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Multi-temporal NDVI and surface temperature analysis for Urban Heat Island inbuilt surrounding of sub-humid region: A case study of two geographical regions

Meenu Rani[a], Pavan Kumar[b], Prem Chandra Pandey[c,*], Prashant K. Srivastava[c], B.S. Chaudhary[d], Vandana Tomar[e], Vinay Prasad Mandal[f]

[a] G.B. Pant National Institute of Himalayan Environment & Sustainable Development, India
[b] Remote Sensing and GIS, Department of Geography, Kumaun University, S.S.J. Campus, Almora, Uttarakhand, India
[c] Institute of environment and Sustainable Development, Banaras Hindu University, Varanasi, India
[d] Department of Geophysics, Kurukshetra University, Kurukshetra, Haryana, India
[e] Haryana Institute of Public Administration, Gurgaon, India
[f] Department of Geography, Faculty of Natural Sciences, Jamia Millia Islamia, New Delhi, India

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ABSTRACT

Rapid growing urban population has resulted in the occupancy of large proportionate of the city and its outskirts, thereby contributing factors to change in the environmental conditions. This has resulted in widespread land acquisition for built up and industrial development, covering the centre of the city while moving at the outskirts of the city as well. Land Use /Land Cover (LULC) changes causes alterations in the land use categories, mostly the concrete forests which has increased the urban temperature as compared to the rural regions due to rapidly growing urbanized environment. Urban Heat Island (UHI) is one of the human-induced environmental phenomenon affecting the urban inhabitant in many ways, such as altering and disturbing the land cover its use which changes thermal energy flow causing elevated surface and air temperature. Temporal satellite datasets (LANDSAT ETM+ image of 1989, 2000 and 2006) can be used to monitor surface temperature while vegetation indices can be used to assess the coverage of the vegetation and non-vegetation area in the region. Temporal NDVI is employed in the study area to analyse the impact of land surface temperature against NDVI in the region. Therefore, temporal remotely sensed data can be used to map LULC and its dynamic changes and other environmental phenomena such as surface temperature over a period of time. Temporal UHI has been estimated using geospatial technology to incorporate it for environmental impact assessment on the surrounding environment. The present research focuses on temporal NDVI and Surface temperature, the methodology used altogether for the assessment of resolution dynamic UHI change on environmental condition for Haridwar district, Uttrakhand India and Kanpur district, Uttar Pradesh in India. Both case study has different environmental conditions, geographical locations and demography. Hilly and forested region with almost no industrial activities for Haridwar while several industrial activities and densely populated region Kanpur located in an Indo-Gangetic plain. The research outcome demonstrates the correlation between temporal NDVI and Surface temperature exemplified with case study conducted over two different regions, geographically as well as economically. There is a need to consider the environmental dimension while making progress to urbanization.

1. Introduction

Urban Heat Islands (UHI) significantly impact the life quality of large cities and has pronounced impact on the environmental surroundings. There are numerous studies conducted to assess the adverse impact of UHI in past decades, and results demonstrated around the major cities of the world such as Athens, Greece (Katsoulis and Theoharatos, 1985), Paris, France (Dettwiller, 1970), Singapore and Kuala Lampur (Tso, 1996), Tokyo, Japan (Fukui, 1968) and Washington DC, USA (Kim, 1992). There are more studies related to UHI concerning

* Corresponding author.
E-mail addresses: meenurani06@gmail.com (M. Rani), pawan2607@gmail.com (P. Kumar), prem26bit@gmail.com, premchandrap@mail.tau.ac.il (P.C. Pandey), prashant.iesd@bhu.ac.in (P.K. Srivastava), bsgeokuk@gmail.com, bschaudhary@kuk.ac.in (B.S. Chaudhary), vandana7232@gmail.com (V. Tomar), vinnumandal@gmail.com (V.P. Mandal).

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the regional urban heat that have been conducted in Australia and Argentina (Camilloni and Barros, 1997), China (Wang et al., 1990), South Korea (Lee, 1993) and United States (Camilloni and Barros, 1997; Johnson et al., 1994). The industrialization and increasing comforts have the adverse effect on surface temperature which is increasing at a fast pace. There is need of green space in the city and surrounding environment.

Urbanization and industrialization endow with many services and advances the human life style steadily but they also affect and imbalance our natural environment such as pollution, temperature increase, solid waste problems (Pandey et al., 2012). In urban areas, there is a UHI effect resulting from the formulation and escalation of heat in the urban mass. Most of the world's population inhabit arid regions and their future growth will occur in urban regions of the world (Baker et al., 2004), thereby moving to urban regions (Sharma et al., 2012), thereby trigger overpopulation of the migrated city resulting in overuse of automobiles, industrial activities, large number of factories, domestic use appliances such as refrigerators. Kumar et al. (2010) concluded in their study that rapid urbanization and population growth has resulted in the damage to landscape resulting in sprawl at outskirt and affecting climatic condition. Thus, this is also a factor to consider for assessing urban as well as outskirt surface temperature for urban heat measurement. This results in elevated surface air temperature of the concerned urban region as compared to the surrounding rural region (Kim and Baik, 2005; Magee et al., 1999), and the difference generally being greater at night than during the day. This phenomenon is known as the UHI which is considered as one of the major problems of a human population in the 21st century (Rizwan et al., 2008; Zhang et al., 2010).

It is mandatory to have information and knowledge of surface temperature to assess and estimate the urban surrounding environment and human health. This temperature difference is due to anthropogenic activities such as industries, factories, automobiles, air conditioning and also due to the geometries of the cities which absorb huge amounts of heat and re-radiate solar radiation producing a large amount of heat. The radiant heat that is absorbed during the day by concreted non-transpiration buildings and construction in urban areas is re-emitted after sunset creating high-temperature differences between urban and rural areas especially higher at night. The energy of solar radiations absorbed by the urban structure such as roads and rooftops can cause urban surface temperatures to be 50–90°F higher than the ambient air. Surface temperature measurements can be made in a variety of ways but surveying large areas requires remote sensing. All surfaces give off thermal energy that is emitted in thermal infrared wavelengths. Thus, sensors in the 10.2–11.0 µm are reported giving the most reliable single-bound estimate of surface temperature.

Thermal channels of remotely sensed data in the spectral region 10.4–12.5 µm of EMR spectrum has proved its capability to identify and assess urban heat islands (Rahman, 2007). The most common and widely available thermal channel comes from LANDSAT-TM and ETM + with the spatial resolution of 60 for estimation of surface temperature. Several research focuses on the use of course as well as medium-resolution remotely sensed datasets i.e. LANDSAT TM (120 m) and ETM + (90 m.) (Kim, 1992; Nichol, 1996, 2005, 2009, 1994; Weng, 2001), Sentinel-2A (10 m.) (Kim, 1992; Nichol, 1996, 2005, 2009, 1994; Weng, 2001). These remotely sensed datasets are available over day time and thus limited to a day time acquisition. Satellite-based remote sensing data estimation and retrieval for radiant temperature is the measure of almost true kinetic energy of the feature surface. The surface energy of the surrounding environment controls the energy demand of the city for its comfort and ease. Summer heat island can increase the surface temperature of the region as well as surrounding environmental temperature, which in turn increases the demand for electrical energy for air conditioning that releases more heat into the atmosphere in the form of greenhouse gas emissions, hence contributing to the degradation of surrounding air quality (Rosenfeld et al., 1998). The disturbance in the air quality and its degradation will have the direct and indirect impact on the human health as heat stress due to heat waves, and especially in the temperate region which is favourable for the spread of-of vector-borne diseases due to increased suitable conditions (Changnon et al., 1996; McMichael, 2000).

Thermal channels used to acquire data in day and night time were incorporated into temperature studies and used to monitor the heat island associated with the surrounding urban environment (Cornélis et al., 1998). Several studies were conducted, in order to establish the role and importance of the thermal channels (LANDSAT ETM+ and ASTER (Advanced Space-borne Thermal Emission and Reflection Radiometer - band 10–14 with 90 m spatial resolution) datasets to LULC mapping, vegetation density and illustrates the efficiency in surface temperature estimation. The present study focuses on the effect of LULC, and vegetation cover over a time period to surface temperature with two case study, Uttrakhand for 1989–2006 and Kanpur for 1989–2006. It illustrates the correlation between temporal vegetation indices over a time period and how it affects the surface temperature in that particular duration. Thus there is an essential need to escalate vegetation for reducing the formation of thermal surfaces in the urban region.

2. Study area

The study is conducted over two selected regions, Haridwar district in Uttrakhand and Kanpur district in Uttar Pradesh. The first case study area is an administrative boundary of the Haridwar district, Uttarakhand, India located at 29°35'37″N to 30°13'29″ N latitude and 77°52′52″ E to78°21′57″ E longitudes covering an area of 1850 sq.km (Fig. 1A). The district is ringed by Dehradun in the northeast, Pauri Garhwal in the east, Muzaffarnagar and Bijnor in the south and Saharanpur in the west. This study area is chosen due to its peculiar location and seasonal effect from surrounding Himalayan ranges. The climate of Haridwar is considerably affected by its proximity to the Himalayan ranges and enjoys extreme seasons of each season. The summer months are extremely hot as the temperature rises up to 41 °C and the winters are too cold with a fall in temperature around 4 °C.

While Second case study area belongs to Kanpur district which harbours small-scale industries, commerce and factories representing a metropolitan city. It occupies over an area of about 1640 km^2 located at following latitude and longitude 26°27' to 26°46' N and 80°20–80°33' E.Kanpur has also peculiar location as shown in Fig. 1(B), surrounded by two major rivers, the Ganges in the northeast, and the Pandu in the south. The climate is sub-humid characterized by hot dry summers except during the southwest monsoon. The average annual rainfall of 821.9 mm, ~90% takes place from the third week of June to September.

3. Material and methods

3.1. Satellite data used

The case study has utilized LANDSAT 7 TM (Thematic Mapper) and ETM+ (Enhanced Thematic Mapper +) data of 1989, 2000 and 2006 for the analysis of surface temperature estimation. Thermal band of the data were being employed to estimate surface temperature while other channels were used to calculate the NDVI of the regions. The pixel size of the optical bands and 57 m. Table 1 illustrates the use of thermal band employed in the present study to conduct the desired investigation.

3.2. Image pre-processing

Resampling was carried out following bilinear interpolation method, taking into account four neighbouring pixels to the computed value of original ETM+ thermal band 6 data. Using the polynomial function and nearest neighbour algorithm with a pixel size of 30 by

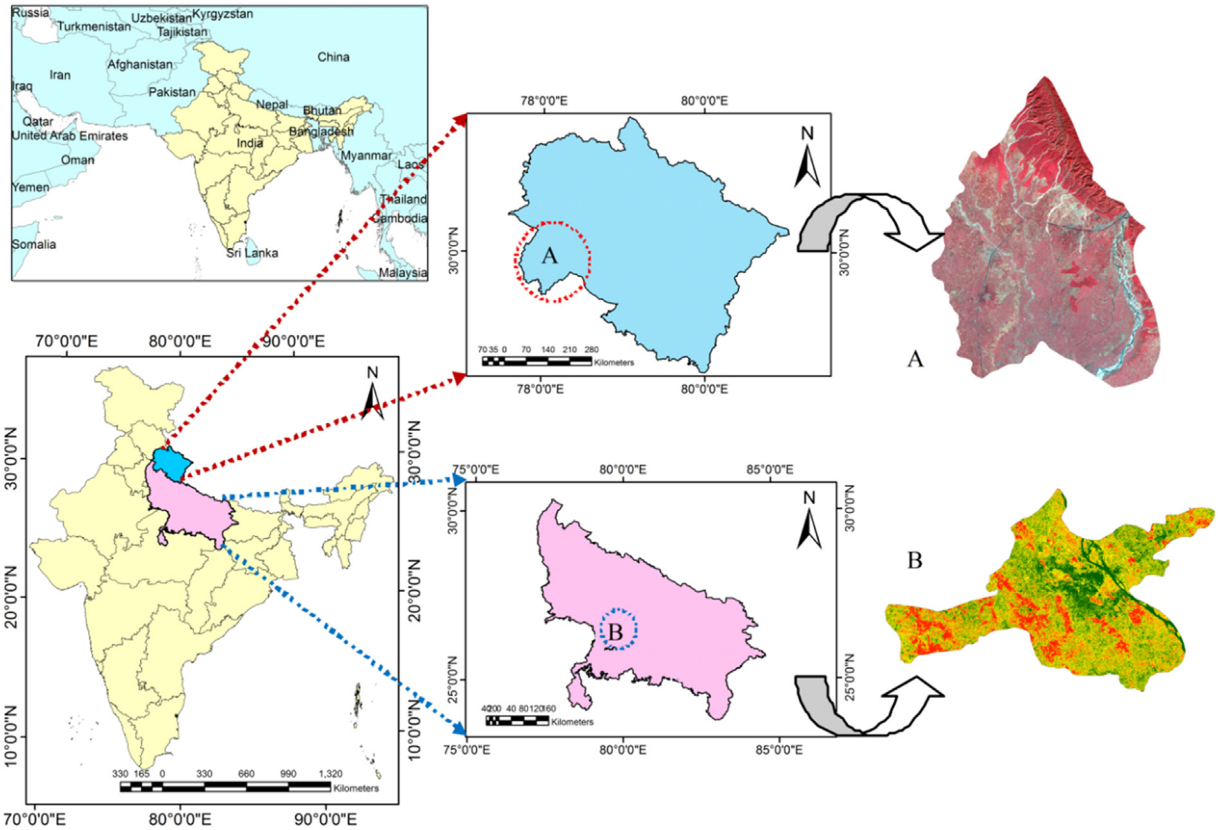

Fig. 1. Location map of the study area (A) Haridwar District and (B) Kanpur District.

Table 1
Descriptions of satellite datsets.

Satellite	LANDSAT
Sensor	TM and ETM+
Scale	1:50000
Band combination	4,3,2
Temporal Resolution	16 days
Year	1989, 2000 and 200

30 m for all bands including the thermal band, the resembling or image warping process is done. An image is geometrically corrected by plotting GCP points (Fig. 2) and models are executed in software ERDAS Imagine 10 and Arc GIS 10.0 (Tomar et al., 2013). Digital image analysis was carried out using ERDAS 10 and Arc GIS 10.0 software package. Digital map imported into PCI Geomatica 10.3 and linear enhancement processes were done then imported into ERDAS IMAGINE-10.0 for rectification process. We have performed supervised classification (maximum likelihood algorithm) for the LULC mapping for each year (1989–2006 for Dehradun and Kanpur). The vegetation indices such as NDVI were calculated for the mentioned duration for each study area. These images were then reclassified in Arc GIS 10 to compare the changes found in these years. To estimate the vegetation characteristics, Normalized Difference Vegetation Index (NDVI) is

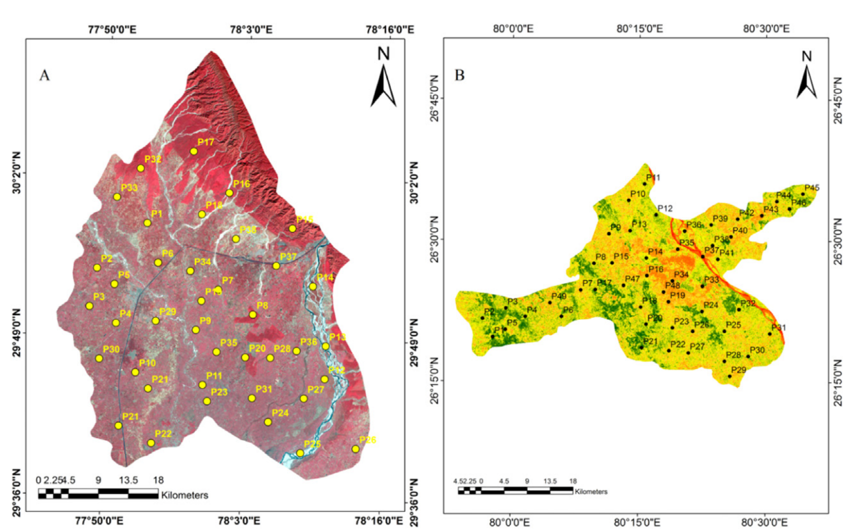

Fig. 2. Field sample location points for the study sites- (A) Haridwar and (B) Kanpur.

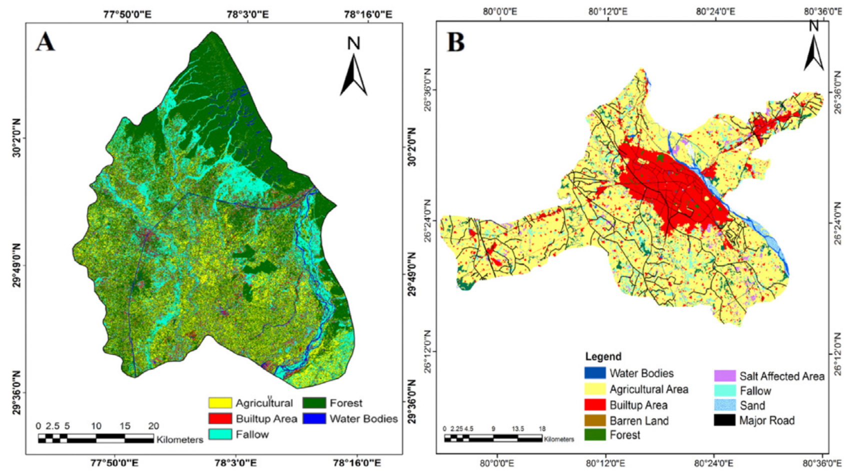

Fig. 3. Land Use/Land Cover map of the study area (A) Haridwar (B) Kanpur.

calculated as follow (Tomar et al., 2013):

$$NDVI = \frac{(NIR - R)}{(NIR + R)} \quad (1)$$

where NIR is Near-infrared and R is the red Channels, NDVI value ranges from −1 to +1.

3.3. Land use and land cover classification scheme

This section deals with the LULC classification parts for two study sites. Maximum Likelihood Classification based on supervised classification algorithms have been employed to classify the study regions and used to assign an unknown pixel to one of given class. In order to generate LULC maps, we have employed supervised classification, taking care the area of interest and field surveys measurements together for training as well as validation parts (Tomar et al., 2013). Therefore, incorporation of classification scheme provides a broad classification for different feature classes. First of all, classification key i.e. cover classes were considered relevant to the existing land use pattern for the selected study sites. There after, about 38 ground control points for Haridwar (Fig. 2A) and 50 ground control points for Kanpur study site (Fig. 2B) has been collected during the field survey. This field points representative training sites for each land use land cover class were randomly selected. Approximately half of the field points were taken during training samples and rest were used for the validation purposes from homogeneous areas for each class follow (Tomar et al., 2013). The separability of the selected training points for all LULC classes was examined in Environment in Visualizing Images (ENVI) 5.2 version which provides computational classification of LULC.

3.4. Temperature estimation

Radiant temperature and a surface temperature of both study sites were estimated from the thermal data of LANDSAT TM of the year (1989, 2000 and 2006). Radiant temperature is derived from the emission and reflection of radiation from these elements, is usually detected by satellite sensors in the atmosphere. The conversion of radiance values of the thermal channel of LANDSAT ETM+ into satellite-derived surface temperature (T_s) can be performed in two stages. First of all, brightness Temperature (T_b) is converted by radiance (Malaret et al., 1985). Second, emissivity correction, have to illustrate about the thermal intensity in the urban environment. The graph of thermal intensity of urban area could increases day by day due to a replacement of vegetated area by non-vegetated area i.e. concrete and metal made buildings and factories. Remote and contact measurements could lead the derivation of emissivity correction in the study area surfaces using instruments which composes the mask having pixels, most importantly differentiate categories as vegetated and on vegetated areas through emissivity values. This emissivity correction process has advantages of creating sharp boundaries which usually characterized the urban area according to the land cover, to distinguish the vegetated cover from non-vegetated.

3.5. Satellite-derived radiant temperature estimation from the resampled thermal channel

a) The following procedure was employed to retrieve the radiant surface temperature (T_{rad}) from the thermal band: Conversion of the image DN values to $TOA_{radiance}$ spectral radiance is given in Eq. (2). Thus, the surface temperature is estimated using the following Eq. (2).

$$TOA_{radiance}(L_\lambda) = ((L_{max} - L_{min})/(Qcal_{max} - Qcal_{min})*(DN - Qcal_{min})] + L_{min} \quad (2)$$

Where, $QCAL_{MIN}$ = 1, $QCAL_{MAX}$ = 255, and QCAL = Digital Number L_{MIN} and L_{MAX} = spectral radiance for band 6:1 at DN 0 and 255.

b) The ETM+ thermal band data were converted from spectral radiance to satellite radiant Temperature using Eq. (3) (Asmat et al., 2003).

$$B_T = K_2/ln[\left(\frac{k_1}{L_\lambda}\right)+1] \quad (3)$$

where, B_T = effective at satellite temperature in Kelvin, K1 = Calibration constant 1 ($W\,m^2\,sr^{-1}$) (666.09); K2 = Calibration constant 2 in K (1282.7); L_λ = Spectral radiance in ($W\,m^2\,sr^{-1}$)

c) For emissivity estimation, the visible spectral channels of the ETM + image were classified into three main LULC classes features namely vegetation, non-vegetation and water. During corrections of emissivity, differences in Land use land cover were calculated using cover type by rating the BBT image with the classified image in which land cover pixel values were swapped with the corresponding emissivity values. In this way, surface temperature (T_s) was derived for corrected emissivity using Eq. (4) (Artis and Carnahan, 1982).

$$Ts = T/[1 + (lT/a)ln\ e] \quad (4)$$

where, l = Wavelength of emitted radiance, a = hc/K (1.438´ 10–2 mK), h = Planck's constant (6.26´ 10–34 J s), c = velocity of light (2.998´ 108 m/s), K = Stefan Bolzmann's constant (1.38´ 10–23 J/K)

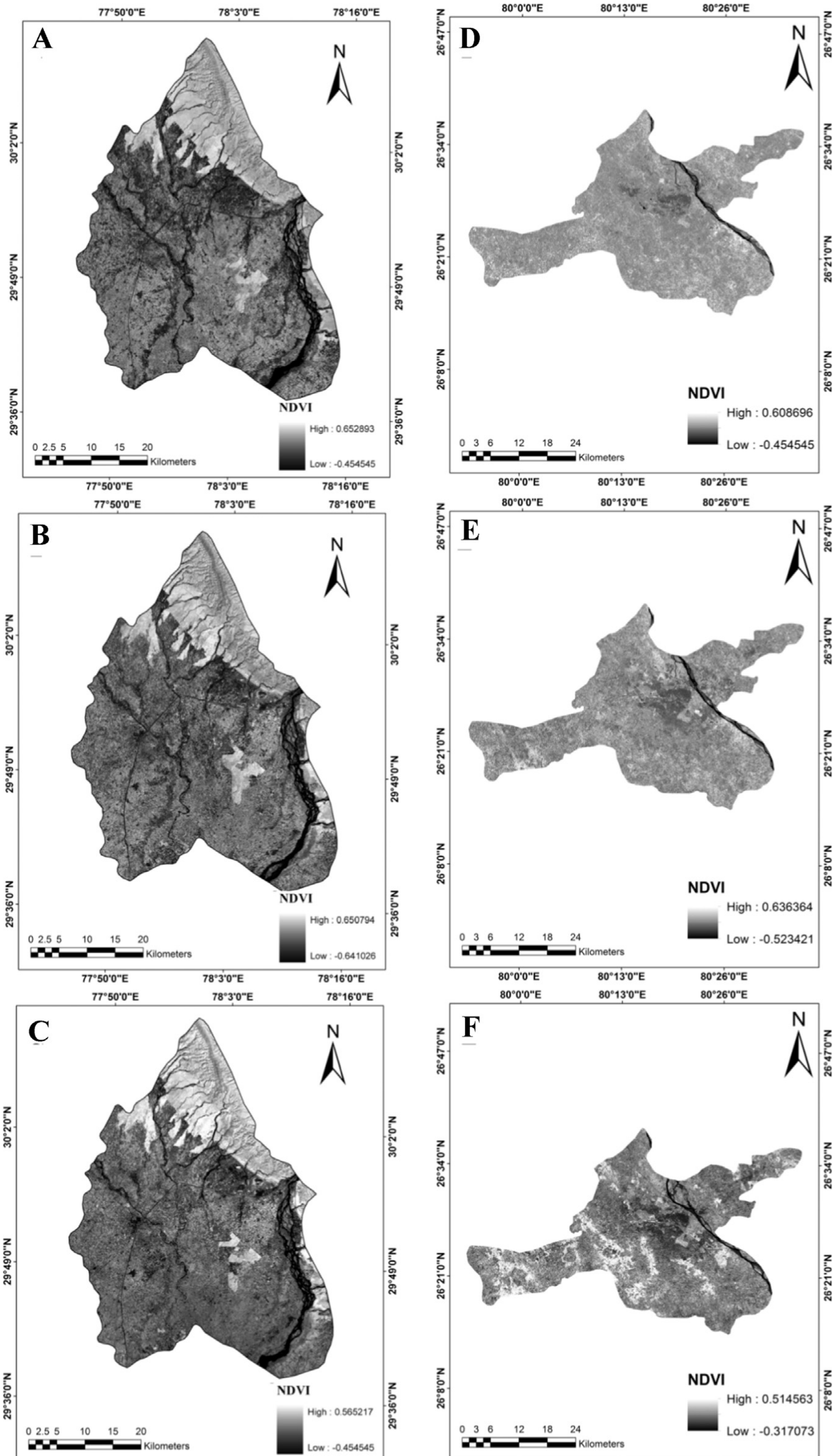

Fig. 4. NDVI maps (a, b, c) of Haridwar District for year 1989, 2000 and 2006 and (d, e, f) Kanpur district for the year 1989, 2000 and 2006.

4. Results and discussion

This study demonstrates the relationship between temporal NDVI and temporal surface temperature at two study region, illustrating the similar relationship. The relationship between T_{rad} and other kinds of spectral parameters such as DNs of spectral bands, vegetation indices and emissivity are as follows.

4.1. Land use/land cover

This section provides brief information about the LULC mapping based on the prior knowledge and field survey conducted in the study sites for the training as well as validation purposes. A classification scheme of land use land cover was employed along with reconnaissance survey as well as GIS and additional information for both study sites, Haridwar and Kanpur site. The selected study sites were classified

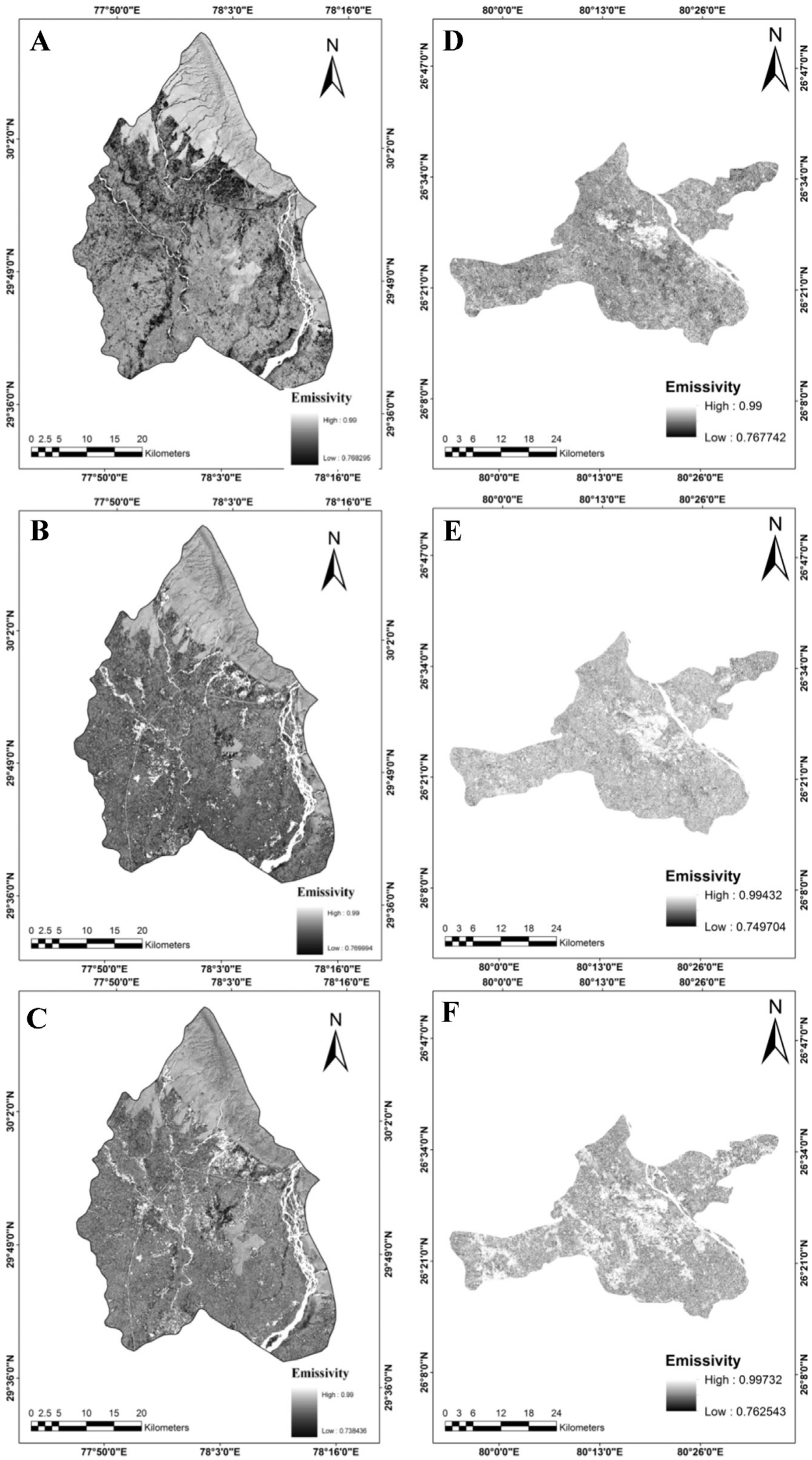

Fig. 5. Emissivity maps (a, b, c) of Haridwar District for year 1989, 2000 and 2006 and (d, e, f) Kanpur district for the year 1989, 2000 and 2006.

according to the training sites (half of the field survey points) and rest were utilized for validation of land use classes. LULC changes are related to the global environmental process and therefore put environmental implication at local and regional levels (Behera et al., 2018). Because elements of the natural environment are interrelated, any kind of direct or indirect effect on one element may cause direct or indirect effects upon others. Five most important land use and land cover classes are delineated through classification (as illustrated in Fig. 3 A and B). The built-up area covered with building, roads and other impervious surfaces absorb higher solar radiation due to higher thermal conductivity during daytime and released slowly at night in the form of emission. Therefore, urban areas tend to experience a relatively higher temperature as compared to adjoining rural areas. Urban development typically responsible for the remarkable change of the earth's surface temperature as vegetation is replaced with metal, asphalt and concrete as non-evaporating and non-transpiring shell.

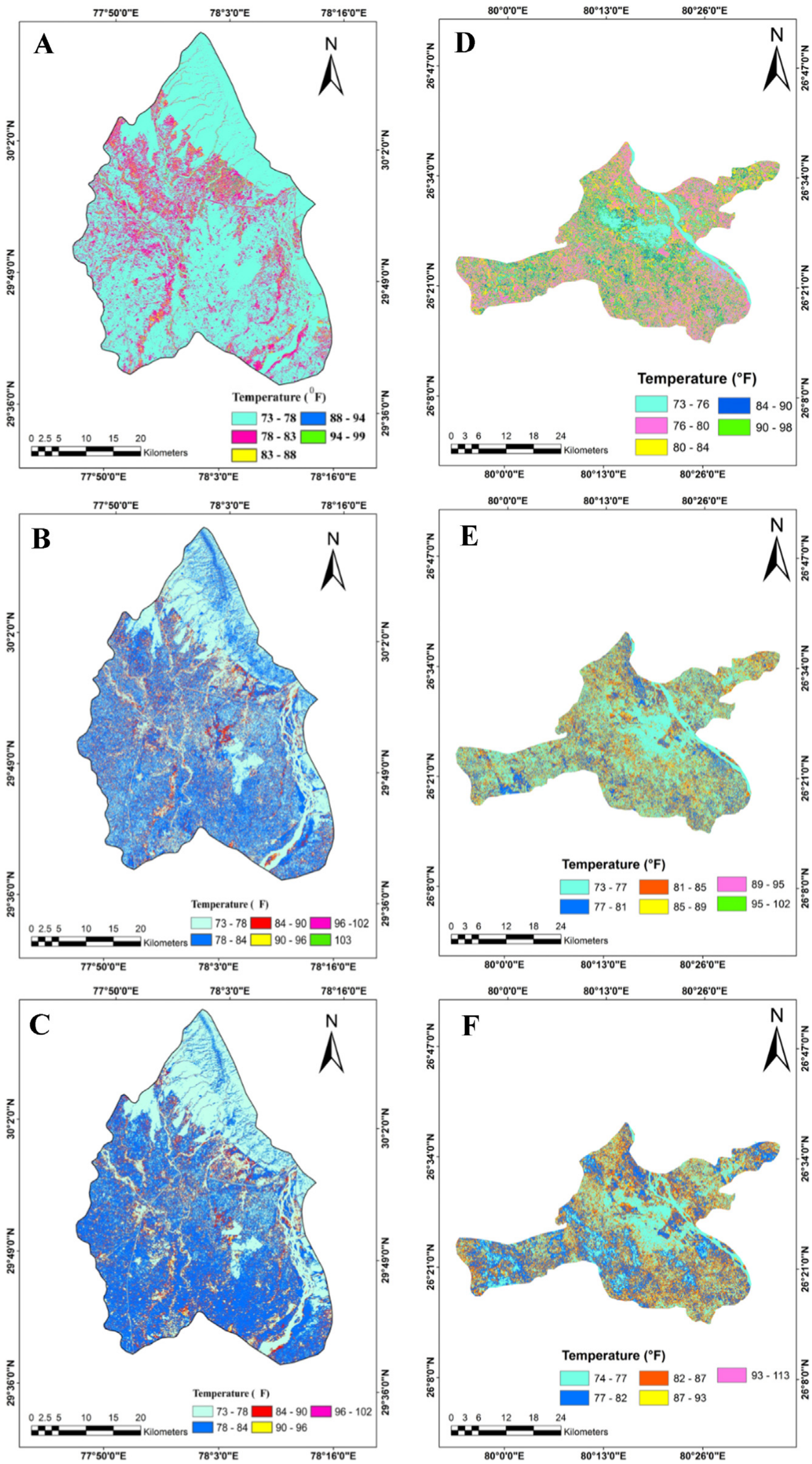

Fig. 6. Surface temperature maps (a, b, c) of Haridwar District for year 1989, 2000 and 2006 and (d, e, f) Kanpur district for the year 1989, 2000 and 2006.

4.2. Normalized Difference Vegetation Index (NDVI)

NDVI is one of the most extensively used indices to differentiate vegetated areas from non-vegetated areas and vegetation health. It transforms raion image of NIR and Red channels into a single band image with range value between − 1 to + 1. The values of NDVI indicate the amount of chlorophyll content present in vegetation, where higher NDVI value indicate dense and healthy vegetation and lower value indicate and sparse vegetation bare soil. Reasons assigned for high NDVI values are due to relatively higher reflectance value in NIR and lower in the red band follow (Tomar et al., 2013). In the case of Haridwar district (case study-1), NDVI values ranges in 1989 are − 0.45 to + 0.65 (as shown in Fig. 4 A) whereas, in 2000, it slightly increases from − 0.64 to + 0.65 (as shown in Fig. 4 B), While, in 2006, NDVI shows the minimum value that is − 0.45 and maximum + 0.56 (as shown in Fig. 4 C). Thus, it is conferred that there is the sharp

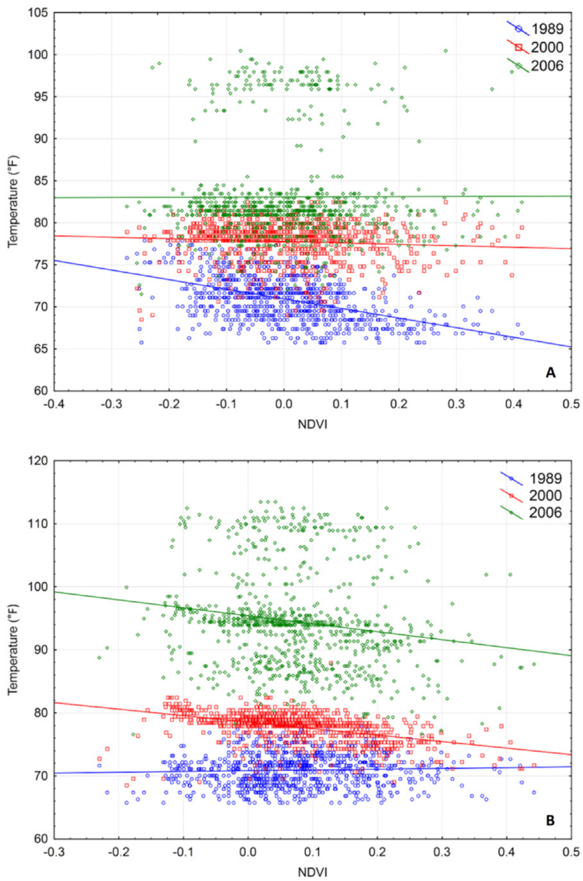

Fig. 7. Correlation between NDVI and Temperature (a) 1989, 2000 and 2006 of Haridwar District and (b) 1989, 2000 and 2006 for Kanpur District.

decline in the vegetation cover of the study area (Fig. 4), resulting in increased temperature over the year as illustrated in Fig. 6. A surface temperature of Kanpur city was generated for 1989, 2000 and 2006 and has shown higher surface temperature than Haridwar (see Fig. 6 D, E, and F). Similarly, NDVI values for Kanpur, is higher in 1989 to + 0.72, which has shown the constant decline with passing time, estimated NDVI for 2000 is + 0.63, and for 2005 it is + 0.60. (see Fig. 4 D, E, and F). This clearly provides an overview of the vegetation cover, which is likely to be sparse or less dense as compared to previous years.

While, second case study (Kanpur), has shown the similar trends in NDVI value ranges, vegetation cover in the city has shown a sharp decline with time as compared to case one. Due to the hasty development and lack of vegetation in urban region of Kanpur city, heat island effect is highly influenced by high surface temperature. An emissivity of land use land cover features has been generated for the year 1989–2006 for both study sites and illustrated in Fig. 5. Fig. 5 (A, B and C) demonstrate the emissivity range for the Haridwar study site for the year 1989, 2000 and 2006 respectively. Similarly, Fig. 5 (D, E, and F) demonstrate the emissivity range for the Kanpur study site for the year 1989, 2000 and 2006 respectively. The range varies from Hardiwar as follow 076–0.99 (1989), 0.76–0.99 (2000) and 0.77–0.99 (2006) while the range for Kanpur site has the similar trend with lowest emissivity 0.74 in the year 2000. And other ranges are 0.76–0.99 (1989), 0.74–0.99 (2000) and 0.76–0.99 (2006).

Table 3
Temperature change from 1989 to 2006 in Kanpur study region.

Temperature (˚F)	1989 Area %	2000 Area %	2006 Area %
73–76	20.39	22.31	20.10
77–81	34.64	30.68	30.49
82–87	31.74	30.49	34.47
88–95	11.70	11.21	12.52
96–100	1.52	2.31	2.42

Surface temperature for Haridwar site shows lower temperature ranging from 73˚ to 78 ˚F (for the year 1989), 78–84 ˚F (for the year 2000) and 73–78 ˚F (for the year 2006) for most of the regions, and has very few regions with higher surface temperature (Fig. 6 A, B and C). As against to this, Kanpur Site has the variable surface temperature for the entire region and for the different year has different surface temperature values. For Kanpur study site, most of the regions have higher surface temperature values. For the year 1989, two ranges are dominating the Kanpur study regions, such as 76–80 ˚F and 84–98 ˚F. While for the year 2000, most of the Kanpur sites have higher surface temperature values ranging from 95˚ to 102 ˚F and for the year 2006 surface temperature ranges from 77˚ to 87 ˚F. This clearly demonstrates lower surface temperature in Haridwar site as compared to the Kanpur site. This may be due to locations and industrial activity in the selected study sites. Industrial activity increases the surface temperature of the surrounding environment and therefore the results demonstrate higher surface temperature for the Kanpur site (Fig. 6 D, E, and F).

4.3. *Influence heat island*

Apart from a higher thermal intensity of underlying surface, the special thermal situation in the urban area may also lead to the increase in thermal intensity and responsible for the formation of the heat island. A viaduct of thermal energy is generated due to traffic lines, factory buildings in industrial areas, densely populated commercial and residential areas. The radiant temperature of different LULC categories in Haridwar was estimated using the thermal band of the LANDSAT TM and ETM+ imagery for the years 1989, 2000 and 2006. In 1989, the high surface temperature area of Haridwar was sited mainly in the central part of the district (Fig. 6 A). At that time, these areas were particularly jam-packed multi-storied houses urban centres with a crowded population. After few years, in 2000 and 2006 (Fig. 6 B and Fig. 6 C), the inner centre of the downtown and the outer circular periphery of the town becomes high-temperature packet. due to fast progress in construction in Haridwar, The inner high temperature and the thermal packet has affected the almost whole city.

Table 2
Temperature change from 1989 to 2006 in the Haridwar study region.

Temperature (˚F)	**1989**		**2000**		**2006**	
	Area (ha.)	%	Area (ha.)	%	Area (ha.)	%
73–78	133,765.7	72.99	80,407.8	43.88	65,448.18	35.71
78–84	40,031.73	21.84	76,645.35	41.82	91,106.1	49.71
84–90	7498.71	4.09	18,575.19	10.14	19,798.29	10.80
90–96	1549.98	0.85	5289.03	2.89	6479.19	3.54
96–102	415.62	0.23	2342.7	1.28	429.93	0.23
103	0.00	0.00	1.62	0.00088	0.00	0.00

This higher range of temperature and growth of the thermal area is because of the existence of concrete coverage such as parking, footpath, road and tile-covered buildings. Sometimes, the temperature difference between this urban area and the suburbs would be 6 °C. The factors related to townships development such as road network, bridges, buildings and construction play a crucial role in the growth of urban heat island.

4.4. Correlation between NDVI and temperature

The NDVI is a term which indicates the photosynthetically active radiation for vegetation. Hereby in Haridwar district, the NDVI value is strongly affected by climatic factor soil and geomorphology. To identify and assess the relationship between Surface temperature and NDVI of the study sites, regression analysis is employed in the study and its also demonstrate the regression trend between temperature and NDVI which are negatively correlated for the study area. This is so far the effect of the expanding built-up area which uses concrete and metal, industrialization and deforestation. In the first study site (Haridwar), the results demonstrate the inverse relationship between temperature and NDVI and negative correlation with NDVI values. Regression analysis trend line during 1989, 2000 and 2006 is slightly parallel to each other and shows the similar relationship between 1989 and 2000 with 7 °F shifts. Most of the cluster of NDVI found − 0.10 to + 0.30 during 1989 whereas it is shifted to + 0.10 to + 0.30 during 2000 (as illustrated in Fig. 7).

It is difficult to show the perfect relationship between temperature and NDVI because of their dependency. Temperature depends on particle size, soil moisture and thermal characteristics of a soil. NDVI values depend on Physio-chemical characteristics of plant and leaf texture.

Table 2 shows that maximum area falls within the temperature range of 73–78 °F during 1989 and 2000 but in 2006 it increased to 78–84 °F for Haridwar study site. Table 3 shows the trend of temperature during 1989, 2000 and 2006 for Kanpur study site which helps in assessing the temperature in these periods. Finally, it gives an idea to interpret the temperature in the region in past and present.

5. Conclusion

The present study demonstrates that the surface temperature and vegetation values depend upon the geographical location, industrial activities and demography. The effect of heat island is not limited to a particular temperature and period, it signals towards the ever-increasing control of anthropogenic heat emissions activities in rapidly developing cities as demonstrated with the two case studies (Haridwar District in Uttrakhand and Kanpur, India). The era we live in is the progressive stage of technological means which somewhere is affecting our quality of life also. The industrialization and increasing comforts have the adverse effect on surface temperature which is increasing at a fast pace. The urbanization is the way to progress but we forget the environmental dimension which must be considered. The paper considers this dimension and calculated UHI at multiple scales through surface conditions such as vegetation. The major part of the field was carried out in moderate summer conditions due to rainfall, however, the heat island intensities discovered in the study are comparable to research observed earlier. Additionally, a very high efficiency of UHI was observed in the later phase of the experiments when usual summer conditions were restored.

The use of the technological resources should be such that it does not affect the sustainability of natural resources. To overcome the undesirable effect of UHI, the nearby area in urban built up should be covered with adjacent green vegetation and there should be an attempt to make green city with urban green space to an extent, but in reality it is very hard due to less urban space and the proclivity of the mankind towards development. The other possible suggestion is the escalation of the vegetation cover around city regions like gardens, green cover on the rooftops of the buildings. Therefore, the study attempted to provide the relationship between the vegetation indices and surface temperature with the time period to demonstrate the effect of vegetation (decrease or increase) of the increasing temperature is related to it. The difference in the variables may be due to the demographic, geographic locations and economic activities in both study sites, as Haridwar is located in the hilly region with no industrial activities while Kanpur is located on the Gangetic plain with several industrial setups. So the influence of geographical location and industrial activity may sometimes influence the temperature of the regions.

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Authors' contributions

All authors approve this final manuscript. Authors have no conflict of interest to declare.

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