

Spatial and Temporal analysis of Landsat data to Retrieve the NDWI, NDVI and Land Surface Temperature by thermal remote sensor: A case study of Hyderabad Metropolitan City, Telangana

YedlaSuneetha^{1,*}, MareddyAnji Reddy²,

¹Vidya Jyothi Institute of Technology, Aziz Nagar, Hyderabad, Telangana,India

²Andhrakesari University, Ongole, Andhra Pradesh, India

Abstract: Urban areas endure larger variations in ground surface temperature, vegetation, and water content than rural areas do due to the accelerated rise of technology, urbanization, and industrialization. These challenges could be investigated by using GIS and remote sensing tools. Using “LANDSAT 5 and LANDSAT 8 OLI/TIRS” data for Hyderabad from 2000 to 2020, this study evaluates changes in vegetation, water availability, and land surface temperature. Variations in NDVI, NDWI, and LST have been observed over time as a result of research on several parameters. Indices of water and vegetation are examined in this study where the Vegetation declined from 0.73006 to 0.49419 between 2000 and 2020, whereas water quantity decreased from 0.7979 to 0.4901 until 2010, at which point it progressively climbed to 0.7015 by that year. Likewise, studies on LST have demonstrated a connection between LST and NDWI. After rising to 40.9°C in 2010 from 39.8°C in 2000, temperatures decreased to 40°C in 2015 and 39.8°C in 2020. This work shows that LST, NDWI and NDVI can be accurately computed using GIS and remote sensing, which is helpful for environmental research and studies.

KEY WORDS: Emissivity, Land Surface Temperature, Landsat5, Landsat OLI/TIRS, NDVI, NDWI, Brightness Temperature.

Introduction:

Rapid growth in urbanization, increasing settlements or built-up areas, establishment and increasing of industries, impervious surfaces of roofs, expanding highways, parking lots and sidewalks have altered dramatically the radiation and metropolitan areas have hotter air and surfaces than the surrounding areas because of the surface's emission characteristics.

To analyze the mentioned phenomenon's accurately remotely sensed images from various satellites like Landsat, Sentinel, IRS etc can be used. To analyze the vegetation cover and changes in water quantity, different indices can be used where NDVI and NDWI can be also some of the better indices.

Without ever touching the surface of the earth, thermal remote sensing provides a realistic means to determine its temperature. To gauge the Earth's surface temperature, a number of GIS software tools and Land sat imagery can be employed. Urbanization and industrialization have made cities into a concrete jungle with fluctuating surface temperatures.

The specific purpose of this study is to retrieve Land Surface Temperature (LST) data for Hyderabad, Telangana from remotely sensed images acquired by the “LANDSAT 5 TM (Thematic Mapper)”[20] and “LANDSAT 8 OLI/TIRS (Operational Land Imager and Thermal Infrared Sensor)”[6] between the years 2000 and 2020, and to conduct a quantitative analysis of the LST with the relation between NDWI&NDVI.

1. Description of the research area:

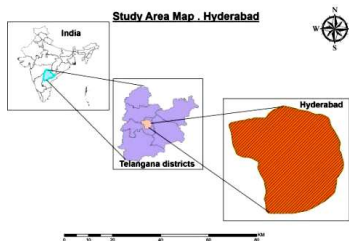


Fig.1. Study area

*Corresponding author: Suneethayedla7@gmail.com

Greater Hyderabad is one of the largest cities of India, having a total land area of 650 km²[1]. With average annual temperature of 26.6 °C, the monthly averages fluctuate between 21 and 33 °C. Usually the summer months between from March to June, the climate turns hot and arid, featuring mean high temperatures ranging from the mid to upper 30s Celsius, frequently exceeding 40°C as maximum temperatures. The two coldest months are December and January, with lows that sporadically dip below 10 °C. December is the coldest month, with daily temperatures between 14.5-28 °C. With daily temperatures ranging from 26 to 39 °C[1], May is the hottest month. My study area is within the range of Outer Ring Road with the perimeter of 158 km road and 1,455 square kilometers of area[2].

2. Data sets and Methods:

Two sensors, Land sat 5 (with its “Thematic Mapper (TM) and Multi Spectral Scanner (MSS instruments”)[3] and “Land sat 8- Thermal Infrared Sensor (TIRS) and operational Land Imager (OLI)”[5], with spatial resolutions of “30 meters (visible, NIR, SWIR), 15 meters (panchromatic) and 100 meters (thermal)”[4], cover the entire planet throughout the year.

To Analyze the Surface Temperature of the land, “LANDSAT 5”[5] (Thermal Band6) with 120(30)m resolution and “LANDSAT8 (OLI/TIRS)[5]with two additional thermal bands TIR-1(Band10) and TIR-2(Band11) with 100m Resolution of satellite images of Hyderabad were used. To analyse NDWI and NDVI, Green, Red, Near Infra Red and Short Wave Infrared bands have been used.

From the downloaded image to calculate LST, NDVI, NDWI, Band_Red, Band_NIR, Band_Green and Band_SWIR1 are used from the following meta data variables(Table 2) used from the mtl text file(Fig 2c).

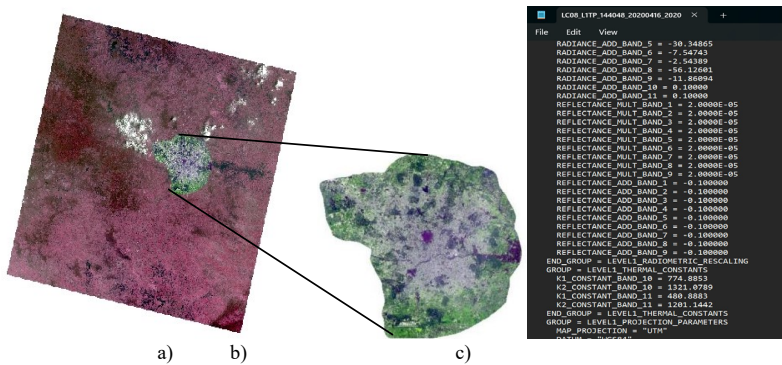


Fig.2. a) Composite band b) Study area pan sharpen band c) Meta data file Land sat 5

From 2000 to 2020, in the months of April or May, Landsat5 and 8 satellite images of the research area with 144 WRS path and 048 WRS row were obtained from the USGS website with less than 2% cloud cover. (Fig3 and 4)

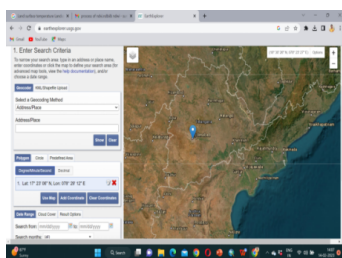


Fig.3. Selection of study area from USGS website

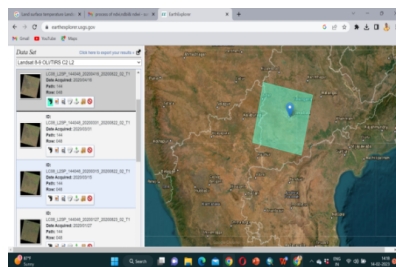


Fig.4. Downloading the satellite image from USGS website

Using the downloaded images to calculate the LST, NDVI, NDWI, both Thermal IR Bands, Band_Red, Band Green, Band-IR and Band SWIR1 have been used from the following meta data variables(Table 1) used from the .mtl text file(Fig 2c).

Table 1. Input Data-Metadata of the satellite image

Variable	Value	
K1 K2	774.8853 1321.0789	LANDSAT 8
L _{Max} L _{Min}	0.0003342 0.1	
Q _{CalMax} Q _{CalMin}	65535 1	
O _i	0.29	
K1 K2	607.76 1260.56	LANDSAT 5
L _{Max} L _{Min}	15.303 1.238	
Q _{CalMax} Q _{CalMin}	255 1	

The study was conducted using ESRI's ArcGIS 10.4.1 software, which was used to extract the study region from a satellite image for further investigation.

3. METHODOLOGY:

1. Data image Extraction:

In this investigation, the cloud cover was under 2% of Landsat 5 and Landsat OLI/TIRS images of Hyderabad from USGS website with outer ring road boundary (WRS Path 144 Row 048) are acquired from 2000 to 2020 with five years of intervals during April or May month, used to be the summer season where higher temperatures will be recorded with less cloud cover.

2. Pre-Image Processing:

The projection method was used to correct images to the Universal Transverse Mercator Zone 44 of the WGS-1984 datum [6]. Thermal infrared (Band 6) resolution on Landsat 5 is 120 meters. The earliest thermal infrared bands on Landsat 8 (Bands 10 and 11) had the 100 meters of spatial resolution, and Band 10 was utilized to measure land surface temperature rather than Band 11.[5][6] The Arc GIS 10.4.1 application is used to perform a number of tasks utilizing the raster calculator to determine LST. The Google Earth image of Hyderabad, which the ORR surrounds, was used to subset the area of interest from the overall image.(Fig 1)

Table 2. Landsat 5 and 8 images taken to calculate LST are

Date	Sensor	Band No	Resolution	Cloud(%)
30 May 2000	TM	Band 6	30m	2.00
07 April 2005	TM	Band 6	30m	2.00
21 April 2010	TM	Band 6	30m	0.00
21 May 2015	OLI/TIRS	Band 10	30m	0.45
16 April 2020	OLI/TIRS	Band 10	30m	1.19-

3. Landsat 5: LST Methodology:

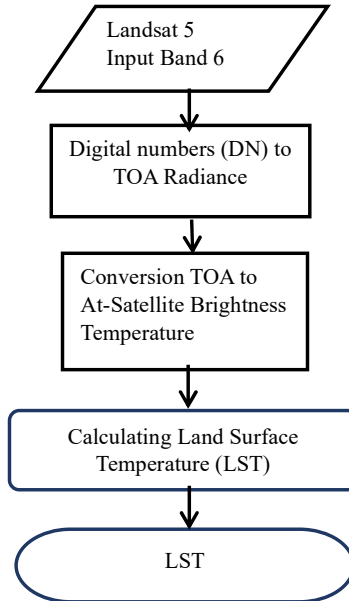


Fig. 5.Flowchart for LST retrieval

3.1 Conversion of Digital Number (DN) to Radiance (L λ):

Using Band 6, a thermal band, the “spectral radiance (L) for Landsat-5”[15] TM imagery was calculated.

$$L_{\lambda} = \frac{(LMax_{\lambda} - LMin_{\lambda}) \times (QcalMax - QcalMin) + LMin_{\lambda}}{QcalMax - QcalMin} \quad (i)$$

Here are the definitions:

L λ - represents Spectral Radiance.

Q cal- “Quantized Calibrated pixel value in DN”[34].

L Max λ -denotes Maximum Spectral Radiance to QCalMax in (Watts/(m²*sr*μm)).

L Min λ -indicates Maximum Spectral Radiance to QCal Min in (Watts/(m²*sr*μm)).

“Qcal Min”- represents the “Minimum Quantized calibrated pixel value in DN”[34]

“Qcal Max”- signifies the “Maximum Quantized calibrated pixel value in DN”[34]

3.2 Conversion of Radiance to Brightness Temperature (In Kelvin):

When referring to the temperature of a surface, the word "surface temperature" is used to refer to the outermost layer of earth. The surface temperature is measured using the thermal infrared spectrum. Landsat-5 TM thermal data may be found in band 6 (10.6-12.51 m). The brightness temperature is calculated by taking the thermal band's spectral radiance (L) value [7] and dividing it by the amount of surface heat radiation that an item emits. Brightness temperature (BT) is calculated as follows [8]:

$$T = \frac{K_2}{\ln(K_1/L_{\lambda}) + 1} \quad (ii)$$

Where:

T= temperature obtained in Kelvin

K₂= constant2

K₁= constant1

L_λ= Radiance in (Watts/(m²*sr*μm))

3.3 Converting from “Kelvin to Degree Celsius:

Subtract T to -273.15°C to convert Kelvin to degrees.

$$BT(K) = \frac{K_2}{\ln[(K_1/L_2) + 1]} - 273.15 \quad (iii)$$

$$C=K-273.15$$

4. Calculation of Normalized Difference Water Index:

To estimate the water content using remote sensing methods, Gao[10] introduced NDWI. Following that, Ho et al. [11] were successful in creating NDWI to differentiate between water and non water locales. By utilizing the Green and Near Infra Red bands of Landsat-5 TM, with the spectral range of 0.45-0.51m and 0.85-0.88 m. The NDWI range, which is -1 to 1. The function employed is:

$$NDWI = \frac{(Green - NIR)}{(Green + NIR)}$$

$$NDWI(TM) = \frac{(Band2 - Band4)}{(Band2 + Band4)} \quad (iv)$$

4.1 Calculation of NDVI:

In remote sensing, vegetation-related objects are frequently described using Rouse's [13] vegetation index, the NDVI. According to Thoha [14], NDVI may be used to detect grass greenness. The measurement is based on information from Landsat-5 TM bands 3 (0.64-0.67 m) and 4 (0.84-0.88 m). The function listed below was utilized: [15]:

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)} \quad (v)$$

$$NDVI = \frac{(Band 4 - Band 3)}{(Band 4 + Band 3)}$$

5. Landsat 8:LST Methodology:

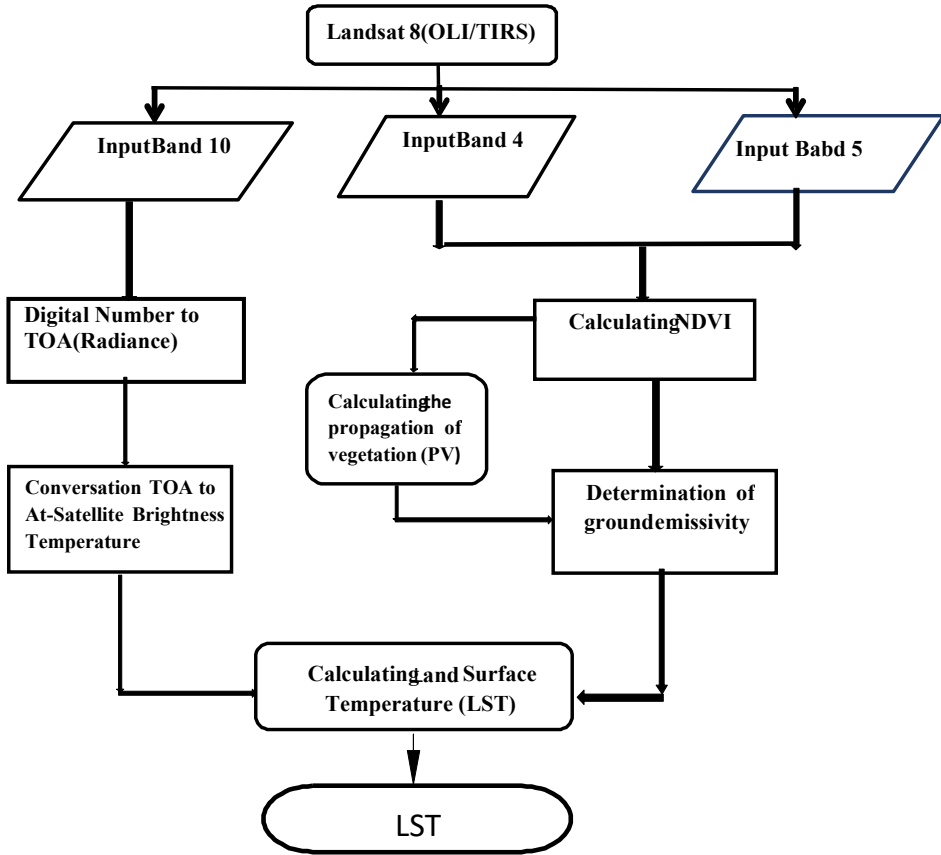


Fig.6. Flowchart for LST retrieval

5.1 Calculation of TOA (Top of Atmospheric) spectral radiance (L_λ).

Commencing with Band 10 as the initial input, the application acquires the top of atmospheric (TOA) spectral radiance (L) by implementing methods found on the USGS website, following the addition of band 10 to the background.

$$TOA(L_{\lambda}) = M_L \times Q_{cal} + A_L - 0.29 \quad (vi)$$

Where:

M_L =RADIANCE_MULT_BAND_10.

Q_{cal}=Quantized Calibrated pixel value in DN

A_L = RADIANCE_ADD_BAND_10

O_i = Band 10Correction value (0.29)

5.2 Calculation of Radiance to Brightness Temperature (BT):

The thermal constants which are K1 and K2 in the metadata file must be used to convert from digital numbers (DNs) before the TIRS band data can be transformed from spectral radiance to brightness temperature (BT). The algorithm of the tool applies reflectance to BT using the following equation:[8,16]

$$BT(K) = \frac{K_2}{\ln[(K_1/L_{\lambda}) + 1]} - 273.15 \quad (vii)$$

As a result, the radiant temperature is modified by subtracting with -273.15°C to obtain the findings in Celsius. [17]

5.3 Calculating NDVI:

For the calculation the Vegetation Index, Landsat’s near-infrared and visible red bands are averaged together. The calculation of NDVI is crucial because it may be used to assess both the quantity and general condition of the vegetation. As a result of their relationship, it is recommended to compute the vegetation proportion (P_v), nearly associated to the NDVI calculation, and the Emissivity (ϵ), is dependent on the vegetation proportion (P_v), after the NDVI calculation.

Healthy vegetation makes a great electromagnetic spectrum absorber for obvious reasons. Chlorophyll is a pigment found in green plants that substantially absorbs the blue, red and green spectral ranges. As a result, healthy vegetation appears green to the unaided eye. Healthy plants reflects high at Near Infrared (NIR). The NDVI is calculated using two bands with high red-spectrum absorption and high NIR-spectrum reflectance, respectively. NDVI can be determined using the formula shown below [31].

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)} \quad (viii)$$

$$NDVI = \frac{(Band\ 5 - Band\ 4)}{(Band\ 5 + Band\ 4)}$$

5.4 Calculation of proportion of vegetation P_v :

P_v is computed utilizing the formula ix[19]. The NDVI values for vegetation is ($NDVI_v = 0.5$) and soil is ($NDVI_s = 0.2$) are suggested by a method for calculating P_v in order to be applicable under global conditions [21]:

$$P_v = \left[\frac{NDVI - NDVI_s}{NDVI_v - NDVI_s} \right]^2 \quad (ix)$$

However, the NDVI value for vegetation, 0.5, is less because NDVI values vary by location. It would be hard to determine global values for an NDVI derived using TOA reflectivity since $NDVI_v$ and $NDVI_s$ are influenced by atmospheric conditions. However, at-surface reflectivity can be used to obtain global NDVI values.

5.5 Calculation of Land Surface Emissivity:

Land Surface Emissivity (LSE) is a measurement of the efficiency with which The atmosphere takes in thermal energy from the surface and is thus crucial to the calculation of LST (Land Surface Temperature). The LSE scaling factor predicts emitted radiance by scaling black body radiance in accordance with Planck’s law [23]. Using data from passive sensors, a variety of methodologies can be utilized to calculate relative or absolute Emissivity. Absolute techniques entail substantial assumptions, whereas relative approaches concentrate on the Emissivity spectrum ratio

The Emissivity of the terrestrial surface is determined using the NDVI Thresholds Method (ϵ)[25]. The examples that follow demonstrate how this method extracts Emissivity information from NDVI:

$$\begin{aligned} &= \epsilon_{soil} && \text{if} && NDVI < 0.2 \\ &= \epsilon_{veg} && \text{if} && NDVI > 0.5 \\ &= (\epsilon_{veg} \cdot P_v) + \epsilon_{soil} (1 - P_v) && \text{if} && 0.2 \leq NDVI \leq 0.5 \end{aligned}$$

Where:

- ϵ_{soil} is the Emissivity of the soil;
- ϵ_{veg} is the Emissivity of the vegetation;
- P_v is the fraction of vegetation cover

"Soil" and "veg" were estimated by Sorbino et al[25]. By using the values at 0.97 and 0.99, respectively. By Using these values, the equation below is produced using the formulas above:

$$\begin{aligned} &= 0.97 && \text{if} && NDVI < 0.2 \\ &= 0.99 && \text{if} && NDVI > 0.5 \\ &= 0.004 \cdot P_v + 0.986 && \text{if} && 0.2 \leq NDVI \leq 0.5 \end{aligned}$$

$$\epsilon = 0.004 \times P_v + 0.986 \quad (x)$$

5.6 Calculation of LST:

The calculation of the Land Surface Temperature (LST) of landsat 8 is carried out [26] where T_s , representing LST in degree Celsius ($^{\circ}C$), which is determined by using Brightness Temperature (BT) ($^{\circ}C$) [27] and the emitted radiance's wavelength(with consideration of peak response and the average of limiting wavelength) [28](= 10.553) [28] will be used), and [29] and [30] are the Emissivity calculations.

$$T_s = \frac{BT}{1 + \left[\left(\frac{BT}{\rho}\right) \ln \epsilon_{\lambda}\right]} \quad (xi)$$

$$\rho = h \frac{c}{\sigma} = 1.438 \times 10^{-2} \quad (xii)$$

Here,

σ is Boltzmann constant (1.38×10^{-23} J/K),

h is the Planck's constant (6.626×10^{-34} J s),

and c is the light velocity (2.998×10^8 m/s),

e is denoted as Emissivity= $1.4388 \times 10^{-2} = 14388$ mK

The values of radiance(λ) for Land sat 8: For Band 10 is 10.653675311351 (10.60 to 11.19)

6. Calculating NDWI:

This can be assessed to analyze the volume of water. To calculate this index, near infrared and green images from remote sensing are used. Information about water is often considerably improved by the NDWI. There is a likelihood of land development, which leads to an overestimation of water quantity. NDVI change products and NDWI products may be used together to learn more about the background of apparent change regions. The only kind of electromagnetic radiation that can be seen reflected by water is the visual variety.

$$NDWI = \frac{(GREEN - NIR)}{(GREEN + NIR)}$$

$$NDWI(OLI) = \frac{(Band3 - Band5)}{(Band3 + Band5)} \quad (xiii)$$

7. Results and Discussions:

Using Landsat imagery, the temporal and spatial data of LST of Hyderabad within the ORR boundary is been assessed. The study examined LST's regional and temporal trends, as well as its interactions with NDVI and NDWI. Given that it monitors the vegetation index, the NDVI is necessary to determine the land surface temperature.

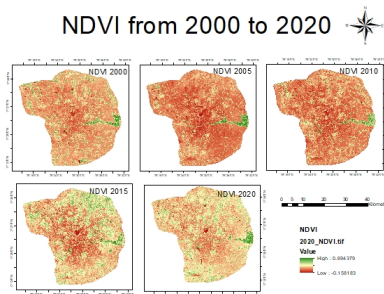


Fig.7. Temporal analysis from 1999 to 2020

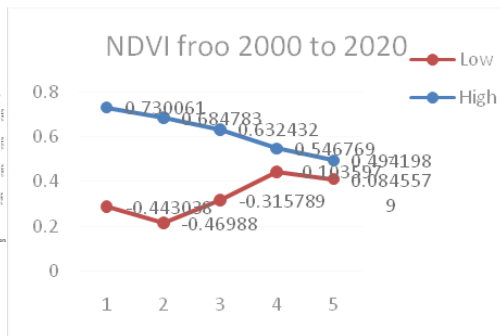


Fig.8. NDVI from 2000 to 2020

The result indicates that LST From the year 2000 to 2005 with $0.2^{\circ}C$ of maximum temperature variation and from 2005 to 2010 is with $0.9^{\circ}C$ and from 2010 to 2015 is with $-1^{\circ}C$ difference and from 2015 to 2020 is with $0.1^{\circ}C$ temperature of maximum difference and $0.3^{\circ}C$, $0.8^{\circ}C$, $0^{\circ}C$ and $1.4^{\circ}C$ (Fig 10) of minimum temperature variation respectively. This explains the gradual

increase of LST from 2000,2005 and 2010 with maximum temperatures of 39.83°C,40.08°C and 40.93°C respectively. in 2015 temperature has decreased to 39.93°C further in the year 2000 decreased to 39.82°C. This shows in Hyderabad City due to urban expansion resulted in raise in temperature from 2000 to 2010 but decreased in 2015 and 2020 could be due to the increasing of water bodies within the ORR region (Fig12).

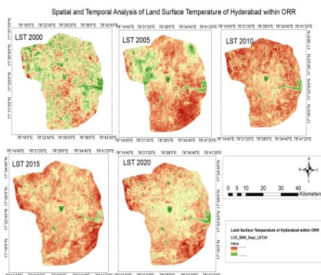


Fig.9. LST from 2000 to 2020

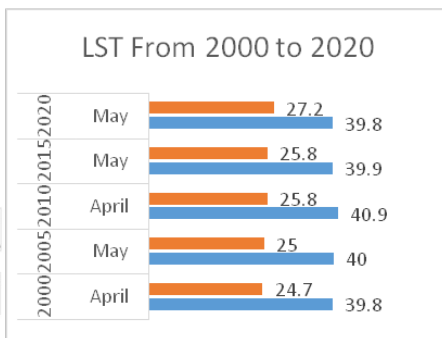


Fig.10. LST from 2000 to 2020

The results of the investigation showed a negative correlation of LST with NDWI. The NDVI and NDWI both recorded higher readings in 2000, 0.73006 and 0.730061, respectively. In 2020, these were 0.49419 and 0.701526, respectively (Fig 8 and 12).

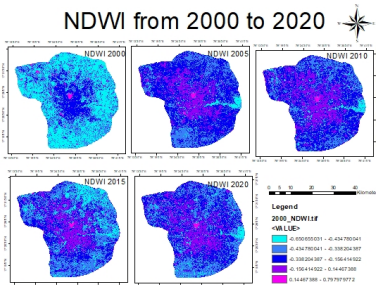


Fig.11. NDWI from 2000 to 2020

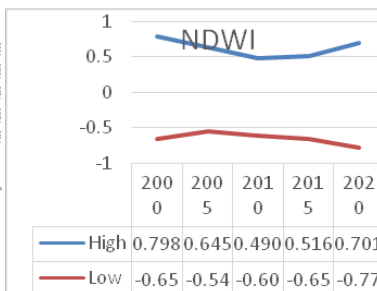


Fig.12. NDWI from 2000 to 2020

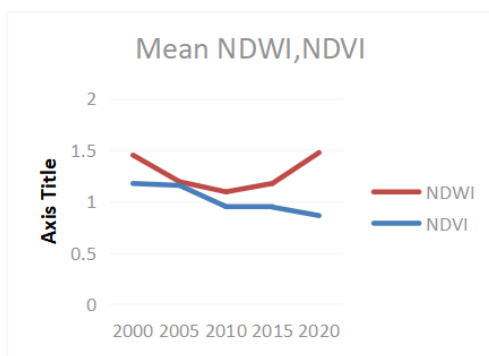


Fig.13. Mean NDWI, NDVI from 2000 to 2020

The relationship with LST with NDWI with the observations, from the year 2000 to 2015 Water Index has decreased with 0.7979 to 0.4901 where as LST has increased from 39.8°C to 40.9°C but in 2015 and 2020 onwards LST has decreased with 40°C and 39.8°C respectively and NDWI has increased with 0.5166 and 0.7015 respectively.

This research describes in this case study that the strong relationship of LST can be observed with NDWI as the water quantity is decreased the LST has increased from 2000 to 2010 where from 2015 to 2020 as the water bodies have increased and the LST is decreased in Hyderabad within ORR region. This enables the urban planners to expand the urban areas to plan in a sustainable way.

8. Conclusions:

The technique in 4.1(v) and 5.3(viii) were used in this study to display the NDVI temporal images from 2000 to 2020, and a considerable difference was seen, as illustrated in fig 7, where the vegetation was noticeably denser along the Musi River in 2000. As more people have been attracted to Hyderabad by IT industry enterprises seeking jobs, the vegetation density has steadily reduced. By 2020, the amount of vegetation has drastically decreased and has started to disperse as a result of increasing urbanization.

By using NDVI values calculation of LST was done by using the formula (iii & xii) for Landsat TM. In 2000 The temperature is 39.83°C where gradually the temperature has increased in 2005 and 2010 where with 40.08°C and 40.93°C respectively, where is decreased to 39.93°C and 39.82°C in 2015 and 2020 respectively. The results indicate the negative relationship of NDVI with Land Surface Temperature (Fig 8 & 10). Water Index results by using the formula 4(iv) and 6(xiii) have shown with decreasing quantity from 2000 to 2010 and gradually increased from 2015 and 2020 (Fig 13). As well as mean values of NDWI and NDVI are showing negative relationship from 2000 to 2020 (Fig 14).

This study has analyzed the vegetation, water bodies and the surface temperature of land by using the Landsat images with the help of Arc GIS 10.4.1 software, where the study reveals that the Hyderabad being the metropolitan city and IT hub has resulted in urban expansion much within two decades. In addition with decreasing of vegetation and water bodies have been observed resulting in gradual increase of temperature from 2000 to 2020. Thus the strong negative correlation of NDVI with LST indicates that the green vegetation reduction increases the land surface temperature.

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