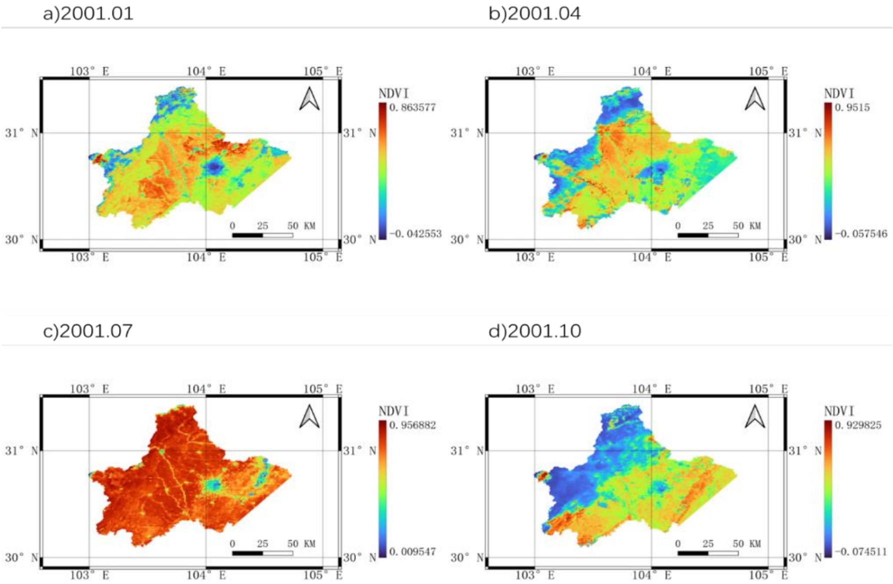


**Figure. 2** NDVI for Four Months in 2001. (Photo credit: Original)

Fig. 2 depicts the spatiotemporal dynamics of the NDVI for the four months of 2001. The NDVI values, ranging from -1 to 1, are commonly employed to assess vegetation presence, with low or negative values indicative of non-vegetated areas (e.g., bare soil, water bodies) and small values associated with urban environments, while higher values correspond to areas characterized by extensive vegetation cover, such as agricultural fields and forests. Examination of Fig. 2 reveals that the main urban area of Chengdu predominantly exhibits low or near-zero negative NDVI values, consistent with the prevailing land use patterns in Chengdu. However, a pronounced seasonal variation is observed, particularly during the summer, when the primary green vegetation in the main urban area of Chengdu reaches maturity. In contrast, the northwest region of Chengdu, encompassing agricultural fields and mature vegetation, exhibits comparatively higher NDVI values. This spatial pattern aligns with the actual land use characteristics of Chengdu. The temporal variation in NDVI values is primarily concentrated within the interval of [0, 0.9]. This phenomenon underscores the high level of urban greening in the main urban area of Chengdu, which contributes positively to the mitigation of the urban heat island effect and the purification of air quality.

### 3.3. NDBI Analysis

The MOD09A1 dataset was processed to remove missing and outlier values, resulting in the extraction of NDBI for four specific months in 2001: January, April, July, and October.

Fig. 3 displays the spatiotemporal dynamics of the Normalized Difference Built-up Index (NDBI) for the four months of 2001. Analysis of Fig. 3 reveals that, over the course of 2001, the NDBI values in Chengdu exhibited certain variations, attributable to the progressive urbanization, expansion of urban building areas, and increased building density. The NDBI values in the Chengdu region remained consistently high, with only localized areas in the northwest exhibiting lower negative values. This spatial pattern reflects the high level of urbanization and building density in the main urban area of Chengdu, accompanied by the reduction of agricultural fields and forests in the northwest region due to ongoing urbanization. Consequently, Chengdu experiences a pronounced urban heat island effect, which significantly impacts various meteorological factors, including diurnal temperature variations and land surface temperatures in the region. Moreover, the NDBI values are also influenced by seasonal variations. As the dominant vegetation in Chengdu progressively matures during the summer, the overall vegetation coverage area increases, leading to a corresponding decrease in NDBI values during this period. This observation highlights a non-linear negative correlation between NDVI and NDBI values [12, 13]. Furthermore, it suggests a potential solution to mitigate the urban heat island effect and other meteorological issues by enhancing the level of urban greening and diversifying the composition of urban vegetation in Chengdu.

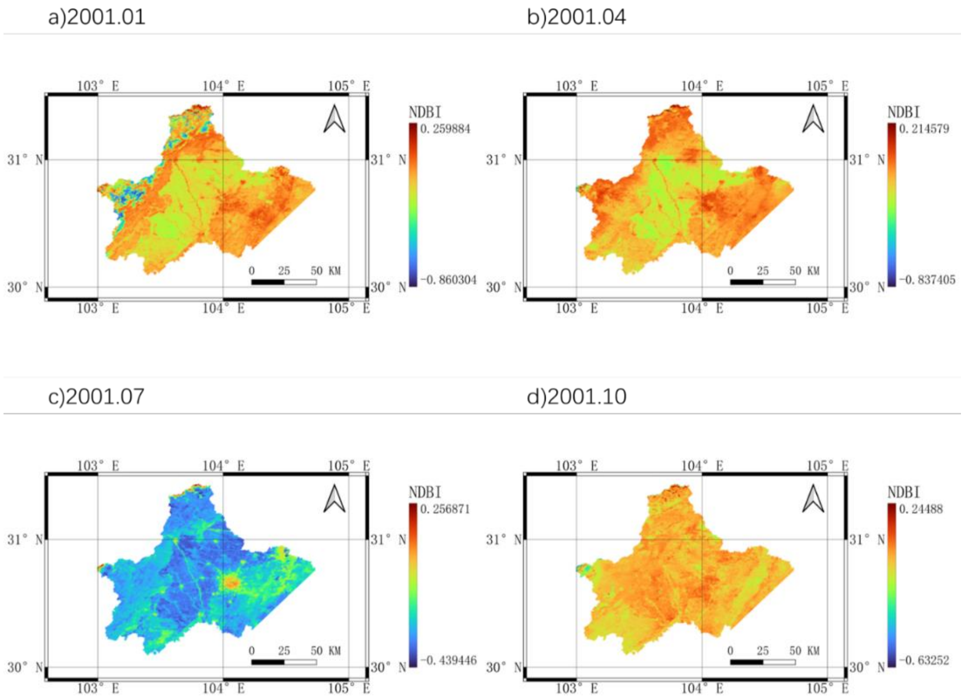


**Figure 3.** NDBI for Four Months in 2001. (Photo credit: Original)

## 4. NDBI and LST Feature Analysis

Fig. 4 and Fig. 5 present scatter plots of NDBI against LST, accompanied by the regression equations for both daytime and nighttime. Analysis of the scatter plots reveals that the regression equations between NDBI and LST exhibit high slopes for both daytime and nighttime, suggesting a robust positive correlation between NDBI and LST with a significant non-linear relationship. This finding provides evidence that an increase in NDBI, corresponding to an expansion of urban building areas, leads to a subsequent elevation in LST, thereby exacerbating the urban heat island effect. Moreover, the gradient of the regression equation between NDBI and daytime LST is higher than that of nighttime LST, suggesting that the impact of urban building area expansion on daytime LST is more pronounced than on nighttime LST.

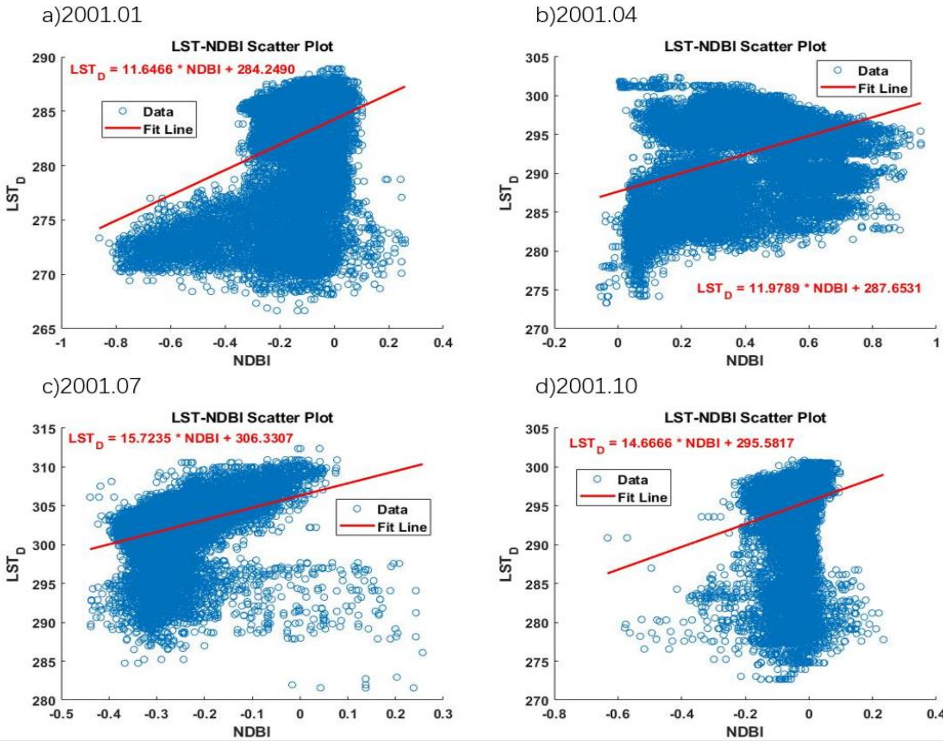


**Figure 4.** Scatter plot of NDBI-LST (daytime). (Photo credit: Original)

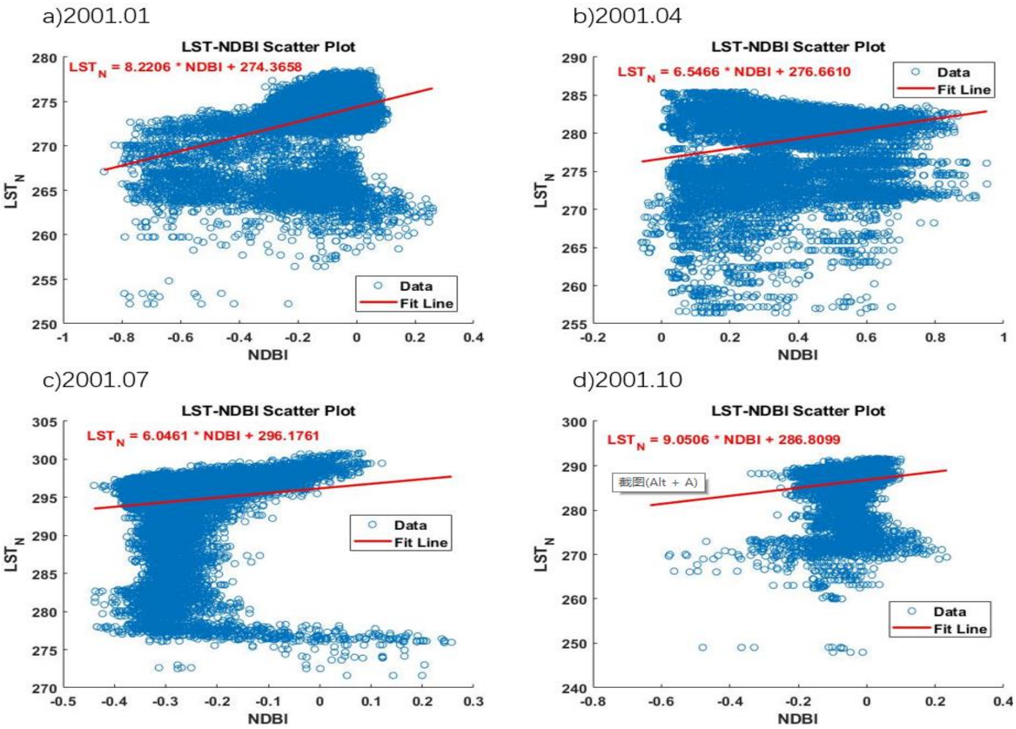


**Figure 5.** Scatter plot of NDBI-LST (nighttime). (Photo credit: Original)

## 5. NDVI and LST Feature Analysis

Fig. 6 and Fig. 7 present scatter plots of NDVI against LST, accompanied by the regression equations for both datasets. Analysis of the scatter plots reveals a poor linear fit between NDVI and LST, indicating that a single model is not suitable for capturing the relationship between these two variables, and a segmented approach is required for fitting. Segmented analysis reveals a clear inverse relationship between LST and NDVI in the high-temperature range, while a positive and unstable relationship is observed in the low-temperature range. Hence, it can be inferred that the NDVI-LST relationship lacks a linear correlation. However, empirical observations and previous research demonstrate that an increase in vegetation coverage contributes to a decrease in LST and mitigates the urban heat island effect to some extent.

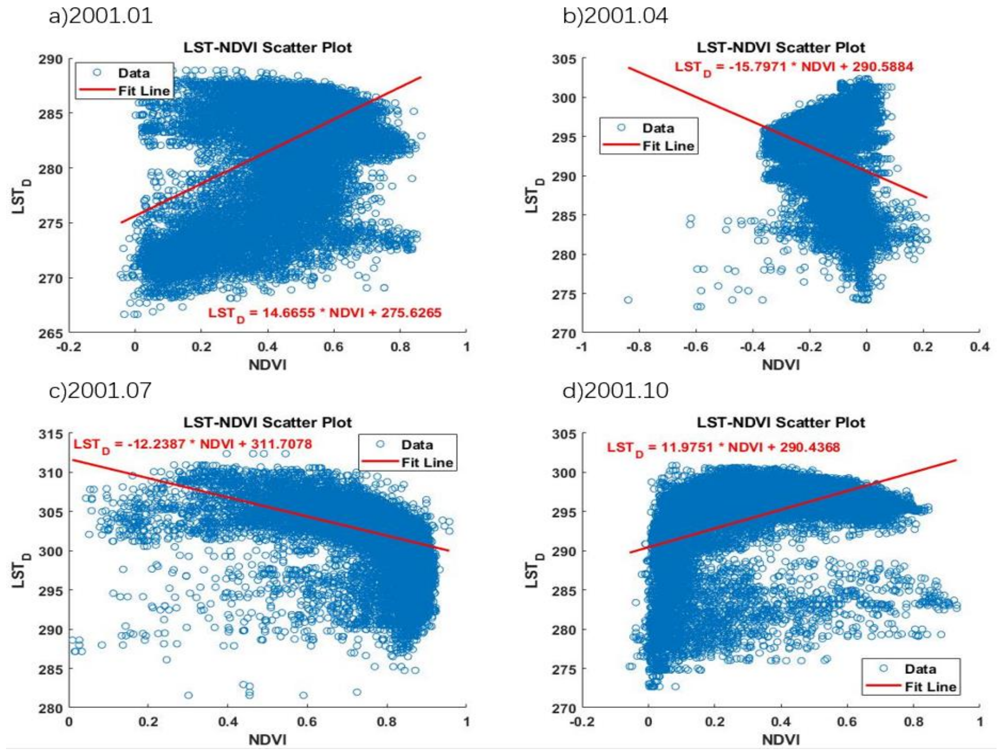


**Figure 6.** Scatter plot of NDVI-LST (daytime). (Photo credit: Original)

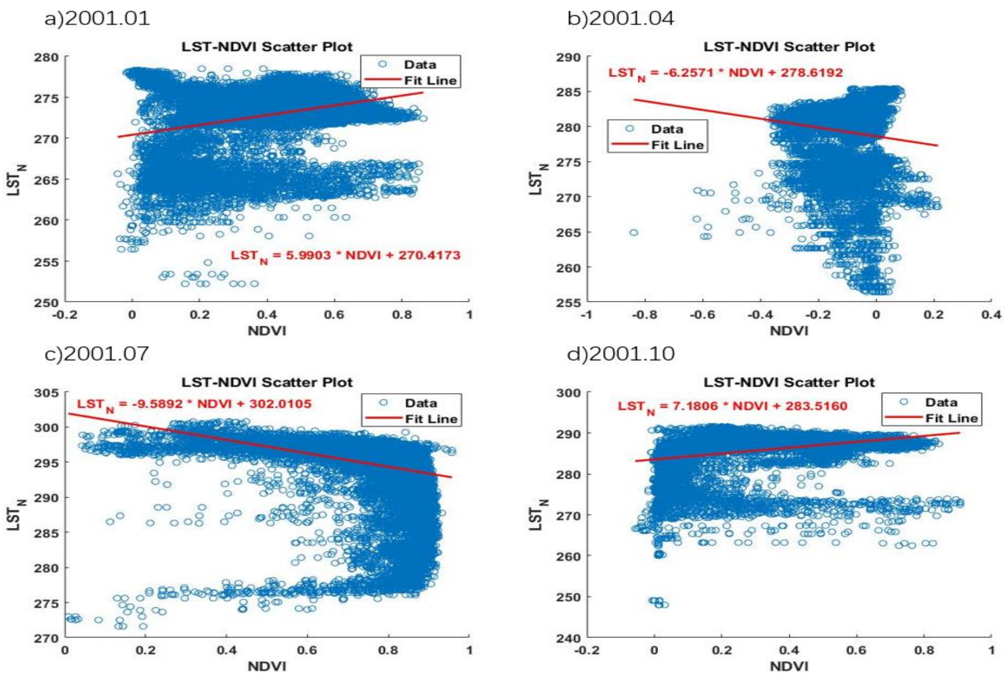


**Figure 7.** Scatter plot of NDVI-LST (nighttime). (Photo credit: Original)

Additionally, the scatter plot investigation of NDVI and LST for January 2001 reveals a triangular pattern, which aligns with prior research findings. The pixels located in the lower left corner of the triangle exhibit low and negative NDVI values, indicating water bodies with lower land surface temperatures. The pixels along the right side of the triangle represent areas with high vegetation index and slightly higher land surface temperatures, indicative of regions with abundant vegetation coverage. The upper side of the triangle corresponds to areas characterized by low vegetation coverage, such as urban and bare soil areas. However, it is important to note that the interpretability of this model is subject to certain limitations, as the scatter plot patterns of NDVI and LST exhibit significant variability across different time periods, and the patterns lack consistent visibility. Consequently, further research is warranted to develop more precise models for elucidating the spatial arrangement of LST based on NDVI.

## 6. Conclusion

This study employed MODIS data to derive LST, NDVI, and NDBI parameters, revealing their spatiotemporal variations within the Chengdu region in 2001. The findings indicated that LST in Chengdu city significantly increased with the expansion of urban built-up areas, while it exhibited a noticeable decline as vegetation coverage increased. The NDBI values in the central urban area and the vicinity of the high-tech zone were notably higher than those in the northwest of Chengdu, resulting in higher LST in the central urban area and the high-tech zone compared to the more open areas in the northwest, thereby indicating a more pronounced urban heat island effect in these regions. To further investigate the relationship between LST and NDBI, as well as NDVI, linear regression equations were established for the three parameters. The findings indicated a direct association between LST and NDBI, indicating a linear relationship that was stronger during the daytime than the nighttime. This implies that with the growth of urban development or expansion of built-up areas, LST also increases accordingly. Alternatively, the linear fit within LST and NDVI was poor, but an increase in vegetation cover was found to effectively reduce LST. As the predominant land use categories, their distribution patterns have a significant impact on urban surface temperature. It is worth noting that this study solely utilized MODIS data, and both the temporal and spatial coverage have limitations. The conclusions drawn regarding the urban heat island effect, the correlation between NDBI and NDVI, and ground temperature are specific to the study area and require further investigation and verification in other regions.

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