RESEARCH PAPER:

The evaluation of heat island effect in various cities in Ganga-Yamuna Doab region using modis land surface temperature product

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SUMMARY

MODIS satellite provides the reflected spectral signature from earth surface for the 36 spectral bands, which are used as input for preparing the various thematic map of world on different scales *i.e.*, daily NDVI (greenness), snow and ice products, Land cover, reflectance, land surface temperature etc. In present study the Land Surface Temperature (LST) product was used to characterize the Urban Heat Island (UHI) for few of the cities in doab region of Yamuna and Ganga. It was based on comparing the day and night time LST images of these cities in the region for June 2006. Results suggested that Urban Heat Island phenomena is well established in Delhi, and also for even in small city like Aligarh, and Agra. In the Delhi region, the night time UHI factor for land surface temperature ranged (6-8 ^{O}C), while for the day time the range of UHI factor was surprising high (4-12 ^{O}C). The small city like Aligarh showed that the day time UHI factor ranged (4 - 8^{O}C), while in night time it ranged (4 - 6^{O}C). In the Agra city the UHI factor during night time ranged (5 – 5.5 ^{O}C), while in day time UHI factor was about 3 – 6 ^{O}C.

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Higher temperature in centre urban cities than that in suburbs is called urban heat island (UHI). This effect is mainly contributed by the densely built-up area in cities along with local climate and land use. The continuous increase in built-up along with engulfing of the green areas between two built up areas resulting in higher intensity of UHI effect in the cities. It results increase in atmospheric temperature in summer time which causes various type of physiological disorders for the vulnerable population of the society specially for children and old persons. UHI effect leads to heat-related diseases and even deaths during summer. It can cause physiological disruption, heat strokes, organ damage which may lead to even death, especially prone populations such as the elderly and children. The continuous exposition of the human body above 40 ^{0}C temperature causes heatstroke and related disorders. The continuous high temperature may cause acute renal failure, coagulation disorders, metabolic acidosis, respiratory alkalosis, acute hepatic necrosis, rhabdomyolysis, hypoelectrolytaemia and leukocytosis (Sharma, 2006a; Bouchama *et al.,* 2007; Sriramachari, 2004; Sharma, 2006 b).The impact of increase in urban environment temperature due to urban heat island along with global warming may cause to increase in heat related problem in coming future. The early mitigation of this problem needed the study of the urban heat island in all size of cities, which were presently conducted only in big cities.

It is important to understand and forecast the different stages of the heat island effect intensity and their development in different stages in different cities. UHI studies require numbers of the meteorological stations at various places in the cities to observe the temporal and spatial variation in atmosphere characteristics. The maintenance and establishing of these stations require logistics, finances and man power; therefore these studies were conducted only for limited cities. But the recent development of the remote sensing observation made such studies feasible at low cost and maintenances. The numerous remote sensing platforms were used for various studies in recent years related to assessment of spatial variation of temperature regime in the cities (Ramachandra, 2009; Balling and Brazell, 1988; Carnahan and Larson, 1990; Gallo and Owen, 1998; Gallo *et al.,* 1993; Kato and Yamaguchi, 2005). Thermal remote sensing imageries were used in assessment of the spatial distribution of land surface temperature in Delhi during day time observation. Now, the MODIS (Terra and Aqua) satellites provide the opportunities to study the land surface temperature of any place of the earth in day and night time. This facility provides the opportunity to study the spatial distribution of land surface temperature in day and night, which can be used as characteristics of the urban heat island in various cities (Jin *et al.,* 2005; Hung *et al.,* 2006; Chen *et al.,* 2009; Hongjie *et al.,* 2005).

In present study, the characteristics of the urban heat island phenomen on was studied using day and night MODIS imageries. The results have been examined the scale of UHI effect in various stages of socio –economic cities in relatively same geographical and atmospheric environments.

MODIS land durface temperature algorithm:

The Moderate Resolution Imaging Spectro radiometer (MODIS) on board, the first EOS platform (called Terra), which was successfully launched on 18 December 1999, provides a new opportunity for global studies of atmosphere, land, and ocean processes, and for satellite measurements of global LST. The strengths of MODIS include its global coverage, high radiometric resolution, appropriate dynamic ranges, and accurate calibration in thermal infrared bands designed for retrievals of sea-surface temperature, LST and atmospheric properties.

The generalized split window LST algorithm:

The LST of clear-sky pixels in MODIS scenes is retrieved with the split-window algorithm in a general form:

$$T_S = C + (A_1 + A_2\frac{1-\varepsilon}{\varepsilon} + A_3\frac{\Delta\varepsilon}{\varepsilon^2})\frac{T_{31}+T_{32}}{2}$$

$$+ (B_1 + B_2\frac{1-\varepsilon}{\varepsilon} + B_3\frac{\Delta\varepsilon}{\varepsilon^2})\frac{T_{31}-T_{32}}{2}$$

where $\varepsilon = 0.5\,(\varepsilon 31 + \varepsilon 32)$, and $\varepsilon = \varepsilon 31 - \varepsilon 32$ are the mean and the difference of surface emissivities in MODIS bands 31 and 32. T_{31} and T_{32} are brightness temperatures in the two split-window bands. The coefficients C, *Ai* and Bi, *i* = 1, 2, 3 are given by interpolation on a set of multi-dimensional look-up tables (LUT) (Hall *et al.,* 1995; Wan and Dozier, 1996). The LUTS were obtained by linear regression of the MODIS simulation data from radioactive transfer calculations over wide ranges of surface and atmospheric conditions. Improvements for the generalized split window LST algorithm incorporated in the establishment of the LUTS include: (1) view-angle dependence, (2) column water vapor dependence, and (3) dependence on the atmospheric lower boundary temperature. The view-angle dependence is kept in one dimension of LUTS for a set of viewing angles covering the whole MODIS swath so that LST can be retrieved at higher accuracies for pixels at both small and large viewing zenith angles. The column water vapor dependence is kept in another dimension of LUTS for a set of overlapping intervals of column water vapor so that the water vapor provided in the MODIS atmospheric product is used as the most likely range of water vapor rather than its exact value because the uncertainties in the atmospheric water vapor may be large. Similarly, the atmospheric lower boundary temperature *(T)* provided in the MODIS atmospheric product is also used to improve the LST retrieval accuracy. The band emmissivities, also called classification-based emissivities(Snyder and Wan,1997 and Snyder *et al.,* 1998) are estimated from land cover types in each MODIS pixel through TIR BRDF and emissivity modeling. In the at-launch MODIS LST processing, the University of Maryland IGBP-type land-cover based on AVHRR data in 90s used to provide global land cover information at 1 km grids. Errors and uncertainties in the classification-based emissivities may be large in semi-arid and arid regions because of the large temporal and spatial variations in surface ernissivities.

The MODIS day/night LST algorithm:

A physics-based day/night algorithm (Wan and Li, 1997) was used to retrieve surface spectral emissivity and temperature at 5km resolution from a pair of daytime and nighttime MODIS data in seven TIR bands (bands 20, 22, 23, 29, and 31-33). The inputs to this algorithm includes the MODIS calibrated radiance product, geo- location product, atmospheric temperature and water vapor profile product, and cloud mask product. In our knowledge, this day/night algorithm is the first LST algorithm that has a limited capability to adjust the uncertainties in atmospheric temperature and water vapor profiles for a better retrieval of the surface emissivity and temperature. In the day/night algorithm, there are 14 unknown variables, 7 band emissivities, surface temperature, atmospheric temperature at the surface level and column water vapor, for daytime and night time, respectively, and an anisotropic factor of the solar beam BRDF at the surface.

Area of study:

In present study, the heat island effect was evaluated for three cities (Delhi, Aligarh and Agra) located in the doab Ganag – Yamuna region. The land of these cities is covered by fluvial deposits by two river Ganga and Yamuna. The fertile soil of doab region along with irrigation facilities in this region provided opportunity for good agriculture production. The selling and buying of the agriculture products at these cities resulted in development of cities in medieval time, which further grown in colonial period with development of small industries. At present these cities are under rapid growth of urbanization due to migration of the people from surrounding rural areas to accesses the city facilities.

Experimental Methodology

In present study, three cities were selected for analyzing UHI (Urban Heat Island) phenomena. The cities are Delhi, Aligarh and Agra and all three cities are situated on the fluvial sand deposited by Yamuan and river Ganga. The MODIS LST product with 1 km spatial resolution ordered through WIST for the dated 26th June 2006 for the study area.

For each of the city, the four vector lines were generated crossing each other over the city by 600, covering city centre and suburb region. The land surface temperature (LST) for each pixel along these lines was extracted using Geomatica 10.01.01 from the day and night land surface temperature images.

Experimental Findings and Discussion

In this study, the nature of urban heat island were analyzed for different cities in Ganga Yamuna, doab region of India based on MODIS land surface product images (Fig. 1 and 2).

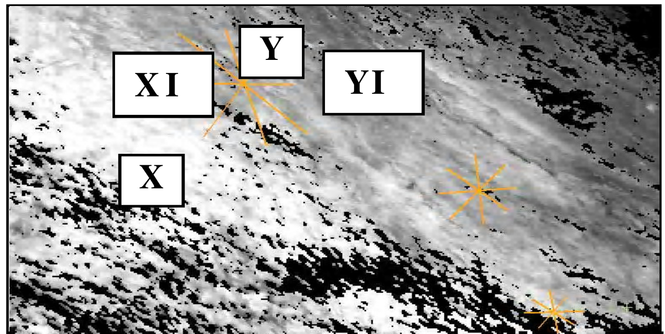

Fig. 1 : Day time LST of the study area, indicating location of the Delhi, Aligarh and Agra

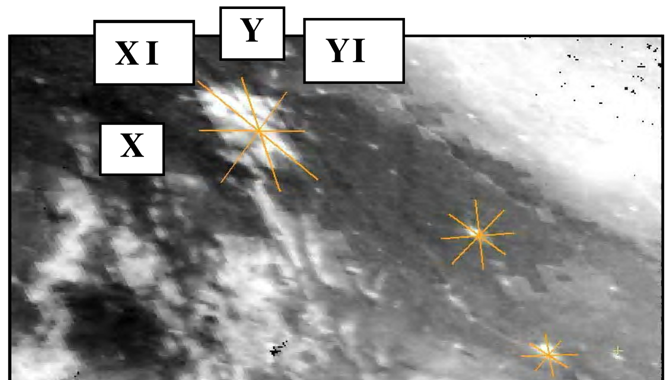

Fig. 2 : Night time LST of the study area, indicating location of the Delhi, Aligarh and Agra

The maximum, minimum land surface temperature during day and night time in the centre of the city and surrounding rural areas along X, Y, X1, Y1 profile are shown in Table1.The nature of urban heat island phenomena has been discussed separated for each city.

Table 1: Maximum, minimum land surface temperature observed along X,Y, X1 and Y1 profile at various cities in Doab region

			X Profile	Y Profile	X1 Profile	Y1 Profile	Average
Delhi	Day	Maximum temperature	46.92	49.32	48.82	50.82	48.97
		Minimum temperature	43.26	37.76	41.4	38.82	40.31
		HI	4	12	7	12	9
	Night	Maximum temperature	25.44	27.44	27.16	26.32	26.59
		Minimum temperature	19.32	19.78	20	18.78	19.47
		HI	6	8	7	8	7
Aligarh	Day	Maximum temperature	46.38	45.88	47.2	48	46.865
		Minimum temperature	42	42.76	42.32	40	41.77
		HI	4	3	5	8	5
	Night	Maximum temperature	20.55	20.88	20.38	20.5	20.5775
		Minimum temperature	26.5	25.32	26.66	25.88	26.09
		HI	6	4	6	5	5
Agra	Day	Maximum temperature	49.04	49.6	49.54	49.6	49.445
		Minimum temperature	44.94	43.88	46.64	43.88	44.835
		HI	4	6	3	6	4.75
	Night	Maximum temperature	26.55	27.32	27	27	26.9675
		Minimum temperature	21.5	21.9	22.1	21.7	21.8
		HI	5	5	5	5	5

Temperature in degree Celsius

The simplified contour map of the MODIS land surface temperature of cities along the the radial vectors x, y, x1 and y1 and land surface temperature of the day and night time are shown in Fig. 3, 4, and 5.

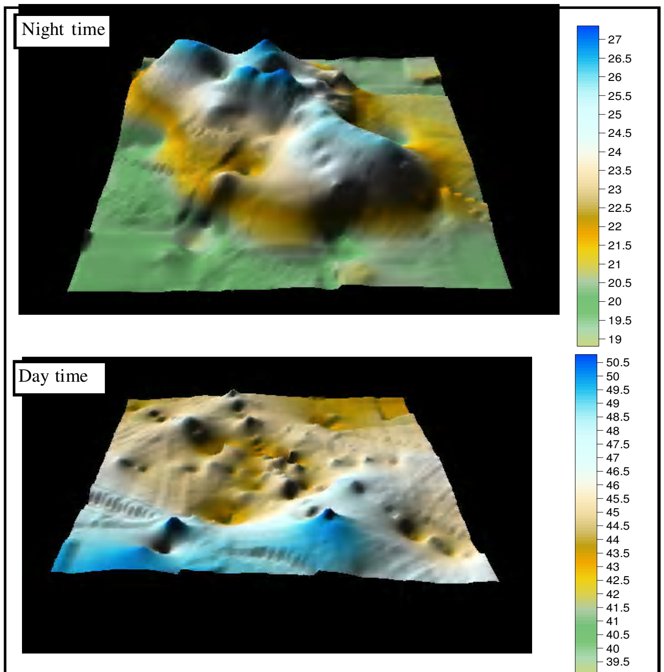

Fig. 3 : Simplified spataial distribution of the land surface temperature in Delhi in day and night time (Temperature in Celsius)

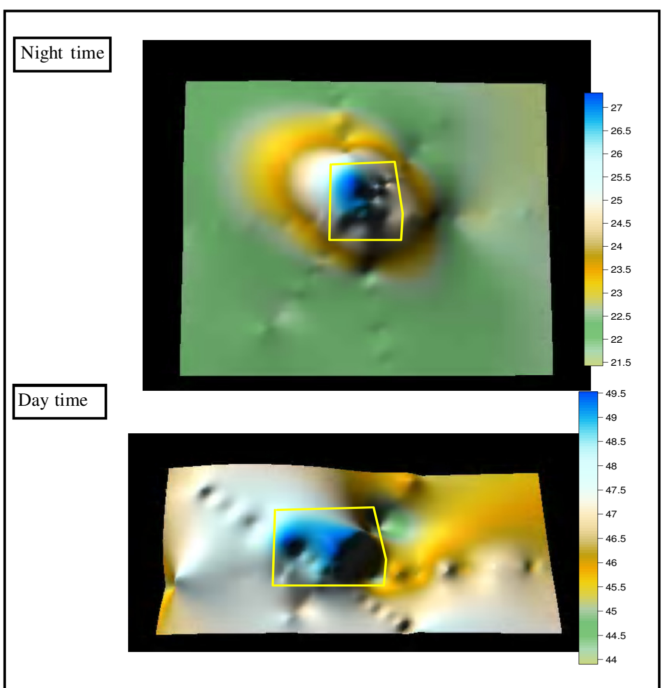

Fig. 4 : Simplified spataial distribution of the land surface temperature in Aligarh in day and night time (Temperature in Celsius)

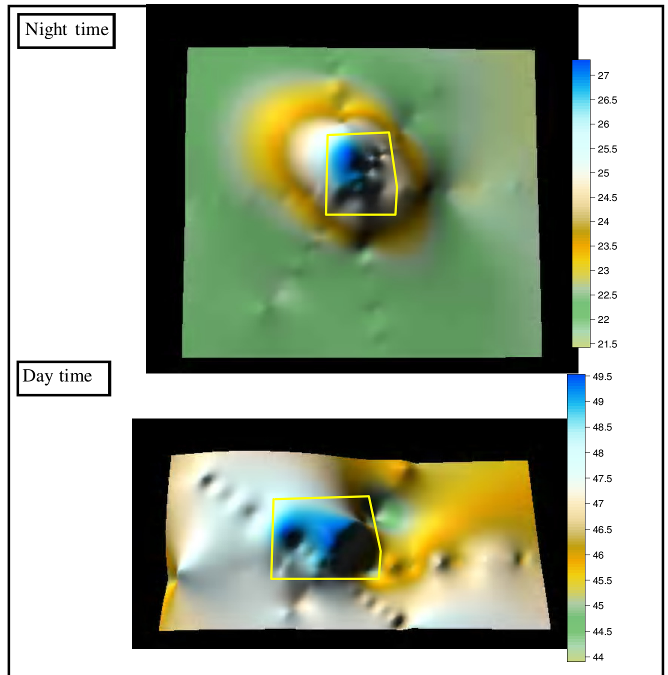

Fig. 5 : Simplified spataial distribution of the land surface temperature in Agra city in day and night time (Temperature in Celsius)

Delhi:

The Delhi is the largest metropolitan and the second largest metropolis by population in India. It is the eighth largest metropolis in the world by population located on the banks of the river Yamuna. Delhi is spread over an area of 1,484 km^2 of which 783 km^2 is designated rural, and 700 km^2 urban. Delhi is located at 28^0 37 ' N 77^0 4 E/ 28^0 61 ' N 77^0 23, borders by the Indian states of Uttar Pradesh on east and Haryana on west, north and south. Delhi lies almost entirely in the Gangetic plains. Two prominent features of the geography of Delhi are the Yamuna flood plain and the Delhi ridge. The UHI effect was studied based on MODIS land surface product in Delhi region and results suggested an average of 9 ^{0}C of UHI factor ranging (4 -12^{0}C) in day time, while in night time average UHI factor is 7 ^{0}C ranging (6 -8^{0}C). The higher UHI effect during day than in night time is related to high heat generation through use of the electrical appliances in commercial complex which accelerated the UHI phenomena in day time. Closing of the commercial complex in night time resulted in lesser heat generation and hence the UHI effect is lesser in night time.

The spatial variation of land surface temperature in Delhi region shows that the southern portion has the highest warming condition during day time (Fig.4). It is related to rocky and barren soil cover in this part. While, centre of the city shows moderate temperature compared to southern side because of higher vegetation cover in this region; Pusa, Delhi Ridge etc. The UHI effect is not very well developed in day time because of the higher instability of the atmosphere, while in the night time this effect shows a pronounce heat island in central Delhi in the most urbanized part of the Delhi.

Aligarh:

It is located at 27°53’N 78°05’E? / ?27.88°N 78.08°E / 27.88; 78.08. It has an average elevation of 178 meters. The city is situated in the middle portion of doab, the land between Ganga and Yamuna rivers. It is an important business centre of Uttar Pradesh which is most famous for its locks industries. The locks that are produced in Aligarh are exported to different parts of the country and world. Due to socio-economic reason the intensity of urbaonization is increasing in Aligarh city. The studies conducted by Farrroq and Ahmad (2008) had shown that rural area is converting into urban area with the rate of 1.428 km^2 per year in the last fifteen years.

With the large built area in city surrounded by a semi – urban and rural environment, the city shows the UHI effect in this study. The temperature profile of the land surface temperature imagery shows that UHI effect is significant with an average of 5 ^{0}C ranging 5 - 8^{0}C in day time, while in night time average UHI factor is 5 ^{0}C ranging 4 - 6 ^{0}C. The higher UHI factor during night than in day time is related to high heat generation through use of the electrical appliances in commercial complex which accelerates the UHI factor in day time. However, closing of the commercial complex in night time results in lesser heat generation and hence the UHI factor is lesser in night but concentrated at centre of city because of the built area.

Simplified spatial distribution of land surface temperature based on MODIS land surface images of the Aligarh city during day and night is shown in the Fig. 1. It shows that SW region represents the highest land surface temperature and distributed uneven. While less intensity of UHI effect occurs during day time in university area. The low land surface temperatures exist in population area of university and surrounding rural area. In the night time, UHI effect is well developed in NW and SE direction, which is the prevalent continuous built area. In the north , the area occupied by University which is less built area and possessed high percentage of the vegetation cover which inhibits the development of the heat island effect in the region.

Agra:

Agra district is situated in western U.P., between 27.11' degree latitude north and 78.0' degree to 78.2' degree longitute east. Its altitude is 169 meters above sea level. On the north it is bounded by Mathura district, on the south it is bounded by Dhaulpur district, on the east it is bounded by Firozabad district and on the west it is bounded by Bharatpur. Agra is situated on the bank of Yamuna river.

Like most cities in India, Agra is growing rapidly and lacks the infrastructure to cope with its rapidly increasing population. The numerous industries produce shoes, glassware, carpets and unlike other Indian cities, Agra also has been designated a world heritage site. the hotel industry is developing in the city region and leading to rapid urbanization in the region. The urbanization is leading to UHI effect in the city and the present study suggested significant difference in land surface temperature in the centre of city and sub-urban area. The average UHI factor based on land surface temperature is 4.75 ^{0}C ranging 3- 6^{0}C in day time, while average UHI factor during night time is about 5.17 ^{0}C ranging 4.9 – 5.4^{0}C.

Simplified spatial distributions of land surface temperature in the Agra city during day and night are shown in Fig. 5. In the city of Agra the distribution of land surface temperature in day time concentrates in middle of the city and decreases gradually outwards in NE direction at other site of the Yamuna river, which is mainly covered by forest. However, the UHI is well prominent in the night at the heart of the city.

Recommendations:

All the above studies show that the UHI effect is well established irrespective of their size *i.e.,* Delhi, Agra and Aligarh. It is also observed that the UHI effect can be prevented by inclusion of sufficient green landscape area between two continuous built up area in urban planning. The increase in reflection of the sun light by the urban surfaces can also be used in preventing high UHI effect. It can be done by choosing white pavements, white coloured roof and buildings and roof gardening for preventing and future and present UHI effect in the city.

Conclusion:

In this study, the heat island effect was evaluated using land surface temperature product derived from MODIS for the different cites in Ganga –Yamuna daob region. Land surface temperature product, suggested that the heat island phenomenon is well established during summer time as indicated in the satellite images for different cities in the region.

These remote sensing techniques are helpful in assessing the characteristics of the urban heat island effect in cities those are poorly equipped with conventional weather stations. Continuous monitoring of MODIS land surface temperature product can be used in long term monitoring for the urban heat island effect for Indian cities situated in Ganga – Yamuna doab region.

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