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Research Paper

Assessment of land surface temperature variation due to change in elevation of area surrounding Jaipur, India

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ABSTRACT

Land surface temperature (LST) is a key parameter for surface energy balance and urban climatology studies. LST is affected by the characteristics of the land surface such as vegetation cover and its type, land use-land cover and surface imperviousness. Incessant urbanization has resulted in many fold increase in the urban area and it has caused significant changes in the land surface. The difference in altitude of two points, that are located at different parts of a vast study area, may be large. The aim of the present study is to investigate the effect of change in elevation over LST. LST data from Moderate Resolution Imaging Spectroradiometer (MODIS) and digital elevation model from ASTER have been used. Consistent inverse linear trend is observed between LST and elevation for all the study seasons. High correlation (R^2 = 0.73–0.87) is found between elevation and mean LST. It is seen that the change in LST due to elevation difference between two points separated in space in horizontal direction varies from 3.5 °C to 4.6 °C per 1000 m which is relatively lesser than the condition when two points are separated in vertical direction (5.0 °C–10.0 °C per 1000 m) i.e. along a vertical column of air. The study concludes that in any study related with spatial distribution of LST over a large area, effect of change in elevation at different locations shall also be considered and LSTs at different location shall be rationalized on the basis of their comparative elevations.

1. Introduction

Land surface temperature (LST) is a good indicator of the energy balance at the Earth's surface and one of the key parameters in the physics of land-surface processes on a regional as well as global scale. It combines the results of surface-atmosphere interactions and energy fluxes between the atmosphere and the ground (Mannstein, 1987; Sellers et al., 1988). LST is generally defined as the skin temperature of the surface which refers to soil surface temperature for bare soil, canopy surface temperature of vegetation for densely vegetated ground. For sparse vegetated ground, LST is determined by the temperature of the vegetation canopy, vegetation body and soil surface (Qin and Karnieli, 1999). LST is determined by the effective radiating temperature of the Earth's surface, which controls surface heat and water exchange with the atmosphere (Yuan and Bauer, 2007).

It has been estimated that more than 50% of the world population lives in urban areas, and this percentage is expected to reach to 69.6% by 2050 (United Nations, 2010). Urbanization has been considered as one of the most important drivers of climate change (McCarthy et al., 2010) and a major cause of many environmental issues (Chen et al., 2006). Continued urbanization has resulted in major changes in land use/land cover (LU-LC) pattern over the past two decades (Turkoglu, 2010; Weng, 2007). One of the significant outcomes from the rapid pace of urbanization is the growth in size and number of cities which cause major changes in LU-LC. Drastic growth of built-up areas has led to a significant decrease in the area of agriculture, gardens, water bodies and wasteland (Mosammam et al., 2016). Urban growth analysis using past and present spatial/attribute data, has been considered as one of the essential requirements of urban geographical studies, future scientific planning of cities and the establishment of political policies for substantial city development (Dadras et al., 2015). LST is one of the key parameters controlling the physical, chemical and biological processes of the Earth and is an important factor for study of urban climate (Pu et al., 2006). LST varies in response to the surface energy balance and modulates the air temperature of the lowest

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layers of the urban atmosphere; is central to the energy balance of the surface and affects the energy exchanges that affect the comfort of city dwellers (Voogt and Oke, 2003).

LST can be retrieved from thermal images by single infrared channel method or the split window method, depending on the number of bands used (Pu et al., 2006). Streutker (2002) mentions that with the use of high resolution Earth-monitoring satellites, it has become possible to study effects of urbanization on meteorology and climate change both remotely and on continental or global scales, which is difficult with in situ measurements. Cheval and Dumitrescu (2009) have found that satellite temperature measurements provide better results than the ones obtained from interpolated ground stations. LST is used for a wide variety of scientific studies (Running et al., 1994; Vining and Blad, 1992; Diak and Whipple, 1995; Crago et al., 1995; Kimura and Shimiru, 1994) and it is a key parameter for measuring surface urban heat islands, estimating building energy consumption and evaluating heat related risks (Weng and Fu, 2014; Hu and Brunsell, 2013; Deng and Wu, 2013; Mathew et al., 2016). LST is sensitive to various land surface features and hence can be used to extract information on different LU-LC types (Sinha et al., 2015). Pal and Ziaul (2016) have observed significant LST variations over various LU-LC types in English Bazar Municipality of Malda District in West Bengal, India. Urbanization is the main driving factor of LC changes and consequently rise of LST and steady growth of LST can disturb the ambient habitat for the human beings and other ecosystem members. LST can also be used for drought assessment providing the surface temperature information about the region (Alshaikh, 2015).

Numerous studies have been performed to understand the variations in the LST as a result of changes in the land surface properties. Since the 1960s, scientists have extracted and modeled various vegetation biophysical variables using remotely sensed data and the normalized difference vegetation index (NDVI) is one such widely adopted index (Jensen, 2000). Inverse relationship has been reported between LST and NDVI and it has been concluded that vegetation can lower the surface temperature i.e. vegetation has a cooling effect on the temperature of an area (Gallo and Tarpley, 1996; Weng, 2001). With the increase in availability of remote sensing data from different sensors and improved computation techniques, the study of LST dynamics has taken a big leap. It has been found that a strong linear relationship exists between LST and percent impervious surface area (%ISA) for different study seasons (Yuan and Bauer, 2007). Similarly, strong positive correlation of LST has been observed between %ISA and normalized difference built-up index (NDBI), which suggest that %ISA combined with NDBI can quantitatively describe the spatial distribution and temporal variation of urban thermal patterns and associated LU-LC conditions (Zhang et al., 2009). In a study on different vegetation types of Gujarat state of India, Parida et al. (2008) have found that the desert based agriculture shows the highest surface temperature followed by rainfed agriculture, irrigated agriculture and forest. It has been concluded that the climatic variation is mostly determined by the different types of vegetation cover on the Earth's surface rather than rapid climate change attributable to climatic sources. LST is a transient and highly non-uniform parameter and it is very important to correlate LST with stable environmental features like terrain and land cover (Fan et al., 2014). Near-surface air temperature and LST are important parameters in studies related to variations in hydrology, biodiversity, energy balance and climate change. Their relationship is greatly influenced by various parameters such as vegetation, soil moisture, elevation, interaction among the satellite view, solar zenith angle, terrain gradient, topographic effects etc. (Lai et al., 2012). The response of top soil characteristics with respect to the multi-temporal changes of LST in arid environments has been analyzed using thermal remote sensing data and it has been observed that some of the land surface features show the same LST on a specific time period and also exhibit significant variations in another time period depending on the season (Ali and Shalaby, 2012).

It is a common knowledge that for a stationary atmosphere, the air temperature decreases with increasing altitude within troposphere and this reduction is referred as environmental lapse rate. Environmental lapse rate is the fall in temperature with altitude, at any location, along the same column of air above the ground surface, i.e. in the vertical direction. The environmental lapse rate varies from 5 °C to 10 °C per 1000 m depending on the moisture conditions. While the effect of land surface characteristics such as NDVI, NDBI, %ISA and soil moisture over LST have been studied, the effect of change in elevation over LST i.e. the difference in LST of two points having similar surface and other characteristics but having different elevation, has not been reported. Gallo et al. (1993) have found that the relationship between the urban/rural difference in NDVI and observed differences in minimum temperatures of the respective locations, improve when analysis is restricted by elevation difference between the sample locations. In many studies encompassing LST the study area may range from few square kilometers to several thousand square kilometers and there can be significant variations in the elevations of such a large area. The objective of current research is to determine the dynamics of LST in relation to general terrain of the ground (expressed in form of elevation). It is required to find the change in LST that will be caused due to change in elevation between two points which may be spatially separated in space over a large area and having similar surface characteristics. The availability of such variation can be utilized for apportioning the contribution of other parameters in causing LST variations by offsetting the effect caused by change in LST.

2. Data and methodology

2.1. Study area

The study area is located in Rajasthan state of India and has been taken as a rectangular area between 26°5′ N to 27°54′ N latitude (length approximately 199 km) and 75°6′ E to 76°53′ E longitude (width approximately 178 km) thereby covering total geographical area of approximately 35,500 km^2. Fig. 1 shows the Google Earth image of the study area, also showing district boundaries. The climate of the study area is mostly semi-arid and is characterized by low rainfall having erratic distribution, extremes of diurnal and annual temperatures, low humidity and high wind velocity. Extreme temperatures are recorded within the study area, with maximum air temperatures as high as 48–50 °C in some parts and minimum air temperatures as low as 0–2 °C. The year can be divided into three seasons broadly: the winter season from November to February (average air temperature ranging from 4 to 28 °C), summer season from mid April to June (average air temperature ranging from 32 to 45 °C) and Monsoon season from July to September (with wider fluctuations in daily average air temperature due to atmospheric conditions). The climate of intervening months of March and October is dependent on extent of temperatures during winter and amount of rainfall during monsoon season respectively. The study area is mostly water scarce and it is dependent on groundwater for meeting out water demands for various uses. Vegetation cover and agriculture in the study area is dependent on rainfall during the monsoon season and it decreases significantly during summer season. The soil and vegetation alters depending upon topography and availability of water. Sandy soil is the predominant soil type in the study area. The main feature of geography of the study area is the Aravali range, mostly in north