Project Report

STUDY AND COMPARISON OF LST, NDVI & NDBI BETWEEN THE OLD AHMEDABAD CITY AND THE NEW AHMEDABAD CITY USING THE LANDSAT-8 SATELLITE

by

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CERTIFICATE

This is to certify that **Mr. Divyakumar A. Kotia**, final year B.Sc. (Physics) student, at the Department of Physics and Electronics, St. Xavier's College (Autonomous), Ahmedabad, has executed a research project under the guidance of Dr. Rajesh Iyer, Mr. Tejas Turakhia and Mr. Akhil S. Nair.

Mr. Divyakumar A. Kotia has successfully completed his research project and submitted his report entitled **'Study and Comparison of LST, NDVI & NDBI between The Old Ahmedabad City and the New Ahmedabad City Using the Landsat-8 Satellite'**.

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Abstract

In this study, Land surface temperature (LST), Normalized difference vegetation index (NDVI), and Normalized difference built-up index (NDBI) were studied and a comparison between the Old Ahmedabad city (areas on the eastern side of the river) and the New Ahmedabad city (areas on the western side of the river) is made in terms of LST, NDVI, and NDBI. These are obtained by using the data derived from the LANDSAT-8 Operational land imager and Thermal infrared sensor (OLI and TIRS). The old Ahmedabad city as being an unplanned city, it is densely packed with old houses and historical architecture. Also, the population density is very high. As a result, the density in the no. of houses and vehicles is also very high. But the area covered by the water bodies and greenery is less than the new Ahmedabad city. From this study, it was found that for the year 2020, the values of NDVI & NDBI of the old city were 27.3 % less and 95.2 % more than the new city respectively. For the year 2020 the mean LST of the old city was about 0.5-0.6 ° C more than the new city which accounts for about 1.8 % more LST value than the new city. It was also observed for both parts of Ahmedabad city that the LST and NDVI are maximumly correlated (negatively) during the monsoon season and LST and NDBI are maximumly correlated (positively) during the post-monsoon season. Also, these correlations were found to be better for the old Ahmedabad city. From this study, it can be known that the old Ahmedabad city is having higher LST values due to its highly dense built-up areas and fewer vegetation areas and this trend is observed for all the seasons of the year.

(Keywords: LST, NDVI, NDBI, Landsat-8)

1. INTRODUCTION

Land surface temperature is an important parameter that contributes to the determination of the health of the modern urban environment. In recent times, urbanization is increasing at an alarming rate all over the world and has led to the conversion of natural land cover (LC) into impervious surface materials like concrete, asphalt, metals etc. and is resulted in the development of urban heat island (UHI) phenomenon. UHI phenomenon means that the urban areas exhibit more air temperature and land surface temperature as compared to the suburban and rural areas. High energy consumption, high emissions of air pollutants and greenhouse gases are some of the major harmful effects of this phenomenon and these effects ultimately lead to ‘global warming. Global surface temperatures have increased by roughly 1°C since the pre-industrial era (1880-1900), which might seem small, but is indicative of a significant build-up of heat since the pre-industrial era. According to NOAA's temperature records, 2020 was the second-warmest year on record. More specifically, the UHI phenomenon is influenced by the reduced vegetation in urban areas, properties of urban materials, urban geometry, anthropogenic heat, weather, and location. The increase of green space generally decreases the LST whereas impervious surfaces increase. It is estimated that the mean LST of impervious surfaces is about 4°C higher than that of green spaces, highlighting the important role that green spaces play in maintaining the land surface temperature.

In the last 10-20 years, Ahmedabad has also developed an extensive urban sprawl. As per one study, urban built-up has increased by 19.28% from 1997 to 2017. Old Ahmedabad city (eastern areas) has more impervious surfaces than the new city (western areas). Since old Ahmedabad city is a heritage city, unplanned urbanization and rapid population growth result in unsustainable development, resulting in increasing impervious surfaces and reduction such as parks, trees, gardens, and agricultural lands.

Out of around 79,91,288 population of Ahmedabad in 2020, 60-65 % belong to the old city. The density of population in the old city and the new city are approximately 20,316/km^2 and 15,221/km^2 respectively. So, it is evident that the old city must contain a greater number of vehicles and houses as well. It was estimated that in 2020 there were 17 lakhs houses and 50-60 lakhs vehicles in Ahmedabad. Out of which around 10 lakhs were in the old city and around 7 lakhs were in the new city. If we talk in terms of density then there were approximately 4,300 houses / km^2 in the old city and 3400 houses / km^2 in the new city. From one study, it was estimated that the average traffic of vehicles on a road in the old city is around 67,000 vehicles and it is 63,000 vehicles for the new city. The area occupied by the parks in the old city is around 0.45 km^2 and it is 1.28 km^2 in the new city. It is equivalent the 26.03 % and 73.97 % respectively of the total 1.73 km^2 of parks spread over the city. In the old city around 0.21 % of the total area is occupied by parks and it is 0.73 % for the new city. If we consider for entire Ahmedabad city then only 0.39 % of the land is occupied by the parks.

Also, as per the recent study, sponsored by the IISC, Bengaluru, the tree cover of Ahmedabad fell from 46% to 24 % over the last 20-25 years, while the built-up area increased by 132%. It also predicted that the vegetation cover will go down to 3% of the city's area and most of this reduction would likely to be occur in the western areas (new city) and it's very likely that in near future the new Ahmedabad city will also be having high LST values like the old city. In this study we will see how LST of two parts (old city and the new city) of Ahmedabad varies from each other and the factors responsible for that by using the satellite data.

1.1 Land surface temperature:

Land surface temperature, or LST, is the radiative skin temperature of the land derived from solar radiation. It refers to how hot it would feel to touch the surface of the Earth in a particular place. From a satellite's point of view, the surface is what it sees through the atmosphere to the ground. Thus, the land surface temperature differs from the air temperature which is reported in the daily weather report. Land surface temperature is determined by measuring the amount of thermal radiance emitted by the land surface where incoming solar energy interacts with and heats the ground or the surface of the canopy in vegetated areas.

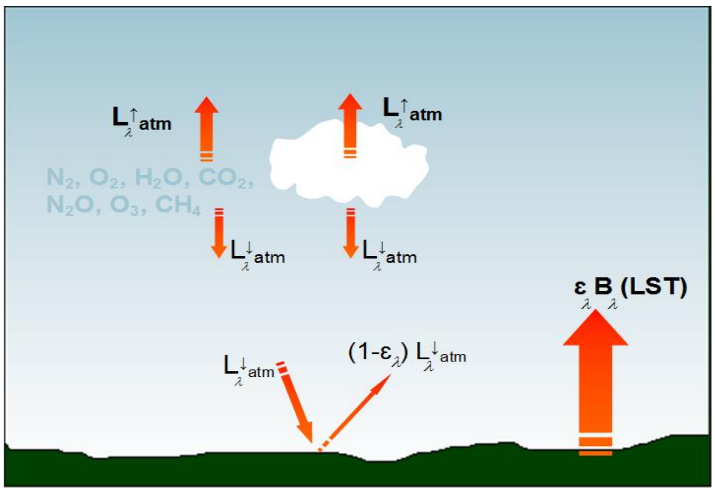

Fig 1. LST energy diagram

LST can be calculated by using the formula as shown below, which is again explained in detail in thapter (5),

$$\boxed{\boldsymbol{LST = \frac{BT}{\left\{1 + \left[\left(\lambda BT/\rho\right) \ln \varepsilon\right]\right\}}}}$$

The following factors can fundamentally affect the derivation of LST:

1. Temperature variations with angles
2. Subpixel inhomogeneities in temperature and cover
3. Surface spectral emissivity at the channel wavelengths
4. Atmospheric temperature and humidity variations
5. Clouds and large aerosol particles such as dust

Studying land surface temperatures has many applications, such as,

1. To evaluate water requirements for the crops.
2. To monitor drought.
3. To understand the effect on the habitat of birds & animals
4. In a study of Urban Heat Islands
5. In urban planning
6. Burned area mapping
7. Climate change

1.2 Spectral index:

The spectral index is a mathematical formula that calculates the spectral intensities of the different bands within an image. Therefore, every pixel has n numbers, where n is the number of spectral bands.

The most common mathematical formulas that are used is the normalized difference:

$$\boxed{\frac{(B_x - B_y)}{(B_x + B_y)}}$$

Here, B_x is the spectral band that is reflected and B_y is the band that is absorbed.

In practical terms, it is the difference between two selected bands normalized by their sum. This method is very useful to minimize the effects of illumination (shadows in mountainous regions, cloud shadows etc.) and enhancing spectral features that are not visible initially.

There are many spectral indices like this that are used for various purposes. Some of these indices are as mentioned below

Index	Formula	Application
Normalized difference vegetation index (NDVI)	$NDVI = \frac{NIR - Red}{NIR + Red}$	To measure vegetation.
Normalized difference built-up index (NDBI)	$NDBI = \frac{SWIR - NIR}{SWIR + NIR}$	To measure the built-up areas.
Normalized difference water index (NDWI)	$NDWI = \frac{SWIR - NIR}{SWIR + NIR}$	To monitor changes related to water content in water bodies.
Normalized multiband drought index (NMDI)	$NMDI = \frac{[NIR - (SWIR1 - SWIR2)]}{[NIR + (SWIR1 + SWIR2)]}$	For monitoring soil and vegetation moisture.

Table 1. Some normalized indexes and their

From these indices, NDVI and NDBI will be our main focus in this study along with the LST

1.2.1 Normalized difference vegetation index (NDVI)

The NDVI is a dimensionless index and it quantifies vegetation by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs) and can be used to estimate the density of green vegetation on an area of land (Weier and Herring, 2000)

$$\boxed{\boldsymbol{NDVI = \frac{NIR - Red}{NIR + Red}}}$$

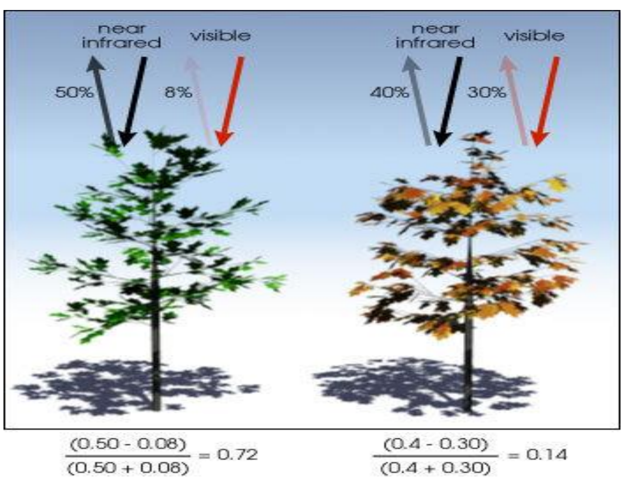

fig. 2 NDVI diagram

Some satellites and their bands combination which can be used to obtain NDVI are as mentioned below:

Satellites	NDVI
Landsat-8	$\frac{B05 - B04}{B05 + B04}$
Sentinal-2	$\frac{B08 - B04}{B08 + B04}$
MODIS	$\frac{B02 - B01}{B02 + B01}$

Table 2. Bands of satellites for NDVI

NDVI always ranges from -1 to +1

NDVI range	Indication
Negative values (approaching -1)	Water
-0.1 - 0.1	Barren areas of rock, sand or snow
0.2 – 0.4	Shrub and grasslands
>0.4 (approaching 1)	Temperate and tropical rainforests

Table 3. NDVI ranges and their indications

1.2.2 Normalized difference built-up index (NDBI)

Like the NDVI, NDBI is also a dimensionless index that is used to determine the built-up areas. Surfaces with more build-up and bare soil reflect SWIR rather than NIR. Thus, NDBI can be calculated as,

$$\boxed{\boldsymbol{NDBI = \frac{SWIR - NIR}{SWIR + NIR}}}$$

The combination of bands for some satellites which can be used to obtain NDBI are as mentioned below:

Satellites	NDBI
Landsat-8	$\frac{B06 - B05}{B06 + B05}$
Landsat-7	$\frac{B05 - B04}{B05 + B04}$
Sentinal-2	$\frac{B11 - B08}{B11 + B08}$

Table 4. Bands of satellites for NDBI

NDBI also ranges from -1 to +1. Negative values represent the water bodies whereas the higher values indicate the built-up areas.

2. OBJECTIVES

- To obtain the mean, minimum and maximum values of LST, NDVI and NDBI for the new Ahmedabad city, old Ahmedabad city and the Ahmedabad city as a whole by using the Landsat-8 data.

- To compare the values LST, NDVI and NDBI between the old city and the new city.

- To obtain the correlation between LST & NDVI and LST & NDBI for both parts of the city and for the whole city.

3. STUDY AREA

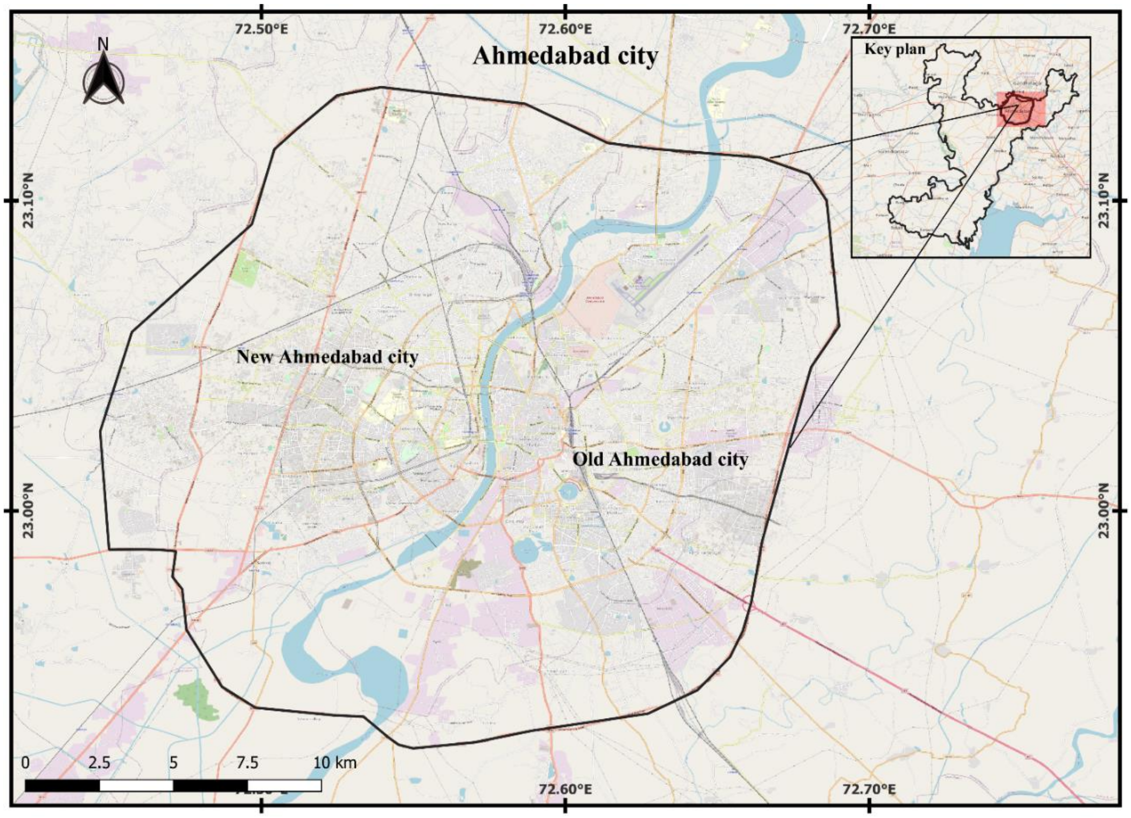

fig 3. Study area, Ahmedabad

Ahmedabad is situated at 23.03°N, 72.58°E. Ahmedabad is the industrial capital of Gujarat and theseventh-largest city of India with a population of 55,77,940 according to the last census (2011) and in 2020 it was around 79,91,288. The climate of Ahmedabad is semi-arid and hot which becomes extremely dry during the summer season. The summer days are extremely hot with a mean maximum temperature of 41.3 °C, while the summer nights are pleasant with a mean minimum temperature of 26.30 °C. In winter, the mean maximum and the mean minimum temperatures are 30 °C and 15.4 °C respectively. In the area, the average annual rainfall is 782 millimetres. On average, the relative humidity is 60% but reaches up to 90% during the rainy season. The Sabarmati River divides the city into two physically distinct parts. The city on the eastern part of the river is the historic walled city of Ahmedabad and on the western part ,it is the newly developed city. The eastern part of the city is densely packed with its unique traditional houses (pols), mills, markets and other historical buildings. The western part of the city houses educational institutions, modern buildings, shopping malls, multiplexes etc. The western part is havmanymuch wide roads and it is very much less dense as compared to the Eastern part of the city.

4. DATA SOURCE

For this study, data from the satellite Landsat-8 was used. The satellite data for the Ahmedabad which is corresponding to row 44 of path and 149 of the Landsat-8 derived from the Operational land imager (OLI) and thermal infrared sensor (TIRS) of the Landsat-8 satellite was used. The OLI sensor collects image data for 9 shortwave spectral bands over a 190 km swath with a 30 meter (m) spatial resolution for all bands except the 15 m Pan band. The TIRS sensor collects image data for two thermal bands with a 100 m spatial resolution over a 190 km swath. But, for this study, TIRS data resampled to 30m was used. The details of the bands of the Landsat-8 satellite along with their applications is are give the table (5).

<table>
<tr><th>Satellite</th><th>Image collection</th><th>Sensors</th><th>Bands used</th><th>Spatial resolution</th><th>Path</th><th>Row</th></tr>
<tr><td rowspan="2">LANDSAT-8</td><td rowspan="2">USGS Landsat 8 Surface Reflectance Tier 1</td><td rowspan="2">OLI & TIRS</td><td rowspan="2">Bands 4 (NIR),
5 (Red),
6 (SWIR)
& 10 (TIR)</td><td rowspan="2">OLI (30 m)
TIRS (Resampled to 30 m from 100m)</td><td>148</td><td rowspan="2">44</td></tr>
<tr><td>149</td></tr>
</table>

Table 5. Details of the satellite data

In the present study, TIRS band 10 was used to obtain the brightness temperature and band 4 and band 5 were used to generate NDVI and for generating NDBI band 5 and band 6 were used. Details of the bands of the Landsat-8 satellite are given in table (6).

<table>
<tr><th>Sensor</th><th>Band</th><th>Wavelength</th><th>Resolution</th><th>Applications</th></tr>
<tr><td rowspan="3">Operational land imager (OLI)</td><td>Band 1 Coastal Aerosol</td><td>0.43 - 0.45</td><td>30</td><td>Coastal and aerosol studies</td></tr>
<tr><td>Band 2 Blue</td><td>0.45 - 0.51</td><td>30</td><td>Distinguishing soil from vegetation, and deciduous from Coniferous vegetation</td></tr>
<tr><td>Band 3 Green</td><td>0.53 - 0.59</td><td>30</td><td>Emphasizes peak vegetation, which is useful for assessing plant vigour</td></tr>
</table>

Operational land imager (OLI)	**Band 4** **Red**	0.64 - 0.67	30	Discriminates vegetation slopes
	Band 5 **Near Infrared (NIR)**	0.85 - 0.88	30	Emphasizes biomass content and shorelines
	Band 6 **SWIR 1**	1.57 - 1.65	30	Discriminates moisture content of soil and vegetation; penetrates thin clouds
	Band 7 **SWIR 2**	2.11 - 2.29	30	Improved ability to track moisture content of soil and vegetation and thin cloud penetration
	Band 8 **Panchromatic**	0.50 - 0.68	15	15 meters resolution, sharper image definition
	Band 9 **Cirrus**	1.36 - 1.38	30	Improved detection of cirrus cloud contamination
Thermal infrared sensor (TIRS)	**Band 10** **Thermal Infrared (TIRS) 1**	10.60 - 11.19	100 (Resampled to 30)	Thermal mapping and estimation of soil moisture
	Band 11 **Thermal Infrared (TIRS) 2**	11.50 - 12.51	100 (Resampled to 30)	Thermal mapping and estimation of soil moisture

Table 6. Details of the bands of Landsat-8

5. METHODOLOGY

- By using the Google earth engine, shapefiles of the study area (New Ahmedabad city, old Ahmedabad city and Ahmedabad city as a whole) were obtained.

- Now, the mean, maximum and minimum values of NDVI, NDBI & LST for all the seasons of the year 2020 and the year 2020 as a whole were obtained by following the method as shown in the flow chart given below by using the LANDSAT-8 Surface reflectance tier 1 dataset in the Google earth engine for the old city, new city and for Ahmedabad city as a whole.

Image courtesy: Remote sensing Based Assessment of Urban Heat Island From TIRS data -A case study of Varanasi city, India

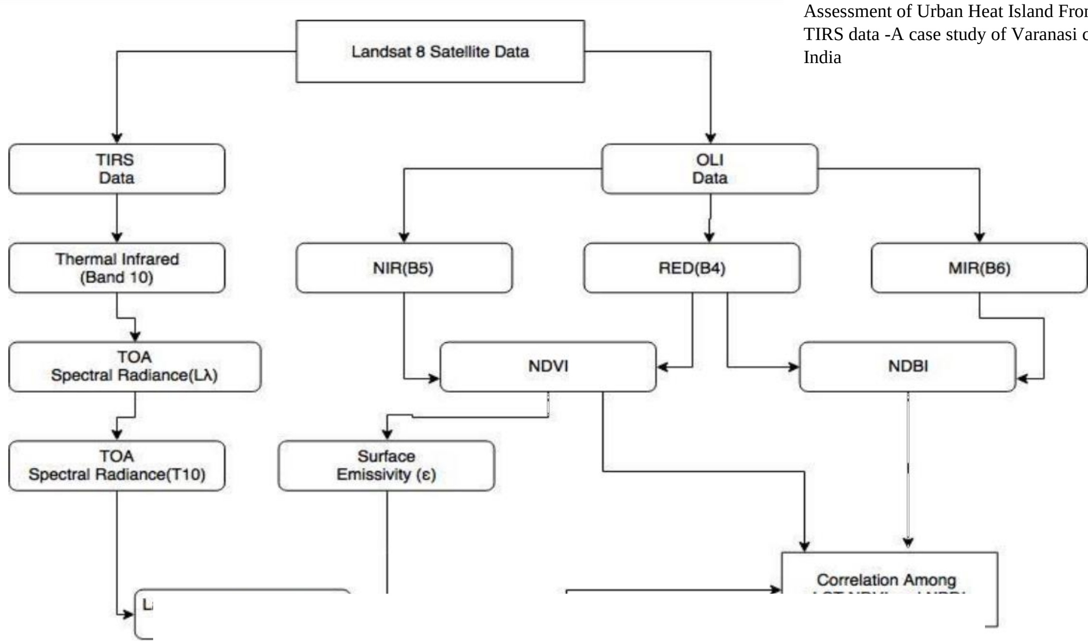

fig 4. Flow chart for LST, NDVI and NDBI retrieval from the Landsat-8 image

of LANDthe SAT-8 Thermal infrared sensor (TIRS) and the following steps are to be followed:

1. **<u>Conversion to At-Satellite Brightness Temperature:</u>**

Utilizing the thermal constants specified in table (7), spectral radiance data is converted to at-satellite brightness temperature (BT).

K_1 K_2	Thermal constant, Band 10	1321.08 777.89
M_L A_L	Rescaling factor, Band 10	0.000342 0.1
O_i	Correction, Band 10	0.29

Table 7. Constants used in the calculation of LST

The following equation is used to convert the radiance into brightness temperature (BT):

$$\boxed{\boldsymbol{BT = \frac{K_2}{\ln[(K_1/L\lambda) + 1]}}}$$

2. Calculating NDVI:

To obtain the NDVI, visible and near-infrared and visible bands of the Operational land imager (OLI) sensor of the Landsat-8 were used. Estimation of NDVI is important because it gives the idea about the vegetation cover of the area and from which we can calculate the proportion of vegetation (P_v) and from that, we can obtain the emissivity (ε) and emissivity is used in the calculation for obtaining land surface temperature (LST).

NDVI was calculated by the formula given below and in the given formula, bands corresponding to the wavelengths of Near-infrared and red light were used:

$$\boxed{\boldsymbol{NDVI = \frac{NIR\ (band\ 5)\ - Red\ (band\ 4)}{NIR\ (band\ 5) + Red\ (band\ 4)}}}$$

3. Calculation of the fractional vegetation cover or proportion of vegetation (P_v):

The proportion of vegetation (P_v) is calculated by using the following equation,

$$\boxed{\boldsymbol{P_v = \left(\frac{NDVI\ -\ NDVI_{min}}{NDVI_{max}\ +\ NDVI_{min}}\right)^2}}$$

4. Calculating Land surface emissivity (ε):

Land surface emissivity (ε) must be known to estimate LST because it is a factor that scales blackbody radiance (Planck's law) to predict radiance emitted from the surface. Also, it represents the efficiency of transmission of thermal energy across the surface into the atmosphere.

Land surface emissivity (ε) is calculated using the following formula,

$$\boxed{\boldsymbol{\varepsilon = 0.004 \times P_v + 0.986}}$$

5. Calculation of land surface temperature (LST):

The land surface temperature is almost equivalent to the brightness temperature as obtained in step (1) onlythe difference is that the LST emissivity is corrected and the brightness temperature is not corrected.

The land surface temperature is obtained by using the following formula,

$$\boxed{\boldsymbol{LST = \frac{BT}{\left\{1 + \left[\left(\lambda BT/\rho\right) \ln \varepsilon\right]\right\}}}}$$

where;

$BT = Brightness\ temperature\ (°C),$

$\lambda = Wavelength\ of\ the\ emitted\ radiance,$

$$\rho = h\frac{c}{\sigma} = 1.438 \times 10^{-2} m\ K,$$

where;

$\sigma = Boltzmann\ constant\ (1.38 \times 10^{-23}\ J/K\ ),$

$h = Planck's constant (6.626 \times 10^{-34} Js),$

$c = Velocity\ of\ light\ (2.998 \times 10^{8}\ m/s)$

By putting all these constant values at last we get the formula for LST as below

$$\boxed{\boldsymbol{LST = \frac{BT}{\left[1 + \left(0.00115 \times BT/1.4388\right) \times \ln \varepsilon\right]}}}$$

- **Calculating NDBI:**

NDBI is calculated in the same way as NDVI which is described in the step (2) for calculating LST.

For obtaining NDBI, the bands corresponding short wave infrared (SWIR) and near-infrared (NIR) are used. For the Landsat-8 these bands are band 6 and band 5.

NDBI is calculated by using the following formula,

$$\boxed{\boldsymbol{NDBI = \frac{SWIR\ 1(band\ 6)\ - NIR(band\ 5)}{SWIR\ 1(band\ 6) + NIR(band\ 5)}}}$$

All these calculations as mentioned above were carried out in the form of a JavaScript code in the Google Earth Engine (GEE) code editor.

The values obtained by performing the calculations as discussed above were imported in .CSV file format to the MS-Excel. Now the seasonal and annual mean, maximum and minimum values of the LST, NDBI & NDVI for the new city and the old city were compared with each other.

By following the steps as mentioned in the fig 4., .tiff files of LST, NDVI and NDBI corresponding to the mean values obtained as mentioned above were also obtained. These .tiff files were analyzed in the Q-GIS software (version 3.24.0) and maps with the proper visualization corresponding to the parameters were obtained.

In the Q-GIS (version 3.24.0), per pixel values of these .tiff files were also obtained and were imported as .csv format to the MS-Excel. These per-pixel values of LST, NDVI and NDBI images were used to obtain the pixel-wise correlation between LST & NDVI; LST & NDBI; and between NDVI & NDBI. The seasonal relationship of LST-NDVI, LST-NDBI and NDVI-NDBI were obtained and was also compared between the old city and the new city.

6. RESULTS AND DISCUSSIONS

By following the method discussed above following results were obtained:

6.1 Tables indicating the values of LST, NDVI and NDBI

6.1.1 Comparison of values of the LST:

Seasons	Study area	Min. LST (°C)	Max. LST (°C)	Range	Mean LST (°C)
Winter	Old city	20.01	33.35	13.49	25.90
	New city	20.75	32.11	11.36	25.59
	Difference	**-0.74**	**1.24**		**0.31**
	% Difference	**-3.56%**	**3.86%**		**1.21%**
Pre-monsoon	Old city	29.26	48.38	19.12	40.32
	New city	29.26	45.74	16.48	39.44
	Difference	**0**	**2.64**		**0.88**
	% Difference	**0%**	**5.77%**		**2.23%**
Monsoon	Old city	21.66	31.84	10.25	27.03
	New city	21.59	31.73	10.14	26.28
	Difference	**0.07**	**0.11**		**0.75**
	% Difference	**0.32%**	**0.35%**		**2.85%**
Post-monsoon	Old city	24.63	37.28	12.65	30.27
	New city	24.64	34.83	10.19	29.65
	Difference	**-0.01**	**2.45**		**0.62**
	% Difference	**-0.04%**	**7.03%**		**2.09%**
Year 2020	Old city	24.55	36.49	11.94	30.46
	New city	24.21	35.28	11.07	29.91
	Difference	**0.34**	**1.21**		**0.55**
	% Difference	**1.40%**	**3.42%**	**1.84**	**1.85%**

Table 8. Comparison of LST of old city with respect to the new city

From table (8), we can say that the LST values of the old city are more than the new city for all the seasons. The highest and the lowest LST values were observed in the pre-monsoon and the winter season respectively. The highest mean LST for the old city was found to be 40.32 °C and it was 39.44 °C for the new city. The lowest LST for the old city was 25.90 °C and for the new city, it was 25.59 °C.

In the pre-monsoon season, maximum ranges of 19.12 and 16.48 for the old city and the new city respectively were obtained and the smallest range for the old and the new city was obtained in the monsoon season and was 10.25 and 10.14 respectively. The reason for this is that the lower limit of the range (min LST) depends on the areas having high NDVI and low NDBI and the upper limit (max LST) depends on the areas having high NDBI and low NDVI. In the pre-monsoon season, NDVI is minimum and the NDBI is maximum because of the less moisture content. Also, the LST is more sensitive to the NDBI as compared to the NDVI. So, in the pre-monsoon season due to the dominance of the high NDBI pixels, the upper limit of LST (max LST) increases. In the monsoon season, the scenario is exactly the opposite, in this season there is the dominance of the pixels having high NDVI and pixels having high NDBI values are very less. So due to less no. of high NDBI pixels upper limit of LST decreases and also due to less sensitivity of NDVI to the LST, the decrease in the lower limit due to the high NDVI pixels is less than the decrease in the upper limit. So, there is a big range of LST in the pre-monsoon and a small range in the monsoon season.

The sensitivity of the NDVI and NDBI with the LST is also the reason for the large difference in the 'maximum LST' values and a very small difference in the 'minimum LST' values, as the areas with 'maximum LST' correspond to the areas with high NDBI and low NDVI and the areas with the 'minimum LST' corresponds to the low NDBI and high NDVI.

From table (8), we can see that the range of the LST for the new city is less than the old city, which clearly shows that the old city is having more no. of high NDBI pixels as compared to the new city and which ultimately increases the temperature of the city.

The maximum difference of 0.88 °C (2.23% more than the new city) in terms of the mean LST was observed in the pre-monsoon season and the least difference of 0.31°C (1.21% more than the new city) was observed in the winter season. For the year 2020 as a whole, mean LST values for the old city and the new city were obtained as 30.46°C and 29.91°C respectively, which means that the LST in the old city was found to be 0.55°C (1.85%) more than the new city.

6.1.1 <u>Comparison of values of the NDVI:</u>

Seasons	Study area	Min. NDVI	Max. NDVI	Range	Mean NDVI
Winter	Old city	-0.34	0.82	0.88	0.19
	New city	-0.38	0.85	1.23	0.27
	Difference	**0.04**	**-0.03**		**-0.08**
	% Difference	**10.53%**	**-3.53%**		**-29.63%**
Pre-monsoon	Old city	-0.08	0.84	0.92	0.20
	New city	-0.21	0.81	1.02	0.26
	Difference	**0.13**	**0.03**		**-0.06**
	% Difference	**61.9%**	**3.7%**		**-23.07%**
Monsoon	Old city	-0.25	0.91	1.16	0.31
	New city	-0.26	0.90	1.16	0.43
	Difference	**0.01**	**0.01**		**-0.12**
	% Difference	**3.85%**	**1.11%**		**-27.91%**
Post-monsoon	Old city	-0.32	0.83	1.15	0.25
	New city	-0.30	0.84	1.14	0.35
	Difference	**-0.02**	**-0.01**		**-0.1**
	% Difference	**-6.66%**	**-1.19%**		**-28.57 %**
Year 2020	Old city	-0.15	0.79	0.94	0.23
	New city	-0.29	0.81	1.1	0.32
	Difference	**0.14**	**-0.02**		**-0.09**
	% Difference	**48.28 %**	**-2.47%**		**-28.13%**

Table 9. Comparison of NDVI of old city with respect to the new city

The mean NDVI of the old city and the new city for the year 2020 was found to be 0.23 and 0.32 respectively which means that the NDVI of the old city for the year 2020 was found to be less than that of the new city by 0.09 which is equal to the 28.13 % of the NDVI of the new city. The NDVI of the old city was less than the new city in the range of 23 % to 30 % across the year 2020. The highest mean NDVI for both parts of the city were observed during the monsoon season and it was 0.31 for the old city and 0.43 for the new city and the least values were obtained in the winter and pre-monsoon season and they were 0.19-0.20 for the old city and 0.26-0.27 for the new city.

6.1.2 Comparison of values of the NDBI:

Seasons	Study area	Min. NDBI	Max. NDBI	Range	Mean NDBI
Winter	Old city	-0.61	0.26	0.87	0.02
	New city	-0.64	0.44	1.08	-0.01
	Difference	**0.03**	**-0.18**		**0.03**
	% More than new city	**4.69%**	**-40.91**		**300%**
Pre-monsoon	Old city	-0.51	0.22	0.73	0.01
	New city	-0.49	0.32	0.81	-0.01
	Difference	**-0.02**	**-0.1**		**0.02**
	% Difference	**-4.08 %**	**-31.25%**		**200%**
Monsoon	Old city	-0.65	0.29	0.94	-0.06
	New city	-0.65	0.19	0.84	-0.12
	Difference	**0**	**0.1**		**0.06**
	% Difference	**0%**	**52.63%**		**50%**
Post-monsoon	Old city	-0.65	0.25	0.85	-0.002
	New city	-0.59	0.34	0.93	-0.05
	Difference	**-0.06**	**-0.09**		**0.048**
	% Difference	**-10.17%**	**-26.47%**		**96%**
Year 2020	Old city	-0.49	0.23	0.72	-0.002
	New city	-0.49	0.36	0.85	-0.04
	Difference	**0**	**-0.13**		**0.038**
	% Difference	**0%**	**-36.11%**		**95%**

Table 10. Comparison of NDBI of old city with respect to the new city

For the year 2020, the mean NDBI of the old city and the new city respectively were found to be -0.002 and -0.04, which means that the NDBI of the old city for the year 2020 was found to be more than that of the new city by 0.038, which is equal to 95% of the NDBI of the new city.

NDBI values for the old city ranged between 50 % and 300 % more than those for the new city for the year 2020. The highest mean NDBI for both parts of the city were observed in the winter and pre-monsoon season and it was 0.01-0.02 for the old city and -0.01 for the new city and the least values were obtained in the monsoon season and they were -0.06 for the old city and -0.12 for the new city.

6.2 Graphs of LST, NDVI and NDBI

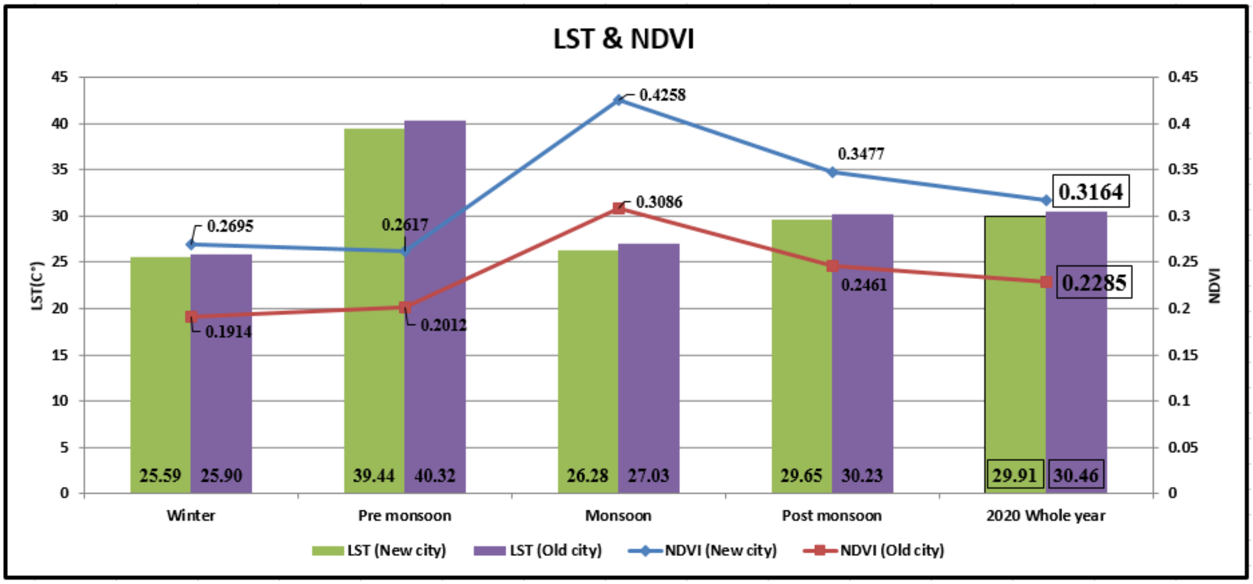

fig 5. Graph of LST and NDVI

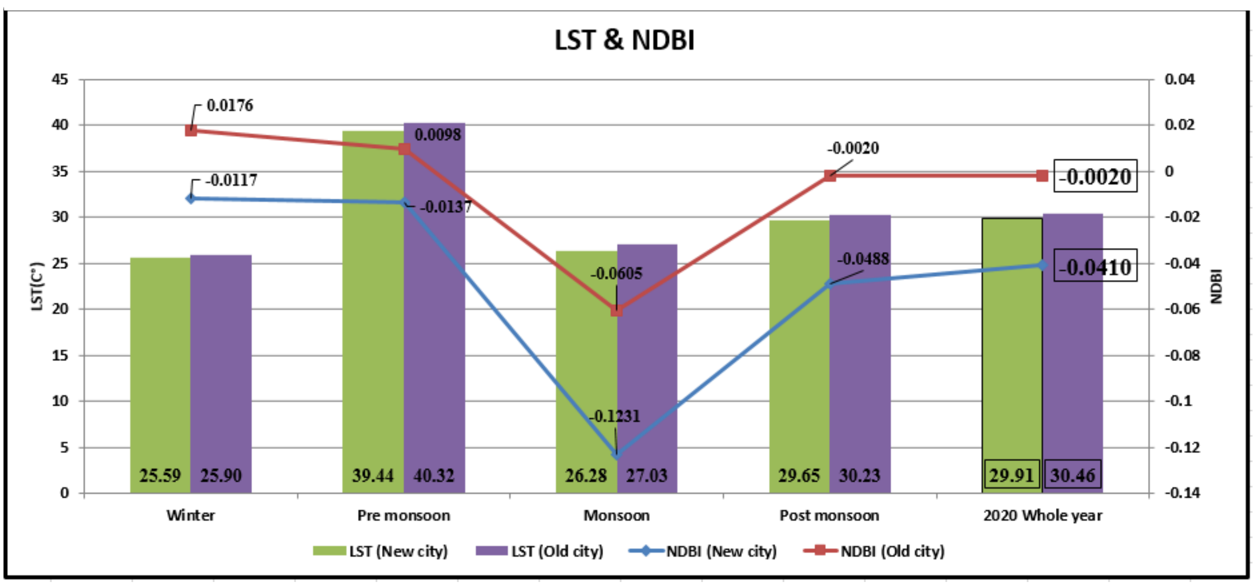

fig 6. Graph of LST and NDBI

6.3 Seasonal values of LST, NDVI and NDBI for the Ahmedabad city-2020

The seasonal values of the LST, NDVI and NDBI were also obtained for Ahmedabad city as a whole for the year-2020, which are as given below in table 11.

Ahmedabad-2020						
		Winter	**Pre-monsoon**	**Monsoon**	**Post-monsoon**	**Year 2020**
LST	Min.	20.01	29.24	21.59	24.63	24.21
	Max.	33.35	48.36	31.83	37.28	36.47
	Range	13.34	19.12	10.24	12.65	12.26
	Mean	**25.71**	**39.93**	**26.66**	**29.91**	**30.15**
NDVI	Min.	-0.38	-0.21	-0.26	-0.32	-0.29
	Max.	0.85	0.84	0.91	0.84	0.81
	Range	1.23	1.05	1.17	1.16	1.1
	Mean	**0.23**	**0.23**	**0.37**	**0.29**	**0.27**
NDBI	Min.	-0.64	-0.51	-0.65	-0.65	-0.49
	Max.	0.44	0.32	0.29	0.34	0.36
	Range	1.08	0.83	0.94	0.99	0.85
	Mean	**0.004**	**-0.002**	**-0.09**	**-0.03**	**-0.02**

Table 11. Seasonal values of LST, NDVI and NDBI for the Ahmedabad city for the year 2020

The mean LST, NDVI and the NDBI for Ahmedabad city as a whole for the year 2020 were 30.15 °C, 0.27 and -0.02 respectively.

The maximum LST (39.23 °C) was obtained in the pre-monsoon season and the minimum LST (25.71°C) was obtained in the post-monsoon season.

The maximum values of the NDVI (0.37) and NDBI (0.004) were obtained in the monsoon and winter seasons respectively and the minimum NDVI (0.23, 0.23) was obtained in the winter and pre-monsoon season and the minimum NDBI was obtained in the post-monsoon season.

As discussed earlier, the largest range of LST is obtained in the pre-monsoon season and the smallest range is obtained in the monsoon season.

6.4 Maps of NDVI, NDBI and LST

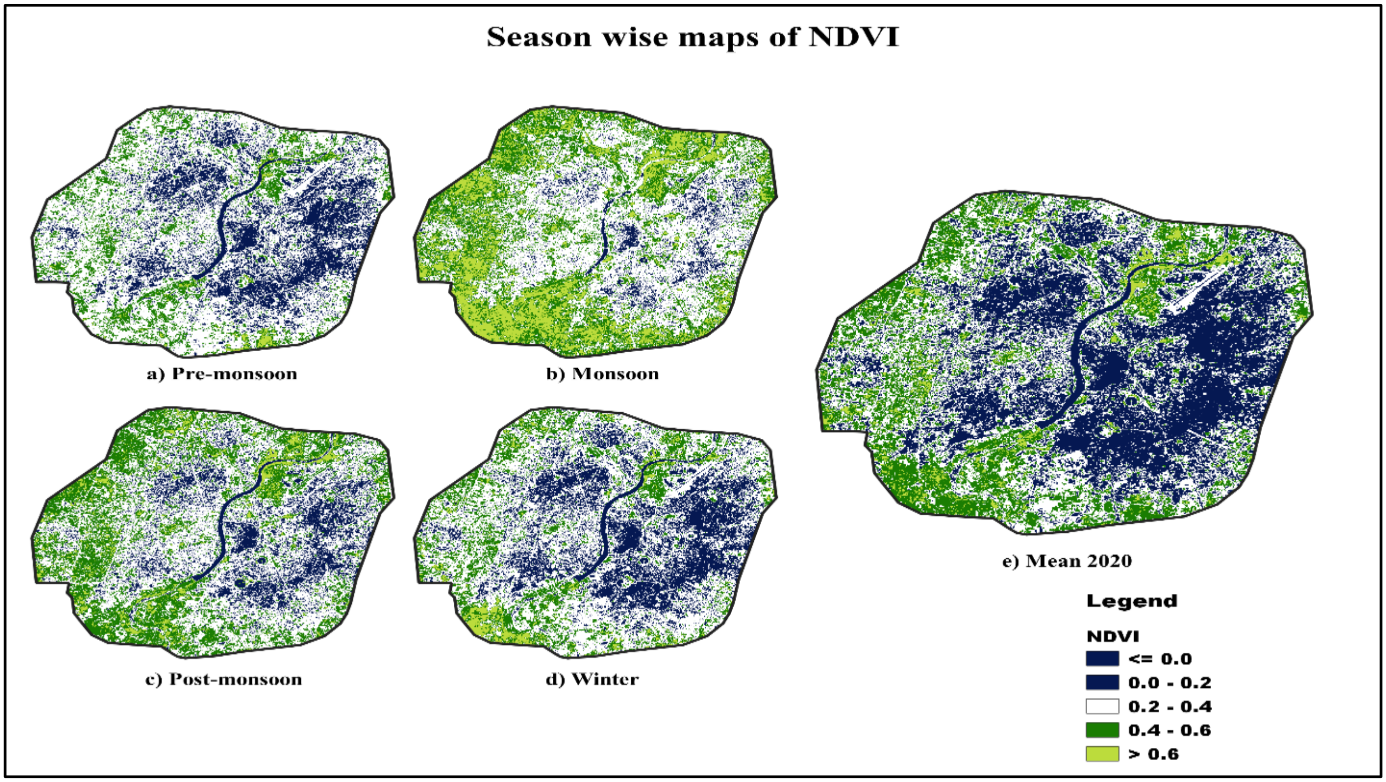

fig 7. Maps of NDVI

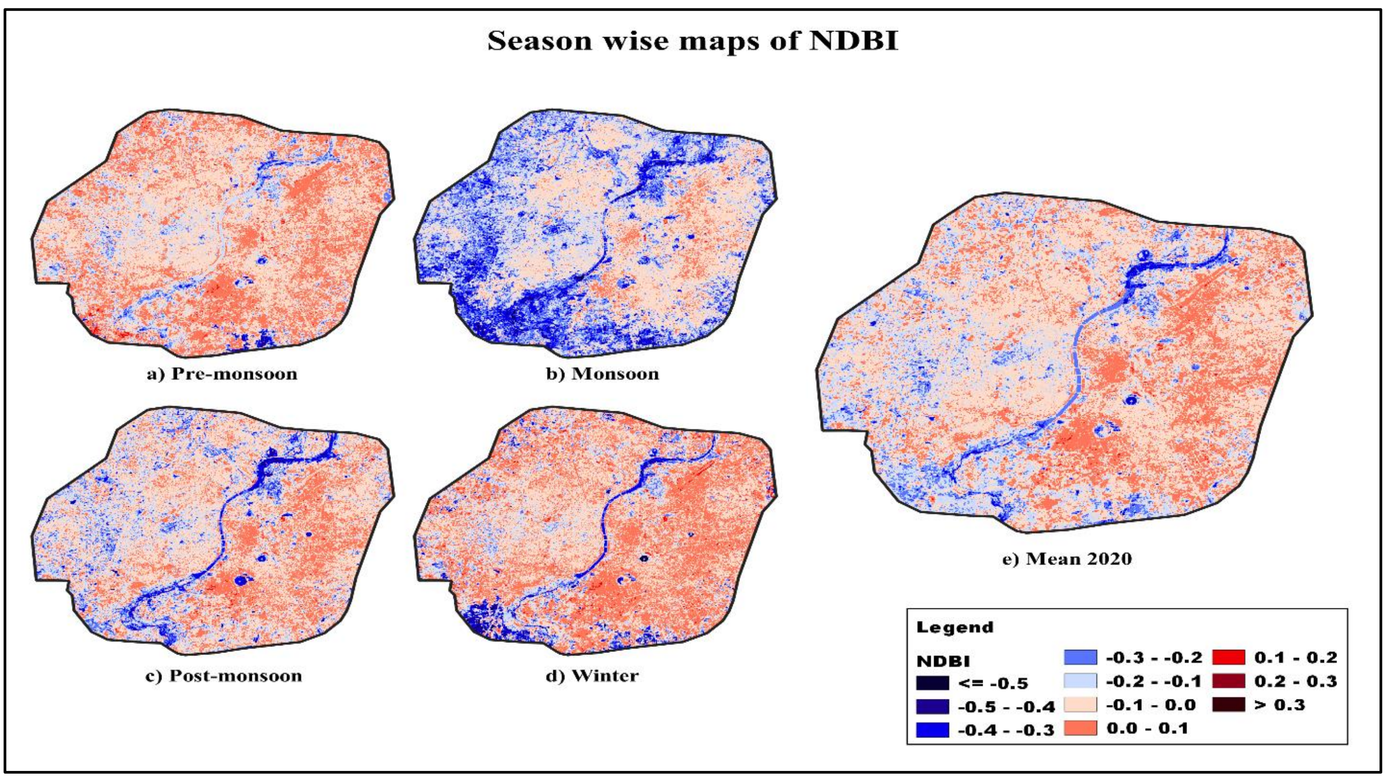

fig 8. Maps of NDBI

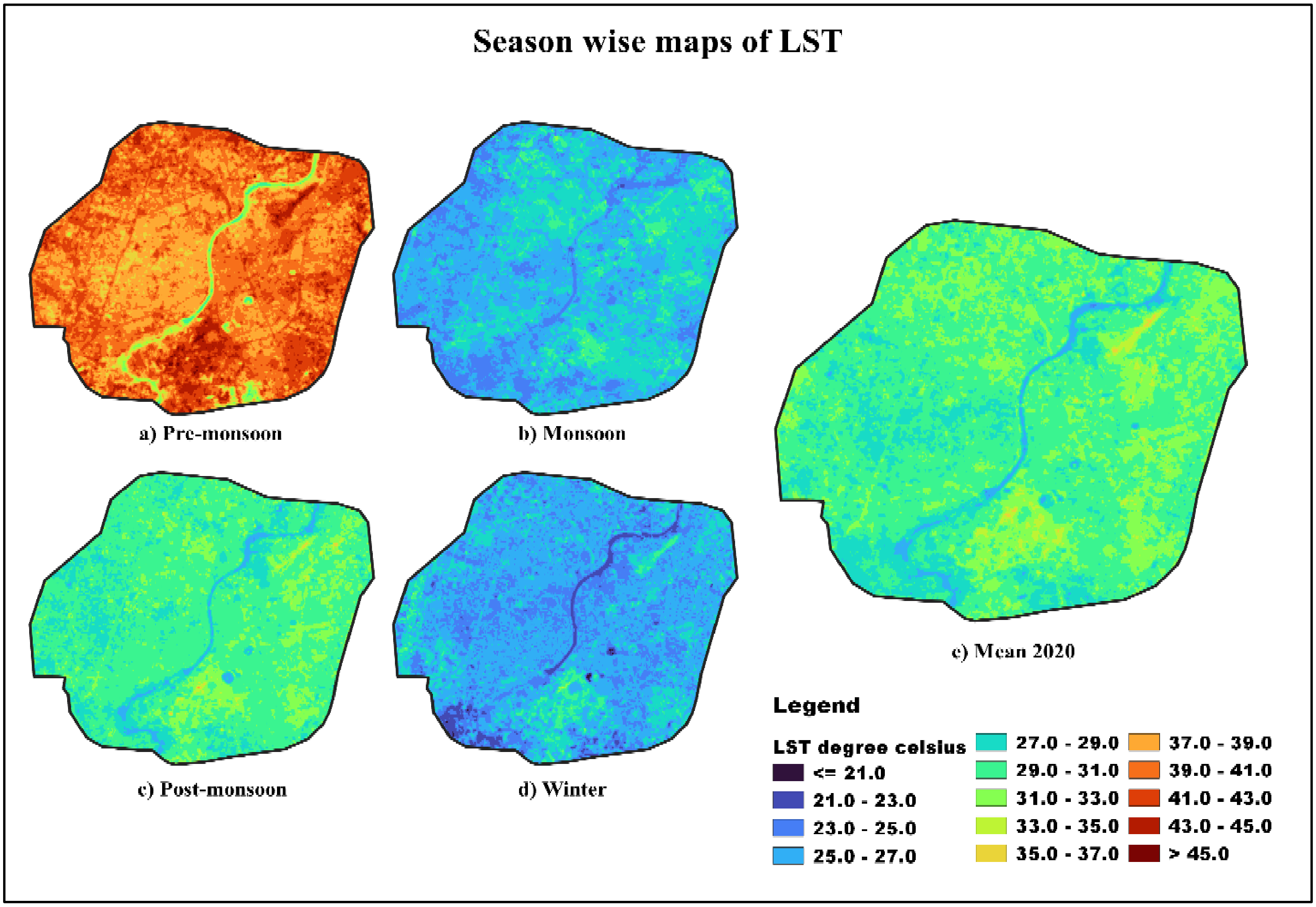

fig 9. Maps of LST

6.5 Correlations:

6.5.1 Graphs:

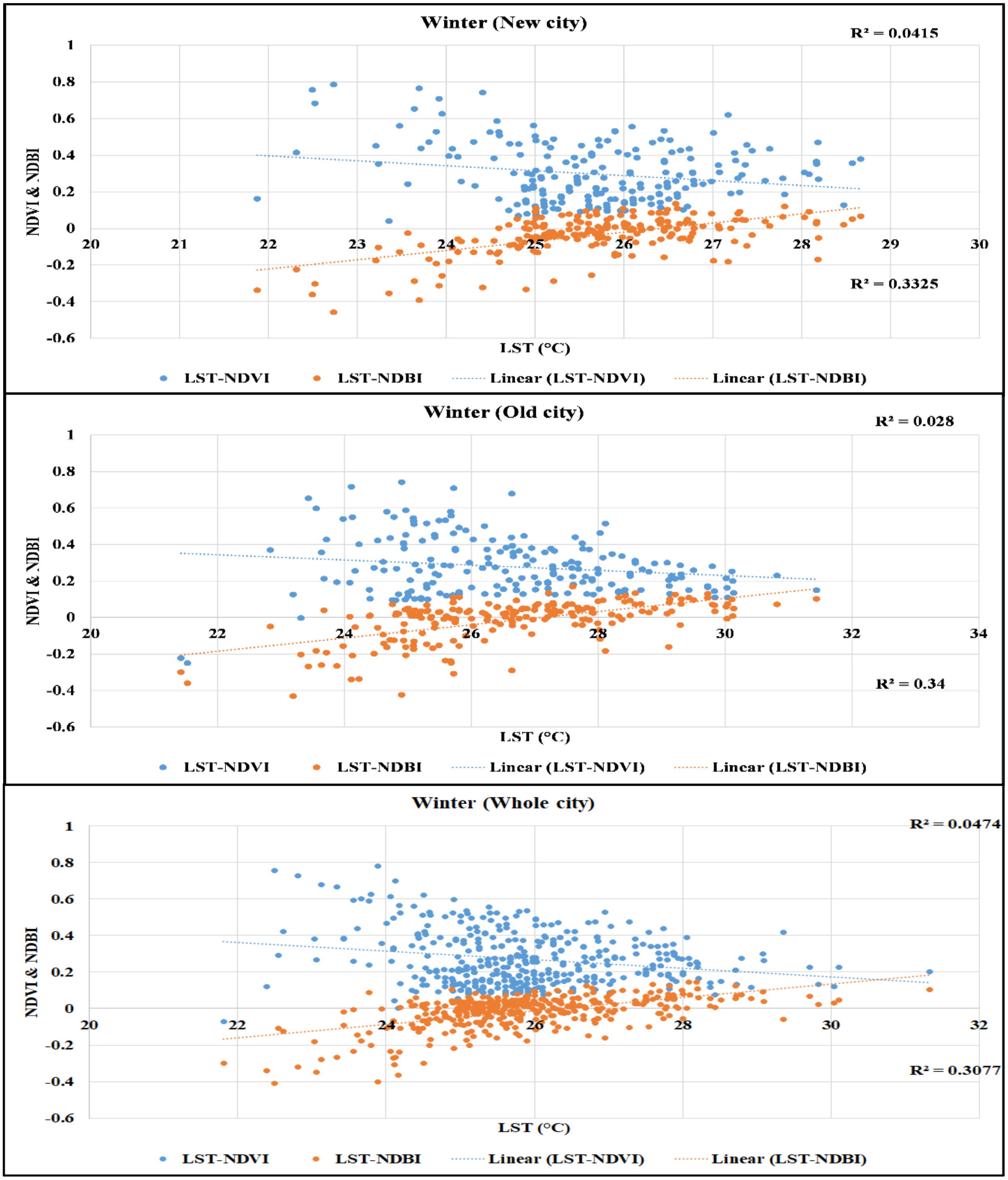

fig 10. Correlation in the winter season

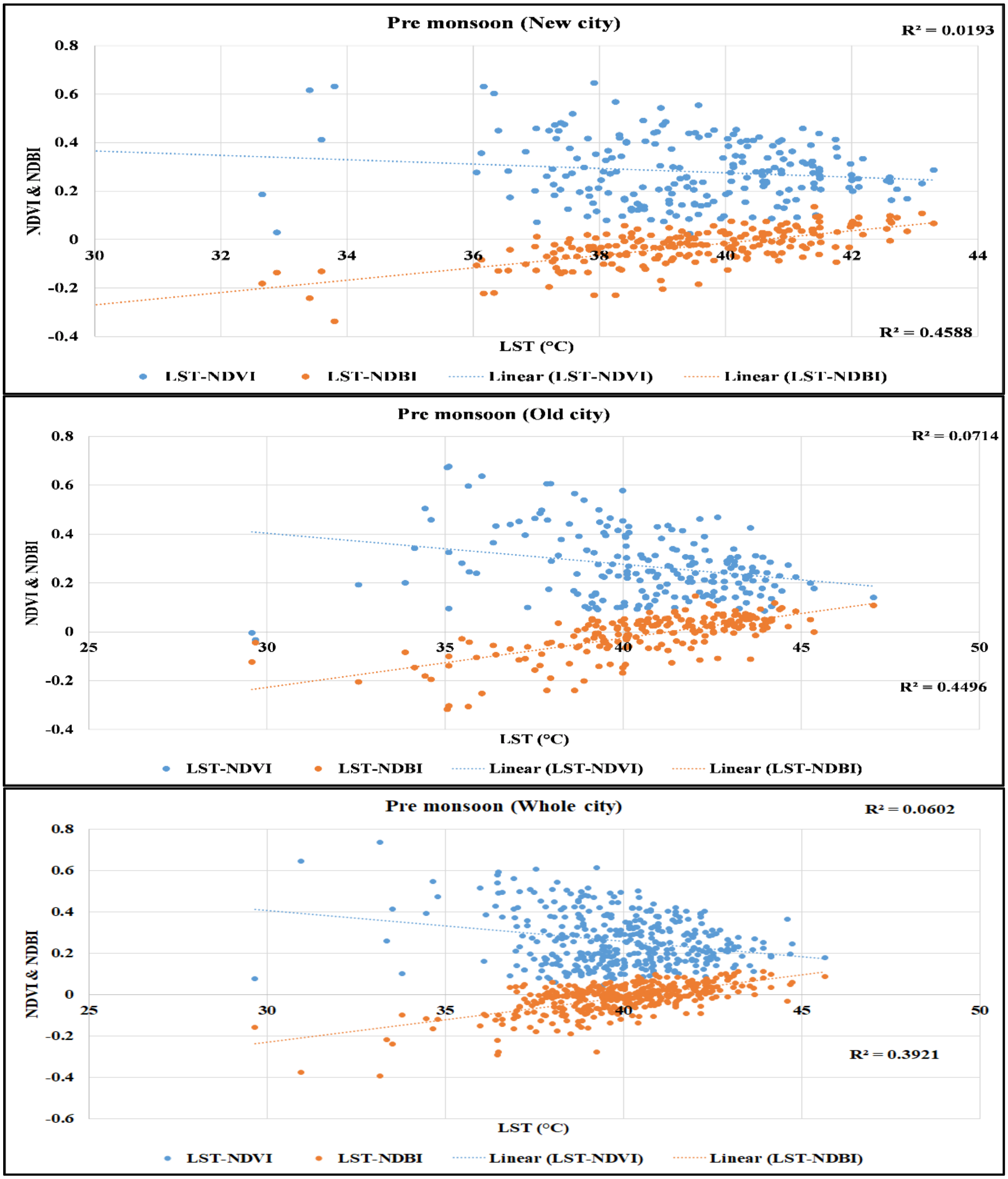

fig 11. Correlation in the pre-monsoon season

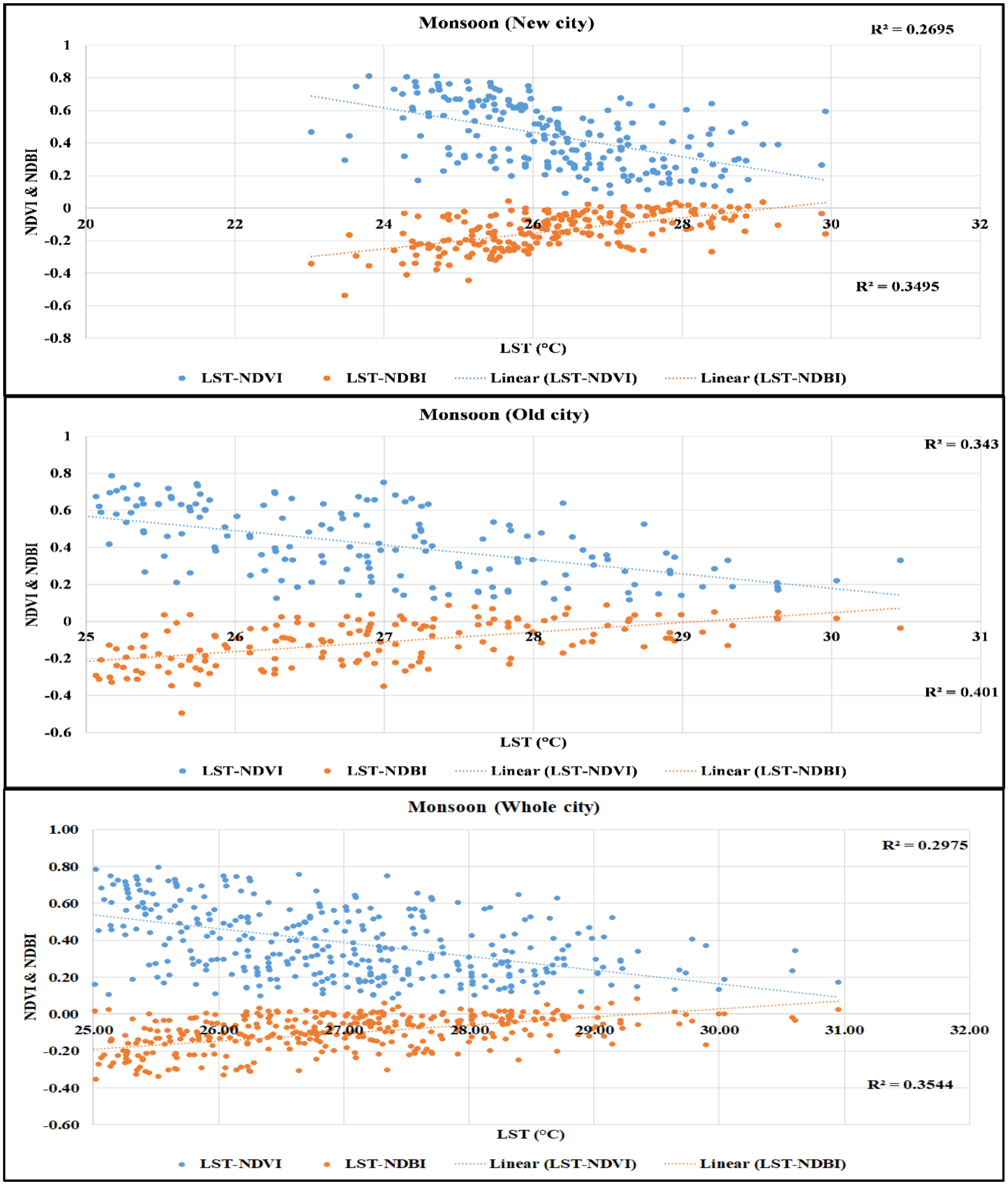

fig 12. Correlation in the monsoon season

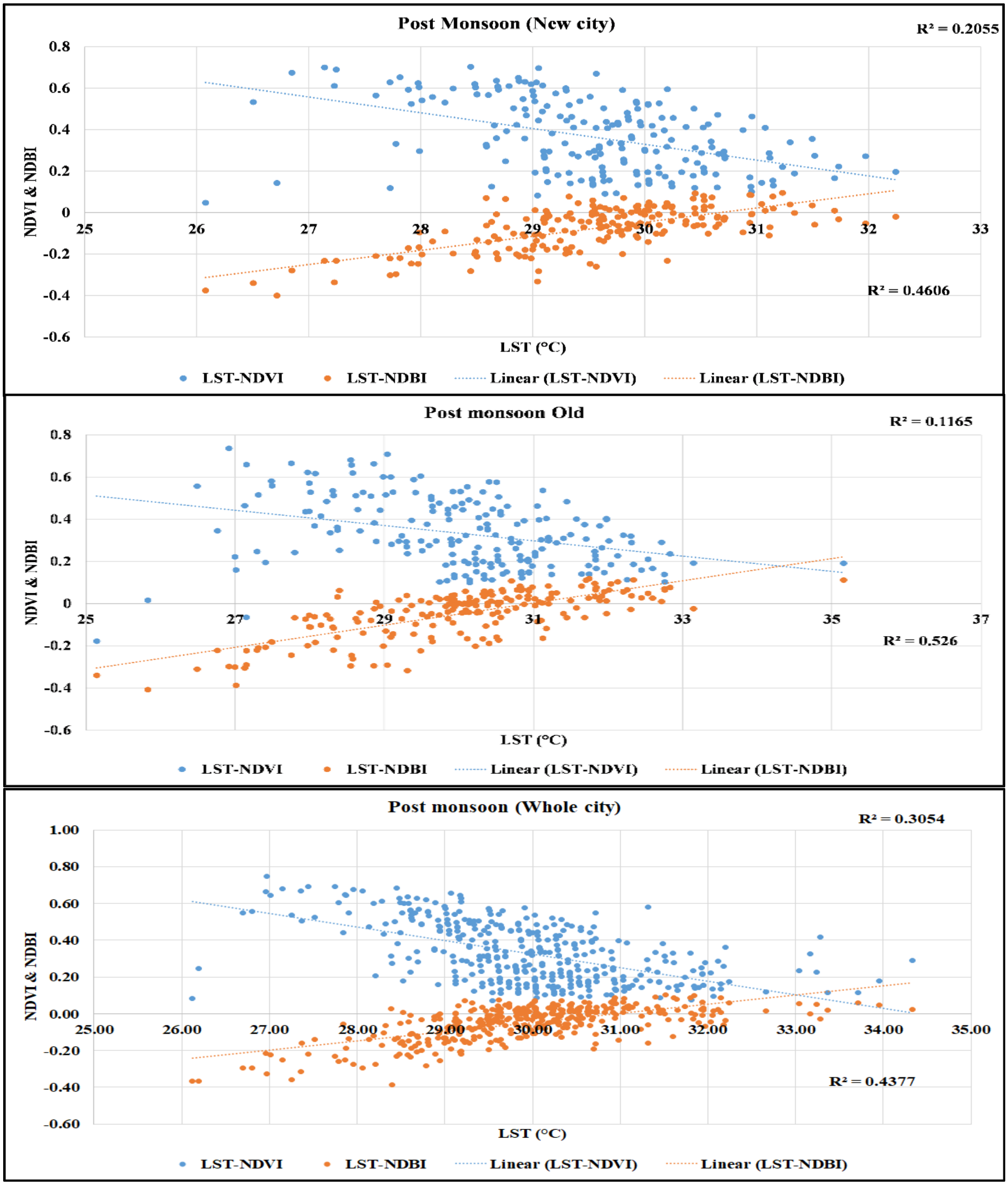

fig 13. Correlation in the post- monsoon season

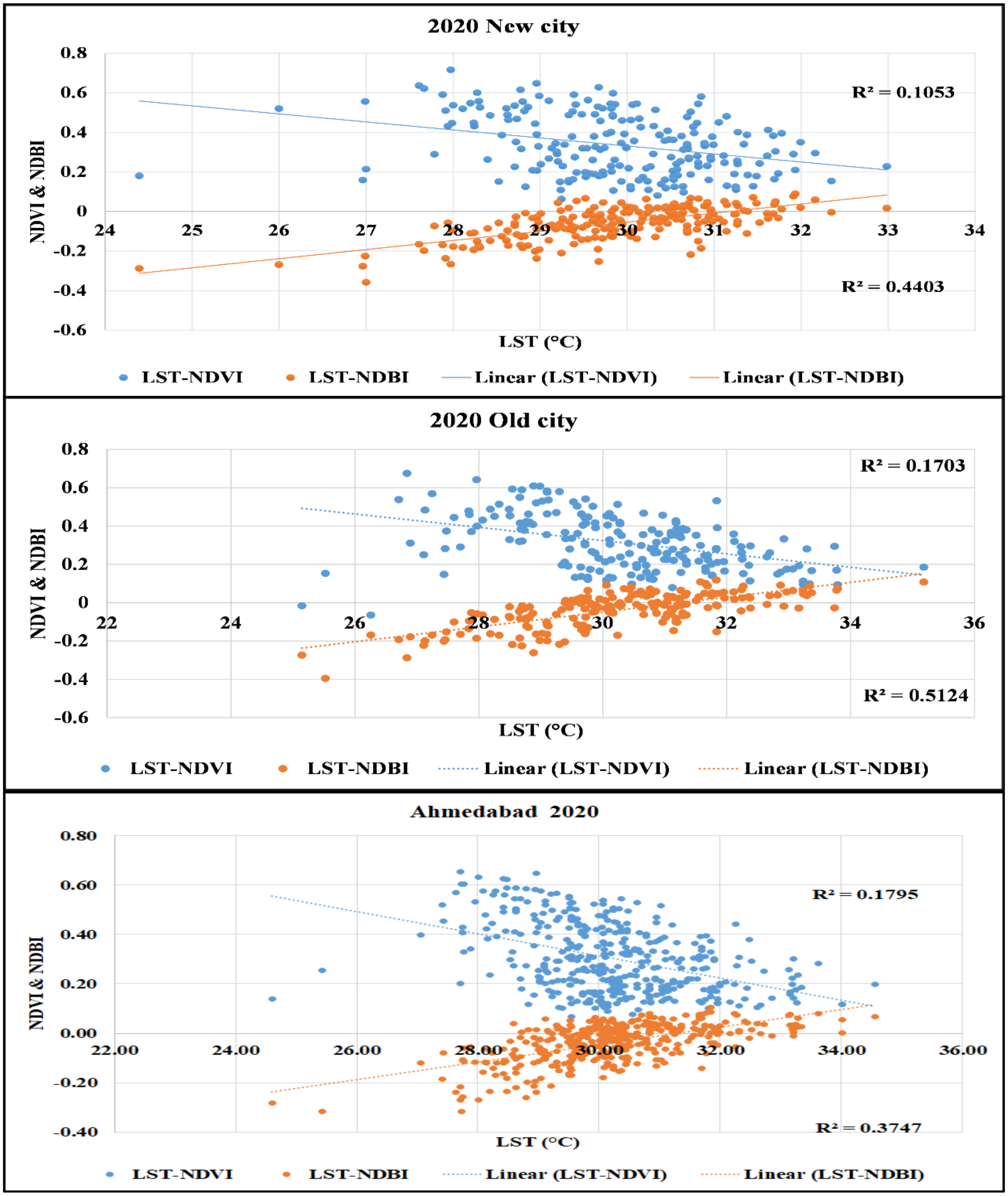

fig 14. Correlation for the year 2020

6.5.2 Tables indicating the correlation coefficient (R):

LST-NDVI

Correlation coefficient (R)

	2020	Winter 2020	Pre-monsoon 2020	Monsoon 2020	Post monsoon 2020
New city	**-0.324**	-0.203	-0.139	-0.520	-0.453
Old city	**-0.413**	-0.167	-0.267	-0.585	-0.341
Whole city	**-0.423**	-0.217	-0.245	-0.545	-0.552

Table 12. Correlation between LST and NDVI

- It was found that the correlation between LST and NDVI for the new city as well as for the old city is maximum in the **monsoon season**.

- The **maximum** correlation between the LST-NDVI for the new city and old city was obtained in the pre-monsoon and winter respectively.

- For Ahmedabad city as a whole, the maximum correlation was obtained in the post-monsoon and the monsoon season and it was minimum in the winter.

LST-NDBI

	2020	Winter 2020	Pre-monsoon 2020	Monsoon 2020	Post monsoon 2020
New city	**0.663**	0.576	0.677	0.591	0.679
Old city	**0.716**	0.583	0.670	0.633	0.725
Whole city	**0.612**	0.554	0.626	0.595	0.661

Correlation coefficient (R)

Table 13. Correlation between LST and NDBI

- It was found that the correlation between LST and NDBI for the new city and the old city is **maximum** in the **post-monsoon**.
- The minimum correlation between the LST and NDBI was obtained in the winter season.
- For Ahmedabad city as a whole, the maximum correlation between the LST and NDBI was obtained in the post-monsoon and it was minimum in the winter.

From correlation analysis, it was found that LST and NDVI are negatively correlated and LST and NDBI are positively correlated.

It can also be observed from the above tables that the correlation between the **LST and NDBI is slightly higher in the old city as compared to the new city**.

It was also observed that the correlation between the **LST and NDBI for the whole city is lesser than the individual values of the correlation between the new city and the old city**.

From the above work, it was also observed that the correlation of LST is better with the NDBI as compared to the NDVI, which means that NDBI is more sensitive to the LST as compared to the NDVI.

7. CONCLUSIONS

- From this study, we can conclude that the NDVI of the old Ahmedabad city is less than the new Ahmedabad city. For the year 2020, the NDVI of the old city was around 28.13% less than the new city, which means that the old city possesses fewer vegetation areas as compared to the new city.

- We can also conclude from the results of this study that the NDBI of the old city is much higher than the new city. For the year 2020, the NDBI of the old city was 95% more than the new city, which means that the old Ahmedabad is having more density of the built-up areas like houses, ancient architectures, markets etc.

- In this study the correlation of LST with NDVI and NDBI was also carried out and it was found that it is having weak or moderate negative correlation with the NDVI and it is having a moderate or strong positive correlation with the NDBI. The correlation of LST with the NDVI is maximum in the monsoon season and with the NDBI it is maximum in the post-monsoon season.

- This shows that NDBI is more sensitive to LST than the NDVI and from this, we can say that even a small increase in the built-up areas can lead to high LST values.

- Also, the correlation of LST and NDBI is stronger for the old city as compared to the new city because in the old city most of the LST values are more influenced by the NDBI than the NDVI.

- Thus, due to the factors like high NDBI values, low NDVI values and high sensitivity of NDBI to the LST, the surface temperature (LST) of the old Ahmedabad city is higher than the new Ahmedabad city and for the year 2020 it was around 0.55 °C more than the new city which accounts around 1.85% of the LST new city.

8. REFERENCES

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Annexure

```
//  To derive LST from the LANDSAT 8
image collection
//cloud mask
function maskL8sr(image) {
  // Bits 3 and 5 are cloud shadow and cloud,
respectively.
  var cloudShadowBitMask = (1 << 3);
  var cloudsBitMask = (1 << 5);
  // Get the pixel QA band.
  var qa = image.select('pixel_qa');
  // Both flags should be set to zero,
indicating clear conditions.
  var mask =
qa.bitwiseAnd(cloudShadowBitMask).eq(0)

.and(qa.bitwiseAnd(cloudsBitMask).eq(0));
  return image.updateMask(mask);
}
// Region of interest (ROI)
var ROI= ee.Geometry(geometry);
Map.centerObject(ROI, 11);

// Visualisation to true colour
var vizParams2 = {
bands: ['B4', 'B3', 'B2'],
min: 0,
max: 3000,
gamma: 1.4,
};

// Landsat 8 SR image
 var l8_image= imageCollection
 .filterBounds(geometry)
 .filterDate('2020-01-01','2020-12-31')
 .filterMetadata('CLOUD_COVER',
'less_than', 90)
 .map(maskL8sr)
 .median()
 .clip(ROI);
print(l8_image, 'l8_image');
Map.addLayer(l8_image, vizParams2,
'l8_image');

// NDVI
{
var ndvi =
l8_image.normalizedDifference(['B5',
'B4']).rename('NDVI');

var ndviParams = {min: -1, max: 1,palette: [
    'FFFFFF', 'CE7E45', 'DF923D', 'F1B555',
'FCD163', '99B718', '74A901',
    '66A000', '529400', '3E8601', '207401',
'056201', '004C00', '023B01',
    '012E01', '011D01', '011301'
  ]};

print(ndvi,'NDVI');
}
//  Mean NDVI
{ var mean_NDVI =
ndvi.reduce(ee.Reducer.median())
                    .clip(ROI);
Map.addLayer(mean_NDVI,
ndviParams, 'NDVI');
}
{
var meanNDVI =
ee.Number(mean_NDVI.reduceRegion
({
reducer: ee.Reducer.median(),
scale: 30,
reducer: ee.Reducer.median(),

scale: 30,
maxPixels: 1e9
}).values().get(0));
print(meanEm, 'meanEm');
}

/ Min and Max of Emissivity
{
var min_em =
ee.Number(mean_em.reduceRegion({
reducer: ee.Reducer.min(),
scale: 30,
maxPixels: 1e9
}).values().get(0));
print(min_em, 'min_em');

var max_em =
ee.Number(mean_em.reduceRegion({
reducer: ee.Reducer.max(),
scale: 30,
maxPixels: 1e9
}).values().get(0));
print(max_em, 'max_em');
}

// Brightness temperature
var brightness_temp=
l8_image.select('B10').multiply(0.1);
var b10Params = {min: 291.918, max:
309.500, palette: ['040274', '040281',
'0502a3', '0502b8', '0502ce', '0502e6',
    '0602ff', '235cb1', '307ef3', '269db1',
'30c8e2', '32d3ef',
    '3be285', '3ff38f', '86e26f', '3ae237',
'b5e22e', 'd6e21f',
    'fff705', 'ffd611', 'ffb613', 'ff8b13',
'ff6e08', 'ff500d',
    'ff0000', 'de0101', 'c21301', 'a71001',
'911003']};
print(brightness_temp,'BT');
//  Mean Brightness temperature
{ var mean_BT =
brightness_temp.reduce(ee.Reducer.median(
))
                    .clip(ROI);
Map.addLayer(mean_BT, b10Params, 'BT');
}

// Min and Max of Brightness temperature
{
var min_BT =
ee.Number(mean_BT.reduceRegion({
reducer: ee.Reducer.min(),
scale: 30,
maxPixels: 1e9
}).values().get(0));
print(min_BT, 'min_BT');

var max_BT =
ee.Number(mean_BT.reduceRegion({
MaxPixels: 1e9
}).values().get(0));
print(meanNDVI, 'meanNDVI');
}
// Min and Max of NDVI
{
var min_ndvi =
ee.Number(mean_NDVI.reduceRegion({
reducer: ee.Reducer.min(),
scale: 30,
maxPixels: 1e9
}).values().get(0));
print(min_ndvi, 'min_ndvi');

var max_ndvi =
ee.Number(mean_NDVI.reduceRegion({
reducer: ee.Reducer.max(),
scale: 30,
maxPixels: 1e9
}).values().get(0));
print(max_ndvi, 'max_ndvi');
}

// NDBI
{
var ndbi =
l8_image.normalizedDifference(['B6',
'B5']).rename('NDBI');
var ndbiParams = {min: -1, max: 1, palette:
['F9DFDC', '0A81AB', '0C4271', '000000']};
print(ndbi,'NDBI');
}
// NDBI
{
var ndbi =
l8_image.normalizedDifference(['B6',
'B5']).rename('NDBI');
var ndbiParams = {min: -1, max: 1, palette:
['F9DFDC', '0A81AB', '0C4271', '000000']};
print(ndbi,'NDBI');
}
```

Annexure

```
//  Mean NDBI
{ var mean_NDBI =
ndbi.reduce(ee.Reducer.median())
                .clip(ROI);
Map.addLayer(mean_NDBI, ndbiParams,
'NDBI');
}
{
var meanNDBI =
ee.Number(mean_NDBI.reduceRegion({
reducer: ee.Reducer.median(),
scale: 30,
maxPixels: 1e9
}).values().get(0));
print(meanNDBI, 'meanNDBI');
}
// Min and Max of NDBI{
var min_ndbi =
ee.Number(mean_NDBI.reduceRegion({
reducer: ee.Reducer.min(),
scale: 30,
maxPixels: 1e9
}).values().get(0));
print(min_ndbi, 'min_ndbi');
var max_ndbi =
ee.Number(mean_NDBI.reduceRegion({
reducer: ee.Reducer.max(),
scale: 30,
maxPixels: 1e9
}).values().get(0));
print(max_ndbi, 'max_ndbi');
}
//Fractional vegetation
{
var fv
=(ndvi.subtract(min_ndvi).divide(max_ndvi.sub
tract(min_ndvi))).pow(ee.Number(2)).rename('F
V');
var imageVisParam2 =
{"opacity":1,"palette":["b7efc5","92e6a7","6ede
8a","4ad66d", "2dc653", "25a244", "208b3a",
"1a7431", "155d27", "10451d"]};
print(fv, 'fv');
}
//  Mean Fractional vegetation
{ var mean_fv =
fv.reduce(ee.Reducer.median())
                .clip(ROI);
Map.addLayer(mean_fv, imageVisParam2,
'FV');
}
{
var meanFV =
ee.Number(mean_fv.reduceRegion({
reducer: ee.Reducer.median(),
scale: 30,
maxPixels: 1e9
}).values().get(0));
print(meanFV, 'meanFV');
}
// Min and Max of Fractional vegetation
{
var min_fv =
ee.Number(mean_fv.reduceRegion({
reducer: ee.Reducer.min(),
scale: 30,
maxPixels: 1e9
}).values().get(0));
print(min_fv, 'min_fv');

var max_fv =
ee.Number(mean_fv.reduceRegion({
reducer: ee.Reducer.max(),
scale: 30,
maxPixels: 1e9
}).values().get(0));
print(max_fv, 'max_fv');
}

//Emissivity
var a = ee.Number(0.004);
var b = ee.Number(0.986);
var Emissivity =
fv.multiply(a).add(b).rename('Em');
var imageVisParam3 = {min:
0.9865619146722164,
max:0.989699971371314};
print(Emissivity, 'Em');

//  Mean emissivity
{ var mean_em =
Emissivity.reduce(ee.Reducer.median())
                .clip(ROI);
Map.addLayer(mean_em,
imageVisParam3, 'Emissivity');
}
{
var meanEm =
ee.Number(mean_em.reduceRegion({
reducer: ee.Reducer.median(),
scale: 30,
maxPixels: 1e9
}).values().get(0));
print(meanEm, 'meanEm');
}

// Min and Max of Emissivity
{
var min_em =
ee.Number(mean_em.reduceRegion({
reducer: ee.Reducer.min(),
scale: 30,
maxPixels: 1e9
}).values().get(0));
print(min_em, 'min_em');
var max_em =
ee.Number(mean_em.reduceRegion({
reducer: ee.Reducer.max(),
scale: 30,
maxPixels: 1e9
}).values().get(0));
print(max_em, 'max_em');
}
// Brightness temperature
var brightness_temp=
l8_image.select('B10').multiply(0.1);
var b10Params = {min: 291.918, max:
309.500, palette:
['040274', '040281', '0502a3',
'0502b8', '0502ce', '0502e6',
   '0602ff', '235cb1', '307ef3',
'269db1', '30c8e2', '32d3ef',
   '3be285', '3ff38f', '86e26f', '3ae237',
'b5e22e', 'd6e21f',
   'fff705', 'ffd611', 'ffb613', 'ff8b13',
'ff6e08', 'ff500d',
   'ff0000', 'de0101', 'c21301',
'a71001', '911003']};
print(brightness_temp,'BT');

//  Mean Brightness temperature
{ var mean_BT =
brightness_temp.reduce(ee.Reducer.m
edian())
                .clip(ROI);
Map.addLayer(mean_BT, b10Params,
'BT');
}

// Min and Max of Brightness
temperature
{
var min_BT =
ee.Number(mean_BT.reduceRegion({
reducer: ee.Reducer.min(),
scale: 30,
maxPixels: 1e9
}).values().get(0));
print(min_BT, 'min_BT');

var max_BT =
ee.Number(mean_BT.reduceRegion({
reducer: ee.Reducer.max(),
scale: 30,
maxPixels: 1e9
}).values().get(0));
print(max_BT, 'max_BT');
}
```

Annexure

```
//LST (Converted to Celsius from Kelvin)
var LST = brightness_temp.expression(
'(Tb/(1 + (0.00115* (Tb / 1.438))*log(Em)))-273.15', {
'Tb': brightness_temp.select('B10'),
'Em': Emissivity.select('Em')
}).rename('LST');
print(LST, 'LST');

var Visparams_LST = {min: 12.19726940544291,
max:41.6701111498399, palette:
['040274', '040281', '0502a3', '0502b8', '0502ce', '0502e6',
    '0602ff', '235cb1', '307ef3', '269db1', '30c8e2', '32d3ef',
    '3be285', '3ff38f', '86e26f', '3ae237', 'b5e22e', 'd6e21f',
    'fff705', 'ffd611', 'ffb613', 'ff8b13', 'ff6e08', 'ff500d',
    'ff0000', 'de0101', 'c21301', 'a71001', '911003']};

//  Mean LST
{ var mean_LST = LST.reduce(ee.Reducer.median())
                .clip(ROI);
Map.addLayer(mean_LST, Visparams_LST, 'LST');
}
{
var meanLST = ee.Number(mean_LST.reduceRegion({
reducer: ee.Reducer.median(),
scale: 30,
maxPixels: 1e9
}).values().get(0));
print(meanLST, 'meanLST');
}
// Min & Max LST
{
var min_LST = ee.Number(mean_LST.reduceRegion({
reducer: ee.Reducer.min(),
scale: 30,
maxPixels: 1e9
}).values().get(0));
print(min_LST, 'min_LST');

var max_LST = ee.Number(mean_LST.reduceRegion({
reducer: ee.Reducer.max(),
scale: 30,
maxPixels: 1e9
}).values().get(0));
print(max_LST, 'max_LST');
}
// To download Min., Max. & Mean in CSV format
var feature = ee.Feature(null,
{
min_ndvi : min_ndvi, max_ndvi : max_ndvi, meanNDVI : meanNDVI,
min_ndbi : min_ndbi, max_ndbi : max_ndbi, meanNDBI : meanNDBI,
min_ndwi : min_ndwi, max_ndwi : max_ndwi, meanNDWI :
meanNDWI,
min_nmdi : min_nmdi, max_nmdi : max_nmdi, meanNMDI :
meanNMDI,
min_fv : min_fv, max_fv : max_fv, meanFV : meanFV,
min_em : min_em, max_em : max_em, meanEm : meanEm,
min_BT : min_BT, max_BT : max_BT, meanBT : meanBT,
min_LST : min_LST, max_LST : max_LST, meanLST : meanLST
});
// Wrap the Feature in a FeatureCollection for export.
var featureCollection = ee.FeatureCollection((feature));
// Export the FeatureCollection.
Export.table.toDrive({
  collection: featureCollection,
  description: 'Data',
  fileFormat: 'CSV'
});
// To download image with visualizations.
var thumbnail3 = mean_NDVI.getThumbURL({
  'min':-1,
  'max': 1,
  'palette': [ 'FFFFFF', 'CE7E45', 'DF923D', 'F1B555',
'FCD163', '99B718', '74A901',
    '66A000', '529400', '3E8601', '207401', '056201',
'004C00', '023B01',
    '012E01', '011D01', '011301'],
  'region': ee.Geometry(ROI),
  'dimensions': 500,
  'crs': 'EPSG:3857'
});
print('LST visualization', thumbnail3);

// Export to drive

Export.image.toDrive({
  image: LST,
  description: 'LST',
  folder: "image EE",
  scale: 30,
  region: l8_image,
  fileFormat: 'GeoTIFF',
  formatOptions: {
    cloudOptimized: true
  }
});
```