ASSESSMENT OF SEASONAL AND LONG TERM QUANTIFICATION OF SURFACE URBAN HEAT ISLAND INTENSITY (SUHII): A CASE STUDY OF VARANASI CITY, INDIA

7.1 INTRODUCTION

Urbanisation has increased at a very fast rate in the recent past decades which has resulted in the formation of SUHI due to increase in built-up land covers, increased population which further results in increased human activity, anthropogenic heat discharge etc. (Grimm et al., 2008; Kuang et al., 2013, 2016). The higher temperature raises the energy demands and emission of greenhouse gases from the use of air conditioners which signifies greater risk of heat waves in cities (Yang et al., 2017; Zhou and Gurney, 2010; Zhou et al., 2012). The study on SUHI intensity has become important due to its adverse impact on the urban environment. In recent era, the development of thermal remote sensing technology with satellite onboard TIR sensors has been proven effective tool for the study of LST variations in urban cities with the growth of man-made activities. SUHII depends on various factors like difference in LULC composition in urban and rural areas, thermal conductivities of urban surface, vegetation coverage within a city, built-up density (Taha, 1997, Sarrat et al. 2006; Mathew et al. 2016).

Mathew et al. 2018 proposed a thermal transect method to analyse the seasonal and temporal variations in SUHI from 2003 to 2015 using MODIS thermal data in Jaipur city and found that area enclosed in each isothermal line increased from 20 to 400% indicating significant SUHI growth in 12 years. Meng et al. 2018 discussed the spatial and temporal behaviour of SUHI by comparing different levels of UHI with urban main built-up area for 12 years in Beijing city of China. Li et al. 2018 developed a new method for quantifying SUHI intensity from the relation of LST with ISA using MODIS data. The ISA was regionalised using Kernel density estimation method (KDE) that showed good linear relation with LST and the slope was found effective to quantify SUHI. Keeratikasikorn and Bonafoni (2018) studied the SUHI pattern for different LULC in Bangkok using Landsat 8 data which can help for better land use planning for SUHI mitigation. Eleftheriou et al. 2018 studied the annual and seasonal trends of day and night LST in Greece using MODIS data. The day time LST was found to show decreasing trend ranging from -1.0 * 10-2 °C to -1.3 * 10-3 °C and night LST showed increasing trend from 4.6 ∗ 10-5 °C to 3.1 ∗ 10-3 °C in the majority areas from 2000 to 2017 in different seasons i.e. winter, spring, summer and autumn.

The quantification of SUHI intensity is important for monitoring of SUHI growth. Some previous studies have compared the temperature values for analyzing SUHI effect for different years (Meng et al. 2018; Yao et al. 2018; Shastri et al. 2017) whereas some studies have determined the area covered by the city showing SUHI effect with its yearly comparison to determine the SUHI growth in the city (Xiong et al. 2012; Shirani-Bidabadi et al. 2019; Mathew et al. 2018). The increase in urbanization not only increases the temperature of a city but also increases the area showing SUHI effect. Thus, the present study focuses on analyzing SUHI growth for winter, summer and post-monsoon season from year 2001 to 2019 using urban heat index (UHI) obtained from MODIS LST images. SUHI intensity has been calculated by combining the UHI values and the percentage of land cover in the city showing SUHI effect for better quantification of SUHI growth with urbanization.

7.2 STUDY AREA AND DATA USED

7.2.1 Study area

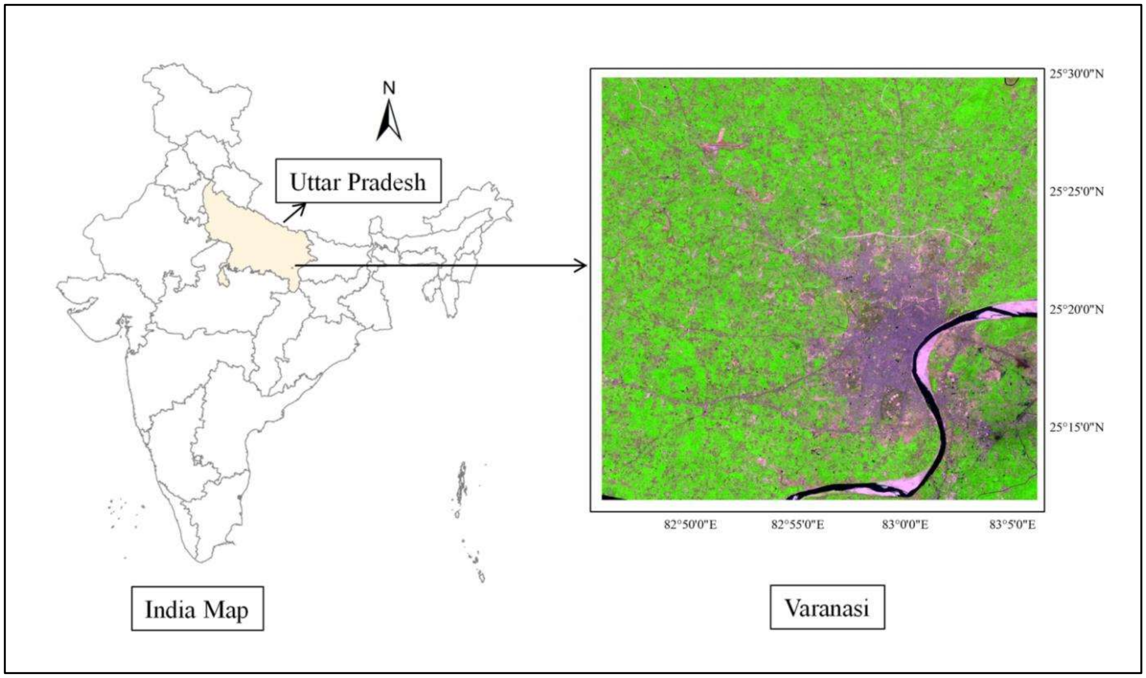

Figure 7.1. Location map of the study area

The present study has been performed on the Varanasi city which is located in the Indo-Gangetic planes of north India with centre coordinates of 250 19' 18.06" N and 820 59' 14.24" E . It is situated between two rivers i.e. River Varuna and River Ganga enhancing the soil fertility making it useful for agriculture purpose. The city is regarded as one of the oldest human settlements in the world. This is considered as a holy city and experiences a humid subtropical climate. Figure 7.1 shows the location map of study area. The image shown is the false colour composite image obtained from Landsat-8 satellite data of Varanasi city, India for the year 2019.

7.2.2 Data used

Table 7.1 Satellite data specification

Seasons	Composite dates (Julian days)		Tiles
	MOD11A2	MOD13Q1	
Winter	17 – 24 25 – 32 33 – 40	17 – 32	h24 v6
Summer	113 – 120 121 – 128 129 – 136	113 – 128	h24 v6
Post-monsoon	289 – 296 297 – 304 305 – 312	289 – 304	h24 v6

MODIS Terra satellite LST (MOD11A2) and Normalized Difference Vegetation Index (NDVI) (MOD13Q1) was downloaded from the USGS LPDAAC i.e. https://lpdaac.usgs.gov/ for the study. MOD11A2 product provides 8-day composite LST data at 1000 m spatial resolution. The LST image obtained was rescaled with a factor of 0.02 to determine MODIS LST image in unit of Kelvin. MOD13Q1 product provides 16 day composite NDVI image at a spatial resolution of 250 m. The MOD11A2 and the MOD13Q1 product was downloaded for three seasons i.e. winter, summer and post-monsoon of the years 2001, 2007, 2013 and 2019. The LST image for each season in a year was obtained by taking average of each pixel from three consecutive images of MOD11A2 product. The data used for this study is shown in Table 7.1.

7.3 METHODOLOGY

7.3.1 UHI calculation and its classification into five thermal levels

The LST image for a particular season in a year was obtained from three consecutive MODIS night LST images by taking the average of each pixel values from the three images. A normalization method was performed on the LST image for the calculation of urban heat index (UHI) as shown in Equation (7.1) (Abutaleb et al. 2015).

$$UHI = \frac{T - T_m}{SD} \tag{7.1}$$

where, T = LST value of each pixel, T_m = mean LST of the image and SD = standard deviation in the LST value of the image.

Further, the UHI values were divided into five thermal levels as shown in Table (7.2). The region-4 and region-5 are the thermal levels which has temperature higher than the medium temperature, depicting SUHI effect.

7.3.2 SUHI intensity calculation

The area within region-4 and region-5 and also mean UHI value in both the regions representing SUHI were calculated. Finally, the SUHI intensity was calculated for the quantification of SUHI effect in the city through Equation (7.2). (Xiong et al. 2012, Shirani-Bidabadi et al. 2019)

$$SUHII = \frac{1}{100m}\sum_{i=1}^{n} w_i \times mean\ UHI_i \times P_i \quad (7.2)$$

Where, m = number of thermal levels, i = thermal levels having UHI value higher than the rural areas, n = number of thermal levels depicting SUHI effect, w_i = weightage values of moderately high and very high temperature region as 4 and 5, respectively. P_i = area of level i in percentage.

Table 7.2 Description of five thermal levels

	Intervals	**UHI classification**
Region – 1	UHI $\leq$ -2	Very low temperature region
Region – 2	-2 $\leq$ UHI $\leq$ -0.5	Moderately low temperature region
Region – 3	-0.5 $\leq$ UHI $\leq$ 0.5	Medium temperature region
Region – 4	0.5 $\leq$ UHI $\leq$ 2	Moderately high temperature region
Region – 5	UHI $\geq$ 2	Very high temperature region

7.4 RESULTS AND DISCUSSION

7.4.1 Seasonal and temporal variation in vegetation covers using NDVI maps

NDVI is a vegetation index which determines the amount of vegetation present in a region. Vegetation content in an agricultural land around the city varies significantly with seasons. The increased urbanization also replaces natural land covers with artificial built-ups.

The vegetation cover in the city were analyzed for the years 2001, 2007, 2013 and 2019 using the NDVI images for different seasons i.e. winter, summer and post-monsoon as shown in Figure 7.2. NDVI value ranges from -1 to +1 and the images were divided into four different regions depending upon the NDVI values. The negative value of NDVI signifies water pixels. The region with NDVI value 0 to 0.25 depicts bare soil/built-up region. The NDVI values of 0.25 to 0.5 represents sparse vegetation and NDVI greater than 0.5 represents dense vegetation (Yadav et al. 2020).

During winter season, the rural land cover was observed to be mainly covered with dense vegetation. The region with NDVI range of values 0 to 0.25 in the image mainly consists of urban built-ups due to very low contribution of bare land in winter season. The increase in urban built-ups from year 2001 to 2019 indicates clear pattern of urban expansion in the city. During summer season, the rural land cover was observed to be mainly covered with bare land/fallow land. The pixels with NDVI values of 0 to 0.25 show contribution from both bare land and urban built-ups. The NDVI image reveals major contribution of bare land and built up land cover in the city. During post-monsoon season, the rural land cover was observed to be mainly covered with sparse vegetation. The pixels with NDVI values of 0 to 0.25 mainly consist of built-up land cover. The NDVI image reveals major contribution of sparse vegetation in rural areas and built-ups in the urban part of the city. The urban part of the city is mainly surrounded by dense vegetation in winter, bare land in summer and sparse vegetation in post-monsoon season. The number of pixels with negative NDVI values was found greater in post-monsoon season as compared to that of summer and winter seasons revealing greater number of water pixels during post-monsoon season.

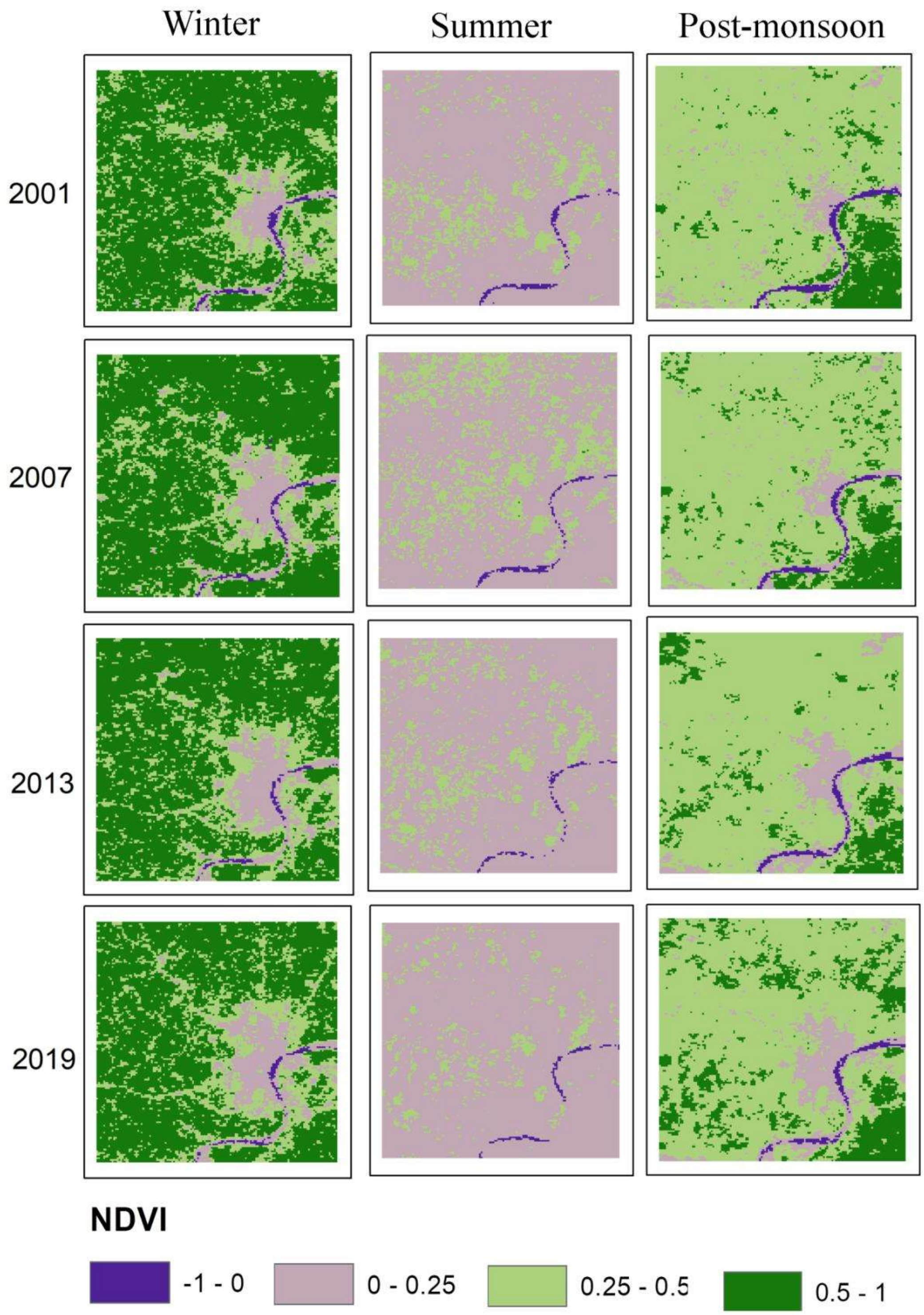

Figure 7.2. NDVI maps for winter, summer and post-monsoon season of years 2001, 2007, 2013 and 2019

7.4.2 UHI maps

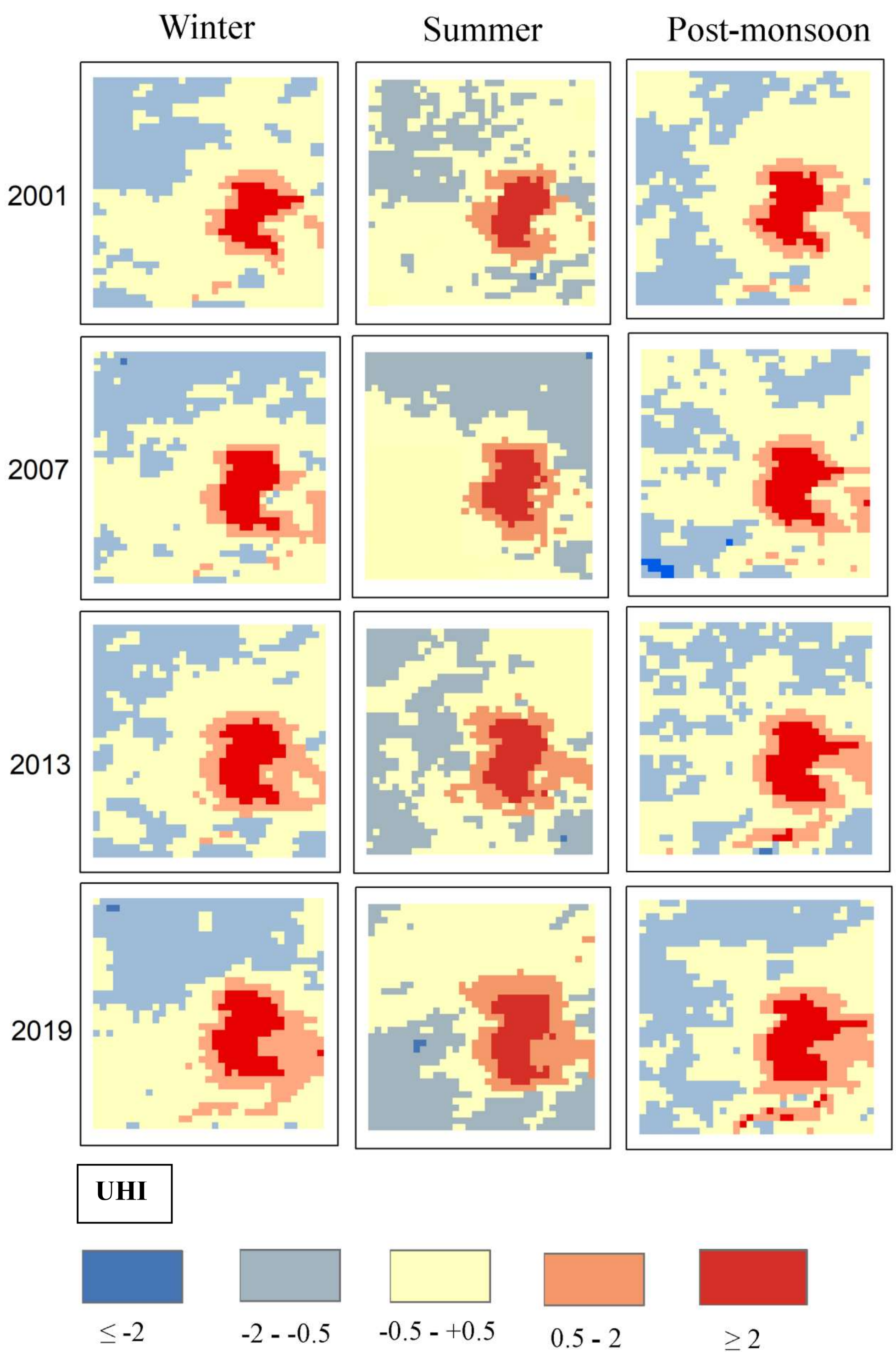

Figure 7.3. UHI maps for winter, summer and post-monsoon season of the years 2001, 2007, 2013 and 2019

Since SUHI phenomena are more prominent during night time at all seasons in the Indian cities (Shastri et al. 2017), MODIS derived night LST data have been used for the present study for the determination of UHI images. The UHI image obtained for the years 2001, 2007, 2013 and 2019 were shown for winter, summer and post-monsoon season in Figure 7.3. The UHI image reveals clear SUHI patterns in the city in the three seasons. The pixels within high temperature region (UHI greater than 0.5) was found to increase from the year 2001 to 2019. This is due to the increase in urban land cover from 2001 to 2019 because of the increased urbanization in the city. The area covered by the high temperature regions for years 2001, 2007, 2013 and 2019 were shown in Tables 7.3, 7.4 and 7.5 for the winter, summer and post-monsoon seasons, respectively.

Table 7.3. Area within regions showing SUHI effect in winter season for the years 2001, 2007, 2013 and 2019

Year	**Area within region-5 (km^2)**	**Area within region-4 (km^2)**	**Total area within SUHI (km^2)**
2001	84	66	150
2007	100	80	180
2013	136	87	223
2019	165	101	266

Table 7.4 Area within regions showing SUHI effect in summer season for the years 2001, 2007, 2013 and 2019

Year	Area within region-5 (km^2)	Area within region-4 (km^2)	Total area within SUHI (km^2)
2001	96	66	162
2007	115	75	190
2013	147	85	242
2019	164	98	262

The area which reveals SUHI effect in the UHI image was found to show clear increment from 2001 to 2019 in the three seasons. The area within region-5 was higher in summer season whereas in region-4 was higher in post-monsoon season. This is because during night time built-up surfaces shows higher LST and also waterbody shows LST higher than other natural land covers. Thus, the moderately high temperature region (Region-4) may include some areas of waterbody. The water content in the river in Varanasi is greater in post-monsoon season as compared to other seasons resulting in higher number of pixels within region-4 in post-monsoon season.

Table 7.5 Area within regions showings SUHI effect in post-monsoon season for years 2001, 2007, 2013 and 2019

Year	Area within region-5 (km^2)	Area within region-4(km^2)	Total area within SUHI (km^2)
2001	98	72	170
2007	106	85	191
2013	134	94	228
2019	151	106	257

Further, mean UHI value was determined for the high temperature regions i.e. region-5 and region-4 and shown in Table 7.6. In region-5, mean UHI value was found lower in post-monsoon season but higher in summer. The thermal inertia of moist rural soil is quite higher than that of dry rural soil (Kumar et al. 2017). As a result, the moist rural soil in post-monsoon season requires more time to cool down than that of dry soil in summer season during night time. This decreases the nocturnal temperature difference between rural and urban regions resulting in lower SUHI effect during post-monsoon season whereas the greater nocturnal urban-rural temperature difference in summer season results in higher SUHI effect. The vegetation and dry bare land shows lower LST values than the water pixels during night time. The greater moisture content in the soil during post-monsoon increases its temperature and vegetation showing lower temperatures results in increased mean UHI value in winter season than post-monsoon season. The rate of increase in mean UHI value from 2001 to 2019 was greater in summer and winter season as compared to that of post-monsoon season. According to post-monsoon season condition, urbanization replaces the moist soil with the urban built-ups whose temperature difference is lower as compared to the temperature difference of dry bare soil or vegetation with that of urban built-ups.

Table 7.6 Mean UHI value of regions 4 and 5 for winter, summer and post-monsoon season of the years 2001, 2007, 2013 and 2019

Year	Winter		Summer		Post-monsoon	
	Region-5	Region-4	Region-5	Region-4	Region-5	Region-4
2001	2.82	1.05	2.90	1.03	2.80	1.12
2007	2.92	1.09	2.97	0.98	2.79	1.05
2013	2.99	1.13	3.03	0.96	2.83	1.11
2019	3.03	1.05	3.08	1.02	2.84	1.09

In region-4, the UHI value of a pixel includes contribution from both urban built-ups and natural land cover. Mean UHI value was found lower in summer but higher in post-monsoon season. During summer season, the dry bare soil along with the urban built-ups results in lower UHI value whereas during post-monsoon season, the contribution of moist soil and increase in water content in the waterbody at the banks of the city results in higher UHI value. The lower thermal inertia of dry bare soil results in lower temperatures at night as it cools down faster whereas the higher thermal inertia of water shows higher temperatures at night as it requires greater time to cool down. Thus, the greater moisture content in the soil during post-monsoon season results in higher temperatures than the dry bare soil during summer season. During winter season, the vegetated land had greater moisture content than the dry bare soil in summer season but lower than that of the water and moist soil in post-monsoon season. This results in lower UHI value of region-4 in winter season than that of post-monsoon season but higher UHI value than that of summer season.

The region-5 shows increase in mean UHI value from 2001 to 2019 because urbanization not only expands the city area but also increased the built-up density in the core of the city. The region-4 does not show a fixed pattern from 2001 to 2019 in the three seasons because of the influence of the natural land cover on mean UHI value.

7.4.3 SUHI intensity determination

SUHI intensity was determined by considering two parameters i.e. the area showing SUHI effect and the mean UHI value of the high temperature regions. The values obtained for the SUHI intensity for winter, summer and post-monsoon season of the years 2001, 2007, 2013 and 2019 are represented in Figure 7.4. SUHI Intensity (SUHII) value was found to increase significantly from 2001 to 2019 for the three seasons in the study with increased urbanization. The SUHII value was found different with seasons for the same year due to the presence of different type of natural land cover around the city with changing seasons which has significant impact on the UHI value in the city. The rate of increase in SUHII was found lower for post-monsoon season because of the low rate in increase of mean UHI value in the region-5 in post-monsoon season as compared to other seasons. Further, the rate of increase in SUHII was found greater in winter than that of summer. According to summer season, the urbanization replaces the dry bare soil with built-ups whereas according to that of winter season, urbanization replaces vegetated land with built-ups. Thus, decrease in vegetation in a city with increased urbanization shows greater impact on increasing SUHII.

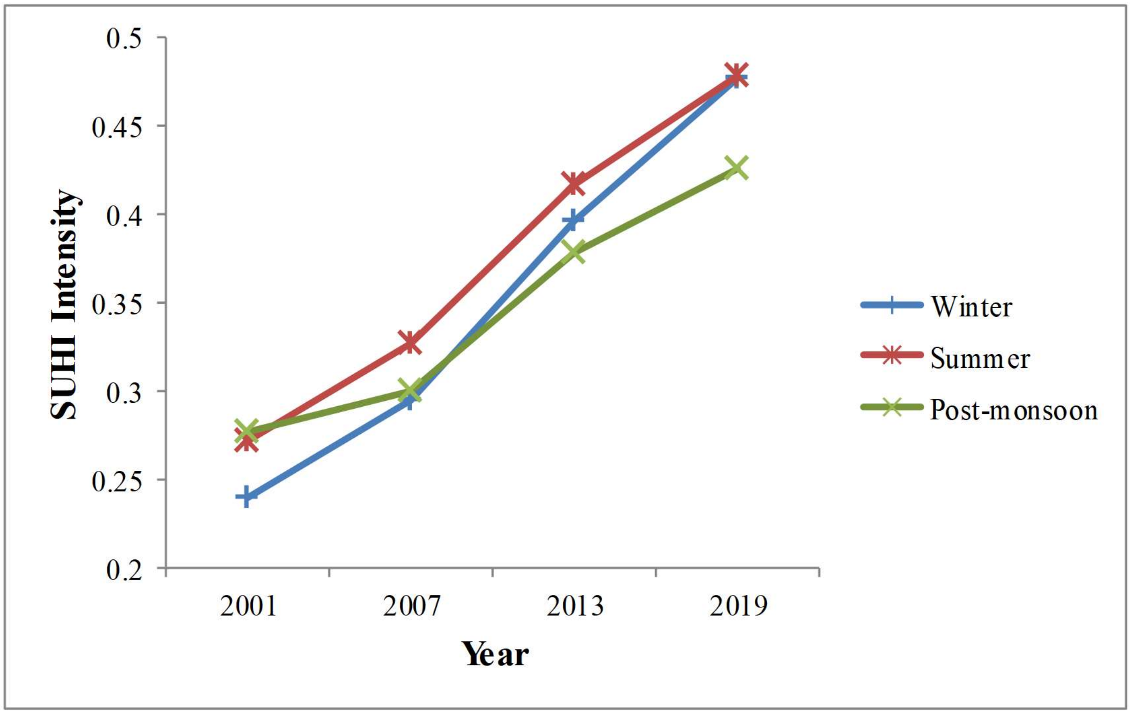

Figure 7.4 SUHI Intensity for winter, summer and post-monsoon season of years 2001, 2007, 2013 and 2019

7.5 CONCLUSION

The present study focuses on the quantification of SUHI intensity for winter, summer and post-monsoon seasons of the years 2001, 2007, 2013 and 2019 in Varanasi city of India using MODIS satellite data. NDVI maps were obtained to determine the seasonal variation in vegetation cover from 2001 to 2019. The rural areas surrounding the city was found mostly covered with dense vegetation during winter, dry bare soil during summer and sparse vegetation during post-monsoon season. The increase in urban land cover in the city was also seen through NDVI maps of winter season from 2001 to 2019. Further, UHI maps were obtained from the MODIS LST images and classified into five thermal levels based on the

UHI values. The region-4 and region-5 of the thermal levels depicts moderately high temperature region and very high temperature region, respectively indicating SUHI effect.

The area and the mean UHI value within region-4 and region-5 were obtained for the three seasons from 2001 to 2019. These two parameters play an important role in the quantification of SUHI intensity. The total area showing SUHI effect showed significant increase from 2001 to 2019 in the three seasons. The mean UHI value was found lower in post-monsoon season but higher in summer and winter seasons in region-5. The greater moisture content in moist rural soil than that of vegetation and dry bare soil results in higher temperature of moist rural soil. This decreases the urban-rural temperature difference in post-monsoon season and shows lower mean UHI values in region-5. Mean UHI value was found lower in summer but higher in post-monsoon season in region-4 due to the contribution from both natural land cover and urban built-ups. The region-5 also shows increase in mean UHI value from 2001 to 2019 because urbanization not only expands the city area but also increased the built-up density in the core of the city. SUHI Intensity value was determined and found to increase significantly from 2001 to 2019 for the three seasons in the study with increased urbanization. The rate of increase in SUHII was found lower for post-monsoon season than other seasons indicating the region with greater moisture content shows lower SUHI effect. Also, the rate of increase in SUHII was found greater in winter than that of summer. Thus, decrease in vegetation in a city with increased urbanization shows greater impact on increasing SUHII.

Therefore, the SUHII calculation method used in this study was found quite appropriate for quantification of SUHI effect in different cities with varied land covers. Further studies can also be performed using other satellite images and also on cities in different climatic zones.