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An assessment of the Relationship between Vegetation (Forest Density Cover) Built-Up Area and City Land Surface Temperature, Generated by LANDSAT-8 OLI/ Thermal band - A Case study of Dehradun, India

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Abstract: Dehradun city is the capital of Uttarakhand state of India. Evidence from the past research and literature [e.g. CDP 2007, Singh et al 2013, Gupta et al 2014] shows that in the late 80s, Dehradun city was much greener compared to the present condition. In the current study, we tried to identify the correlation between land surface temperature (LST) with Forest cover density classes (FCDC) and built-up area with open land. The current study reveals that there is a relationship between FCDC and LST in the study area. The range of LST recorded is between 32.07 to 43.99 °C. Among all the classes, minimum LST record in VDF class is 32.07°C and maximum LST record in built-up area 43.99°C. The present study shows the importance of vegetation cover in urban areas to reduce LST, air temperature and maintain the urban microclimate as well as to help reduce air pollution.

Key words: Relationship, LST, NDBI, FCDC

Introduction

Forests have been an essential component and have an impact on local and global environments. They moderate the diurnal temperature range of the air and retain humidity concentrations in the atmosphere (Packiam 2015). Forests cover provides multiple ecosystem functioning, biological diversity, carbon dynamics, and climate-related goods and services such as food, wood, and water (Duguma et. al 2019). However, continued access to forest resources is becoming increasingly challenged by deforestation and or degradation of forests (Wimberly and Ohmann 2004). The forests of the world have been under pressure for several decades because of the escalation of the human population and urbanization, because of this biodiversity has been lost and greenhouse gasses have increased with far-reaching impacts (Wachiye, Kuria and Musiega 2013). It is estimated that the average temperature will rise between 4 ° and 7 ° C under present emission trends by 2100, with possibly disastrous social and environmental effects, including large-scale ecosystem transformations (Moutinho 2005). The forests are interlinked with individuals socially and environmentally and play a major part in the region's economic welfare and growth. Forests can have a powerful impact on local surface temperature (LST), as they usually have lower surface albedo and higher evapo-transpiration (ET) relative to open physiognomy of vegetation. Urbanization is growing worldwide and is regarded as a major driver of environmental change (Grimm et al. 2008). In 2014 about 54 percent population of the world resided in the urban area and it will increase very rapidly and reach 66 percent in 2050 (United Nations, 2014). Urbanization and dense population create the environment to develop urban heat island (UHI). The UHI phenomenon is the cause of higher temperature in city centre area corresponding to other surrounding areas (Voogt and Oke, 2003). The UHI happening is normally estimated by LST. (Ngie et al 2015).

LST is known as an important variable for maintaining microclimate of the earth surface in which radiation is the main cause for LST transfer within the atmosphere (Suresh et al 2016). LST is not only considered as a controller of the microclimate of land surface and physical phenomena in local and global scale but also an important parameter for latent heat flux exchange (Aires et al 2001). LST is the top surface temperature of the soil, forest cover and water content (Prasad R. et. al, 2015) and contribute valuable information about physical characteristics of the surface and climatic changes. Natural and man-made activities in land use–land cover (LULC) lead to a change in the environmental condition of the regional landscape which causes a change in the value of LST and changes local climate condition (Rajeshwari et.al, 2014). People migrate to urban area from the small towns and rural area for better living facility available in the urban area, which stretches the urbanization. Dehradun is the fast-growing city and such growing momentum leads to reducing current greenery in the city, which cause increased land surface temperature and changed urban microclimate (Nor et al., 2013). Urban greenery not only maintains urban temperature but also serves as a regular tool against city pollution in the urban climate condition (Buyadi et al., 2015). In this study LST has been evaluated on the basis of surface emissivity and brightness values.

Objectives of the study

1. To identify the urban heat island via land surface temperature using Landsat-8 thermal infrared band.

2. To find the importance of forest density class against Dehradun city Land Surface Temperature[LST]

3. To identify the relation between Built-up area and forest density classes

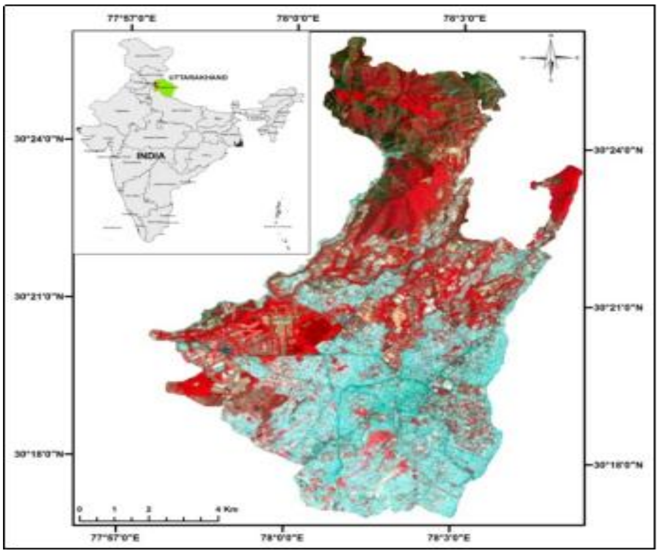


Fig 1: Study Area Map

Study area:

For the current study, we chose Malsi forest range under Dehradun forest division, because Malsi forest range covers entire Dehradun city and has a range of dense to open forest area also. Dehradun city is the capital of Uttarakhand state. Geographical extension of the present study area is between

77°57'25.292"E to 78°3'52.503"E longitude & 30°16'52.399"N to 30°26'1.347"N latitude at an elevation ranging between of 680m to 1080m amsl. The study area is surrounded by two major rivers Song in eastern side and Tons in western side. Forest types within study area are 5B/C1-a Dry Siwalik Sal Forest and 3C/C2-a Moist Siwalik Sal Forest (FSI, FTM 2011). Mostly urban area vegetation is plantation apart some natural Sal (*Shorea robusta*) patches. Total population of Dehradun city according to the last Census of India (2011) is

5,78,420 with 9833 per Km^2 population density.

Material and Methods

For the current study, LANDSAT-8 Operational Land Imager (OLI)/Thermal Infrared Sensor (TIRS) C1 level-1 satellite imagery (acquisition date 15-June 2019, path-146 & row-39), was downloaded from United States Geological Survey website (http://earthexplorer.usgs.gov/). The map projection satellite imagery is universal transverse Mercator (UTM) with WGS-84 Datum, spatial resolution of panchromatic, spectral and thermal bands are 15, 30 and 100 respectively. To achieve study objectives, we used panchromatic, spectral and thermal bands, in which spectral bands false-color composite (543) image was used to generate FCDC map, band 5 and 4 used to generate Normalized difference vegetation index (NDVI), 15m spatial resolution panchromatic band (8) was used for fusion (resolution merge) with a FCC image (543 band combination) to generate a moderately high resolution multispectral image for visible image interpretation. For the Normalized Difference Built Index (NDBI), we used SWIR band 6 and NIR band 5. In Thermal Infrared Sensor (TIRS), we used long wavelength infrared band 10, because Landsat 8/TIRS Band 11 have large uncertainty and are not found appropriate for LST estimation as compared to TIRS band 10 single spectral band (Wang et al. 2015 and Bendib et al., 2016).

Table 1: Landsat-8 Operational Land Imager OLI & Thermal Infrared Sensor (TIRS) bands used in current study

S. no	Band Number	Description	Wavelength	Resolution
1.	Band 3	Visible green	0.525 to 0.600 µm	30 meter
2.	Band 4	Visible red	0.630 to 0.680 µm	30 meter
3.	Band 5	Near-infrared	0.845 to 0.885 µm	30 meter
4.	Band 6	Short wavelength infrared	1.56 to 1.66 µm	30 meter
5.	Band 8	Panchromatic	0.50 to 0.68 µm	15 meter
6.	Band 10	Long wavelength infrared	10.3 to 11.3 µm	100 meter

(source:- https://landdast.gsfc.nasa.gov/landsat-8/landsat-8-bands/)

Forest cover density classes (FCDC)

FCDC map with classification of Very Dense Forest (VDF, tree canopy density of 70 percentage and more), Moderately Dense Forest (MDF, tree canopy density of 40 percentage and more but less than 70 percent), and Open Forest (OF, tree canopy density of 10 percent and more but less than 40 percent) (FSI, ISFR-2019) of study area was generated using Supervised image classification on Landsat-8 OLI false-color composite image (band combination 543). Training data (GPS point of particular class) was collected from the different parts of study area for generating specific class signature to train satellite data for final output.

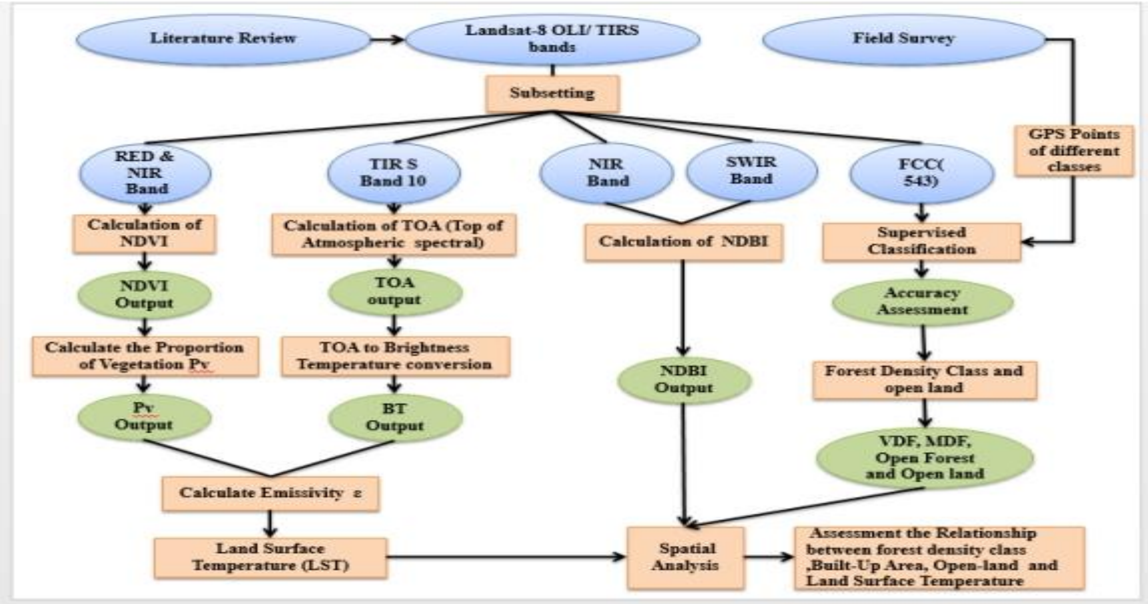
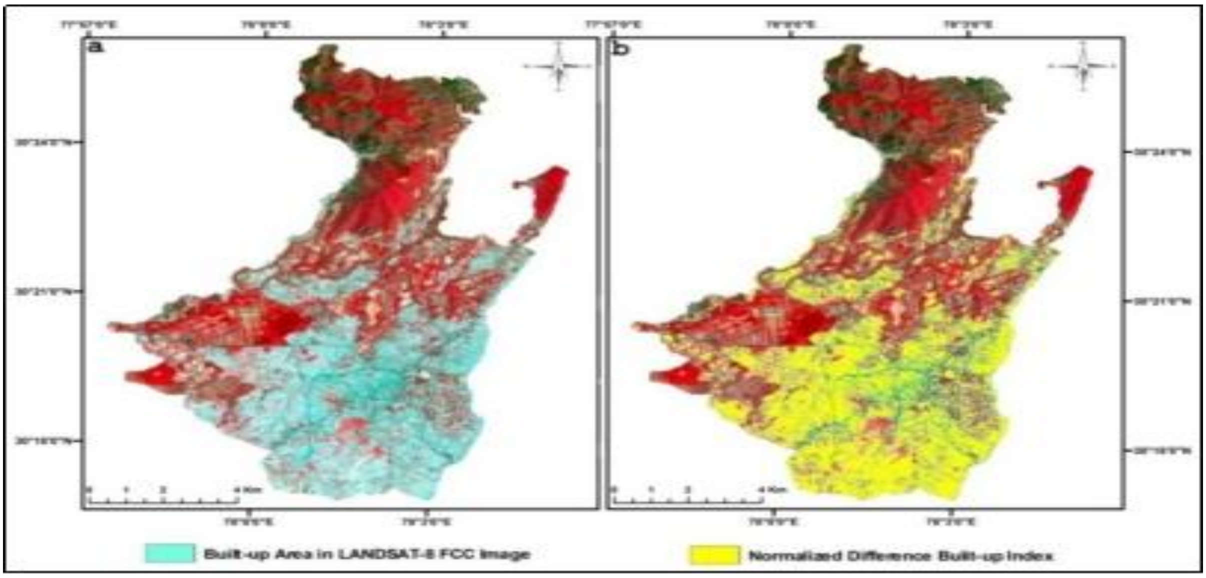


Fig 2: Flow chart Normalized Difference Built-up Index (NDBI)

Fig 3: (a) Showing Landsat-8FCC image, (b) Showing Normalized difference built-up index



The NDBI is a satellite bands based formula method to extract built-up area using SWIR and NIR band of multispectral sensors (Zha, Y., J. Gao, and S. Ni 2005. LANDSAT-8 OLI bands-6 (SWIR) and band 5 (NIR) used for NDBI. The NDBI is calculated by the following formula

$$NDBI = \frac{(SWIR - NIR)}{(SWIR + NIR)}$$

Where SWIR (short-wave infrared band) cover the range of 1.56 to 1.66 µm and
NIR (Near-infrared band) cover the range of 0.85- 0.88µm.

Post classification

For the post-classification of FCDC and NDBI with open land output, we used resolution merge option (using ERDAS imagine software 2011 ver. - 11.0.5) in which we used a multispectral image (543) and panchromatic band 8 with a spatial resolution of 30m and 15m respectively. The benefit of resolution merge option is that it provides 15m spatial resolution multispectral FCC image [as shown in Figure 4]. On-screen visual image interpretation was done in resolution merge image and manually digitized the small patches of VDF, MDF, OF and built-up area with open land for replacing or eliminating wrong classes in FCDC and NDBI with open land.

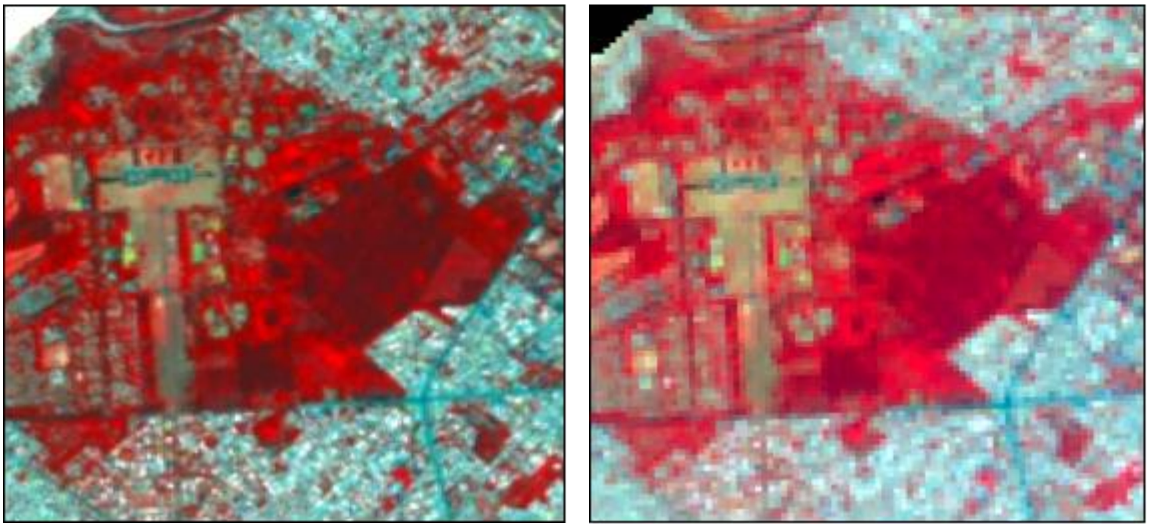


Fig.4 Result comparison of resolution merge image (a.) FCC image with 30m spatial resolution, (b.) FCC image with 15m spatial resolution after resolution merge

2.3 Data Processing

Study area Calculation Land Surface Temperature (LST) Calculation steps

In the current study, we used landsat-8 TIR band 10 to calculate the LST. Through TIR band we can record the earth surface temperature using the radiant energy. (Suresh at al., 2016 and Kumar 2018). To obtain Land Surface Temperature from Landsat-8, certain set of equations are explained in the following steps. All calculations are done in raster calculator in ArcGIS Software 9.3 version.

1. Calculation of TOA (Top of Atmospheric) spectral radiance. (Barsi et al., 2014; Rajeshwari and Mani, 2014).

TOA (Lλ) = ML * Qcal + AL

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Where:

ML = Particular band, multiplicative rescaling factor obtain from landsat-8 metadata file.

Qcal = band 10 Quantized and calibrated image of landsat-8 TIR bands.

AL = Band-specific additive rescaling factor obtain from landsat-8 metadata file.

TOA = 0.0003342 * “Band 10” + 0.1

2. **TOA to Brightness Temperature conversion** (Shaohua et al., 2009; USGS, 2013; Rajeshwari and Mani, 2014; Ugur and Gordana, 2016).

$$\mathbf{BTmp = (K_2 / (ln (K_1 / L) + 1)) - 273.15}$$

Where:

K_1 = Particular band thermal conversion constant value is 774.88.

K_2 = Particular band thermal conversion constant is 1321.07.

L = TOA

To correct the radiant temperature, absolute zero (approx. -273.15°C) add in the equation to achieve the outcomes in Celsius. [Xu and Chen, 2004; USGS, 2013]

BTmp = (1321.0789 / Ln ((774.8853 / “% TOA %”) + 1)) – 273.15

3. **Calculation of the NDVI** (Yannawut and Teerawong, 2016).

NDVI = (Band 5 – Band 4) / (Band 5 + Band 4)

In this step, we calculate the NDVI using band 4 and band 5, which is very important, because in further process proportion of vegetation (Pv) will calculate, and pv is linked to NDVI and emissivity (ε), is related to the P_v.

NDVI = Float (Band 5 – Band 4) / Float (Band 5 + Band 4)

4. Calculation of the proportion of vegetation P_v (Shahid, 2014; Rajeshwari and Mani, 2014; Ugur and Gordana, 2016).

$$P_v = Square\ ((NDVI - NDVI_{min}) / (NDVI_{max} - NDVI_{min}))$$

NDVI min and max value copy from NDVI image properties.

P_v = Square ((“NDVI” – 0.216901) / (0.632267 – 0.216901))

Calculation of Emissivity ε (Suresh et al 2016)

Before the final step, in which we will convert brightness temperature (BT) into Land surface temperature (LST), emissivity is required. We apply the formula in the raster calculator.

$$\mathbf{\varepsilon = 0.004 * P_v + 0.986}$$

5. Calculation of Land Surface Temperature

Equation to obtain LST

$$\mathbf{LST = (BT / (1 + (0.00115 * BT / 1.4388) * Ln(\varepsilon))}$$

Result and Discussion

The LST obtained from Landsat-8 TIR band-10 shows the LST ranges between 32.07 to 43.99 °C. Once the LST, FCDC and built-up with open land data layer was generated, "Zonal Statistics As Table" option in ArcGIS was used to extract LST in the individual patch of each layers, such as VDF, MDF, OF and built-up with open land. Through zonal statistics, we calculated the minimum, maximum, average and standard deviation of LST occurs in VDF, MDF, OF, FCDC and built-up with open land.

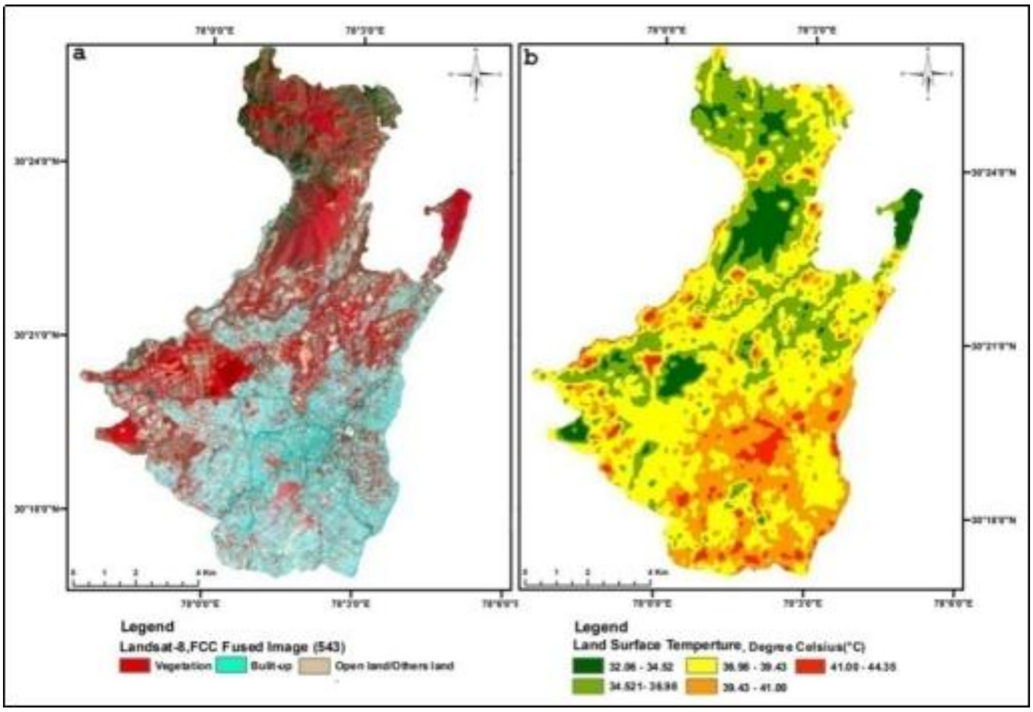

Fig 5. Landsat-8 FCC image and Land surface temperature (LST)

Table.2 Showing LST in Minimum, Maximum, Mean and Standard deviation of Different classes.

Sl.no.	Classes	MIN	MAX	MEAN	STD
1	Built-up	34.38	43.99	39.43	1.11
2	Open land	34.41	43.72	38.98	1.30
3	VDF	32.07	40.70	35.12	1.57
4	MDF	32.26	41.73	36.12	1.69
5	Open forest	33.10	44.35	37.64	1.55

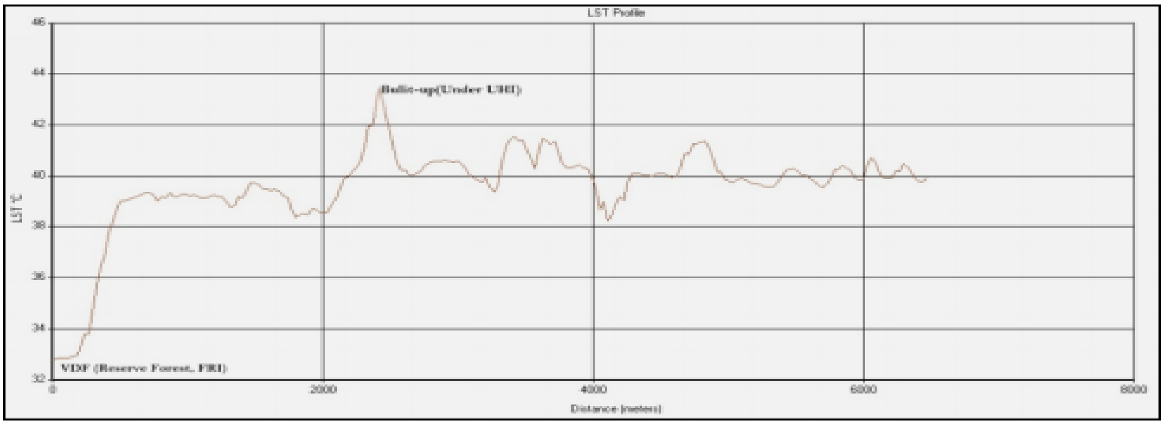

Fig .6 Distance LST profile representation of Minimum LST

The study reveals that among all classes, minimum LST record in VDF class is 32.07°C and maximum LST record in built-up area is 43.99°C. Mean LST under VDF is low amongst other FCDC; so it can be easily understood from mean LST value which is around 35.12°C in VDF class. However, gradually LST rise as forest canopy density reduce from VDF to MDF 36.12°C, MDF to OF 37.64°C, OF to open land 38.98 °C and open land to built-up area 39.43 °C. In the core area of VDF patch, min and max LST are 32.40°C and 36.43°C respectively and core area of built-up patch min and max LST are 38.59°C and 43.99°C respectively.

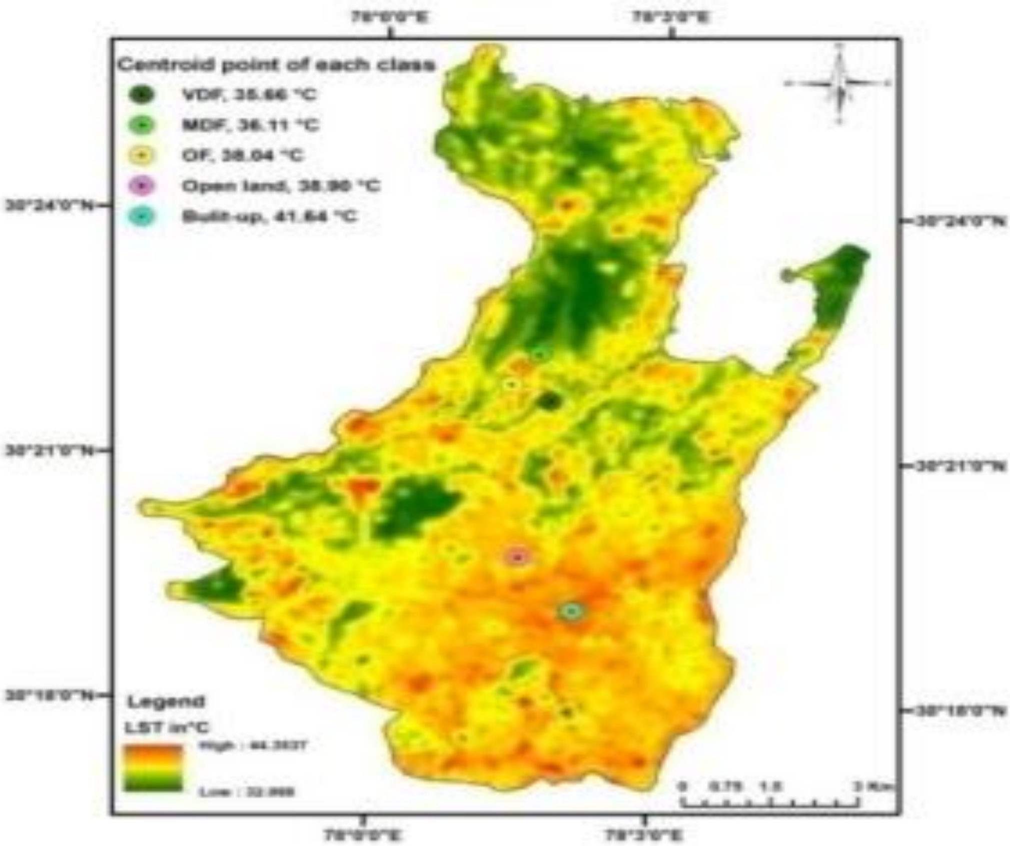

Fig 7: Graphic representation of Minimum LST

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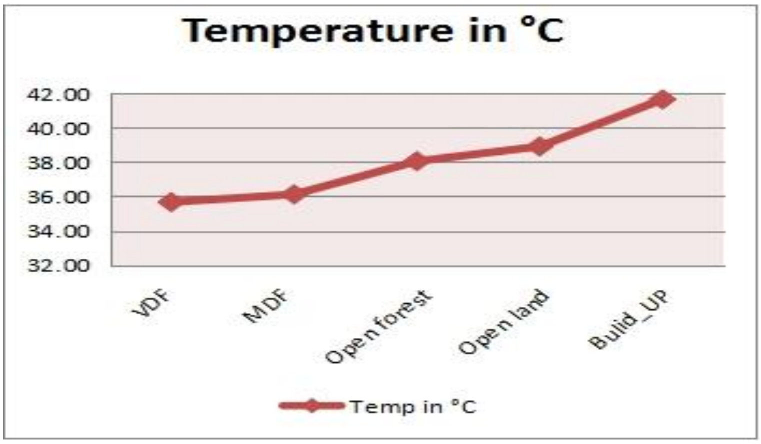

Fig 8: Centroid generated for each class to obtain LST

To evaluate the importance of FCDC in the current study, we generate random centroid point on FCDC and built-up area with open land [as shown in Figure 8] and extract the LST value for each centroid points. Through this method again VDF shows low LST 35.66°C, similarly MDF 36.11°C, OF 38.04°C and Built-up area 41.64°C and open land 38.90°C respectively.

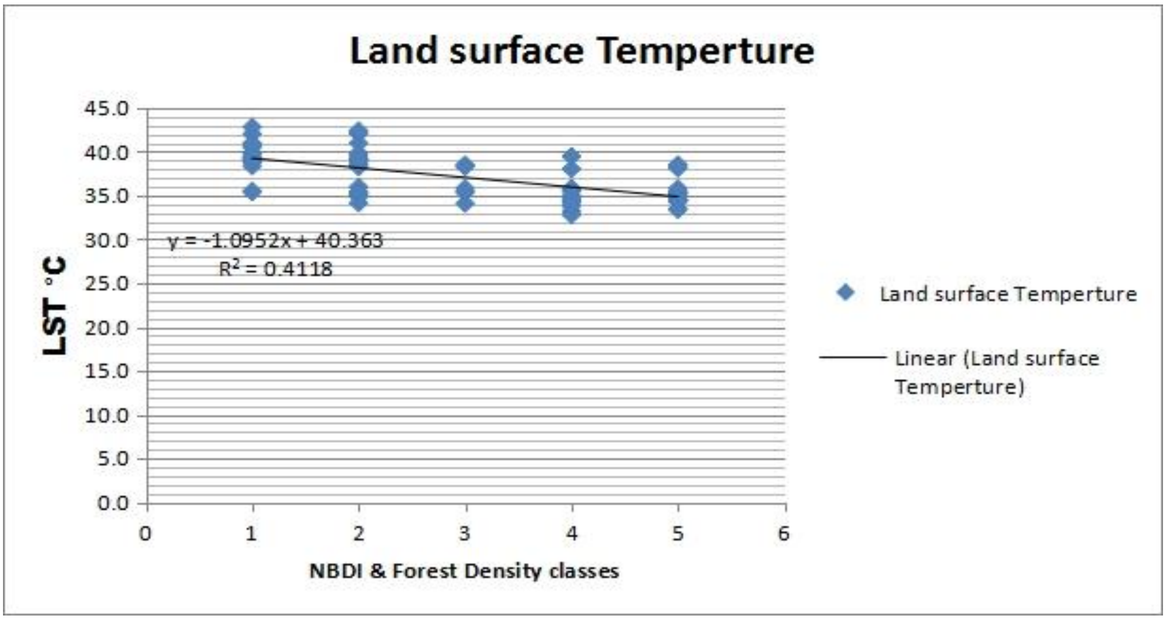

Fig 9.Correlation of LST with all classes

Note: NBDI & Forest Density Classes: 1: Built-up area, 2: Open land, 3: OF, 4: MDF, 5: VDF

Conclusion

The current study reveals that due to rapid urbanization and increase in dense commercial complexes, residential areas , depleting green cover in the core area of the Dehradun city and an UHI has developed. From the Darshanlal Chowk (Chowk is the local name for crossing of four roads at a point) to Saharanpur Chowk (Gandhi road to railway road via Prince chowk), the whole area is coming under UHI and unveil that within 1 km buffer zone area, LST as calculated on 15 June 2019 shows a range between 41˚C to 43˚C, which is comparatively higher than those areas which are covered with VDF, MDF, OF and tree outside forest. Thus we conclude from this study that natural and planted trees play a crucial role to manage city environment. Green Cover and trees not only maintain the temperature of the area but also improves the air quality and reduce the impact of carbon monoxide, hydrocarbons, nitrous oxides, carbon dioxide, produced by fossil fuel (used by vehicles and generators).

The study clearly reveals how the LST changes with the different forest density classes. It is very clear that with the increase in density of forest, the LST decreases and vice versa.

Recommendations

Terrace-gardening, green roof (vegetative layer grown on the roof top), green walls (using of creepers in walls) are some of the best solutions to reduce heat expansion and heat-trapping. If a proper estimate is made on the concrete roof area covered in Dehradun city, it will be very clear to the municipal corporation that this huge area can be covered into green by a strong policy initiative which will save the city from losing its greenery, rainfall, clean air etc. If a study is carried out regarding the energy consumption in the traditional concrete roof and the green roofs in the study area , it will help to make a clear cost benefit analysis and will give a clear picture for policy implementation. Since urban development nowadays are mostly vertical expansions due to land area constraints, roof terrace-gardening can be made mandatory by the local administrative authority in every houses, housing complexes, commercials complexes and office buildings. Apart from natural forest, the tree outside forest (TOF) and plantation are very important because they help to reduce the nearby temperature and increasing oxygen supply. Annual plantation by different departments under different schemes, NGOs etc should be encouraged with a proper record of survival rate of the plantation programme since in many cases it is found that the plantation programme are being done by NGOs and various organizations but at a later stage the survival rate of such plants are not monitored which actually dilutes the purpose of plantation and the expenditure incurred in it. The recent initiative by the Government of India " One student one tree' is highly welcome. For achieving the sustainable development it is the need of the hour that the present generations are fully aware regarding the various environmental effects that we are going to face in the future start taking very small initiatives from very tender age so that the culture of conservation of nature is imbibed within them. For a city like Dehradun major steps should be taken for roadside plantation, especially in new developing areas of the city. The municipal corporation should come out with a policy where a certain amount of land has to be kept construction free for garden /planting trees for the new complexes coming up in the city. Office building, market building and residential terrace floor can be painted with white color, which causes a very few amounts of solar radiation absorbed and the temperature of the house or office buildings can be restricted. This will also reduce energy consumption in the form of fans, air conditioners etc to some extent. Moreover all the roads in the city should be encouraged to be made concrete roads rather than charcoal road because charcoal roads absorb the solar radiation and emit solar radiation in the form of thermal radiation which increases the LST temperature of the city. To encourage these, banks can give credits at low interest rates for projects, houses, complexes that has green roof in their plan because this can help in storm water management, increase water efficiency, conserve energy and can help in increasing rainfall. Even while taking tenders for government infrastructural works, green infrastructure development needs to be prioritized. If the city administration and planners do not take immediate action, the hydrological cycle and the natural ecosystem and greenery of Doon Valley will be affected which can result into quite severe consequences in the future.

References

Aires Filipe, Prigent Catherin, Rossow WB and Rothstein, M. (2001). A new neural network approach including first guess for retrieval of atmospheric water vapour, cloud liquid water path, surface temperature, and emissivities over land from satellite microwave observations. *Journal of Geophysical Research*. 106. 14887-14908. 10.1029/2001JD900085.

Agnihotri A K, Ohri A and Mishra S (2018). Impact of Green Spaces on the Urban Microclimate through Landsat 8 and TIRS Data, in Varanasi, India International Journal of Environment and Sustainability [IJES] ISSN 1927-9566 Vol. 7 No. 2, pp. 72-80

Barsi JA, Schott JR, Hook SJ, Raqueno NG, Markham B., and Radocinski RG (2014). Landsat-8 thermal infrared sensor (TIRS) vicarious radiometric calibration. Remote Sensing, 6 (11), 11607–11626.

Bendib S, Zegadi A, Djeffal N (2016). Improved sensitivity of 2D annular photonic crystal biosensor working at THz frequency range. Opt Quant Electron **48,** 528. https://doi.org/10.1007/s11082-016-0803-8

Buyadi S N A, Mohd W M N W, Misni A (2015). "Vegetation's Role on Modifying Microclimate of Urban Resident", Procedia -Social and Behavioral Sciences. Elsevier B.V., 202(December 2014), pp. 400–407. doi: 10.1016/j.sbspro.2015.08.244

City Development Plan: Dehradun(2007) Revised Under Jawaharlal Nehru National Urban Renewal Mission (JNNURM), Urban Development Department Government of Uttarakhand.

Duguma LA, Atela J, Minang PA, Ayana, AN, Gizachew B, Nzyoka JM, Bernard F (2019). Deforestation and Forest Degradation as an Environmental Behavior: Unpacking Realities Shaping Community Actions. Land, 8(2), p.26.

Foley, J.A., DeFries, R., Asner, G.P., Barford, C., Bonan, G., Carpenter, S.R., Chapin, F.S., Coe, M.T., Daily, G.C., Gibbs, H.K. and Helkowski, J.H., (2005). Global consequences of land use. science, 309(5734), pp.570-574.

Forest Survey of India (FSI), (2017). Uttarakhand. In: India State of Forest Report (2017). Forest Survey of India, Dehradun, Uttarakhand, India, pp. 1–367.

Grimm NB, Faeth SH, Golubiewski NE, et al . (2008). Global change and the ecology of cities. Science **319**: 756–60.

Gupta P, Goyal S (2014). Urban Expansion and Its Impact on Green Spaces of Dehradun City, Uttarakhand, India. International Journal of Environment, 3(4), 57–73. https://doi.org/10.3126/ije.v3i4.11731

ICFRE (2001). Forest Statistics, India 1987-2001, Dehradun, India: Indian Council of Forestry Research and Education

Moutinho, Paulo(2005). Tropical deforestation and climate change. Edited by Stephan Schwartzman. Environmental Defense,

Nations U, (2014). World Urbanization Prospects the 2014 Revision. Available at https://population.un.org/wup/Publications/Files/WUP2018-Report.pdf

Ngie, Adeline & Abutaleb, Khaled & Ahmed, Faruk & Taiwo, Olalekan & Darwish, A.A. & Ahmed, Mahmoud. (2017). An estimation of land surface temperatures from landsat ETM+ images for Durban, South Africa. Rwanda Journal. 1. 10.4314/rj.v1i2S.2D.

Nor, S. et al. (2013). “Green Spaces Growth Impact on the Urban Microclimate", 105, pp. 547–557. doi: 10.1016/j.sbspro.2013.11.058

Packiam MSM (2015). Deforestation: Causes And Consequences. The International Journal of Social Sciences and Humanities Invention, 2(3).

Prasad Rajendran, Mani. K (2015), “Estimation of Spatial Variability of Land Surface Temperature using Landsat 8 Imagery”, The International Journal of Engineering And Science (IJES), Volume 4, Issue-11,pp-19-23.)

Rajeshwari A and Mani ND (2014), “Estimation of Land Surface Temperature of Dindigul District using Landsat 8 Data”, IJRET: International Journal of Research in Engineering and Technology, Vol.03, Issue.05.

Singh O, Arya P, Chaudhary BS (2013). On rising temperature trends at Dehradun in Doon valley of Uttarakhand, India. Journal of Earth System Science, 122(3), pp. 613–622.

Suresh. S , Ajay Suresh. V , Mani.k (2016). Estimation of Land Surface Temperature of High Range Mountain Landscape of Devikulam Taluk Using Landsat 8 Data IJRET: International Journal of Research in Engineering and Technology, eISSN: 2319-1163 | pISSN: 2321-7308 DOI:10.15623/ijret.2016.0501017

Urbanization and Development: Emerging Futures. World Cities Report (2016).Available at https://unhabitat.org/world-cities-report

USGS. (2013). Using the USGS Landsat 8 Product http://landsat.usgs.gov/Landsat8UsingProduct.php [accessed 01/05/2013].

Ugur Avdan and Gordana Jovanovska. (2016). Algorithm for Automated Mapping of Land Surface Temperature Using LANDSAT 8 Satellite Data. Journal of Sensors. Article ID 1480307, 1–8.

Voogt, J.A., Oke, T.R., 2003. Thermal remote sensing of urban climates. Remote Sens. Environ. 86 (3), 370e384.

Wachiye SA, Kuria DN, Musiega D (2013). GIS based forest cover change and vulnerability analysis: A case study of the Nandi North forest zone. Journal of Geography and Regional Planning, 6(5), pp.159-171.

Wang F, Qin Z, Song C, Tu L, Karnieli A, Zhao S (2015). An Improved Mono-Window Algorithm for Land Surface Temperature Retrieval from Landsat 8 Thermal Infrared Sensor Data. Remote Sens., 7, 4268–4289

Wimberly MC, Ohmann JL (2004). A multi-scale assessment of human and environmental constraints on forest land cover change on the Oregon (USA) coast range. Landscape Ecology, 19(6), pp.631-646.

Xu HQ, Chen BQ (2004). Remote sensing of the urban heat island and its changes in Xiamen City of SE China. Journal of Environmental Sciences. 16 (2), 276–281.

Yannawut Uttaruk and Teerawong Laosuwan. (2016). Remote sensing based vegetation indices for estimating above ground carbon sequestration in orchards. Agriculture and Forestry, 62 (4), 193–201.