Urban Climate 24 (2018) 19–25

Contents lists available at ScienceDirect

Urban Climate

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

Analyzing land surface temperature trends using non-parametric approach: A case of Delhi, India

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ARTICLE INFO

Keywords:
Urban Heat Island (UHI)
LST
Trend Robustness
MODIS
Mann Kendall and Theil-Sen slope

ABSTRACT

Urban Heat Island (UHI) creates backwash effect in the system. The existing studies consider averaging of Land Surface Temperature (LST) over the area of a land-use/land-cover for analysis of UHI, whereas it is not necessary that all pixels observe similar behavior. Besides this, averaging of LST over space obstructs the spatial continuity. The analysis of the behavior of LST over a pixel is important. The pixel-wise temperature trend analysis will further open up the layers of intensities in a particular land-use/land-cover, and is more meaningful. The LST images have been used for trend analysis in different studies but the robustness has never been analyzed. In this research, the robustness of the LST trend is analyzed pixel-wise by using non-parametric Mann-Kendall to detect trends in monthly LST, and Theil-Sen slope estimator for analyzing the extent of significance of this trend in Delhi. MODIS data from 2001 to 2015 has been used. The results highlighted a mix of positive and negative trends in monthly LST. February (nighttime) and September (daytime) trends are most important due to high robustness at all significance levels. This research concludes that there is a positive temperature trend throughout the study period especially in night time in Delhi.

1. Introduction

Atmospheric and the surface temperatures have significantly increased in the urban system as compared to the periphery areas. The existing literature has presented this phenomenon of rise in temperature in the core of the urban system as compared to their counterparts periphery as Urban heat Island (UHI) (Howard, 1818; Voogt, 2004; EPA, 2008; Estoque et al., 2017). Burning more amount of carbon in the core area more or less results in this phenomenon. Radiated and reradiated energy is major constituent in analyzing energy balance equation (Nunez and Oke, 1977). Surface temperature is one of the important parameters, which is used for analyzing the spatial and temporal dynamics of urban thermal environment. Land Surface Temperature (LST) is used not only for calculating the surface UHI but also contributes significantly in analyzing the canopy layer of the heat island (Roth, 2013). Satellite data provide great vision and effective method for extracting land surface temperature. Various remote sensing studies have been carried-out regarding LST extraction (Weng, 2009). Thermal images from different satellites using ASTER satellite for night, and Landsat ETM + for day (Nichol, 2005), NOAA AVHRR data for regional scale urban temperature mapping (Gallo and Owen, 1998). Landsat TM and ETM thermal infrared (TIR) data with 120 m and 60 m spatial resolutions, respectively, have also been utilized for local-scale studies for surface temperature analysis (Weng, 2001). MODIS provide high temporal resolution data to the great deal for extracting land surface temperature (Rajasekar and Weng, 2009). The existing studies consider averaging of LST over the area of a

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https://doi.org/10.1016/j.uclim.2018.01.003
Received 26 September 2017; Received in revised form 27 November 2017; Accepted 24 January 2018

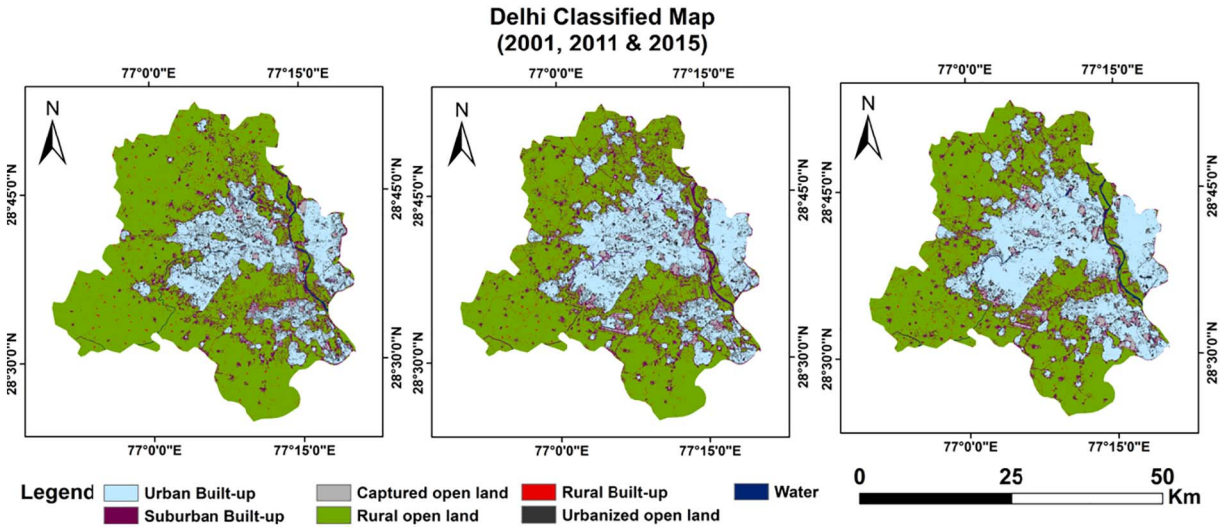

Fig. 1. Land cover classification of Delhi for the year 2001, 2011 and 2015.
(Source: authors).

land-use or land-cover for analyzing the UHI, whereas it is not necessary that all pixels belonging to that area in specific land-use or land-cover have similar behavior. Besides this, averaging of LST over space obstructs the spatial continuity of the study area. The pixel-wise temperature trend analysis will further open up the layers of intensities in a particular land-use or land-cover, and is more meaningful (Weng, 2009). The LST images have been used for trend analysis in different studies but the robustness has never been analyzed.

For pixel wise spatial analysis of a series of LST observations over time, it is important to understand whether the temperature is going up, or down, or doesn't show any change. The statistical significance of trend in time series is analyzed by using Mann Kendall (MK) test (Mann, 1945; Kendall, 1954), and it is observed that it has great statistical significance. Subsequently, Salmi et al. (2002) describe the conditions for applicability of Mann-Kendall test. The magnitude of trend in monthly data series is determined by using Sen's slope estimator (Thel, 1950) (Salmi et al., 2002), which is also referred as “Kendall's slope” or the “Nonparametric Linear Regression Slope”. Theil-Sen slope estimator is a more viable alternative to standard linear regression slope. The non-parametric Mann-Kendall and Theil-Sen slope have been employed by various authors (Aziz and Burn, 2006) (Cannarozzo et al., 2006) (Wilks, 2006) in last two decades to detect the monotonic trends in series of environmental, metrological or hydrological (Jianfen et al., 2013). The present investigation proposes a trend based pixel wise LST extraction technique, where nonparametric Mann-Kendall (MK) and Theil-Sen Slope estimator tests are used to detect trends in monthly land surface temperature for each pixel of the study area from the year 2001 to 2015.

2. Study area profile

Delhi, the capital city of India, (Fig. 1), situated on the banks of river Yamuna, which is lying between 28°24′17″ N to 28°53′00″N latitudes and 76°45′30″E to 77°21′30″E longitudes, has been selected for analysis of the proposed model. Delhi attracts in-migration from the entire nation for employment opportunities as it is the political center and one of the major economic hubs of India. It has maximum number of vehicles in India, and the governments have remained pioneer in implementing the exemplary policies and committed to deliver best in the country for the benefit of its citizen due to economies of scale. Delhi has composite climate. Monsoon season starts from July and end up in September. In summer season, temperatures reach up to 45 °C or higher. The population, urban area, number of houses has almost doubled from the year 1991 to 2015. During the same period, road length has increased just only 1.5 times, but the vehicles have amplified approximately 5 times, which resulted into increase the built-up area and anthropogenic heat sources in the study area. Having the aforesaid reasons in mind, the authors have chosen the study area for the present investigation.

3. Data used

MODIS/Terra global land surface temperature 8 day L3 (MOD11A2) downscaled to 500 m pixel resolution, from January 2001 to December 2015 are used in the present investigation to calculate both daytime and nighttime land surface temperature for Delhi. It is downloaded from the REVERB site. MOD11A2 product represents the average LST over 8-day period and 1 km pixel resolution, which is derived from the daily land surface temperature product (MOD11A1) over such periods. The eight-day compositing period (MODA11A2) is well suited for climate studies because twice of such period is the exact ground track repeat period of the Terra platform. The data with > 30% missing pixels (which represent cloud cover) in shape file of the study area are rejected through