Effect of Vegetation and Urbanization over Land Surface Temperature: Case Study of Jaipur City

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Abstract. The introduction of new surface materials coupled with emission of heat, moisture and pollutants change radiative, thermal and emission properties of the surface and the atmosphere above [1]. Such modifications, normally due to urbanization, lead to a modified thermal climate which is warmer than the surrounding non-urbanized areas, particularly at night [2]. The objectives of present research are to analyze the spatial pattern of the night land surface temperature (LST) observed by remote sensing satellites and to investigate the effect of vegetation and urbanization over LST of Jaipur city, India. Enhanced vegetation index (EVI) has been used as an indicator for vegetation level and road density for level of urbanization. The study has been undertaken for summer, monsoon and winter seasons. Since the average night temperatures for different seasons are different, Normalized LST (NLST) for each season was calculated using maximum and minimum temperatures of that image. Road network map was used to calculate road density (RD) per pixel. It was found that about 3% pixels with highest RD values, representing highest level of urbanization, had lowest EVI values. It was also observed that all the pixels in the lower 25% range of NLST values were only those pixels where RD value was less than 5, indicting correlation between NLST and RD. In winter season, a reasonable good negative correlation is seen between EVI and NLST. For pixels having zero RD, representing non-urbanized areas, no correlation was found between NLST and EVI. Study concludes that even though there is some correlation between LST, EVI and RD, effect of some other parameters such as elevation and distance from hotspots needs to be further investigated.

Keywords. Urban Heat Island, Land Surface Temperature, EVI, MODIS, Road Density

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 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 [1]. 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. This phenomenon is referred as Urban Heat Island, UHI [2,3,4]. 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 layer (UBL) (layer above UCL that is influenced by the underlying urban surface) [2]. The study of SUHI has been largely dependent on

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remote sensing data. Land surface temperature (LST) derived from the satellite data has extensively been used for SUHI studies.

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 sparsely vegetated ground. Satellite derived LST has been used in many studies [3,5,6,7,8,9]. The area considered for the studies varied from small blocks [7] to several cities [4]. Hung et al. [4] studied UHI effect in eight cities and found that the selected cities were experiencing intense SUHIs in the range of 5-8°C in the dry season of 2001-2002. Zhangyan et al. [3] studied UHI of Beijing city and found that average urban LST was 4.5 and 9°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 [6] 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.

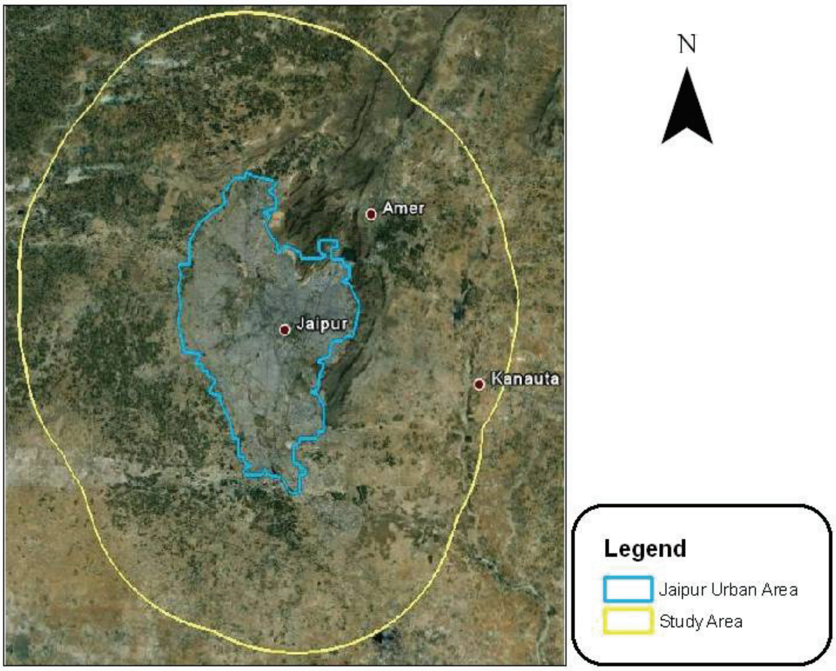
LST has been computed from different satellite data such as Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) [6, 7], NOAA AVHRR [10], MODIS [4, 8] etc. LST computed from thermal infrared data of Moderate Resolution Imaging Spectroradiometer (MODIS) is freely available and has been used for the present study. MODIS products include two vegetation indices. One is the standard normalized difference vegetation index (NDVI), which is similar to the NOAA-AVHRR derived NDVI and is calculated from radiations of near-infrared and visible bands. The other is an 'enhanced' vegetation index (EVI) which is calculated similarly to NDVI but with improved sensitivity into high biomass regions and improved vegetation monitoring through a decoupling of the canopy background signal and a reduction in atmosphere influences [11]. The MODIS Enhanced Vegetation Index (EVI) product is computed from atmospherically corrected bi-directional surface reflectance that has been masked for water, clouds, heavy aerosols, and cloud shadows. EVI minimizes canopy background variations and maintains sensitivity over dense vegetation conditions. The EVI also uses the blue band to remove residual atmosphere contamination caused by smoke and sub-pixel thin clouds [12].

The effect of urbanization has long been studied and its effects have been reported on soils [13], temperature and environment [14], stream habitat [15], groundwater [16] and even dietary habits [17]. The degree of urbanization keeps on increasing as the city develops. Extent of urbanization increases with increase in population density which results in increase in percent impervious area and road density. Since road map of urban area is normally available, road density of that area can be easily calculated. In the present study, road density has been considered as an indicator of degree of urbanization.

The objectives of this research are to investigate the effect of vegetation and urbanization over LST of Jaipur study area, using EVI as an indicator for vegetation level and road density for degree of urbanization.

1. Study Area

The study area chosen is Jaipur city (Figure 1), the capital of the state of Rajasthan, India. According to the census of 2001 the urban population was 2,322,575 [18]. 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 city is normally considered in two parts namely the old city (walled city, enclosed by high walls, constructed during initial period of development of the city almost 300 years back) and the city outside the walled city. The old city is closer to the hills and is characterized by mostly built-up and paved areas having very less vegetation cover. The outer 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.



Source: Base map from Google Earth

Figure 1. Study Area

In order to study the UHI, it is important that the urban boundary of Jaipur city is first defined. MODIS yearly land use/land cover map of 2008 was used to extract the urban boundary of Jaipur city. The urban area polygon from land use/land cover map was automatically converted by using Raster to Polygon conversion tool. Then a buffer area around urban boundary, including rural belt is taken as study area. A preliminary analysis indicated that a buffer of 12 km outside of the urban boundary is sufficient to include rural belt outside the city area and therefore ArcGIS Buffer tool with 12 km distance outside the urban boundary was used to mark the boundary of study area as shown in Figure 1. East to West and North to South dimensions of the study area are approximately 38 km and 48 km respectively.

2. Data and Methodology

Eight day, 1 km MYD11A2, land surface temperature and emissivity product [19] and 16 day 250 m MYD13Q1, vegetation indices product of MODIS Aqua of overlapping dates have been used for the study. The study has been undertaken for three different periods of summer, monsoon and winter seasons of the year 2008/2009. The composites of the study area were downloaded as per Table 1.

Table 1. MODIS Products and data used for the present study

MODIS Product	Platform	Short Name	Season	Day No. (Period)	Year
Land Surface Temperature and Emissivity	Aqua	MYD11A2	Winter	001 (00:00:00 hrs on 1 Jan to 23:59:59 on 8 Jan)	2009
			Summer	121 (00:00:00 hrs on 1 May to 23:59:59 on 8 May)	2008
			Monsoon	265 (00:00:00 hrs on 22 Sep to 23:59:59 on 29 Sep)	2008
Vegetation Indices	Aqua	MYD13Q1	Winter	361 (00:00:00 hrs on 27 Dec to 23:59:59 on 11 Jan)	2008/ 2009
			Summer	121 (00:00:00 hrs on 1 May to 23:59:59 on 16 May)	2008
			Monsoon	265 (00:00:00 hrs on 22 Sep to 23:59:59 on 7 Oct)	2008
Land cover Dynamics	Combined Aqua and Terra	MCD12Q2	All	Yearly	2008

These products 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. MYD11A2 [20] and MYD13Q1 products have 12 Science Data Sets (SDS) layers each and MCD12Q2 has 16 SDS layers. MODIS Reprojection Tools (MRT) [21] was used to reproject, subset and change format of downloaded data. The format of the data was changed from HDF-EOS to GeoTIFF. The data downloaded was of a very large area and sub setting of the data was done within 27.9°N, 75.1°E (upper right corner) to 26.1°N, 76.9°E (lower right corner) coordinates. Data from Sinusoidal projection was re-projected to UTM projection system with WGS84 datum (Zone 43N). The data in GeoTIFF format was then analyzed using ArcGIS software. LST_Night_1km layer of MYD11A2, 250 m_16 days_EVI layer of MYD13Q1 and Land_Cover_Type_1_ Assessment layer of MCD12Q2 product were used for the study. The MYD11A2 product is available with quality flag and the same was checked to include only the good quality pixels in the analysis.

The MODIS product MYD13Q1 gives vegetation indices at approximately 231 m ground resolution, whereas MYD11A2 product for Night LST, henceforth referred as LST, has a resolution of approximately 926 m. In order to compare EVI with LST it is important to have both of them at same resolution and hence EVI layers were aggregated to the same resolution as of LST layer and they were also snapped to LST image.

The road map of Jaipur city and its surrounding area was prepared by on-screen digitization. The roads were divided into three categories namely, highways and major roads; main roads and secondary roads and streets. These three categories are distinctly visible on Google Earth [22] at different zoom levels. The roads were digitized on screen over the roads visible on Google Earth. The digitized roads were then thoroughly checked for duplication/omission/errors. Figure 2 shows the LST and EVI images of study area for May 2008 and the road network layer of the study area.

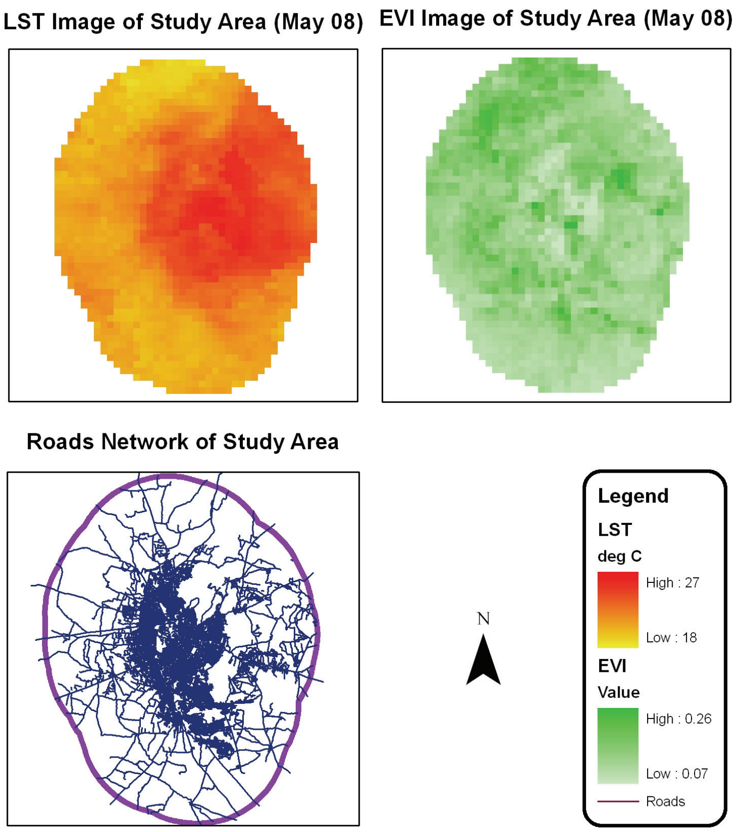


Figure 2. LST Image, EVI Image and Road Network of Study Area

The study area is mainly water scarce area and is dependent on rainfall during monsoon season which is from July to September. Most of the water requirements of the vegetation are normally met during the monsoon season. The months of April to June are characterized by very high temperatures with frequent dust storms. Vegetation cover during this period is minimal with most of the area having bare soil cover. During the monsoon season the vegetation cover starts increasing due to availability of water. The months of December to February are cold with very low temperatures during nights. This is also evident from the maximum and minimum values of *LST* for different seasons which are 26.4 and 18.6^{o} C for May 2008; 24.8 and 19^{o} C for October 2008; 11.9 and 2.7^{o} C for January 2009 respectively. As the variation in maximum and minimum values of LST is high for different data sets, *LST* was normalized as below:

$$NLST_{date} = \frac{LST_{date} - LST_{\min date}}{LST_{\max date} - LST_{\min date}} \qquad (1)$$

where $NLST_{date}$ is normalized *LST* value for a particular pixel on a particular day; LST_{date} is the *LST* value for that pixel for the same day; $LST_{min\ date}$ and $LST_{max\ date}$ are the minimum and maximum *LST* values, within the study area, for that day.

A road network map was used to calculate road density (RD) per pixel using "Line Density" tool of ArcGIS software. ArcGIS calculates line density as a magnitude per unit area from polyline features that fall within a radius around each cell. Density is calculated in units of length per unit of area. Radius of 655 was used so that it covered one complete cell of approximately 926 m. Cell size for density layer was kept same as that of LST layer. For the study area, value of RD varies from zero to 26.8 km per square km.

After resampling and snapping the remaining layers to LST layer, values of LST, EVI and RD was extracted and $NLST_{date}$ calculated for each pixel. 1598 data points were generated for the study area corresponding to each image date corresponding to three study seasons. In order to study the effect of RD and EVI over LST simultaneously for all the three data sets, RD was divided in four categories. All the pixels with zero RD, falling mainly in rural belt and undeveloped area were kept in category '0'; those having RD between zero and five in category '1'; RD between 5 to 10 in category '2' and remaining in category '3'. Figure 3 shows categorized RD image of the study area.

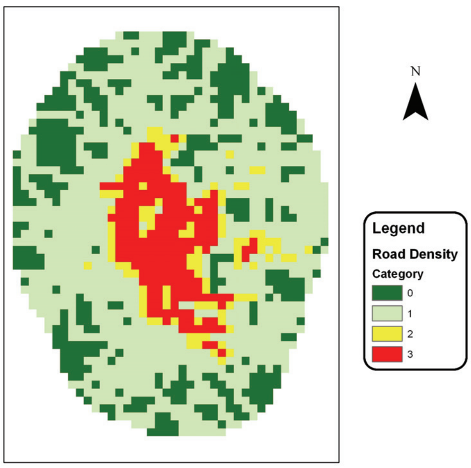


Figure 3. Categorized Road Density Image

3. Results and Discussions

The extracted values of EVI were plotted against NLST values for the study area for different RD categories as shown in Figure 4. The study seasons have been indicated in different colours (green, red and yellow for winter, summer and monsoon season respectively). Similarly RD category has been indicated using different shapes of the symbols. It is seen from the plot that summer EVI values are very low ranging from 0.1 to 0.2, whereas the monsoon EVI values are higher than summer EVI Values, ranging from 02 to 0.45 and the winter EVI values are within the complete range. This is due to the dependence of vegetation, for growth, on rainfall during monsoon season.

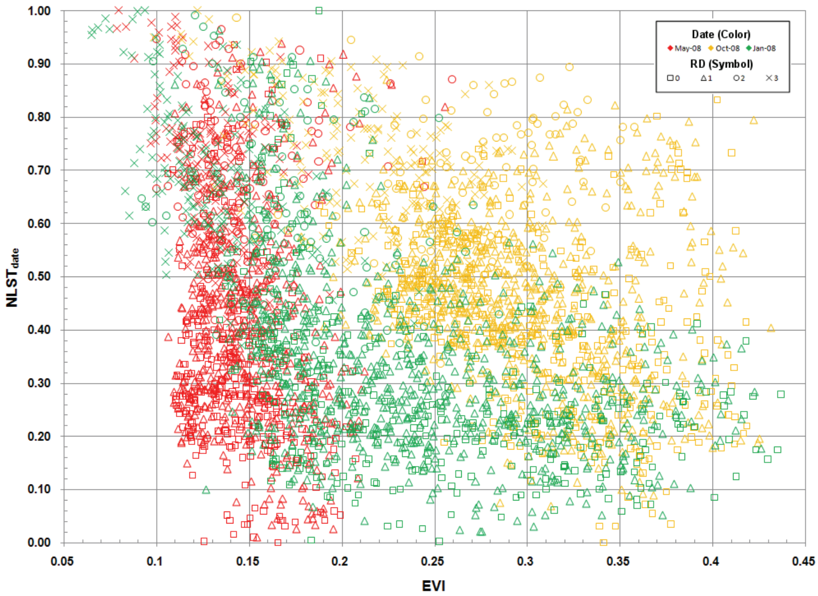


Figure 4. Scatter plot of $NLST_{date}$ and EVI for Different RD for all three dates

Rainfall provides the necessary supply of water and consequent increase in vegetation cover, indicated by relatively high EVI values. During winter season the supply of water decreases and the vegetation cover and its density reduces, indicated by complete range of EVI values. Further due to high temperatures and scarcity of water in summer season the EVI values are very low. It can also be seen from the scatter plot that higher values of $NLST_{date}$ mostly comprise of high RD pixels (represented by cross and round symbols), where as lower values mostly comprise of low RD values (represented by triangle and square symbols). This indicates that road density effects the LST (indicated by NLST) of an area and there exists an inverse relationship between road density and surface temperatures. Careful study of the plot shows that approximately 3% pixels with highest RD values representing highest level of urbanization have lowest EVI values, indicating that urbanization leads to reduction of vegetative cover and consequent increase in surface temperatures. All the pixels having the lower 25% range of NLST value were only those pixels where RD value was less than 5. A distinct trend visible only in the January is that for lower EVI values the NLST values are only on the higher range whereas for higher EVI values the NLST values area only on the lower range, indicating inverse relationship of EVI and surface temperatures. The category ‘0’ representing RD value of zero has very high variation in EVI and NLST values and this indicates that there are other factors also responsible for variation in LST like elevation etc. and need to be further investigated.

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