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# Land surface temperature variations: Case study Bhopal (MP)

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## Abstract

With the increasing urbanization the cities today are facing multiple urban risks. Rising temperatures within the city is one such risk that the city dwellers are exposed to. Not only is the temperature both air and surface an issue of concern, but also the varied distribution of this increase is a cause of many issues. The land surface temperature study is important to address and analyse the various impacts caused thereby. The land surface temperature is globally rising all across the world. The present study takes Bhopal in Madhya Pradesh as a case study to develop a framework for the estimation of land surface temperature. The temperatures have been compared for the month of June in year 2014 and 2019. Normalized vegetation index and land surface temperature data has been computed for the case study to analyse the area under various temperature ranges. Results have been drawn through a correlation of NDVI and LST and the impact of reduction in the area of upper lake.

**Keywords:** Urban Heat Island, Land surface temperature, LANDSAT 8, Microclimatic conditions, Climate Change, GIS, Global Warming

## 1. Introduction

The Earth's climate is changing, and it is evolving at a much rapid rate today with the advent of multiple urban risks that the cities are exposed to. The vulnerability of communities at large is globally increasing with every passing day. It is visibly affecting the environment with prominent changes and social issues pressed upon the society with the increased exposure.
The ice is melting, the sea is rising and the temperature is getting hotter day by day. To understand the global changes that occurring, one must realize the micro implication that are being faced by the population.
The cities are facing microclimatic changes which are more prominent than ever. Urban heat island which is defined as a metropolitan area being significantly warmer than its surrounding rural areas due to human activities. The phenomena is not limited to a boundary of "urban" and "rural" but has over the years and with the complicated intermix of activities and spaces in the urban centres, have transitioned to a more varied heat island distribution within an urban area itself.

Due to the ever-increasing pressure of built up areas encroaching over the liveable spaces within the cities, the microclimatic conditions have started to deteriorate at much higher rate than it did a decade ago, thereby creating urban heat island pockets inside the city boundaries making the harsh climate even more un-bearable.
In order to cope with the challenges of the changing climate, climate risk mitigation strategies and climate adaptation strategies should be incorporated in the urban centres at all levels (national,

state, city, community and individual) to prepare and adapt the urban development. This, however, is a challenge in itself considering the rigid nature of plans that are in place for cities today.

Land surface temperature is how hot the surface of the Earth would feel to the touch in a particular location. From a satellite's point of view, the surface is whatever it sees when it looks through the atmosphere to the ground. It could be snow and ice, the grass on a lawn, the roof of a building, or the leaves in the canopy of a forest.

Land surface temperature (LST) is defined by the International LST and Emissivity Working Group as a measure of how hot or cold the surface of the Earth would feel to the touch (*Comprehensive Remote Sensing, 2018*)

## 2. Research methodology

The methodology of research implementing the Technical paper broadly involves the following stages:

1. **Stage I:** This initial stage involves necessary background study associated with the literature analysis of the data available on the land surface temperature and the urban heat islands. Study of best practices were undertaken around the globe to foster the use of GIS based technology to calculate the land surface temperature using satellite data and establishing the relevance of the same in Indian context.
2. **Stage II:** This intermediate stage involves analysis of the data obtained from LANDSAT-8 for the case study area for various years. The stage involves the processing of the various bands of the image retrieved from USGS, while applying the various formulas for estimating first the land surface temperature and then the urban heat island intensity of the study area.
3. **Stage III:** This stage involves establishing the differences between the time frames and the percentages of the area under the urban heat island and analysing how the changes in the vegetation index impact the intensity of the urban heat island.
4. **Stage IV:** The final stage tries to establish the co relation between the vegetation index and the land surface temperature. A way forward is suggested in the paper to mitigate and offset the increasing land surface temperature.

## 3. Objectives of the Study

An attempt is made in the research paper to devise a generic methodology, which can be implemented in other urban areas to establish such relationship between the vegetation intensity of a city and the urban heat islands within the city. The Research also tries to establish the mitigating measures to be implemented at spatial planning stages of such urban areas to counter the increasing the temperature through suitable systems in place.

## 4. Approach for Estimation of land surface temperature

The calculation of the land surface temperature is done using the data from LANDSAT 8 retrieved from USGS earth explorer. The Land Surface Temperature can be estimated or calculated using the Landsat 8 thermal bands with the following formulas:

i. **TOA (Top of Atmospheric) spectral radiance**

$$\mathbf{TOA\ (L) = M_L * Q_{cal} + A_L}$$

where:
ML = Band-specific multiplicative rescaling factor from the metadata (Radiance_Mult_Band_x, where x is the band number).
$Q_{cal}$ = corresponds to band 10.
AL = Band-specific additive rescaling factor from the metadata (Radiance_Add_Band_x, where x is the band number).

ii. **TOA to Brightness Temperature conversion**

$$\mathbf{BT = (K2 / (\ln (K1 / L) + 1)) - 273.15}$$

where:
K1 = Band-specific thermal conversion constant from the metadata (K1_Constant_Band_x, where x is the thermal band number).
K2 = Band-specific thermal conversion constant from the metadata (K2_Constant_Band_x, where x is the thermal band number).
L = TOA

iii. **Calculate the NDVI**

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

iv. **Calculate the proportion of vegetation Pv**

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

v. **Calculate Emissivity ε**

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

vi. **Calculate the Land Surface Temperature**

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

vii. **Calculation of urban heat island intensity**

$$UHI = \mu + \sigma / 2$$

in which μ is the mean LST value of the study area, and σ is the standard deviation of the LST.

## 5. Case study area

Bhopal is the capital of the central state of Madhya Pradesh and the administrative headquarters of Bhopal District. Bhopal is known as the City of Lakes for its various natural as well as artificial lakes. It is one of the greenest cities in India. It is the 17th largest city in the country and the 131st in the world. Bhopal has been selected as one of the cities to be developed as a smart city under the Smart Cities Mission. It houses various institutions of national importance, including ISRO's Master Control Facility and BHEL.The city acts as a nodal center of trade and commerce of regional importance. Furthermore, the city being relatively well-provided with various services and facilities, acts as a major service center for the region.

Bhopal District has a population of 23.7 lakh with an area of 2772 $km^{2.}$ The district is divided into 2 parts, Berasia and Huzur subdistrict. Bhopal sub district (Huzur) has a population of 21.1 lakh with an area of 1345 $km^2$Out of the total Huzur tehsil the population of the Bhopal municipal corporation is 17.98 lakh with an area of 422 $km^2$. And the population of the rest of tehsil is around 3.09 lakh.

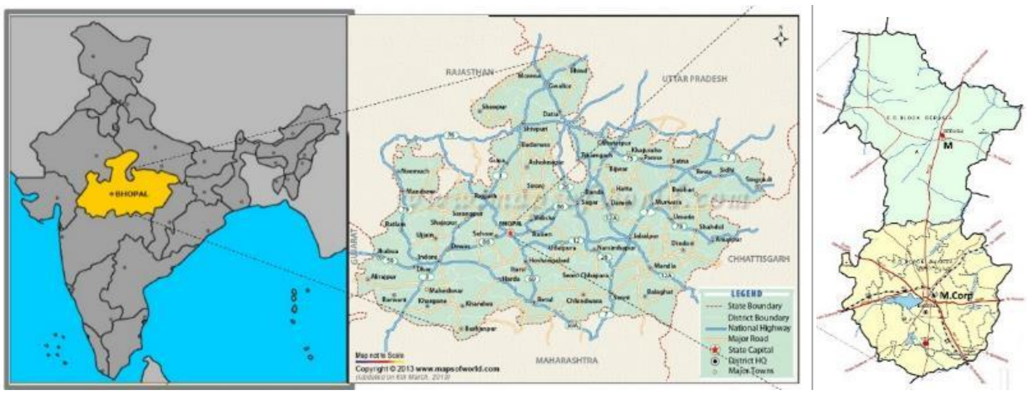


Figure 1 Location of Bhopal (Madhya Pradesh, India)

## 6. Results

NDVI or the normalized vegetative index of Bhopal was computed from the Band 5 and Band 4 of the Landsat 8 data retrieved from USGS Earth explorer for 2014 and 2019 for the month of June. In June 2014 NDVI values ranged from -0.049 to 0.48 whereas the range is -0.0445 to 0.428 in 2019. The NDVI value is an indication of the vegetation in the area. A higher value of the NDVI represents healthy dense vegetation whereas a low value of the NDVI value represents less to no vegetation in the area.

The comparison of both the NDVI value ranges and the area extent under each value suggests that the area under the healthy dense vegetation has decreased from 2014 to 2019 by 22%. Also the area under water body category has reduced by 24%. The changes in such land cover categories can be attributed to the significant increase in the built up area in the city. The development is observed to be significantly higher in the peri urban areas I.e area outside the city municipal corporation boundary thus a higher variation is observed in the reduction ofthe vegetation in this area. The map shows the highest change in the NDVI is near the upper lake of Bhopal, indicating reduction in water.

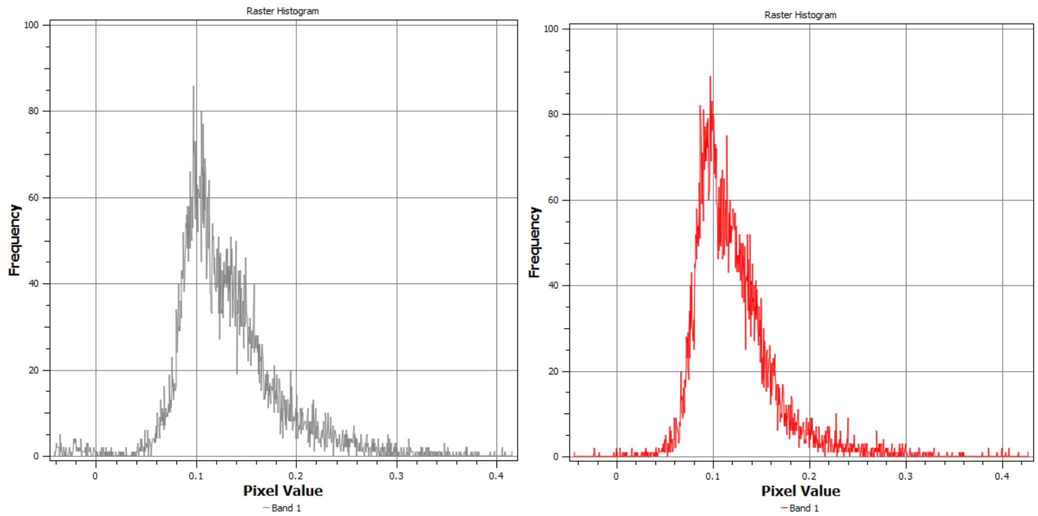



Figure 2 Left: NDVI distribution in 2014 Right: NDVI distribution in 2019
Source: Author

Subsequently the change in the land surface temperature were studied and a similar pattern of higher land surface temperatures was observed in the peri urban areas of the city. The Highest LST in Bhopal in June 2014 was of 39.81 deg C and in 2019 the highest lst increased to 46.62 deg c, a difference of 6.81 deg C in the highest LST. The lowest LST in june 2014 was 28.62 deg C whereas it increased in 2019 to 38.53 deg C indicating a difference of 9.91 deg C. Impact of the water body can be seen on the LST of Bhopal in both 2014 as well as 2019. The periphery of the planning area is having higher temperature due to sparse vegetation (indicated by the NDVI maps). The core city has a lower temperature due to the presence of upper lake.

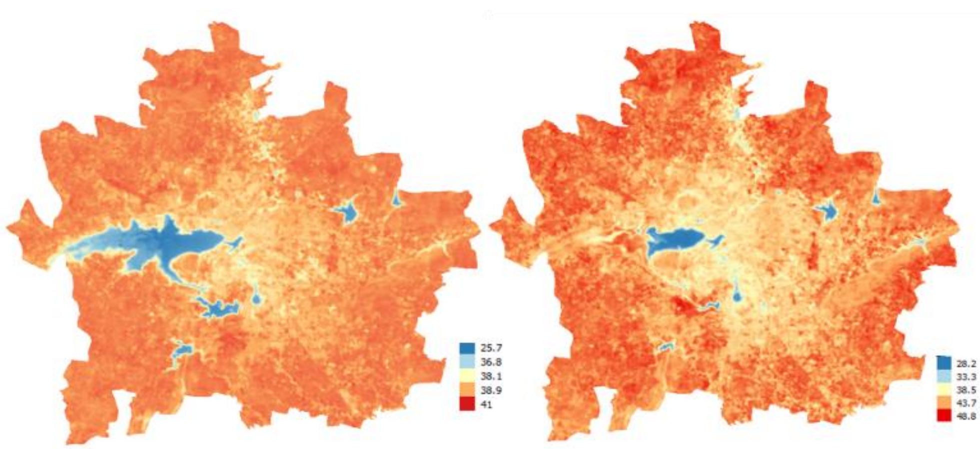



Figure 3 Left: LST in 2014 Right: LST in 2019
Source: Author

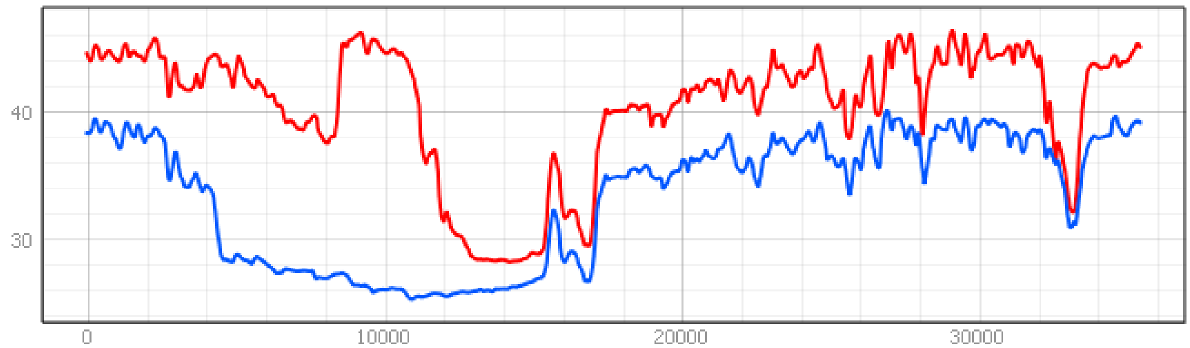



Figure 4 Land surface temperature variation across the city in 2014 (in blue) and 2019 (in red)
Source: Author

The cross section of the surface temperature profile of the city shows that the surface temperature is the lowest in the inner parts of the city due to the presence of water bodies. The temperature is highest in the barren lands.

Table 1 Area under each land surface temperature range (Source: Author)

| Land surface temperature in $^0$C (2014) | Percentage of land (2014) | Land surface temperature in $^0$C (2019) | Percentage of land (2019) |
|---|---|---|---|
| 28.62 | 10.22 | 29.5 | 3.7 |
| 31.42 | 1.1 | 34.2 | 1.08 |
| 34.21 | 7.8 | 38.9 | 16 |
| 37.01 | 27.3 | 43.6 | 76 |
| 39.81 | 53.5 | 48.3 | 2.7 |

The above table shows the range of land surface temperature in the city with the percentage of land having a specific temperature. It was observed that only 10.2% of the area in the municipal corporation boundary of bhopal has the lowest land surface temperature whereas 53.5% of the area has the maximum surface temperature in the city. Similar analyses was done for the year 2019 and it was found that only 3.7% area in the city has the lowest land surface temperature of 29.5 deg c whereas76% of the total area has a lst of 43.6 deg c and about 2.7% area has the highest temperature of 48.3 deg c. In 2019 55% of the land has the temperature range in the Urban Heat Island intensity range.

The variation around the upper lake was observed to be maximum in the month of June (peak summer season). The satellite imagery of the upper lake area was compared for the 10 june 2014 and 10 june 2019 in order to investigate the change in the extent and area of the water body. A reduction of 33% was observed during this period in the area of the lake.

Figure 5 Reduction in the upper lake area Left: June 2014 Right: June 2019
Source: Satellite Imagery

The land surface temperature was analysed at the cross sections of the upper lake. And it was observed that around the water body the surface temperatures were significantly lower than the surroundings. An average dip of 11.38 deg C in the land surface temperature was observed in 2014 whereas a dip of 13.68 deg c was observed in 2019.

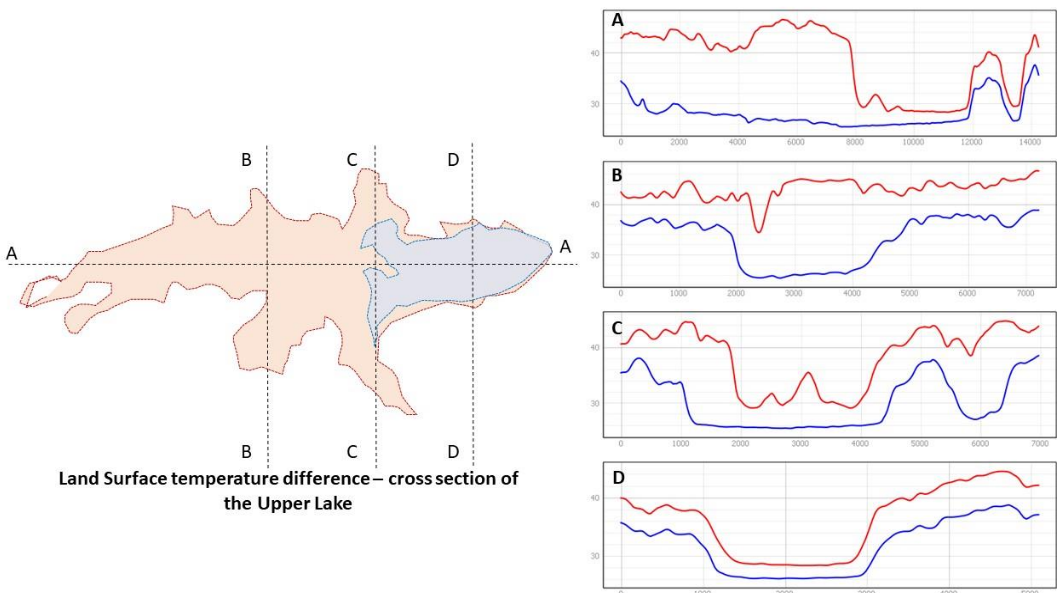



Figure 6 LST distribution across cross-sections
Source: Author

The cross-section study shows that as the distance from the water body increases, the land surface temperature increases. The water body reduction has a direct impact on the surface temperature of the surrounding areas. The temperature range has significantly risen due to reduction in the area of upper lake.

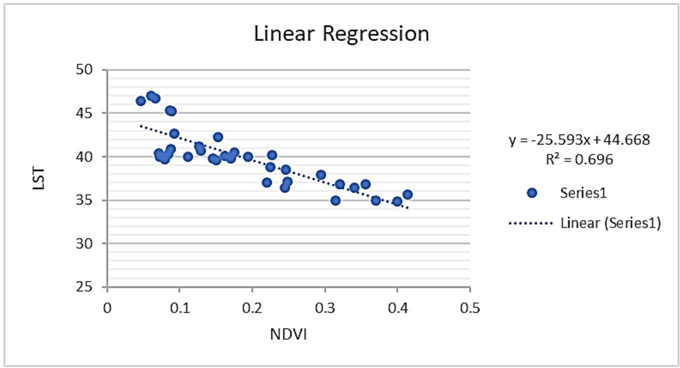
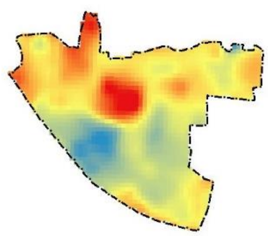
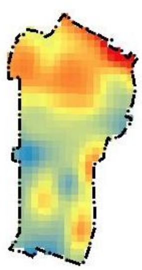
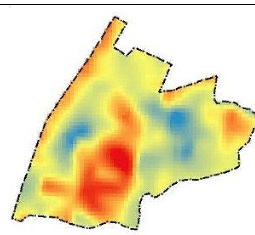
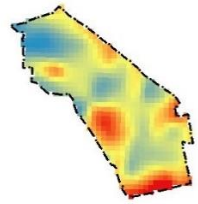
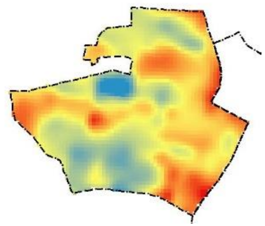
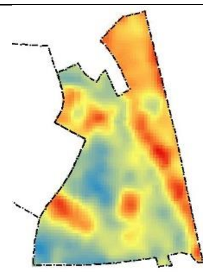
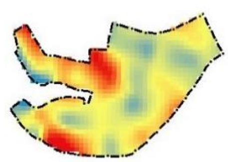



Figure 7 Linear regression of LST and NDVI (Bhopal 2019)
Source: Author

The above figure shows the strong negative correlation between the LST and the NDVI values. R square value of 0.696 is observed while establishing a linear regression between LST and NDVI which means the lower the NDVI value (apart from when the land cover is water) the higher the surface temperature and the higher the NDVI value or more the vegetation, the lower the land surface temperature in the area. Many areas with built-up area in the New Bhopal area show a lower surface temperature because of extensive roadside vegetations, neighborhood parks and green areas. Based on the above results, 7 wards land surface temperature data were extracted, to study the applicability of the procedure at ward level.

Table 2 Land surface temperature (Ward level)

| **Ward Google Imagery** | **Ward LST** | **Ward LST Details** |
|---|---|---|
|  |  | Min : 36.853515625<br>Max : 43.193862915039<br>Mean : 39.751423104643<br>Std Dev. : 1.0770747440295 |
|  |  | Min : 39.510990142822<br>Max : 41.574016571044<br>Mean : 40.272219041771<br>Std Dev. : 0.3540140703135 |
|  |  | Min : 37.185962677001<br>Max : 43.275787353515<br>Mean : 40.130275343481<br>Std Dev. : 1.1086464154171 |

| | | |
|---|---|---|
|  |  | Min : 39.151416778564<br>Max : 41.709804534912<br>Mean : 40.034357658652<br>Std Dev. : 0.4391963005309 |
|  |  | Min : 34.295551300048<br>Max : 41.602771759033<br>Mean : 38.649149136958<br>Std Dev. : 1.0659266014733 |
|  |  | Min : 37.961879730224<br>Max : 42.68310546875<br>Mean : 40.129185254536<br>Std Dev. : 1.0095025352363 |
|  |  | Min : 38.006340026855<br>Max : 42.275524139404<br>Mean : 40.302230212332<br>Std Dev. : 0.5744307031627 |

Source: Author

## 7. Conclusion

The results of the study indicate that greens along the road and at local level are very crucial in reducing the land surface temperatures. The dense built-up areas in the old Bhopal lack green spaces both as parks as well as roadside plantation and thus experience higher land surface temperatures. The crop lands within the boundary also show higher temperatures, thus tree plantation in the boundaries of crop lands is suggested to lower the temperatures in the peri urban areas of the city. The difference in the temperatures in last five years are maximum in the hinterlands because of the extensive construction in the sprawling city and the increasing distance of the development from the water bodies. Water bodies can be planned in specific locations to maintain the microclimate of the city. Local level strategies specific to the land cover and land use of the local areas (wards) should be made to bring down the land surface temperatures and the subsequent urban heat island intensities in wards.

## 8. Way Forward

The findings of the research study establishes the importance of extraction of data at city level and at ward level. Presently there is a huge data gap. City level information is available only through published research work, state level information however is available at multiple portals. There is a requirement of city level data spatially understand the implications of human activities, physical conditions and the thermal conditions. The authors of the paper are working on a proposal to build a web portal and mobile app, which would have updated spatial information about cities urban heat islands. This application would show the cities microclimatic conditions and how it has been changing and by what rate or degree. The portal would also indicate remedial measures and their outcomes if implemented (i.e if tree plantation is done in an area how much would it affect the land surface temperature or if a water body is introduced what would be the impact).

## References

Javed Mallick, Y. K. (2008). Estimation of land surface temperature over Delhi usingLandsat-7 ETM+. *J. Ind. Geophys. Union* , 131-140.

Jeevalakshmi. D, D. S. (2017). Land Surface Temperature Retrieval from LANDSAT data using Emissivity Estimation. *International Journal of Applied Engineering Research*, 9679-9687.

Ramachandra T. V., B. H. (2012). Land Surface Temperature Analysis in an Urbanising Landscape through MultiResolution Data. *Journal of Space Science & Technology*, 1-10.

S.B. Ali, S. P. (2017). Microclimate land surface temperatures across urban land use/land cover forms. *Global J. Environ. Sci. Manage*, 231-242.

Sun, Y. (n.d.). Retrieval and Application of Land Surface Temperature.

Ugur Avdan, G. J. (2016). Algorithm for Automated Mapping of Land Surface Temperature Using LANDSAT 8 Satellite Data. *Journal of Sensors*.

Patnaik, S; Ali, S.B., 2018. Parks and Gardens of Bhopal: Development and attributes of urban green space in the city, Urban India 37(2).

Ali, S.B.; Patnaik, S., 2017. Thermal comfort in urban open spaces: Objective assessment and subjective perception study in tropical city of Bhopal, India, Urban Climate.