ISPRS Journal of Photogrammetry and Remote Sensing 141 (2018) 59–71

Contents lists available at ScienceDirect

ISPRS Journal of Photogrammetry and Remote Sensing

journal homepage: www.elsevier.com/locate/isprsjprs

Assessing local climate zones in arid cities: The case of Phoenix, Arizona and Las Vegas, Nevada

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ARTICLE INFO

Article history:
Received 5 December 2017
Received in revised form 24 March 2018
Accepted 19 April 2018
Available online 26 April 2018

Keywords:
Local climate zone
Land use land cover
Sky view factor
Land surface temperature
Phoenix
Las Vegas

ABSTRACT

The local climate zone (LCZ) classification scheme is a standardization framework to describe the form and function of cities for urban heat island (UHI) studies. This study classifies and evaluates LCZs for two arid desert cities in the Southwestern United States – Phoenix and Las Vegas – following the World Urban Database and Access Portal Tools (WUDAPT) method. Both cities are classified into seven built type LCZs and seven land-cover type LCZs at 100-m resolution using Google Earth, Saga GIS, and Landsat 8 scenes. Average surface cover properties (building fraction, impervious fraction, pervious fraction) and sky view factors of classified LCZs are then evaluated and compared to pre-defined LCZ representative ranges from the literature, and their implications on the surface UHI (SUHI) effect are explained. Results suggest that observed LCZ properties in arid desert environments do not always match the proposed value ranges from the literature, especially with regard to sky view factor (SVF) upper boundaries. Although the LCZ classification scheme was originally designed to describe local climates with respect to air temperature, our analysis shows that much can be learned from investigating land surface temperature (LST) in these zones. This study serves as a substantial new resource laying a foundation for assessing the SUHI in cities using the LCZ scheme, which could inform climate simulations at local and regional scales.

1. Introduction

The urban heat island (UHI) effect is defined as the phenomenon that an urban area is significantly warmer than its rural surroundings. UHI magnitude is conventionally quantified through UHI intensity, denoted as $\Delta T_{\text{u-r, max}}$, which is defined as the maximum difference between the urban air temperature and the surrounding rural background (Oke, 1973) using either 2-m air temperature measured in the urban canopy layer or air temperature measured in the urban boundary layer. In this context, two main issues have been found for the use of air temperature data collected from fixed weather stations at screen height. First, "urban" or "rural" has no single, objective meaning because the urban-rural system is complex, and the boundary is always fuzzy (Stewart and Oke, 2012; Unger et al., 2014). Second, air temperature data collected from various sites in the urban area can yield different $\Delta T_{\text{u-r, max}}$ values due to distinctive thermodynamic characteristics of surface materials and local surroundings (Stewart and Oke, 2012; Alexander and Mills, 2014). It is therefore difficult to compare results across cities. To facilitate inter-site comparison and improve the effectiveness of measuring the magnitude of the UHI effect in cities around the world, Stewart and Oke (2012) proposed a classification scheme named Local Climate Zones (LCZs) that comprises 17 classes based on surface cover properties, structure, materials, and human activity. Each LCZ class describes either a built type or a natural land cover type. In addition, the LCZ classification scheme takes geometric, surface cover, thermal, radiative, and metabolic properties into consideration that make each LCZ type unique from the others. The LCZ system can provide a disjoint and complementary partition of the landscape that covers major urban forms and land cover types (Stewart and Oke, 2012; Bechtel et al., 2015a,b).

In recent years, studies have employed the LCZ classification scheme to describe the thermal properties of cities using mobile measurements, weather station data, remotely sensed images, land

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https://doi.org/10.1016/j.isprsjprs.2018.04.009
0924-2716/

use and land cover (LULC) data, and urban morphology data acquired from different sources (Bechtel, 2011; Bechtel and Daneke, 2012; Alexander and Mills, 2014; Lelovics et al., 2014; Stewart et al., 2014; Unger et al., 2014; Bechtel et al., 2015a,b, 2016; Leconte et al., 2015; Lehnert et al., 2015; Geletič and Lehnert, 2016; Geletič et al., 2016; Zheng et al., 2017), and reported high effectiveness of this scheme. Yet, few studies to date have been conducted in arid desert cities. Cities such as Phoenix, Arizona and Las Vegas, Nevada, USA, may exhibit lower daytime temperatures than the surrounding desert due to the "oasis effect" that creates a cooling effect (Georgescu et al., 2011; Middel et al., 2014; Fan et al., 2017; Potchter et al., 2008; Hao et al., 2016). It is therefore necessary to evaluate the LCZ classification scheme performance for desert cities in arid environments.

Since the 1960s, with the advent of earth-monitoring satellites and high-resolution digital satellite imagery, remote sensing technology has been widely utilized to assess the surface UHI (SUHI) effect using remotely-sensed land surface temperature (LST), or skin temperature, retrieved from a thermal infrared band image. Satellite images provide continuous data at large spatial coverage, but at a relatively coarse temporal resolution (16 days for ASTER and Landsat data). Although MODIS LST data are collected daily with both daytime and nighttime observations available, the spatial resolution is too coarse. Remotely sensed data also do not fully capture radiant emissions from vertical surfaces such as building walls, because sensors mostly observe energy emitted from horizontal surfaces such as streets, roof tops, and tree tops. Third, observed radiation travels through the thick and dense atmosphere, requiring radiometrical and atmospherical corrections of LST data. Nevertheless, satellite imagery provides fine-scale thermal information that is difficult to obtain through transect measurement campaigns or weather station networks and therefore offer the potential to investigate the SUHI signature of LCZs.

Three popular computer-based approaches to delineate LCZs have been reported in the literature. The first technique is GIS-based (Lelovics et al., 2014; Geletič and Lehnert, 2016) and uses urban structure parameters such as building height, sky view factor (SVF), and building fractions as inputs to be processed in a fuzzy preliminary classification and a post-processing scheme. The output map consists of aggregated LCZ polygons with a minimal size of 500 × 500 m. This method has the aggregation advantage and does not require a selection of training samples. However, the approach requires large amounts of input data that vary in quality and accessibility between cities. The second approach uses satellite remotely sensed data and a classifier, e.g. random forest (Bechtel and Daneke, 2012; Bechtel et al., 2015a). This method is more universal and widely accepted, because input data and software are readily available. It also does not require software expert knowledge and is less computationally demanding. The third method is an integrated approach (Gál et al., 2015) that performs post-classification filtering in addition to the satellite-image based method. It requires a major filter of a specific resolution (100-m), and the preparation of filter input data is time-consuming. Taking all the advantages and disadvantages of different LCZ mapping methods into consideration, this study uses the satellite-image based method for LCZ delineation and mapping, because remotely-sensed imagery has continuous spatial coverage, is available for various dates, and has high spatial resolution.

To promote the concept of LCZ for arid desert cities, this study has three main objectives. The first objective is to classify LCZs for two large desert cities in the Southwestern United States - Phoenix, Arizona and Las Vegas, Nevada using the World Urban Database and Access Portal Tools (WUDAPT) LCZ classification methodology that employs the satellite-image based approach (Bechtel et al., 2015a,b). Second, we calculate LST averages for each LCZ in the two cities to investigate SUHI profiles. Finally, we evaluate LCZ properties for each city based on the attribute ranges proposed by Stewart and Oke (2012).

2. Study area

Phoenix, Arizona and Las Vegas, Nevada (Fig. 1) are large cities in the Southwestern United States, typical of hot, subtropical desert climates (Köppen climate classification: BWh). Phoenix, Arizona is located in the northeast part of the Sonoran Desert and is the fifth largest city in the United States by population. Las Vegas, Nevada (28th largest city in the U.S.) is in a basin on the floor of the Mojave Desert. Both cities are among the hottest of any major city in the United States, characterized by long, hot summers, warm transitional seasons, and short, mild to chilly winters. July is the warmest month with an average high temperature of 41.2 °C in Phoenix and 40.1 °C in Las Vegas (U.S. Climate Data, 2017). Winter months feature mean daily high temperatures above 13 °C and low temperatures rarely below 4 °C.

The average annual precipitation over the past 30 years was 204 mm (8.04 in.) for Phoenix and 106 mm (4.17 in.) for Las Vegas (U.S. Climate Data, 2017), respectively. Phoenix has higher precipitation than Las Vegas due to the North American Monsoon that normally occurs between early July and early September (Adams and Comrie, 1997). The monsoonal moisture influx increases humidity, thunderstorm activity, and can precipitate heavy rainfall and cause extensive flooding. The highest mean daily precipitation in Phoenix occurs in July and August with monthly averages of over 23 mm (Balling and Brazel, 1987; Vivoni et al., 2008). Most of the annual precipitation in Las Vegas falls during the winter months, but even the wettest month (February) averages only four days of measurable rain. Las Vegas is among the sunniest, driest, and least humid locations in North America, with exceptionally low dew points and humidity that sometimes remains below 10%. Winds are generally light, but are normally higher in Las Vegas than Phoenix, both with well-defined diurnal wind regimes (Stewart et al., 2002). On average, winds are 3–5 m/s in Las Vegas, and 1–3 m/s in Phoenix.

Another important characteristic shared by both cities, discussed below, is the similarity in urban morphology and major LULC types that include open soil, grass, trees, paved and impervious surfaces, commercial, industrial, and residential areas (Myint et al., 2015; Wang et al., 2016).

3. Data and methods

3.1. Local climate zone classification

Using the full definition and surface property values of LCZs proposed by Stewart and Oke (2012) as guidance, together with supplemental aerial photographs, this study classified LCZs for the Phoenix and Las Vegas metropolitan areas except built types 1 (compact high-rise), 2 (compact midrise), and 3 (compact low-rise) for both cities and land cover type A (dense trees) for Las Vegas, because preliminary evaluation indicated these LCZ classes are rarely found in the two cities.

Training samples for the LCZ classification were selected using high spatial resolution satellite imagery in Google Earth. The number of training samples was determined proportionally to the area percentage of each LCZ in each city (Table 1). This study follows the World Urban Database and Access Portal Tools (WUDAPT) method proposed by Bechtel et al. (2015a,b) using SAGA GIS to perform the LCZ classification. For the regions of interest in each metropolitan area, cloud free Landsat 8 images were retrieved for all four seasons for 2014–2016 (Table 2) and resampled to 100-meter resolution. Then, the "Local Climate Zone Classification tool" was