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Characteristics of Surface Urban Heat Island (SUHI) over the Gangetic Plain of Bihar, India

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Abstract: The rapid urbanisation impacts on environment, climate, agriculture, water resources trigger several problems to human beings. The present study is carried out to estimate intensity and trend of Urban Heat Island (UHI) as Surface UHI (SUHI) over towns/cities of the Gangetic plain of the state of Bihar, India, in which urban areas show relatively greater Land Surface Temperature (LST) than its rural surroundings especially during night times. The LST data (2001-14) of Moderate Resolution Imaging Spectroradiometer (MODIS) is used for five major towns/cities of Bihar namely, Bhagalpur, Gaya, Patna, Purnea and Muzzaffarpur. Each city is classified into Urban, Suburban and Rural zones as per land cover of the area. During winter months (January, February, November and December), UHI is more intense over all towns/cities. Mann-Kendall Test is applied on Surface Urban Heat Island Intensity (SUHII) in which MK-Test Statistic (S) shows a significant increasing trend. This trend would alarm a risk to increase in air pollution, heat related biohazards, energy demand in the region. This study shows the need of urban greening and proper town planning over the considered areas to mitigate the changes.

Key words: Surface Urban Heat Island (SUHI), Land Use Land Cover (LULC), Mann-Kendall Test, Bihar

1. Introduction

The fast urbanisation has been impacting water resources, agriculture, environment (micro and meso scale) and created several problems to human beings. Changes in urbanisation through expansion (vertical and horizontal) of the city alter surface temperature over that area. Due to fast rate of urbanisation, suburbs of cities is expected to decrease in vegetation cover and rise in surface temperature. Such Changes in surface temperature lead to phenomena known as Urban Heat Island (UHI) and are generally associated with changes in Land Use Land Cover (LULC) over the area (Kalnay and Cai, 2003; Ding and Shi, 2013; Meng and Liu, 2013). LULC changes may be responsible for changes in heat fluxes, albedo, evapotranspiration rate, biogeochemical cycles (Tian et al., 2014), moisture exchange (Kharol et al., 2013), cyclone track (Badrinath et al., 2012), ecosystems (Hyman et al., 2000; Gupta and Roy, 2012; Karwariya and Tripathi, 2012; Mishra et al., 2014), hydrological cycles and water resources (Aggarwal et al., 2012; Garg et al., 2012), and increase run off (Carlson and Arthur, 2000). LULC changes are influencing the formation of UHI (Nesarikar-Patki and Raykar-Alange, 2012). Researchers (Kalnay and Cai, 2003; Voogt and Oke, 2003; Meng and Liu, 2013; Bahi et al., 2016) suggested that LULC and Land Surface Temperature (LST) are important parameters for the study of UHI.

The profound effect of urbanisation is changes in LST profile and formation of UHI (Ding and Shi, 2013) in which urban areas show relatively greater temperature than its rural surroundings (Zhou et al., 2013), especially during night time (Tam et al., 2015). UHI, particularly after sunset, can have intensity of as much as 12°C (USEPA, 2015), or between 10-15°C during night (Lokoshchenko et al., 2015). In general, UHI is either determined by station data (Jiang et al., 2006; Meng and Liu, 2013) or by remote sensing data (Rao, 1972; Meng and Liu, 2013). Quantification of Intensity of UHI is important and LST difference is an indicator for UHI Intensity (UHII) (Voogt and Oke, 2003; Singh et al., 2014). The LST depends upon surface albedo, moisture content and most importantly LULC Changes (LULCC) (Xian, 2008). The formation of UHI takes place due to dense building structure in the urban area which receives large amount of solar radiation in the daytime. The surface undergoes nocturnal irradiative cooling, and thus retarding the rate of decrease in air temperature, whereas in rural areas nocturnal cooling occurs more rapidly (Lee and Baik, 2010). This difference in surface energy balance causes a markedly difference between urban and rural LST, resulting in formation of UHI. The UHII varies with morphology and size of the city (Oke, 1973; Sakakibara and Matsui, 2005; Hoffmann et al., 2012). The land cover also has a major influence on the extension and geometry of the UHI (Cheval and Dumitrescu, 2009). Decrease in Urban Greens can intensify the UHII while increase in greenery can mitigate its impact (Chen et al., 2014). UHI has strong impact on air quality (Sarrat et al., 2006; Davies et al., 2007; Sarkar and Ridder, 2011). UHI may trigger heat related illness, affect urban air quality (Qi et al., 2007), induce heat waves (Holderness et al., 2013) and adversely affect local climate (Van Weverberg et al., 2008; Sarkar and Ridder, 2011). Tan et al., (2010) found that heat related mortality is higher in city than in suburbs and 3°C UHI may cause increase in hospital

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admissions (Lai and Cheng, 2009).

In the past, quantification of land cover classes and urban land surface temperature regarding UHII is relatively less discussed over the Gangetic plain. Asraf (2014, 2015) quantified LST over urban area of Patna, state of Bihar, India and showed that it has been doubled in past 25 years and average LST has been increased 2.5°C for January and February in the year of 1989, 1993, 2003, 2005, 2010 and 2014. Ghosh and Mukhopadhayay (2014) quantified the heat island effects over different cities of Bihar in a limited time span (only three months viz February, March and November from two years i.e. 2004 and 2011 were taken). The quantification of UHII with respect to build up zones is necessary to understand trend of urbanisation and LULC change, because urbanization has impacted on land cover classes and urban land surface temperature and may be responsible for developing UHI over the densely populated Gangetic plain which has been experiencing fast urbanization and needs quantification of UHI and UHII and its trends over towns/cities lying over the Gangetic plains of the state of Bihar, India. Such study is useful to understand the temporal and spatial trend of urbanisation. Above issues are not discussed by earlier researchers, therefore, it is aimed to study UHI formation and its characteristics over cities of the Gangetic plains of Bihar, India. In this paper, Introduction is kept in section 1. Study area, data and methodology is placed in section 2. Results and discussions and conclusions are in section 3 and 4, respectively

2. Study area, data and methodology

a. Study area

The study area is comprised of five towns/cities of the state of Bihar, India. Figure 1 shows selected town/cities namely Patna (Lat. 25.5°N-25.6°N, Lon. 84.9°E-85.2°E), Gaya (Lat. 24.7°N-24.8°N, Lon. 84.9°E-85.0°E), Bhagalpur (Lat. 25.1°N-25.2°N, Lon. 86.8°E-87.0°E), Muzaffarpur (Lat. 26.02°N-26.22°N, Lon. 85.28°E-85.5°E) and Purnea (Lat. 25.6°N-25.8°N, Lon. 87.3°E-87.5°E) of the state of Bihar (Lat. 24.3°N-27.5°N, Lon. 83.3°E-88.2°E), India. These town/cities are densely populated and eminently developing in recent years on the Gangetic plains of Bihar. The river Ganga flows transversely from west to east, the Gangetic plain stretches from Uttar Pradesh in west to West Bengal in East. These five towns/cities are spread over north and south of the Ganga in Bihar. A more detailed overview of the terrain and topography can be found at http://www.lib.utexas.edu, http://www.surveyofindia.gov.in and interactively at http://bhuvan.nrsc.gov.in. The ISRO-BHUVAN data shows more than 70% of the total area of the state falls under Agricultural land use, and ISRO-BHUVAN LULC data of 2012 when compared to data of the year 2006 shows urban land cover has increased by 4.5% for the state of Bihar as whole, and urban built up of stations namely Patna, Gaya, Bhagalpur, Muzaffarpur and Purnea has shown a growth rate of 32.71%, 6.57%, 30.07%, 19.8% and 88.75% respectively (Source: http://bhuvan-noeda.nrsc.gov.in/gis/thematic/index.php).

b. Data

The LST data of Terra-MODIS (Moderate Resolution Imaging Spectro radiometer) (Table 1) under Monsoon Asia Integrated Regional Study (MAIRS) at 1 km and 0.5 km resolution are collected from National Aeronautics and Space Administration (NASA)-site GIOVANNI (http://disc.sci.gsfc.nasa.gov/giovanni) for the period of 2001-2014 (Acker and Leptoukh, 2007; Bhati and Mohan, 2016). These data are filtered, corrected, geo-referenced and processed. The data for the summer monsoon season (June-July-August-September)

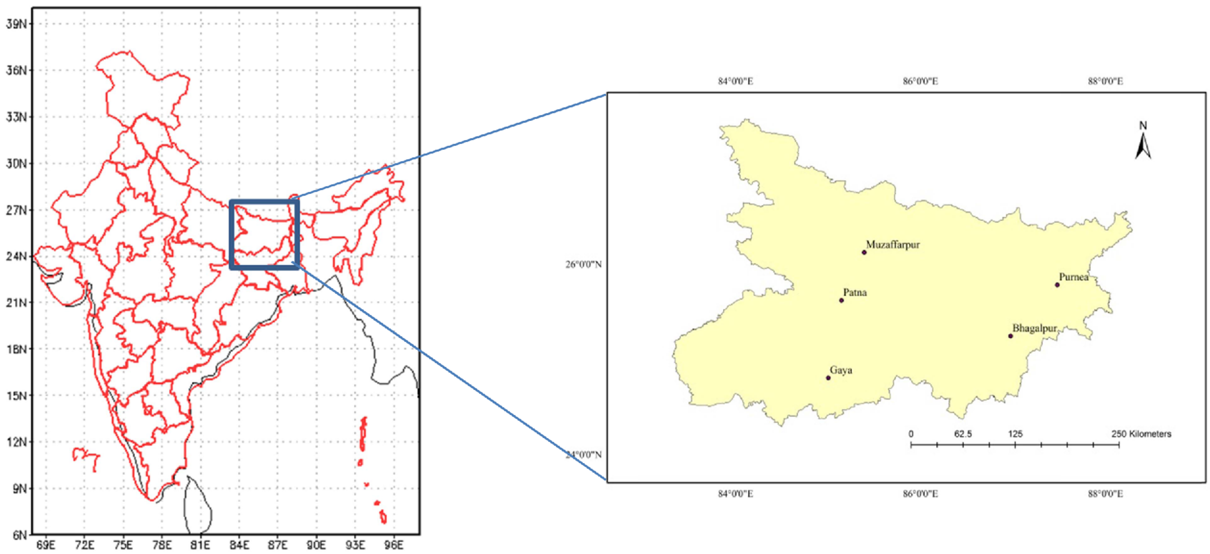

Fig. 1. Selected stations of the state of Bihar, India for study.

Table 1. Details of data types, their spatial and temporal frame and source.

Data Types	Spatial Resolution	Temporal Frame Used	Source
IGBP Land Cover Types (MCD12Q1_MAIRS_IGBP.005)	0.5 Km × 0.5 Km	2001	Terra-MODIS
Land Surface Temperature (Night) (MOD11A2_MAIRS.005)	1 Km × 1 Km	Jan-2001 - Dec-2014	Terra-MODIS

was not available over the study area, hence they are not considered. The base map is of De_Lorme world base map and Topographic base map is taken from online user resources of arcgisonline.com. Delineation of boundaries of study area is done on ArcGIS 10.1. Classification and quantification of data is carried out by GrADS software.

c. Methodology

For the analysis the study area is divided into three major categories viz. Urban (U), Suburban (SU), and Rural (R) based on the LULC data. This type of segment categorisation (commonly a three segment categorisation) is widely used in LST, UHI and LULC Changes based on microclimatic studies (Lowry, 1977; Cheval and Dumitrescu, 2009; Ding and Shi, 2013; Meng and Liu, 2013; Chen et al., 2014). The distance from outer U periphery to outer SU periphery and further from outer SU to outer R zone periphery is considered to be of 2KM. As the gangetic plain is a densely populated area the 2 km distance (width of rural zone) was taken to ensure that one city's rural zone does not spread to the outer periphery of neighboring town. Moreover at least 2KM optimized buffering distance (as SU zone) between U and R is also maintained, so that the considered zones show their distinct and independent trends. Various methods are used for estimating UHII (Voogt and Oke, 2003; Bahi et al., 2016) out of which estimation of Surface UHI (SUHI) or satellite derived UHI or remotely sensed UHI is most feasible technique (Rao, 1972; Meng and Liu, 2013). For the purpose, LST is considered for measuring UHI (Voogt and Oke, 2003; Singh et al., 2014). Researchers (Jiang et al., 2006, Meng and Liu, 2013, Sheng et al., 2017) suggested that for UHI study over a bigger city, a large number of station data in and around the city is required which is not easy to generate, therefore satellite data is used for the same purpose. For city like Delhi in India at least 30 observational stations are required for UHI assessment (Bhati and Mohan, 2016). Therefore satellite data is used for the study.

In present study, night time LST data is used for quantification of temperature profile over U, SU and R zones, for quantification of Urban to rural UHI intensity ($UHII_{u\text{-}r}$) and to visualise the trend of $UHII_{u\text{-}r}$. To know UHII, LST difference between urban to rural, is calculated (Oke, 1973; Shigeta et al., 2009; Hoffmann et al., 2012; Zhang et al., 2014) by the following relation.

$$UHII_{u\text{-}r} = \Delta T_{ur} = T_u - T_r$$

where T_u is urban LST and T_r is rural area LST.

To know significance of trend (Singh et al., 2008) in UHII (2001-14), Mann-Kendall Test is applied. The moving average technique is also applied on trend of $UHII_{u\text{-}r}$ for entire time period to remove excessive fluctuations. Since UHI is using surface temperature data, UHI and UHII are basically Surface Urban Heat Island (SUHI) and its intensity (SUHII) in this study.

3. Results and discussions

To assess variation in intensity of UHI in considered months (2001-14) over different town/cities, time series of LST at rural, suburban, urban and UHII in the months of January, February, March, April, May, October, November and December during 2001-2014 over Bhagalpur, Gaya, Patna, Muzzaffarpur and Purnea are shown in Figs. 2 a-e. The large difference in LST between rural/suburban and urban is seen in the month of January, February, November and December over Bhagalpur, Gaya and Muzzaffarpur; Patna shows large difference in LST between rural/suburban and urban in the month of January, February, March, November and December; not much LST difference is noticed between rural/suburban and urban over Purnea. In Fig. 2a, large difference in LST between Urban and rural is seen in months of January, February, November and December and therefore remarkable variation in intensity of UHI is noticed over Bhagalpur. However, over Gaya (Fig. 2b), January, February, November and December months show comparatively less difference in LST over urban and rural zones, hence, comparatively low UHII is seen in Gaya for the aforementioned months. In the months of January (2007 onward), February (in recent years) and December, UHII is prominent over Patna (Fig. 2c) due to large LST differences over urban and rural temperature. In Fig. 2d, over Muzaffarpur, UHII is more prominent from 2005 onward in months of January, February, November and December. UHII is clearly noticed in months of January, February, March, November and December over Purnea (Fig. 2e). The UHII appears to be more significant in winter months (January, February, November and December) and especially in the starting or ending months. It may be noticed that (Figs. 2a-e) majority of stations shows prominent increase in UHII since the year of 2005. Tian et al., (2014) suggested that urbanization in India has been increasing rapidly since 2005 and it may be correlated with increase in UHII in the current analysis. The difference in LST between urban, suburban and

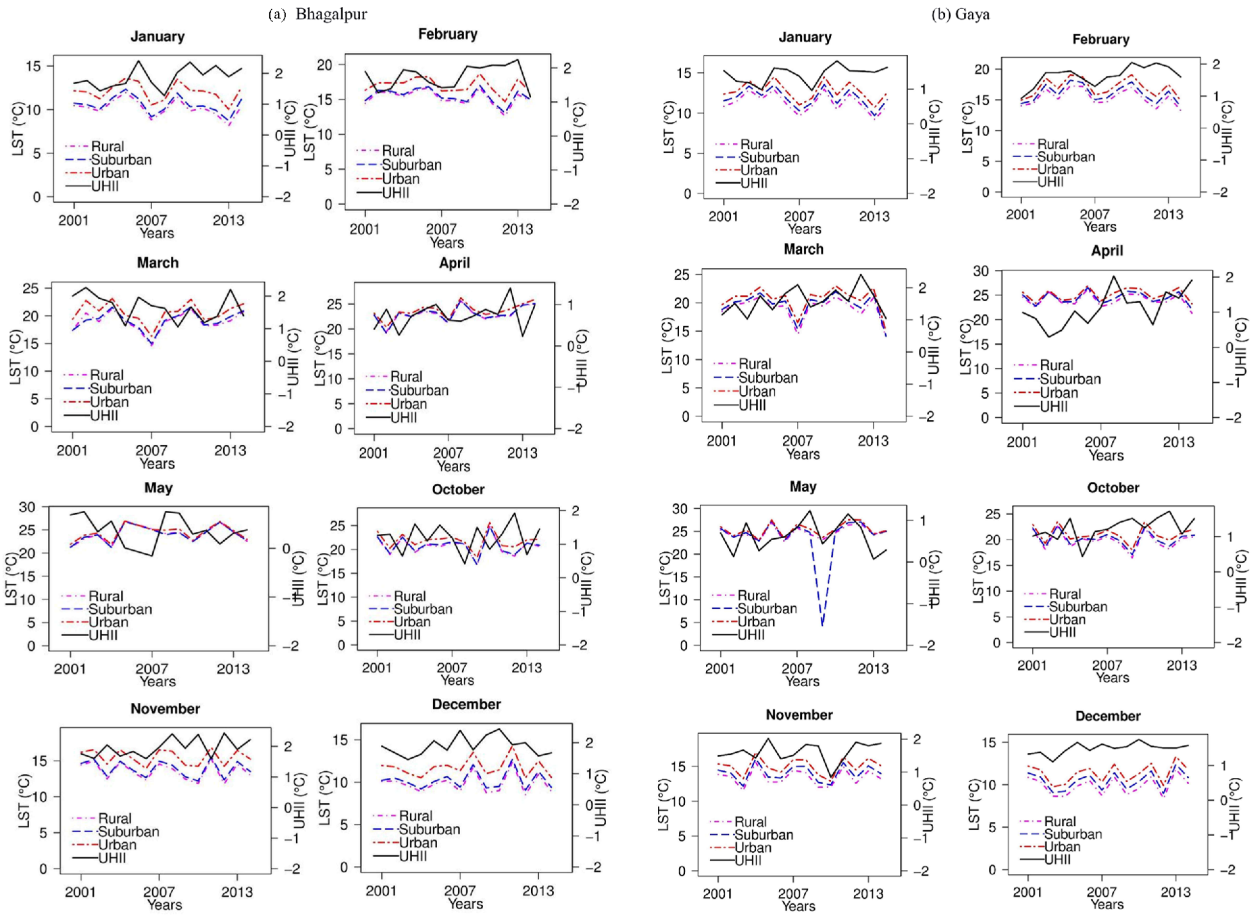

Fig. 2. Temporal profile of LST over different zones and Surface UHII for the period of 2001-2014 over (a) Bhagalpur; (b) Gaya; (c) Patna; (d) Muzaffarpur; and (e) Purnea, respectively.

rural is less during month of May due to existence of meso-scale phenomena such as heat waves (Wilby, 2003; Kharol et al., 2013) over the Gangetic plain. During winter months, microscale phenomenon is dominating and therefore large difference in LST increases UHII over the stations.

Table 2 shows peak in observed UHII for the period of 2001-14 over Bhagalpur, Gaya, Patna, Muzzaffarpur and Purnea. Maximum UHII is noticed over Patna followed by Muzzaffarpur, Bhagalpur, Gaya and Purnea. It seems that fast urbanisation over Patna may be responsible for comparatively more UHII.

The spatial extent of UHI may be correlated with urbanization of towns/cities and so spatial extent of mean LST (shown by contour) and UHI (shaded colour) over Bhagalpur, Gaya, Patna, Muzzaffarpur and Purnea is shown in Figs. 3a-e. The maximum mean LST is found over Patna followed by Bhagalpur, Gaya, Muzzaffarpur, and Purnea, and almost similar trend is noticed for maximum intensity of UHI. Over Patna, comparing to other stations, larger area is under maximum intensity of UHI. The towns/cities over Bihar are behaving like pockets of heat (Ghosh and Mukhopadhyay, 2014).

The spatial extent of LST and UHII on a particular date (as specified in Table 2) during 2001-2014 for Bhagalpur, Gaya, Patna, Muzaffarpur and Purnea, respectively, is shown in Figs. 4a-e. UHII is maximum over Patna followed by Bhagalpur, Gaya, Muzaffarpur and Purnea, respectively. Extreme UHII over Patna, compared to other towns/cities, may be seen as impact of fast urbanization (Ghosh and Mukhopadhyay, 2014). The peak differences in temperature between core urban to rural area shows an UHII of 8°C to 9°C (Fig. 3c). It may be summarized that Patna, the capital of the state, is growing at a rapid pace compared to other places and such increment may be expected in upcoming years.

For town/cities planning, it is necessary to assess trend in UHII and therefore Mann-Kendall test is applied on UHII for the period of 2001-2014 (Khambhammettu, 2005; Singh et al., 2008) using MiniTab® software. In Mann-Kendall Test, null hypothesis is proposed for no trend and alternative hypothesis is for existence of any increasing or decreasing trend. Mann-Kendall Test (MKT) for N number of data points is given as follows

$$MKTestStatistic\ (S) = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} sgn(x_j - x_i)$$

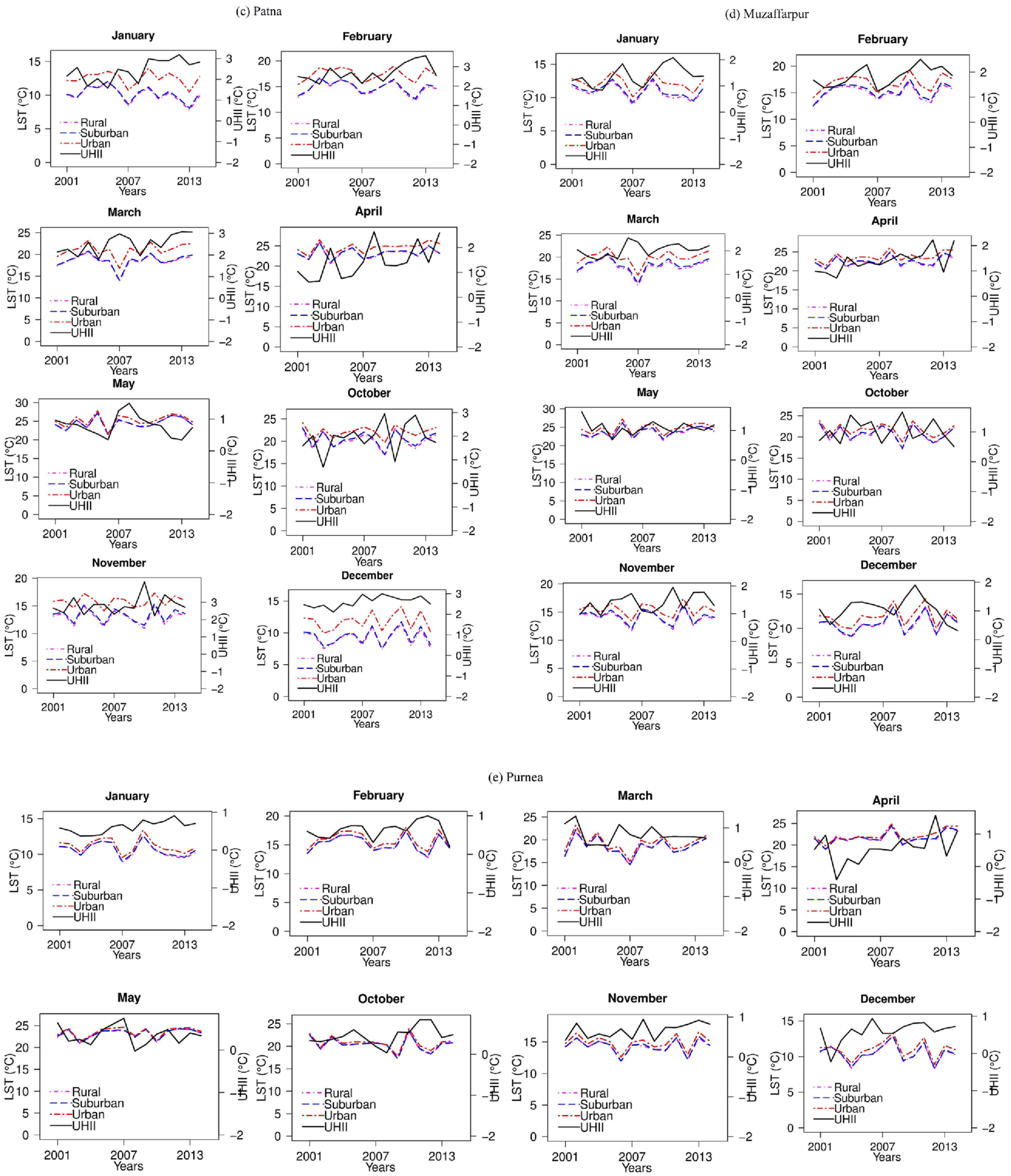

Fig. 2. (Continued) Temporal profile of LST over different zones and Surface UHII for the period of 2001-2014 over (a) Bhagalpur; (b) Gaya; (c) Patna; (d) Muzaffarpur; and (e) Purnea, respectively.

where

$$sgn(x_j - x_i) = 1 \text{ if } (x_j - x_i) > 0$$
$$= 0 \text{ if } (x_j - x_i) = 0$$
$$= -1 \text{ if } (x_j - x_i) < 0$$

A positive value of MK Test Statistic (S) indicates an increasing trend, whereas a negative value shows a decreasing trend. The test is carried out at 95% confidence level (α is considered to be 0.05). For testing of significance, Z statistic, Cumulative Distribution Function (CDF) is computed and the

Table 2. UHII over Bhagalpur, Gaya, Patna, Purnea and Muzzaffarpur for the period of 2001-2014.

Stations	Maximum Monthly Mean UHII °C (Month) during 2001-14	Years (Max. Mean UHII °C)	All-time peak in UHII °C (Month, Year)
Bhagalpur	1.95 (*Nov.*)	2012 (1.69)	2.44 (Dec., 2010)
Gaya	1.64 (*Feb.*)	2012 (1.68)	2.41 (Mar., 2012)
Patna	2.83 (*Nov.*)	2012 (2.67)	4.17 (Nov., 2010)
Purnea	0.80 (*Mar.*)	2012 (0.82)	1.57 (Apr., 2012)
Muzaffarpur	2.03 (*Mar.*)	2012 (1.67)	2.54 (Mar., 2006)

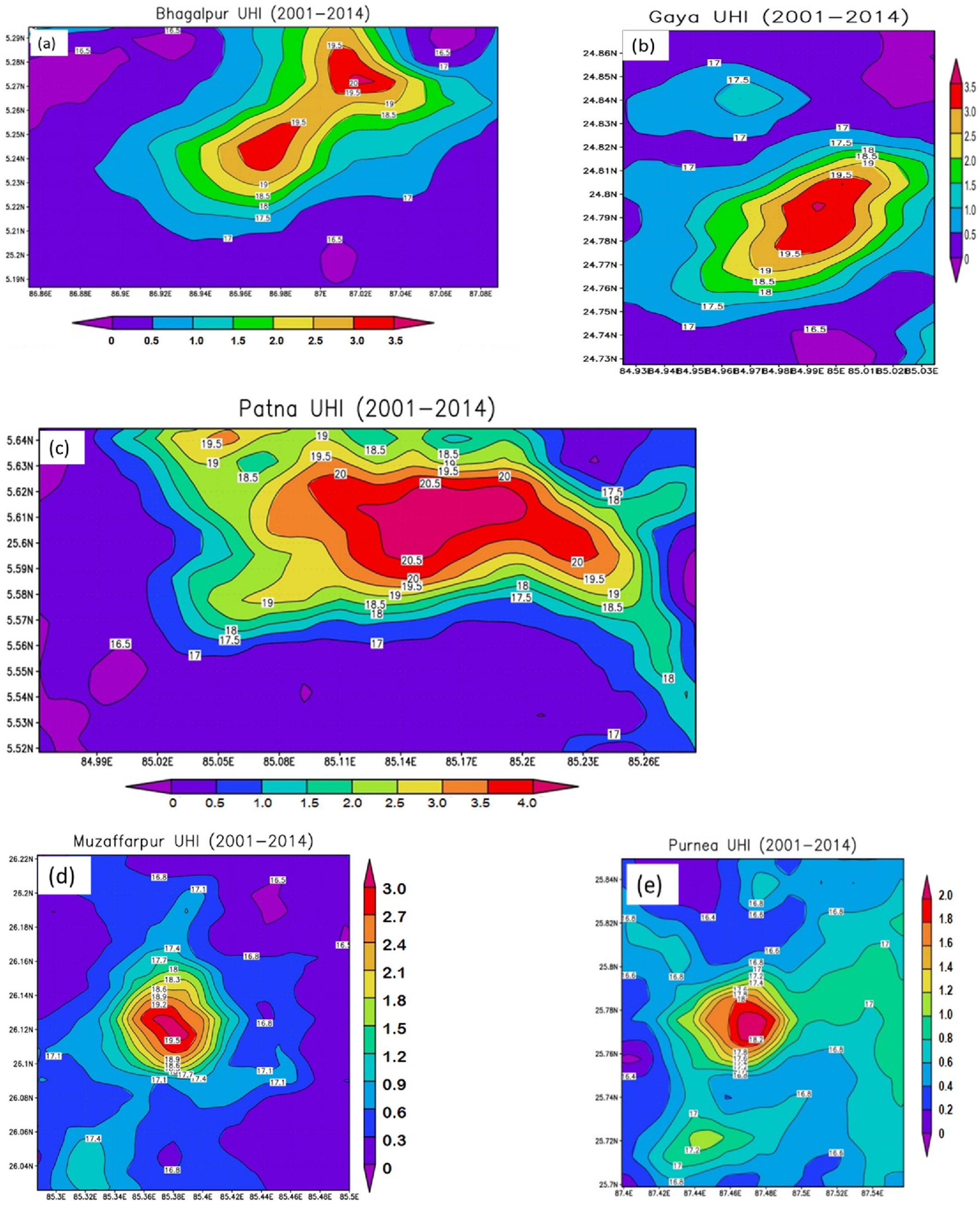

Fig. 3. Spatial Distribution of Mean LST (denoted by contour lines) and Mean UHII (denoted by shaded color bar) for the period of 2001-2014 over (a) Bhagalpur (b) Gaya (c) Patna (d) Muzaffarpur and (e) Purnea, respectively.

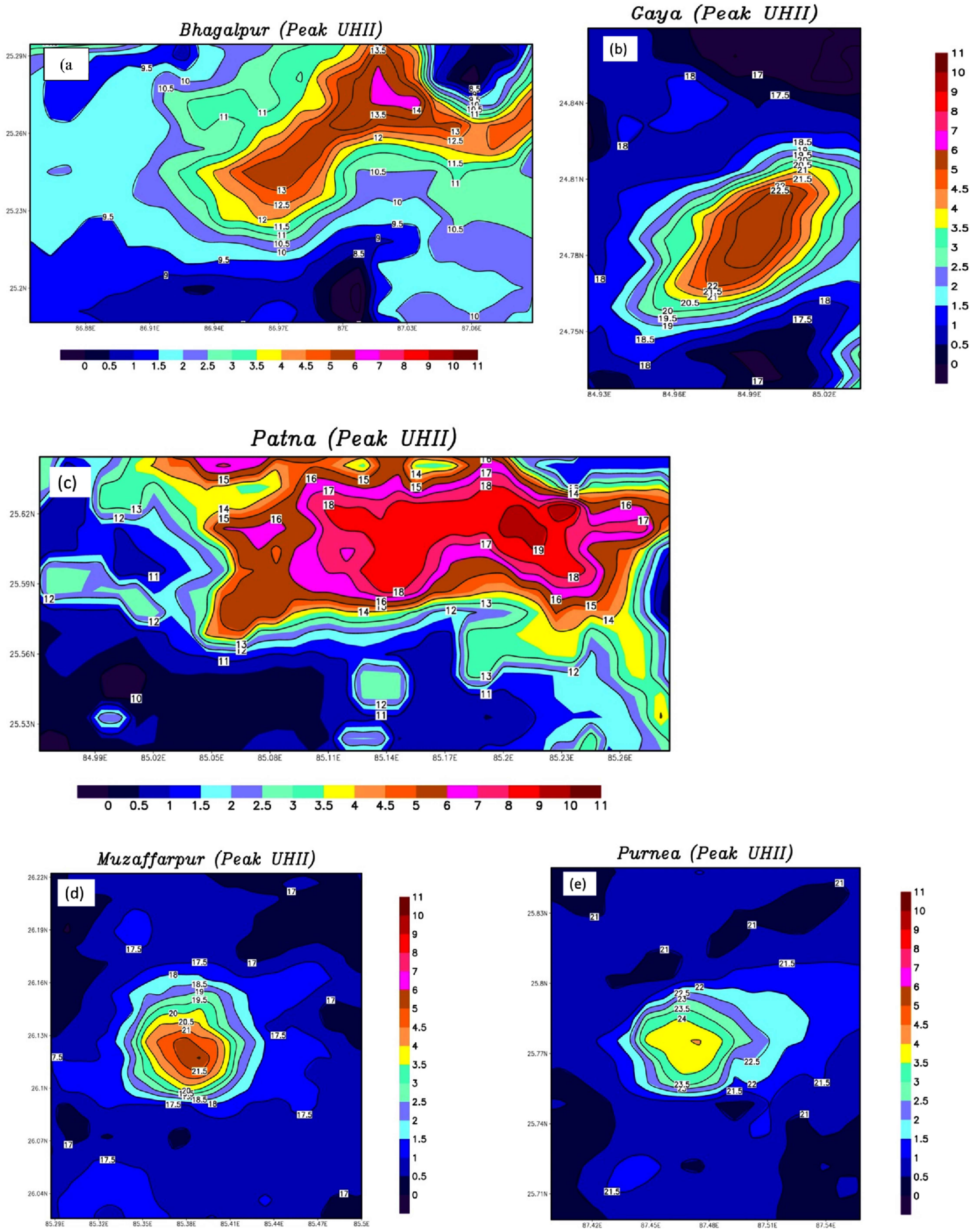

Fig. 4. Spatial Distribution of LST (denoted by contour lines) and UHII (denoted by color bar) on a particular date (as specified in Table 2) during 2001-2014 over (a) Bhagalpur (b) Gaya (c) Patna (d) Muzaffarpur (e) Purnea, respectively.

probability is determined in increasing or decreasing trend. The details of the software operation can be found on http://support.minitab.com. The code for computing the trend and significance can be accessed at http://support.minitab.com/en-us/minitab/17/MKTREND.mac. Mann Kendall test of UHII for the period of 2001-2014 over Bhagalpur, Gaya, Muzzaffarpur, Patna, and Purnea is shown in Table 3. Significant increasing trend of UHII is found over Bhagalpur, Muzzaffarpur, Gaya, Patna and Purnea in the month of December (not significant over Muzzaffarpur), January, February and April. UHII during winter is becoming more intense and significant (Lee and Baik, 2010) which may be due to remarkable increase in night time temperature over urban areas (IPCC, 2007, 2014). The rural areas do not show much

Table 3. Mann Kendall Test of UHII for the period of 2001-2014 (Y = Yes, N = No).

	Bhagalpur	Gaya	Patna	Muzzaffarpur	Purnea
	Significant Increasing Trend	Significant Increasing Trend	Significant Increasing Trend	Significant Increasing Trend	Significant Increasing Trend
January	Y	Y	Y	Y	Y
February	Y	Y	Y	Y	Y
March	N	Y	Y	N	N
April	Y	Y	Y	Y	Y
May	N	N	N	N	N
October	N	Y	Y	N	Y
November	Y	N	N	Y	Y
December	Y	Y	Y	N	Y

increase in night time temperature during winter season. It seems that urban area becomes a micro level heat pocket in comparison to rural area. The fast development of build-up of urban area (Nesarikar-Patki and Raykar-Alange, 2012) seems to be responsible for increase in surface temperature.

As impact of UHII over towns/cities of the Gangetic plain of Bihar, risk of increase in air pollution and heat related health hazards may take place. UHI may deteriorate urban air quality (Qi et al., 2007) and strongly affect local climate (Van Weverberg et al., 2008; Sarkar and Ridder, 2011). There may be possibility of change in micro-level climate (Kim and Baik, 2004) over those towns/cities in Bihar. In order to minimise the risk, conservation of urban ecosystem services and policies such as development of green belts, green building, green architectures, reduction of carbon footprint etc. may be planned. The health sector may have moderate to major consequences and more cases of respiratory and cardiac disease arises due to stress caused by UHII. Children and older people may be at higher risk (USEPA, 2015) due to UHII.

4. Conclusions

The Urban Heat Island (UHI) and its intensity (UHII) are increasing significantly over considered towns/cities of Bihar in India. It is noticed that urbanisation over suburban area is taking place more rapidly especially around Patna followed by Bhagalpur, Muzzaffarpur and Gaya and UHI is also increasing in terms of spatial coverage. UHII is stronger during winter months (November, December, January and February) in compare to other months due to large difference in LST between Urban, Suburban and Rural zones. Spatial distribution of UHI shows that area within the suburban periphery has weak UHII while densely build-up areas are showing even stronger values of UHII. It may be possible that UHI phenomenon in the study area is primarily governed by LULC changes. Spatial and temporal changes in UHII may impact micro climate, circulation of pollutants in atmosphere, more cases of respiratory and cardiac and other health problem. There is an inkling of micro level climatic change in the study area, which seems to be mainly driven by LULC change. Increase in urban greenery on a large scale during town planning is much needed to mitigate such changes.

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