Urban Expansion and The Microclimate Characteristics Evolution of Lhasa

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Abstract. Urban expansion is the process of growing urban population and expanding land for residential and productive use. Microclimates are small-scale climates with relatively uniform and changeable climatic characteristics. In the context of climate change on the Tibetan Plateau, the microclimate of Lhasa will respond to urban expansion. With the support of landset8 OLI_TIRS data, this study uses the unsupervised classification method ISO-data algorithm to extract information on construction land and calculate the intensity of urban sprawl. In order to analyze and investigate the evolution of urban expansion and microclimate characteristics in Lhasa city from 2014 to 2021, the radiative transfer equation method was chosen to invert the surface temperature and calculate the heat island effect characteristic-related index. The results of the study show that the area of built-up land in Lhasa city increases and the heat island intensity rises during 2014-2021. This study contributes to urban planning in Lhasa and provides a case study of climate change and cities on the Tibetan Plateau.

Keywords: Remote sensing; urban expansion; heat island effect, microclimate, Lhasa.

1. Introduction

With the increase of urbanization, urban population and industrialization, the substratum of the city changes, the residents' production and living continuously release heat, and the urban microclimate changes accordingly. Microclimate is the term used to describe any small, relatively homogeneous and variable area where the effects of weather are relatively uniform and easily changed [1]. One of the most obvious features of the urban microclimate is the heat island effect. Therefore, its characteristics can be analysed in the field of tropical island effect characteristics, including the heat island effect index U (Eq. 1), the heat contribution index H (Eq. 2) and the cold contribution index C (Eq. 3). Urban sprawl, which primarily refers to the increase in the area of urban building land and the increase in urban population, is one of the most noticeable spatial features of urbanization. Urban sprawl can result in a number of ecological issues, and it is primarily reflected in the increase in the area of urban building land and the increase in population. The expansion intensity index of urban construction land can be calculated by (Eq. 4).

$$U = LST_{\text{construction site}} - LST_{\text{average}} \tag{1}$$

$$H = \frac{\sum_{j=1}^{m+}(LST^{+}_{\text{construction site}j} - LST_{\text{average}})}{\sum_{i=1}^{n+} LST_{\text{average}i}} \times 100\% \tag{2}$$

$$C = \frac{\sum_{j=1}^{m-}\left(LST^{-}_{\text{construction site}j} - LST_{\text{average}}\right)}{\sum_{i=1}^{n-} LST_{\text{average}i}} 100\% \tag{3}$$

Where $LST_{\text{construction site}}$ is the average surface temperature of the construction site in the research area, LST_{average} is the average surface temperature in the study area. m^+ is the number of pixels in the construction site that are above the average temperature in the study area, LST^+ construction site j is the temperature value of the j pixel in the construction site that is above the average temperature in the research area, n^+ is the number of pixels in the study area that are above the average temperature. m^- is the number of image elements in the construction site that are below the average temperature of the research area, LST^- construction site j is the temperature value of the j image element in the

construction site that is below the average temperature of the study area, n- is the number of image elements in the study area that are below the average temperature.

$$G = \Delta A/TA \times T^{-1} \times 100 \quad (4)$$

Where ΔA is the net increase in urban sprawl per unit time (km^2); TA is the total area of the study area (km^2); T is the length of the time period (a).

Due to changes in the city's substrate, air pollution, and the release of artificial waste heat, the urban heat island effect causes a city's temperature to be much higher than that of the suburbs. This phenomenon resembles a hot island [2]. Peng Shaolin et al. showed that the heat island effect can cause meteorological anomalies in cities [3]. Kang Wenxing et al. found that the heat island effect not only accelerates atmospheric circulation and damages the atmospheric environment, but also changes the habits of organisms [4].

In recent years Lhasa's socio-economic development has become increasingly rapid, the urban population has grown rapidly and the built-up area of the city has expanded, while the majority of areas with ecological fragility above the moderate level have been occupied [5]. Studies have shown that the annual change in heat island intensity in Lhasa has gradually increased since the reform and opening up, with an average increase of 0.24 °C per decade from 1978 to 2011, and is mainly concentrated in winter [6,7]. Current research findings on the UHI effect and urban sprawl in Lhasa in recent years are scarce, so it is of great significance to study the relationship between urban sprawl and microclimate response in Lhasa in depth.

In an existing study, TSERING Pema et al. analysed the factors influencing heat island intensity in Lhasa based on meteorological station data, but a more spatially accurate analysis of the changes is lacking [7]. The remote sensing technology has the characteristics of large-area simultaneous observation and strong timeliness, so it is widely used in the study of urban heat island effect, for example, LABA ciren et al. used MODIS surface temperature data combined with meteorological station data to study the spatial and temporal distribution of heat island effect in Lhasa [8]. The majority of recent pertinent studies on Lhasa City have mainly analyzed the effects of changing land use on the heat island effect. There are fewer studies on the evolution of urban expansion and microclimate characteristics, for instance, Gao Jiajia et al. analyzed the relationship between the spatial and temporal distribution characteristics of the heat island effect and land use cover in Lhasa from 2012 to 2016 using data collected by automatic meteorological observation stations and combined with landsat8 image data [6]. These studies provide precedents for the research in this paper.

Based on land use data, this paper analyses the intensity of urban expansion, carries out surface temperature inversion and analyses the characteristics of the heat island effect, on the basis of which the response characteristics of urban expansion and the heat island effect are analysed to provide a theoretical basis for urban planning in Lhasa and scientific support for ecological environmental protection in highland cities.

2. Data and Methods

2.1. Overview of the Study Area

Lhasa is located in the south-central part of the Tibetan Plateau, in the Lhasa River basin, a tributary of the Yarlung Tsangpo River. It is located at 29°14'26"-31°03′45 "N and 89°45′9"-92°37′16 "E. It has a temperate semi-arid monsoon climate, with no severe cold in winter and summer heat, strong solar radiation, over 3,000 hours of sunshine and an average annual temperature of 4.7 degrees Celsius. This study takes the most heavily urbanised and densely populated major urban area, Chengguan District, as the study area, including one city and three districts. The main urban area includes the central city, the northern city area, the western city area and the Lalu Wetland Nature Reserve, while the three new areas are the Dongcheng New Area, Dongga New Area and Liuwu New Area.

2.2. Pre-Treatment

The data were obtained from the geospatial data cloud. In this paper, three phases of landset8 OLI_TIRS remote sensing image data with a spatial resolution of 30m were selected from 2014, 2017 and 2021, and the months of January to February, when the heat island effect is more intense, were chosen. Pre-processing such as radiometric calibration, atmospheric correction, image fusion and cropping were carried out using ENVI software to facilitate subsequent studies such as construction land information extraction and surface temperature inversion.

2.3. Urban Construction Land Information Extraction

On the basis of ENVI5.3 platform, the ISODATA algorithm was used to unsupervisedly classify the remote sensing images of 2014, 2017 and 2020 respectively. The ISODATA algorithm, first proposed by Ball, G. H. and David J. Hall, is an iterative self-organizing data analysis or dynamic clustering [9]. ISODATA is a soft classification algorithm for cluster partitioning, which performs classification without prior knowledge and is unsupervised. Firstly, several clustering centres are selected and samples are clustered in each clustering centre according to the minimum distance criterion. The initial clustering result is judged to meet the requirements, and if not, the clustering set is split and merged to obtain new clustering centres, and then the result is judged to meet the requirements until it does [10]. In order to achieve more objective and realistic clustering results, it can automatically alter the number of categories and category centers during the clustering process. In this work, there are 8 groups identified, and there have been 15 iterations.

2.4. Inversion of Surface Temperature

The inversion of surface temperatures in the research area was conducted using the radiative transfer equation approach [11]. The surface specific emissivity was determined first. Using the radiative transfer equation as a basis (Eq. 5), B(Ts) was calculated using the Atmospheric Correction Parameter Calculator (nasa.gov) obtained from the official website of NASA, combined with the surface specific emissivity (Eq. 6), and then the Planck radiation equation was used to find Ts (Eq. 7).

$$L_{sensor}(T_b) = (\varepsilon B(T_s) + (1-\varepsilon) L^{\downarrow}{}_{atm})\tau + L^{\uparrow}{}_{atm} \quad (5)$$

$$B(T_s) = \frac{C_1}{\lambda^5(\frac{C_2}{e\lambda\tau s-1)})} \quad (6)$$

$$T_S = \frac{K_2}{\ln(1+\frac{K_1}{B_{T_S}})} \quad (7)$$

Where $L_{sensor}(Tb)$ is the brightness of thermal infrared radiation received by the sensor, Tb is the bright temperature data, ε is the surface specific emissivity, Ts is the surface temperature (K), $L^{\downarrow}atm$ and $L^{\uparrow}atm$ are the downward and upward atmospheric radiation respectively, and τ is the total atmospheric transmittance. K_1 and K_2 are pre-set constants before emission. For ETM+8, K_1=77.489 $m \cdot W \cdot cm^{-2} \cdot sr^{-1} \cdot \mu m^{-1}$, K_2=1321.08 K.

2.5. Comparison of Relative Thermal Environmental Effects

In order to be able to compare the remote sensing data from the three phases and analyse the changes in the heat island effect, the temperature was divided into 15 classes by using ENVI software for grey-scale segmentation. The urban building site temperatures are mainly in the range of classes 1-5.

3. Results and Analysis

3.1. Construction Land Expansion Characteristics

As can be seen from Figure 1, the seven-year period from 2014 to 2021 shows a trend of expansion of construction land in Lhasa's Chengguan District. after 2017, the rate of expansion accelerates.

The expansion before 2017 was mainly concentrated in the North City Area and Lhalu Wetland Reserve, with sporadic area expansion; after 2017 the urban expansion was mainly concentrated in the East City New Area and Liuwu New Area, turning to ground expansion, with a strip expansion along National Highway 318 in the east and a gradual evolution from strip to piece along the Lhasa River in the south. Quantitative analysis is currently lacking as there are inaccuracies in the classification results.

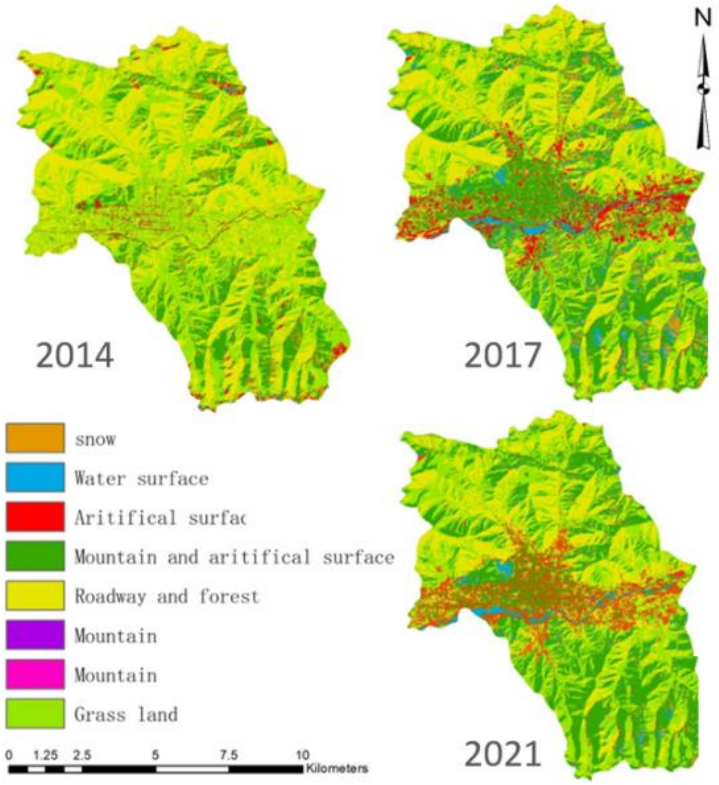


Fig. 1 Lhasa City Construction Site Plan 2014-2021

3.2. Microclimate Evolutionary Characteristics

The LST class distribution map (Figure 2) of the study area from 2014-2021 shows that the high temperature zones are mainly mountains and cities at higher elevations, while the non-high temperature zones are mainly green areas, water bodies and mountain shadows. In 2014, the temperature in the city was relatively uniform, with no obvious high-temperature centres. In 2017, the high-temperature zones increased, especially in the northern and eastern parts of the central city, and in 2021, the temperature in the high-temperature zones in the city increased significantly and the area expanded significantly, with many high-temperature centres dotted in the northern part of the city and striped high-temperature zones in the western part of the city.

Temperatures in the central city have continued to rise over the three years, and temperatures along the Lhasa River have also continued to rise along its distribution. Higher temperatures in the hills around the city due to solar radiation are not taken into account, except for the negligible reflection of solar radiation from the hills to the ground.

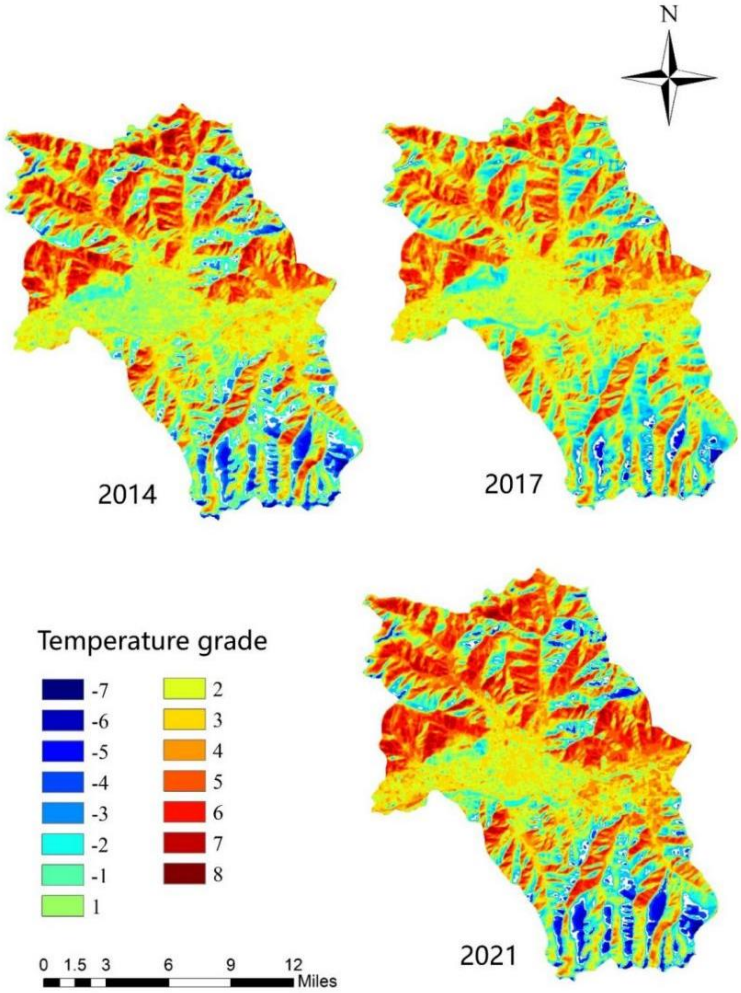


Fig. 2 Temperature classification for Lhasa City 2014-2021

3.3. Discussion

The analysis shows that the heat island effect is stronger in the southwest and southeast of the city where urban expansion is faster. The reason for this is the increase in urbanisation and construction of the population in Lhasa since 2014, the increase in heat emissions from production and living, the increase in vehicles and the change in the nature of the subsurface. In order to alleviate the heat island effect, Lhasa should implement more greening projects and continue the "trees on the hill" policy in collaboration with the government and the public. The development pattern should be optimized to guide the surrounding counties of Lhasa to take over the concentrated population. At the same time, the industrial structure should be optimised and the number of tourist arrivals should be reasonably controlled so that the cultural and tourism industry can develop with high quality. There are many shortcomings in the current study, as there is little data to quantify the relationship between elevation, land use and temperature, or to calculate the heat island effect index and urban sprawl intensity. In future studies, the relationship between the quantitative results of microclimate characteristics and urban sprawl intensity may be analysed and calculated.

4. Conclusion

In this paper, surface temperature is inverse by radiative transfer equation method and urban construction land is extracted by unsupervised classification of the city using isodata algorithm. The response characteristics of construction land expansion and microclimate evolution are analysed. From 2014 to 2021, the construction land in Lhasa city shows an expansion trend, and the expansion pattern changes from point-like dispersion to small-scale surface expansion. As the city expands, the

temperature in the central city of Lhasa continues to rise, and continuous patches of high-temperature heat islands appear in the eastern and southwestern islands. To alleviate the heat island effect in Lhasa, government departments should plan the urban layout rationally and increase the greening of the city. Residents should reduce man-made heat emissions by reducing the use of electrical appliances such as air conditioners, televisions and refrigerators, taking public transport and travelling green. In the context of the rapid development of tourism and urbanisation in Lhasa, research on the heat island effect remains a hot topic for the future. This paper has certain limitations and future research will focus on combining meteorological monitoring data and quantitative analysis of the spatio-temporal relationship between heat island intensity and the intensity of urban expansion, while the influence of atmospheric factors on the heat island effect will be considered.

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