Analyzing the relationship between urban thermal environment and Local Climate Zone in a tropical island country: a case study of Singapore in 2018

Ran Wang, Conrad Heinz Philipp, Chao Ren

Abstract

Urbanization which is regarded as one of the examples of human's modification of the earth's surface has dramatic effects on the living environment of city dwellers. It is predicted that the population living in urban areas will cover up to 68% of the global population by 2050. The number of residents in cities located in subtropical or tropical regions is projected to increase rapidly and significantly in the future. Such cities are more vulnerable to deterioration of the living environment and climate-related hazards caused by continuous urbanization. Urban Heat Island (UHI) effect, known as the hotter temperature in urban areas than rural areas, is one of the common and notable consequences of fast urbanization and proved to cause human health problems. Analyzing the relationship between UHI effect and land use and land cover will help city planners mitigate UHI effect based on scientific understanding, however, due to the atmospheric condition over equator, cloud-free remote sensing images are few, accordingly, investigation of UHI effect and its relationship to land use and land cover in tropical areas was limited.

This study explored the spatial characteristics of the urban thermal environment and its relationship to local land cover and land use types in a typical high-rise high-density country, Singapore. Based on the cloud-free Landsat 8 image acquired on May 24, 2018, first, the Local Climate Zone (LCZ) map of Singapore was generated following the World Urban Database and Access Portal Tool (WUDAPT) workflow. Second, the land surface temperature (LST) of Singapore in 2018 was retrieved by using radiative transfer equation-based method which is proved to achieve the highest accuracy, compared to the single-channel method and split-window method for Landsat 8 TIRS data. To spot the hot and cold areas in Singapore, LST values were classified as five levels (very low, low, medium, high and very high) based on averages and standard deviations of LST across the study area. Third, Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), and Normalized Difference Built-up Index (NDBI) were chosen as representative indices which depict the fundamental characteristics of local land cover and land use. And Pearson's correlation was applied to explore the quantitative relationship between NDVI, NDWI, NDBI, and LST in Singapore in 2018. Last but not least,

since surface UHI is reported to have influences on human health, combing population data of Singapore in 2018, living areas within different LST levels were identified.

The results showed that, first, most areas of Singapore were built-up LCZ types, distributed in northern, southern and eastern areas of Singapore. Rural LCZ classes, such as LCZ A dense trees, LCZ G water bodies, were mainly distributed in central and northwest parts of Singapore. Second, the spatial distribution of LST generally echoed the spatial features of LCZ classes. High and very high LST were mainly observed in LCZ 1-4 (compact and open built types) in residential areas and Central Business District along the Singapore River, and LCZ 8 (large low-rise) in the southwest. While low and very low LST were observed in LCZ A and LCZ G mainly located in the central catchment and the northwest part of Singapore. Third, Pearson's correlation analysis indicated that both NDVI and NDWI were negatively correlated to LST, while NDBI was positively correlated to LST. The impervious surface had stronger influences on LST than greenery and water bodies in Singapore with correlation coefficients of 0.552, -0.203, -0.476, respectively. Lastly, the current thermal living environment of residents in Singapore is not optimistic. 25.63% of the total population is living in areas with very high LST, only 0.86% and 7.34% population are living in areas with very low and low LST. The results of this study confirmed the cooling effects of vegetation and water bodies in a tropical area, but controlling the impervious surface area is more important since its stronger correlation with LST. In addition, city planners and government officials should take actions to alleviate the current "hot" living environment in Singapore to build a comfortable living environment.

Keywords
Land surface temperature (LST), Local Climate Zone (LCZ), tropical area, correlation analysis, thermal living environment