Ecological Indicators 91 (2018) 155–170

Contents lists available at ScienceDirect

Ecological Indicators

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

Original Articles

Monitoring and forecasting heat island intensity through multi-temporal image analysis and cellular automata-Markov chain modelling: A case of Babol city, Iran

Mohammad Karimi Firozjaei[a], Majid Kiavarz[a,*], Seyed Kazem Alavipanah[a], Tobia Lakes[b], Salman Qureshi[b,c,*]

[a] Department of Remote Sensing and GIS, University of Tehran, Iran
[b] Department of Geography, Humboldt University of Berlin, Berlin, Germany
[c] School of Architecture, Birmingham City University, Birmingham, United Kingdom

ARTICLE INFO

Keywords:
Monitoring
Spatio-temporal
Land-use
Urban ecology
Landsat
UHI

ABSTRACT

An urban heat island is one of the most vital environmental risks in urban areas. The aim of this study was to assess the spatial-temporal patterns of land use changes and heat island intensity for the city of Babol, Iran, between 1985 and 2015 and to predict likely future heat island intensity variations. Multi-temporal Landsat images were acquired and analysed in this study. First, single channel algorithms were used to calculate the land surface temperature (LST), and a Maximum Likelihood Algorithm was utilized to classify images. Second, land use changes (LUCs) and LST were examined, and the relationship between the fractional vegetation cover (FVC) and land-use changes was analysed using the normalized land surface temperature. By using the mean and the standard deviation of the normalized thermal images, the area was divided into five thermal categories: very low, low, medium, high and very high. Then, by applying the heat island intensity index, the heat island changes in the studied period were investigated. Possible future land use changes were investigated using a cellular automata-Markov model, and the heat island intensity changes were anticipated. The results indicate that the area of built-up land increased by 92% between 1985 and 2015, and that the area of agricultural land noticeably decreased. The built-up land changes trend has an inverse relationship with the trend of FVC changes and follows the same trend as the normalized surface temperature changes. Most changes in the surface temperature of the area are located within 0–800 m of a built-up area. The main reason for these changes could be the conversion of agricultural and green space land areas into built-up land. The largest area of the temperature categories in all years is the medium temperature category, which covers the suburban land areas. The low- and very low-temperature categories, which follow a decreasing trend, are related to land areas far from the city. In addition, the high- and very high-temperature categories, whose areas increased annually, are adjacent to the city core and the exits from the city. The average surface temperature in all land uses increased during the studied period. Nevertheless, the rate of temperature rise is higher in the built-up uses. The index ratio of the heat island during this period shows an increasing trend, and its value changed from 0/5 in 1985 to 0/67 in 2015. An increase in the heat island intensity has a direct relationship with the area population growth and, thus, the increase in the built-up land area. Anticipation of land use changes and the process of heat island intensity variations for the studied area show alarming results that call for decision-makers to address this important challenge.

1. Introduction

In recent decades, the surface of the earth has experienced various changes such as deforestation and urban expansion due to human activities (Baker, 1989; Brunsell, 2006). These widespread human changes pose several adverse problems. For instance, a decrease in environmental quality may lead to a reduction of living quality (Wu, 2014). One important example is the urban heat island, which describes an urban environment that is warmer than the surrounding rural areas (Amiri et al., 2009; Oke, 1982; Voogt and Oke, 2003). A precise and comprehensive study of this phenomenon and an investigation of its mechanism play a vital role in urban planning. Replacing natural land cover with urban Complications, such as pavements, buildings and concrete, are perceived as the main factors in creating heat islands,

* Corresponding authors at: Department of Geography, Humboldt University of Berlin, Berlin, Germany (S. Qureshi).
E-mail addresses: salman.qureshi@hu-berlin.de, salloo19@yahoo.com (S. Qureshi).

https://doi.org/10.1016/j.ecolind.2018.03.052
Received 10 July 2017; Received in revised form 23 January 2018; Accepted 21 March 2018

which cause the land surface cooling effects to slowed down considerably (Panah et al., 2017). Moreover, skyscrapers and narrow streets diminish the airflow and give rise to an increase in the temperature of the environment. These factors all take part in the formation of an urban heat island (Liu and Zhang, 2011; Xu et al., 2011). Several additional factors, such as heat and pollution from vehicles, industries and big factories, equipment for air refining and other human activities, increase the air temperature and exacerbate the heat island effects (Rizwan et al., 2008; Yuan and Bauer, 2007). The first crucial effect of the urban heat island is the rise in energy, water and electricity consumption and subsequently, the noticeable increase of per capita financial burden especially during the warmer months of the year. Second, the UHI has a significant impact on air quality in the urban districts. Air pollution and particulate matter can form a shield that traps heat, which increases the urban temperature. Urban Heat Islands increase the demand for more cooling energy to maintain comfort levels in building structures. An increase in urban air temperature will increase harmful emissions such as SO_2 and NOx, which are produced when fossil fuels are burned to generate electricity (Han-qiu and Benqing, 2004). In addition, the heat island phenomenon is a sign of the inordinate lack of urban green space (Hiemstra et al., 2017). As a result of the lack of urban green space, several major problems can occur, such as an increase in the level of various forms of air pollution, water contamination, rainwater loss, and disturbing noises as well as psychological and health problems. To address the imminent population increase and concerns about creating high-quality urban areas as well as concerns about energy consumption and minimizing energy use, investigating the urban heat island is essential and a decisive factor in achieving heat welfare for the inhabitants of urban areas (Mackey et al., 2012).

Land surface temperature (LST) is a key parameter for monitoring and evaluating physical, chemical and biological surface processes and is an important factor for climate studies in urban areas (Panah et al., 2017). Although thermal data are recorded frequently by synoptic stations, these data lack a suitable spatial resolution. Remote sensing images are considered to be an appropriate information resource for preparing heat maps. These images also contribute heavily to a wide range of applications for the precise investigation of climate changes and urban and non-urban land use changes due to their continuous and extensive coverage, timeliness and the ability to acquire information in the reflective and thermal range of electromagnetic waves (Voogt and Oke, 2003; Sobrino et al., 2004; Walawender et al., 2014; Weng et al., 2004). The type of land use is one of the most decisive factors that affect the surface temperature. Assessing and investigating the type of land use are therefore necessary for assessing the urban heat island. The anticipation of possible future land use changes may then provide important information about likely future urban heat intensities. Existing studies have successfully applied the combination of remote sensing technology and prediction models for land use changes such as CA-Markov to explore future urbanization (Sang et al., 2011; Yang et al., 2012).

Over the past two decades, the demand for LST information for environmental studies and activities associated with managing earth resources has led to the use of thermal remote sensing technology as a substantive scientific issue (Voogt and Oke, 2003). NOAA AVHRR sensor data were used in several studies in which the urban heat situation was investigated using thermal infrared data (Gallo et al., 1993; Streutker, 2002). The spatial resolution of the NOAA AVHRR thermal band was 1.1 km, which is merely suitable for preparing a large-scale map of city temperatures. The ability to extract the LST and the precise study of urban heat islands were recently facilitated using thermal infrared Landsat (TM, ETM+ and TIRS) and ASTER data, and there are several relevant studies in the literature (Amiri et al., 2009; Panah et al., 2017; Liu and Zhang, 2011; Weng et al., 2004; Chen et al., 2006; Haashemi et al., 2016; Li et al., 2012; Rajasekar and Weng, 2009; Weng, 2009; Xiao and Weng, 2007; Xunqiang et al., 2011; He et al., 2017; Estoque and Murayama, 2017). Most of the studies have focused on LST patterns and their relationship to urban surface biophysical indices, especially vegetation cover indices and various uses of land coverage (Liu and Zhang, 2011; Weng et al., 2004; Chen et al., 2006; Li et al., 2012; Chakraborty et al., 2015). The surface emissivity varies for various types of land coverage depending on several factors, such as the humidity, the chemical composition, the physical structure and the coarseness, and it directly affects the land surface temperature (Weng et al., 2004). Studies in this field have investigated the relationship between LST and NDVI (Amiri et al., 2009; Gallo et al., 1993; Olivera-Guerra et al., 2017). Subsequently, several studies have been conducted using other biophysical indices such as fractional vegetation cover (FVC) and the percentage of impervious surfaces. The findings confirm the strong correlation between the aforementioned indices and the land surface temperature (Yuan and Bauer, 2007; Weng et al., 2004; Haashemi et al., 2016; Deng and Wu, 2013; Heinl et al., 2015; Rotem-Mindali et al., 2015). In some studies, the spatial distribution patterns of the urban green spaces and impervious surfaces were investigated using landscape indices such as the patch density, edge density, and landscape shape index, and the correlation with the land surface temperature was analysed (Li et al., 2012; Li et al., 2011; Zhou et al., 2011). Various studies performed in different cities around the world have indicated the profound effect of urbanization on meteorology parameters and land surface features that have culminated in numerous changes of domestic climate (Atwater, 1975; Cotton and Pielke, 2007; Schwarz et al., 2012). Whereas most of the previous studies have concentrated solely on the changes of the urban heat island in the past, this study focuses on the urban heat island changes in the past and predicts possible urban developments and heat island effects for the future.

The aim of this study is a spatial-temporal assessment of land use changes and heat island intensity between 1985 and 2015 and a prediction of heat island intensity variations for the specific area studied in the city of Babol.

2. Study area

For this study, the city of Babol was chosen because its population is increasing steadily as a result of population growth and emigration from villages, which has led to excessive and unplanned construction, alterations in the physical model of the city and the expansion of the city in various directions. Physical expansion leads to numerous changes in urban land use and suburban agricultural land use. Consequently, several serious problems occur, including adversity in usage, urban environmental disorder and the vanishing of suburban agricultural lands and their use change into urban uses (e.g., residential or industrial). One of the adverse effects of urban physical expansion and changes of green space and agricultural uses into urban uses is the rise in the surface temperature. To implement the planning, discreet guidance and essential organization of cities and to avert their physical expansion in inappropriate directions, studying and investigating the urban physical expansion, resultant use changes and surface temperature trends are important. The case study is located on a flat plain, located between 52°37′16″E–52°43′02″E and 36°30′49″N–36°35′1″N, with the area of 6666.66 ha. The city is situated between the Caspian Sea and the Alborz mountains, at a distance of 15 km from the Caspian Sea and 210 km northeast of Tehran. The elevation of the city is 2 m lower than sea level. Fig. 1 shows the location of the studied area.

3. Data and methodology

3.1. Data

In this study, satellite images of Landsat 5, 7 and 8 were used from the years 1985, 1992, 2001, 2008 and 2015. The years were chosen because the interval of time between each of the images used to study