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Spatial variation of the daytime Surface Urban Cool Island during the dry season in Erbil, Iraqi Kurdistan, from Landsat 8

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ABSTRACT

Differences between the energy balance of cities and their non-urban surroundings exist due to modification of surface properties. In temperate and sub-tropical climates, these differences are manifest as the Urban Heat Island (UHI) effect. However in more arid environments man-made modifications of the environment can cause urban cooling relative to the surrounding landscape particularly during the dry season. This research examines the spatial formation of the daytime Surface Urban Cool Island (SUCI) effect of Erbil city in Iraq, as a case study of cities in semi-arid climates. Six satellite images acquired by Landsat 8 during the period from 1st July to 19th September 2013 are used to retrieve Land Surface Temperature (LST), identify Land Use/Land Cover (LULC) classes and investigate the spatial variation of LST and the SUCI intensity. In order to find out the key drivers of the observed patterns of LST, the relationship with wetness, brightness, bareness, built-up and vegetation index maps are examined. The results indicate that densely built-up areas, such as central districts of the city, green areas and water bodies, had lower LST acting as cool islands, compared to the non-urbanized area around the city. In contrast, the airport, open spaces and new low-density housing developments on the outskirts of the city, experienced higher LST and showed an SUHI effect. A very strong inverse relationship is evident between surface temperature and wetness index ($r = -0.9$; $p < 0.01$). A strong positive correlation ($r = 0.75$; $p < 0.00001$) is apparent with the brightness index. In contrast, between surface temperature and the greenness index a moderate negative correlation was found ($r = -0.39$; $p < 0.01$) for a typical dry season day. The results show that during the daytime residential areas in the city centre recorded an LST of 46.2 ± 1.74 °C. Urban Cool Island Intensity (UCII) of the city ranged from 3.5 to 4.6 °C compared to a 10 km buffer zone around the city. This study shows that during the dry season in some cities, such as Erbil, the surface wetness is the main determinant of the UCI effect, and not vegetation cover.

1. Introduction

The difference between the characteristics of surface cover in urban and non-urbanized areas in terms of 3-d geometry of the built area, heat absorption, the building materials, surface albedo and amount of vegetation lead to different air and

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surface temperatures within a city relative to the surrounding area. Therefore, urban expansion can lead to radical changes in the nature of the surface of the urbanized area. Usually, this urban extension causes temperatures to increase in temperate and sub-tropical climates, a phenomenon known as the Urban Heat Island (UHI) effect (Oke, 1987; Weng et al., 2004; Farina, 2011). In contrast, built-up areas in semi-arid regions have been found to exhibit lower surface temperatures compared to non-urbanized dry surroundings (Frey et al.; Cai and Du, 2009; Shigeta et al., 2009), which has been termed the Urban Cool Island (UCI) effect.

Satellite sensors can be used to obtain the surface temperature of urban areas and to study the spatial variations of UHIs and their development (Watson, 2012). Rao (1972) reported the first study of Surface Urban Heat Island (SUHI) based on satellite imagery. He used thermal Infrared Radiometer (IR) data of the Improved TIROS Operational Satellite (ITOS-1) to study the; surface temperature patterns of the mid-Atlantic coast. Subsequently, Matson et al. (1978) detected the night-time UHI of the Midwestern and Northwestern United States from NOAA 5 satellite data. The UHI of the New York City/New England area was also detected by Price (1979). Since then, SUHIs and surface temperatures have been observed from different platforms including satellites, aircraft and ground-based sensors. Landsat TM and ETM+ are widely used to investigate the expansion of SUHIs and to assess the relationship between Land Surface Temperature (LST) and Land Use/Land Cover (LULC) (e.g. (Xu, 2009; Li et al., 2011; Ukwattage and Dayawansa, 2012).

It is notable that very few investigations of the SUHI/SUCI effect in arid environments have been published. One exception is the study by Lazzarini et al. (2013) who used MODIS data to analyse daily differences of LST and UHI in Abu Dhabi. Their findings indicate the presence of a standard nocturnal UHI, in contrast to a daytime UCI. The amount of soil moisture within the urban area has an effect on the thermal environment because evaporation reduces land surface temperature via latent cooling. As such, the Lazzarini study demonstrated the existence of a UCI in Dubai compared with the surrounding desert; both residential districts and industrial areas had lower temperatures than sand zones (Frey et al.; Frey et al., 2006).

The correlation between LST and Normalized Difference Vegetation Index (NDVI) values has been applied extensively in UHI studies (Weng et al., 2004; Sun and Kafatos, 2007; Weng and Lu, 2008; Schwarz et al., 2012). The existence of a strong linear inverse relationship was confirmed by Liang and Shi (2009) and Bajaj et al. (2012). On the contrary, Zhang et al. (2008) referred to the absence in the relationship between LST and NDVI in Shanghai, China. Similarly, Yuan and Bauer (2007) confirmed that this relationship suffers from clear seasonal variations. In order to examine the relationship between air UHI and surface UHI, atmospheric temperature and LST data have been combined by several researchers (e.g. Gallo and Owen, 1999; Voogt and Oke, 2003; Hartz et al., 2006). A strong relationship has been found between the air and LSTs in Leipzig city in Germany, in relation to the UHI effect (Schwarz et al., 2012).

Early research used a Tasselled Cap to extract parameters from the Multispectral Scanner Sensor (MSS) of Landsat 1 (Kauth and Thomas, 1976). This method has subsequently been widely applied, because in addition to the collection of multiple measurements in different bands it shows the physical properties of the scene (Liu et al., 2014).

Chen et al. (2006) used a range of indices (Normalized Difference Bareness Index (NDBaI), Normalized Difference Built-up Index (NDBI), NDVI and Normalized Difference Water Index (NDWI)), to examine the relationship between UHI and LULC changes. In this study we use NDVI and NDBI to examine how they influence the SUCI intensity in a semi-arid environment.

Research on the UCI effect is still in its infancy (Li et al., 2011) and its characteristics in semi-arid environments still need to be better quantified and understood. The objective of this study is to quantify the spatial structure of the SUCI in Erbil, as a case study of a semi-arid climate and to establish the key determinant factors and patterns of the spatial distribution of LST and SUCI. The contribution and novelty of this paper is:

- Determination of the spatial distribution of the patterns of LST and SUCI in the different LULC and districts of the city of Erbil.
- Using wetness, brightness and greenness components derived from Landsat OLI by Tasselled Cap transformation (TCT), to find key factors responsible for the spatial LST variation.

1.1. Study area

Erbil is the capital city of the Kurdistan Region of Iraq. The city is located in northern Iraq and lies between 36°08′N to 36°14′N, and 43°57′E to 44°03′E. (Fig. 1). It is located 412 m above sea level (Sharif, 1998).

In 2010, the estimated population of Erbil Governorate was 1,820,000, whilst the population in the city was 852,000 (KRSO, 2012). The population density of Erbil district is 472.9 (persons/km^2) (Amjed et al.). The city has experienced extensive growth over the past two decades, both in terms of population and infrastructure.

Erbil is selected as a case study located within a semi-arid and continental climate. According to the Köppen climate classification, the city is tropical/subtropical semiarid (BSh) (Hasan, 2006). It experiences cool, rainy winters and warm, dry summers. The average annual temperature and precipitation of Erbil is 21.85 °C and 386 mm, respectively (Meteorological and Seismological Department of Erbil Governorate, 2014). July and August are the hottest months of the year; air temperatures during these months can reach 49 °C. Usually, summer months are dry; the majority of the year's precipitation falls between March and December.

Land use/land cover are strongly dependent on the seasonality of the precipitation, hence winter grain cultivation such as wheat and barley is common in rural areas. Inside the city, residential land use is most dominant. The residential buildings are usually block and concrete.

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