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Study of Land Surface Temperature Variations with Distance from Hot Spots for Urban Heat Island Analysis

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ABSTRACT

Vegetation cover has been replaced by impervious areas in most parts of the world in recent years thus giving rise to urban heat island (UHI), in which the temperature of urban areas is several degrees higher than non-urbanized areas surrounding them (Streutkar, 2003; Voogt & Oke, 2003). Land surface temperature (LST) data of years 2005 and 2008 from Aqua/MODIS has been used for determination of maximum temperature areas (hot spots) in different imageries. The analysis has been carried out for three seasons of summer, monsoon and winter seasons. These hot spots from different imageries are compared to find the single hot spot which appears in maximum number of images. Variation in mean LST with distance from this hot spot has been analyzed. Very high correlation coefficient of 0.96-0.98 have been obtained between mean LST and distance from hot spot for different seasons. As the temperature ranges for different seasons of a particular year and for different years of a particular season are normally highly variable, it is essential to bring the different dates LST range to same range, by normalization. Normalized land surface temperature (NLST) has been calculated with values between 0 and 1 for studying the relationship between LST and distance from hot spot. The coefficient of correlation between NLST and distance from hot spots for the years 2005 and 2008 are 0.99 and 0.98 respectively, for polynomial relationship of second order, thus indicating that the UHI effect decreases with increase in distance from hot spots..

1. Introduction

All cities of world have witnessed rapid urbanization, which causes the natural landscape having predominantly vegetation cover and pervious areas, converted into built up and impervious area. This impervious area is largely contributed by use of materials like concrete, bricks, tiles etc for buildings and bitumen etc. for roads and parking lots. The introduction of new surface materials coupled with emission of heat, moisture and pollutants dramatically change radiative, thermal, moisture, roughness and emission properties of the surface and the atmosphere above (Roth, 2002). In addition, urbanization also causes generation of large amount of heat by vehicular traffic, industries and domestic buildings. These modifications cause increase in local air and surface temperatures. Surface and atmospheric modifications due to urbanization generally lead to a modified thermal climate that is warmer than the surrounding non-urbanized areas, particularly at night and this phenomenon is referred as Urban Heat Island, UHI (Voogt and Oke, 2003, Zhangyan et. al., 2006, Hung et. al., 2006). Heat islands can be defined for urban surface (surface urban heat island, SUHI), urban canopy layer (UCL) (layer of urban atmosphere extending from surface to mean building height, CLUHI) and urban boundary

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layer (UBL) (layer above UCL that is influenced by the underlying urban surface) (Voogt and Oke, 2003). The study of SUHI has been largely dependent on remote sensing data and land surface temperature (LST) derived from the satellite data is used for that purpose.

LST is generally defined as the skin temperature of the surface which refers to land temperature for bare soil, canopy surface temperature for densely vegetated ground and combination of two in case of sparely vegetated ground. Satellite derived LST has been used for a number of UHI studies (Zhangyan et. al.; 2006, Jusuf et. al., 2007; Yuan and Bauer, 2007; Liang and Weng, 2008; Parida et. al., 2008; Cheval and Dumitrescu, 2009; Khandelwal and Goyal, 2010), in which LST dynamics with one or more of surface biophysical properties and urbanization has been studied. The area considered for the studies varied from small blocks (Liang and Weng, 2008) to several cities (Hung et. al., 2006). For example, Zhangyan et al. (2006) studied UHI of Beijing city and found that average urban LST was 4.5 and 9 ^{o}C higher than the temperature in suburban and outer suburban areas respectively. Negative correlation was also found between LST and Normalized Difference Vegetation Index (NDVI) in urban area. Yuan and Bauer, 2007, investigated the relationship between the LST, percent impervious area (%ISA) and NDVI and concluded that percent impervious area is an accurate indicator of SUHI effects with strong linear relationship between LST and %ISA for all study seasons. Khandelwal and Goyal (2010) investigated the relationship of LST with NDVI, enhanced vegetation index (EVI) and road density (RD) and found negative polynomial relationship of second order between LST and both the vegetation indices, NDVI and EVI. However the relationship between LST and RD was positive.

LST has been computed from different satellite data such as Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) (Yuan and Bauer, 2007, Liang and Weng, 2008), NOAA AVHRR (Streutker, 2002), MODIS (Hung et. al., 2006, Parida et. al., 2008) etc. LST computed from thermal infrared data of Moderate Resolution Imaging Spectroradiometer (MODIS) is freely available and has been used for the present study. In most of the UHI studies discussed above, the central business area is normally the hottest part of the study area, whereas the outer periphery of the study area has the lowest range of temperatures. Major objective of the present research is to study the variations in LST with distance from that part of the study area which consistently encounters maximum temperature range. Such point that remain hot compared to other parts of the study area are referred as hot spot (HS).

2. Methods and Results

2.1 Study area

The study area chosen is Jaipur city, the capital of the state of Rajasthan, India. The city is located on a predominantly flat plain and is surrounded by hills on the north, north-east and east sides. Due to the hills, the development of the city has been more along south and west. The part of city closer to the hills is characterized by mostly built-up and paved areas having very less vegetation cover. Rest of the city has a mixture of barren land, low to medium height vegetation and built-up areas in form of buildings, roads, industries etc. The climate of the city is arid with high temperatures during summers and low temperatures during winter nights. Figure 1 shows the study area for the present study in which MODIS yearly land cover dynamics of 2008 was used to extract the urban boundary of Jaipur city. The Jaipur urban area polygon from land cover dynamics image was automatically converted by using Raster to Polygon conversion tool. A preliminary analysis indicated that a buffer of 12 km is sufficient to include rural belt outside the city area and therefore Buffer tool with 12 km distance outside the urban boundary was used to mark the boundary of study area as shown in fig. 1. The study area has mainly three seasons and the study has been carried out for all three seasons namely summer, monsoon and winter season.

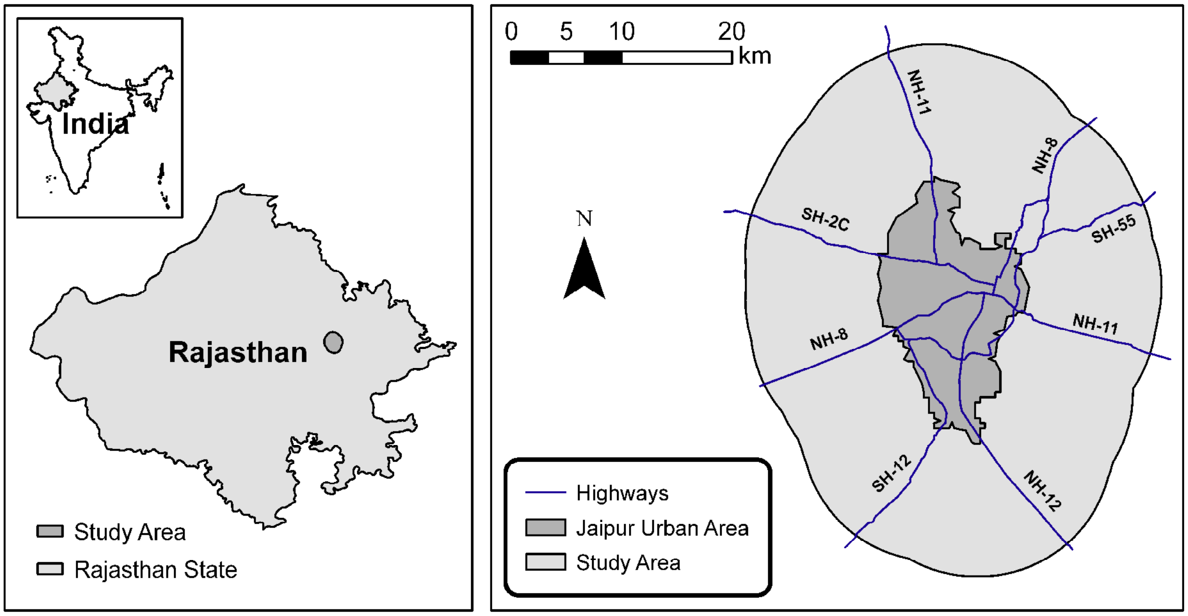

Fig. 1: Study Area

2.2 LST Data

Moderate Resolution Imaging Spectroradiometer (MODIS) is a sensor on board Terra and Aqua platforms that provides information about the Earth's surface in 36 wavebands covering the visible, near-infrared, shortwave infrared (SWIR) and thermal ranges. Land surface temperature and emissivity product, MYD11A2 of Aqua-MODIS has been used in the present study. MYD11A2 is an eight-day LST product by averaging from two to eight days of the clear-sky MYD11A1 daily product of Aqua-MODIS and has 12 Science Data Sets (SDS) layers (Wan, 2007). MODIS is particularly useful for the LST product because of its global coverage, radiometric resolution and dynamic range for a variety of land cover types. It has high calibration accuracy in multiple thermal infrared bands designed for retrievals of SST (Sea Surface Temperature), LST and atmospheric properties (Wan, 1999). A split-window algorithm is used for calculating LSTs. The day/night LST method retrieves land-surface temperature and band emissivity simultaneously from pairs of daytime and nighttime MODIS data in seven TIR bands.

LST composites were downloaded from Land Processes Distributed Active Archive Center (LP DAAC) website using NASA Warehouse Inventory Search Tool (WIST). The downloaded data is in HDF-EOS format and in Sinusoidal Projection System (Land Processes Distributed Active Archive Center, 2010). The data was re-projected from Sinusoidal projection to UTM Zone 43N projection system with WGS84 datum and was reformatted from HDF-EOS to GeoTIFF format. In order to investigate the relationship of LST with hot spots, 8 day LST for day numbers 121-128 (first week of May) representing summer season, day numbers 265-272 (last week of September) representing monsoon season and day numbers 001-008 (first week of January) representing winter season is used. The study has been carried out for all three seasons of 2005 and 2008. Night time LST (here after referred as LST only) has been used for the present study. The raster cell size of MODIS LST product is approximately 926 m.

2.3 Image Processing

The downloaded MODIS LST is of a very large area and the raster image corresponding to study area was extracted. Figure 2 shows the LST variations over the study area for all three seasons of 2008. It can be seen from the images that the highest temperature range is concentrated consistently in the central area and the outer boundary of the study area has lowest temperature range.

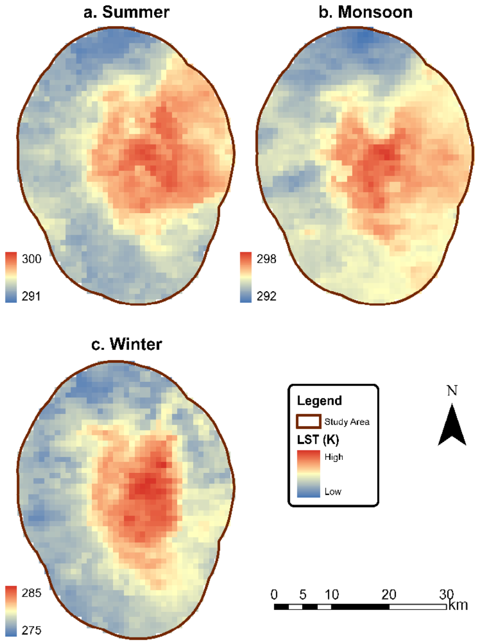

Fig. 2: LST Image for three different seasons

The LST images of the study area were analyzed for identifying maximum temperature pixels and it was seen that the maximum temperature pixel was variable for different seasons and years. Hot spot has been defined as the pixel which remains in the higher temperature range for maximum images. LST data of both the years of 2005 and 2008 has been used for determination of such hot spot in different imageries. The hot spots from different imageries are compared to find the single hot spot which appears in maximum number of images and the same has been shown in figure 3. After identifying the HS, the distance of all the pixels from hot spot is found and the distance image is also shown in figure 3. The Distance from HS (DHS) varies up to 26.2 km.

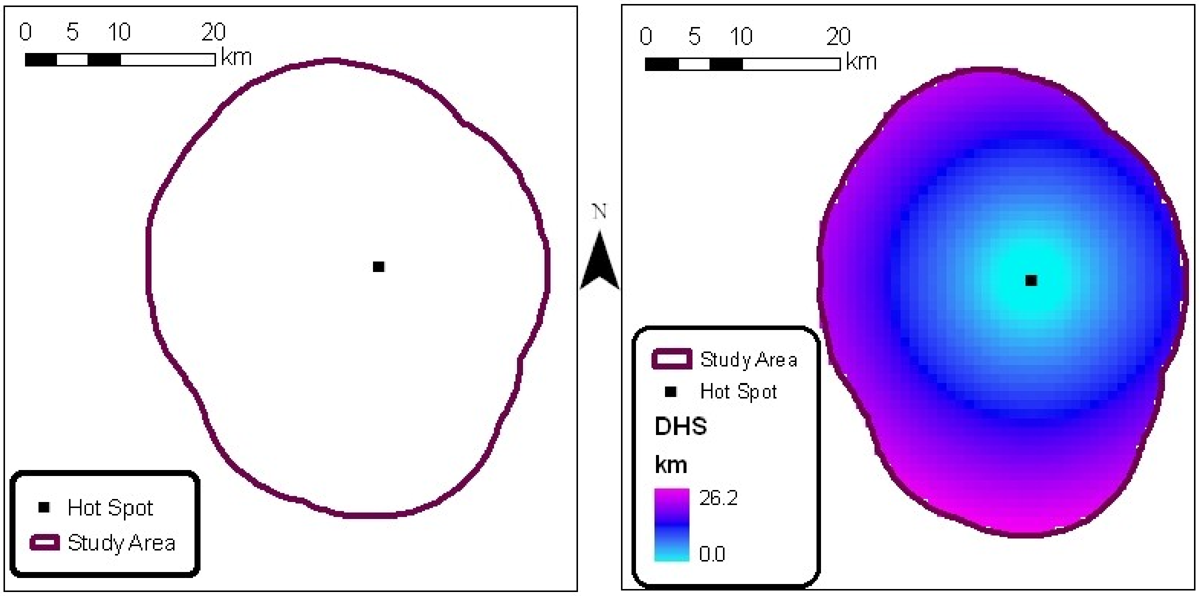

Fig. 3: Hot Spot location and Distance from Hot Spot image

To investigate the relationship of LST with DHS, a zonal analysis was done to calculate mean value of LST at each 1km increment of DHS. A clear falling trend was found between LST and DHS. Figure 4a and b show the relationship between LST and DHS for all three seasons of year 2005 and 2008 respectively. The polynomial relationship of second order between LST and DHS has been found. Figure also show the equation and coefficient of correlation of the relationship. It can be seen from the figure that the equation of relationship between LST and DHS for a particular season is almost similar for both the years thus indicating a consistent pattern of the relationship for a particular season. The coefficient of correlation is very high and its values are 0.96, 0.98 and 0.98 respectively for summer, monsoon and winter season of year 2005. Corresponding values for the year 2008 are 0.96, 0.96 and 0.98. The difference in equations for different seasons may be due to the different temperature range for different seasons.

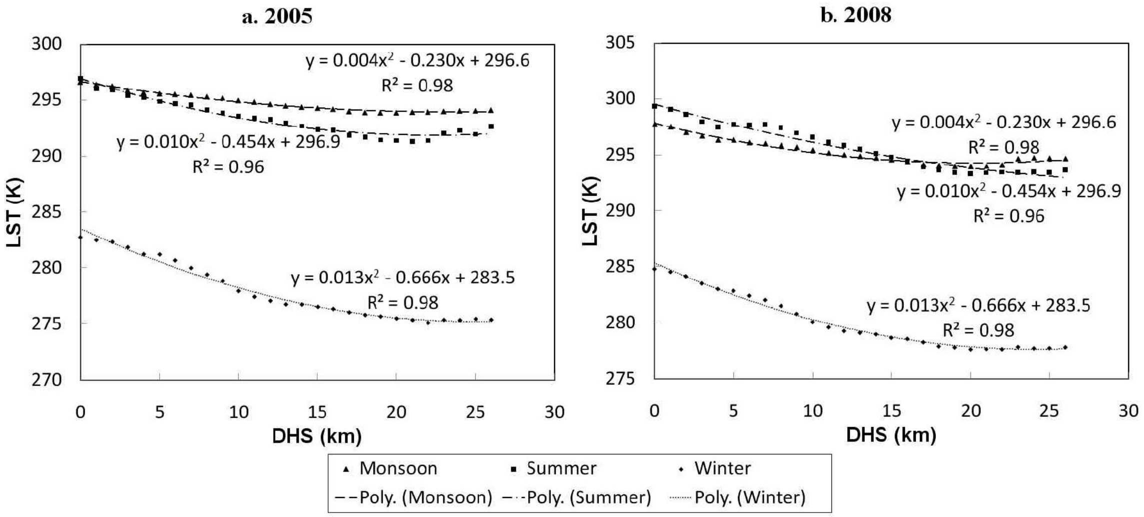

Fig. 4: Relationship of LST and distance from HotSpot for different seasons of 2005 & 2008

To further investigate the relationship of LST with DHS for entire year without considering the season, it is important to bring temperature range of different seasons within same range. Therefore a Normalized LST (NLST) index has been defined in equation 1 below, which is the normalized LST of that cell.

$$\mathrm{NLST_{Cell}} = \frac{(\mathrm{LST_{Cell}} - \mathrm{LST_{min}})}{(\mathrm{LST_{max}} - \mathrm{LST_{min}})} \times 100 \qquad (1)$$

where

$\mathrm{LST_{Cell}}$ = LST of a particular cell
$\mathrm{LST_{min}}$ = Minimum LST for the Study Area of that particular Image
$\mathrm{LST_{max}}$ = Maximum LST for the Study Area of that particular Image

The range of $\mathrm{NLST_{Cell}}$ is between 0 and 100. Figure 5 shows the relationship between NLST and DHS and the relationship is very strong for the both 2005 and 2008 with R^2 value of 0.99 and 0.98 respectively. The curves follow almost the same trend for most of the part and the relationship equation is also almost same thus indicating that the relationship between NLST and DHS is not only independent of season but also it is not dependent on year.

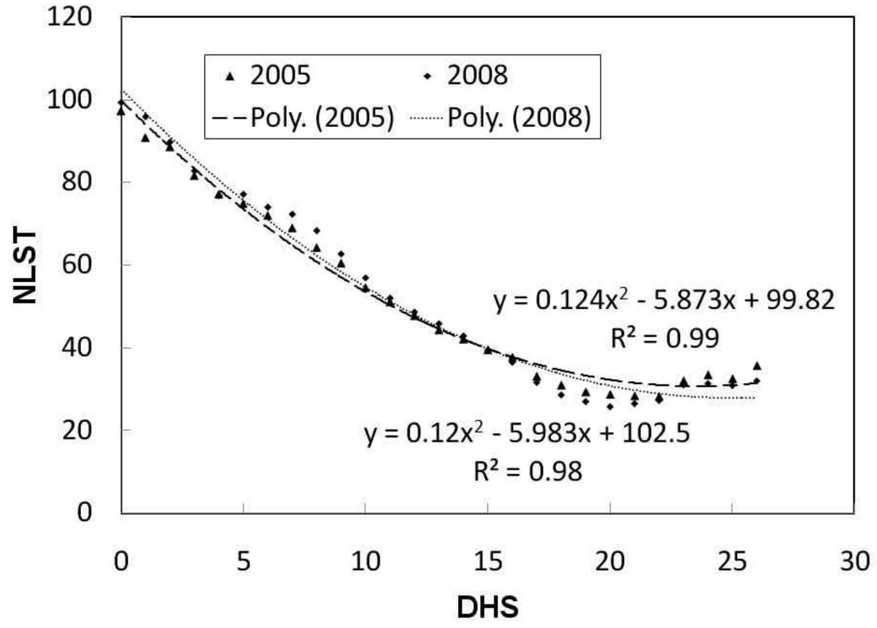

Fig. 5: Relationship of NLST with distance from Hot Spots for different years

3. Conclusions

Relationship between night time LST and distance from hot spots in urban areas has been studied in this paper, where hot spots is defined as a spot where night surface temperatures are consistently higher. It is found that the LST decreases with increase in DHS. Coefficient of correlation for polynomial relationship of second degree is found to vary between 0.96 to 0.98. Relationship is also found between normalized LST and DHS. This relationship is also consistent with R^2 values of 0.98 and 0.99 for years 2005 and 2008 respectively.

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