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# Spatial and Temporal Nature of Urban Heat Island in Roorkee

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## ABSTRACT

Urban areas occupy less than two per cent of the Earth's land surface but house 50 per cent of the world's population. By 2030, Urban areas will hold 60% of the world's population (United Nations, 2014)Cities are point sources of pollution and are responsible for 50-70% of Greenhouse gas emissions (Oke *et al.*, 2017) Urbanization has led to a phenomenon called Urban Heat Island(UHI) resulting in microclimatic variations in the city; characterized by higher temperatures when compared to the surrounding landscape. This can have an adverse impact on the health and comfort of the people and energy efficiency of the city. It is imperative to understand the phenomena of Urban Heat Island at different scales and come up with mitigation measures to make our cities more sustainable.

According to 2011 census of India, there are 468 cities with population exceeding 1 lakh. For this study, the categorization of cities done by Indian Government for House Rent allowance is adopted. As per this, cities are classified into 3 different categories ;

- Category X - Cities with population exceeding 50 lakhs,
- Category Y - Cities with population between 5 lakh and 50 lakh,
- Category Z- Cities with population between 1 lakh and 5 lakh.

Based on 2011 Census data, there are 8 category X, 88 category Y and 372 category Z cities in India. Currently, the UHI research is only focused at the scale of category X and Y cities like Nagpur, New Delhi, Kochi, Chandigarh, Noida etc. (Kotharkar and Bagade, 2018) (Thomas *et al.*, 2014) (Mathew, Khandelwal and Kaul, 2016). There are 372 cities which are at a nascent urbanization stage compared to the Category X and Y cities.There is a big gap in understanding of UHI in these smaller scale cities. By better understanding, there is great opportunity to intervene and mould these cities at this nascent urbanization stage. This paper intends to understand the Urban Heat Island phenomena in a Category Z city like Roorkee with population of 2,38,422. R

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The methodology involves generating LCZ maps for multiple cities using WUDAPT process in India to understand the composition of morphology in Category Z cities. This will throw light into the evolution their morphology. Further, CUHI (Canopy layer Urban heat island) will also be investigated spatially through mobile traversing techniques using Roorkee as a case study. Through this process, the phenomena and trends of UHI will be established in smaller scale cities.

# Introduction

## Urbanization in India

Over the last couple of decades urbanization trends in India have accelerated to increase the total urban population of India. Certain estimates put the Indian urban population to be at 460 million people which is 33.6% of the total urban population (Census of India, 2011). It has also been shown that more than 2/3$^{rd}$ of the national GDP is being contributed by urban areas in India (Bhagat, 2014). As such the construction boom in the country has been astronomical along with associated energy consumption. It has been shown that the annual growth rate of energy consumption in India is above 8% (Ministry of Urban Development Government of India, 2010). It suffices to say that the urban development in India has been exponentially growing and the impacts are being felt not only nationally but also internationally. This has led to a few studies covering Urban Heat Island impacts in the country. This paper looks in to the urban morphologies surrounding heat islands.

## City categories in India

For any discussion about cities in India, the categorization and classification of cities need to be addressed. While various methods of categorizing cities exist, this paper utilizes the classification of cities as recommended by the sixth pay commission under the department of expenditure in the government of India (Ministry of Finance, 2008). This classification depends upon the cost of living expected in the cities mentioned and the average cost of living in India depends on multiple factors, including but not limited to income level, population, availability of buildable land and existing infrastructure within the city limits (Government of India, 2008). The cities considered to have the highest cost of living were classified as category X with the highest percentage, 30% of the basic pay granted as Home Rent Allowance (HRA) to the government employees in these cities. The next category was declared to be the category Y with 20% of the basic pay given as HRA and the last was category Z with 10% of the basic pay granted as HRA. Of particular interest is the fact that the urban agglomerations that come under category Z seem to be the areas where urbanization seems to have taken hold and the initial symptoms of growth have appeared but the general cost of living in these regions are still quite low.

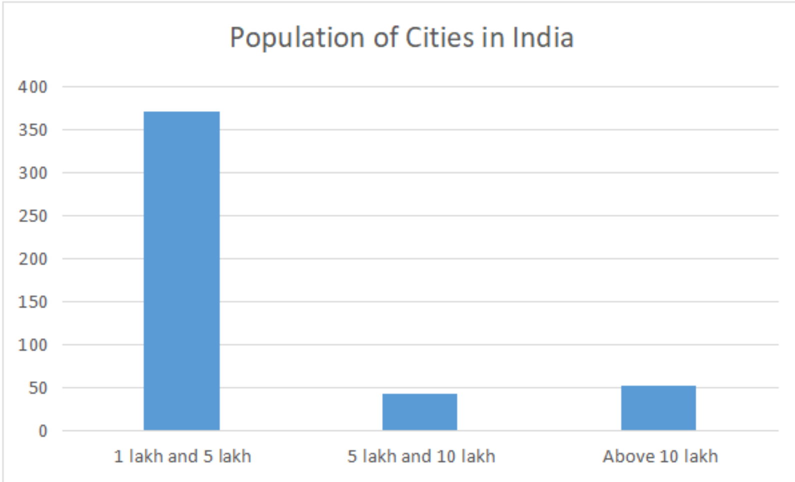


*Figure 1- Population of Indian cities, there are 372 cities in India with population 1 lakh to 5 lakh.*

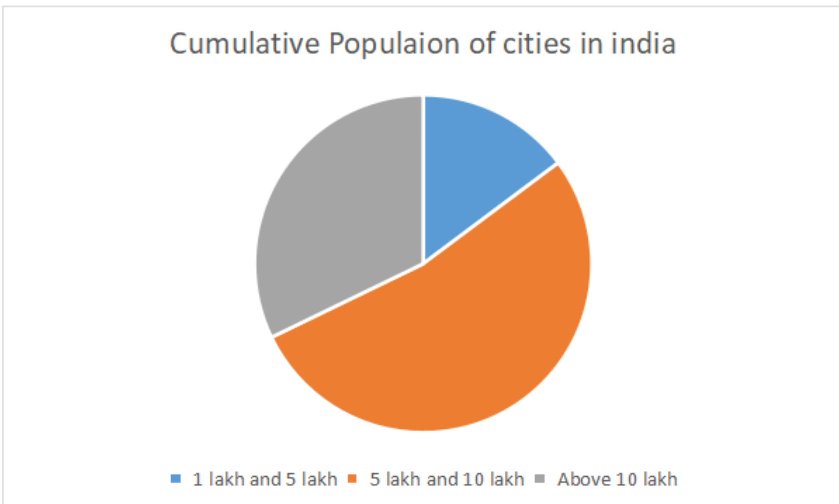


*Figure 2 - Cumulative population of Indian cities shows that even though there are 372 cities with a population under 5lakh, the larger cities especially the one with 5 lakh to 10 lakh population make up the bulk of the Indian urban population.*

## Nature of urban heat island in India

The Urban Heat Island phenomenon has been explored and documented sufficiently in India. It has been noted that the urban heat island effects in certain areas of the National Capital Region (NCR) have ranged from 4 deg. Celsius to 12 deg. Celsius (Mohan *et al.*, 2009). Parts of Bhubaneshwar have recorded UHI intensities of 1.5 deg. Celsius or above and the cities of Mumbai, Kolkata and Bangalore have recorded UHI intensities of 2 deg. Celsius at the very least (Govindarajulu, 2014). The UHI effect in India is much more pronounced in the night time as has been observed world over and rapid urbanization has led to documented conversion of blue and green spaces in to urban built-up (The Hindu - Special Correspondent, 2017). It is worth noting at this point that a highly populated and fast urbanizing nation such as India could very easily create urban hot pockets that could become a slow onset disaster through unregulated propagation of Urban Heat Islands. Based on 2011 Census data, there are 8 category X, 88 category Y and 372 category Z cities in India. Currently, the UHI research is only focused at the scale of category X and Y cities like Nagpur, New Delhi, Kochi, Chandigarh, Noida etc. (Kotharkar and Bagade, 2018) (Pandey *et al.*, 2014) (Thomas *et al.*, 2014) (Mathew, Khandelwal and Kaul, 2016). There are 372 cities which are at a nascent urbanization stage compared to the Category X and Y cities. There is a big gap in understanding of UHI in these smaller scale cities. The low cost of living in the category Z cities has seemingly led to a situation where a certain kind of construction seems to be favoured by the residents of such cities which in turn has led to Urban Heat Island effect being prevalent in the centres of such urban regions. This is precisely the effect that is to be explored by the research described.

## LCZ & WUDAPT

### LCZ and evolution of a city

The concept of Local Climate Zones as a basis for temperature studies in the urban context was first proposed by I. D. Stewart and T. R. Oke in their seminal paper titled Local Climate Zones for urban temperature studies (Stewart *et al.*, 2012). The paper proposes 17 standard classes defined by land cover and structural properties. The urban and rural areas of the world may be classified under these types and then studied for their climatic behaviour. Specifically, these climate zones are instrumental in affecting the air temperature of the area at screen height. The authors of the paper validated their proposal through a follow-up study which showed that there are measurable and sharp contrasts between the air temperature ranges among the identified classes (Stewart, Oke and Krayenhoff, 2014). The validation process also proved that the air temperature at screen height are determined by factors such as building height and spacing, pervious surface fraction, tree density and soil wetness. The use of a function called inter-zone temperature difference to quantify the magnitude of heat island intensity was also justified by the same publication. As a result of their efforts in creating a Local Climate Zone classification, a universal approach in the characterization of physical nature of cities became available to the urban climatologist. This eventually gave rise to the World Urban Database Access Portal Tools or (WUDAPT).

### WUDAPT methodology

World Urban Database Access Portal Tools or (WUDAPT) is an international community based initiative to collect and disseminate relevant climatic data for analysis purposes (Ching *et al.*, 2018). The methodology for creating a Level 0 urban information map is available on the WUDAPT website (www.wudapt.org). The LCZ mapping of a city forms the primary basis for the Level 0 WUDAPT. As part of this paper, the LCZ map preparation method as suggested by the WUDAPT methodology was followed.

### LCZ and UHI study

Building on the LCZ classification types and the WUDAPT methodology, the Urban Heat Island (UHI) scenario in Roorkee is being studied in this paper. The LCZ mapping for the city of Roorkee and two other category Z cities are done along with an on-ground traverse survey of Roorkee city to validate the observations from remote-sensed data.

## Methodology of the study

### Process of selection of the cities

All cities selected were category Z cities with a population of less than 5 lakh. The city of Roorkee was selected as the researchers involved are very familiar with the urban morphology of the city which is an important criterion for validation of LCZ maps created as per the WUDAPT methodology. Additionally, Sonipat and Kadapa are two cities selected are category Z cities which the researchers are familiar with. These cities also have a fairly long history and are close to industrial areas or contain major industrial complexes within their peripheries. Additionally, all of them have urbanized within the last two decades.


*Figure 3- The location of the selected category Z cities in India. From the North they are, Roorkee in the state of Uttarakhand, Sonipat in the state of Haryana and Kadapa in the state of Andhra Pradesh.*

### Methodology for remote sensing study

The remote sensing data was collected from Landsat 8 as available on the Earth Explorer platform of the USGS portal (https://earthexplorer.usgs.gov). The data collected was classified on the basis of training areas defined within the Google Earth software as per the WUDAPT methodology mentioned earlier. The work was carried out using SAGA GIS and later using QGIS.

**Methodology for UHI study**

The local traverse survey of Roorkee was done in the month of March 2019 which is the end of spring or the cooler season. The skies mostly remain clear during this period and therefore the readings are considered highly reliable. The traverse survey was done on three separate days using two separate two-wheelers and two air temperature sensors (Onset HOBO MX2301A Outdoor Bluetooth Humidity Data Logger) during the night time from 10:00 pm to 1:00 am period. Two separate tracks were traversed, one of 20km and another of 18km distance. The average time taken for each traversal was 1 hour 15 minutes as the traversal speed was kept in between 20 to 30 km/hr. Wherever the road or traffic conditions dictated a slowing down or speeding up of the traversing vehicles, the values recorded were eliminated to reduce outliers and inconsistencies. Data collected from highways and arterial roads was not considered. Further, the data from transition areas between different Local Climatic zones was purged. Only remote sensing studies were conducted over the other cities selected.

The identification of the temperature profile within as LCZ can be used to understand the inter-zone temperature difference. Temperatures in the urban fringes can be considered as the standard temperature of an area undisturbed by urbanization while other areas can be expected to have increased temperatures. This inter-zone temperature difference observed between the various LCZ classes of Roorkee will show the Urban Heat Island characteristics of Roorkee. As the traverse survey was conducted with GPS, the data is geo-referenced and as such can be directly used to validate the temperature profile based on the boundaries of the LCZs.Further to understand the strength and the weakness of the LCZ classification system few segments under the same LCZ were identified so that the temperatures readings in these segments can be analyzed

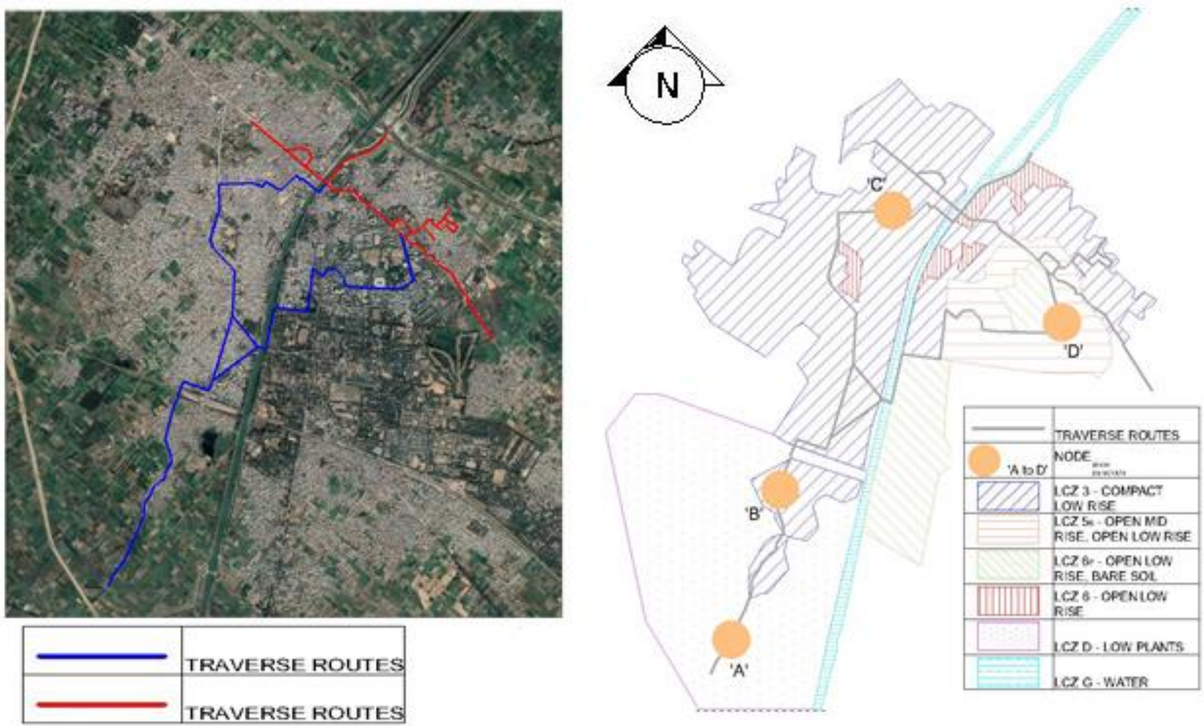


*Figure 4- The traverse routes taken across Roorkee are indicated on the satellite imagery to the left and the nodes within the respective local climate zones are marked out on the drawing to the right.*

# Analysis

## Data filtering process

The first step of analyzing the data is the filtering process as mentioned earlier. The filtering is to avoid any outliers in the temperature data and to create a geo-referenced temperature record for the same points along the traverse survey for the three days on which the survey was conducted. Further, data pertaining to highways, arterial roads, transition areas between different LCZ's was purged to get data representative of the morphological structure.

## Mapping

Maps have been generated for the three cities based on the remote sensing data obtained from the earlier mentioned sources after following the process as provided by the WUDAPT platform. Table 1 shown below lists the 17 major built and land cover types as proposed in the LCZ classification system by Stewart and Oke (Stewart *et al.*, 2012).

*Table 1 - The built and land cover types as per the Local Climate Zone classification system proposed by Stewart and Oke in 2012 which forms the basis of WUDAPT classification*

| **Local Climate Zone Classification identifier** | **Built types / Land cover types** |
|---|---|
| G | Water |
| F | Bare Soil or Sand |
| E | Bare Rock or Paved |
| D | Low plants |
| C | Bush, scrub |
| B | Scattered Trees |
| A | Dense Tress |
| 10 | Heavy Industry |
| 9 | Sparsely Built |
| 8 | Large low-rise |
| 7 | Lightweight low-rise |
| 6 | Open low-rise |
| 5 | Open mid-rise |
| 4 | Open high-rise |
| 3 | Compact low-rise |
| 2 | Compact mid-rise |
| 1 | Compact high-rise |

The generated maps for three cities along with the associated colour coding as recommended by the WUDAPT platform are provided in Figures 5, 6 and 7. These images show a high prevalence of Compact low-rise and open low-rise built up structures or LCZ classifier 3 which is in fact consistent with the lower income profile of Category Z cities of India. Low income profile cities tend to spread out and occupy cheaper land areas as the population in the city increases. The high-rises are yet to appear in these cities. The built types as a percentage are expressed in the bar graphs shown in Figures 4, 5 and 6.

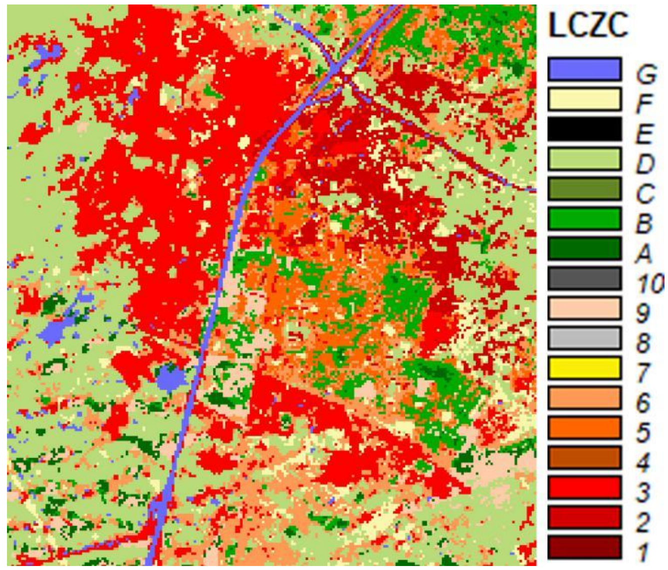


*Figure 5 - Local climate zone classification for Roorkee*

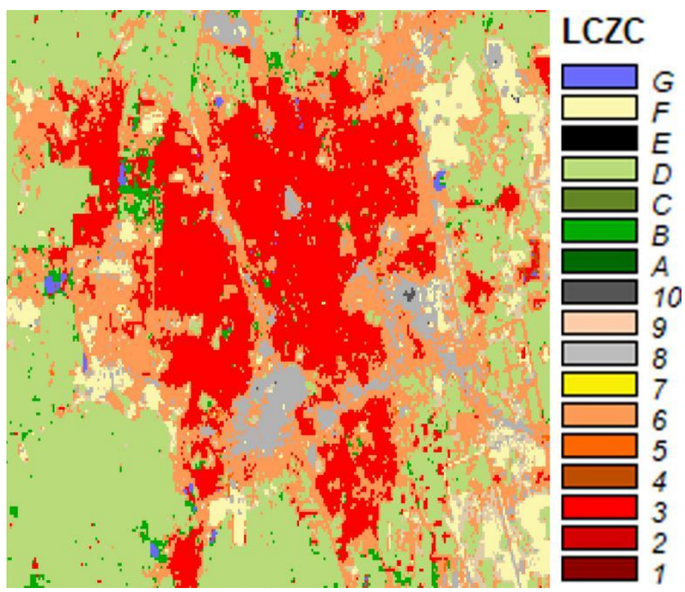


*Figure 6 - Local climate zone classification for Sonipat*

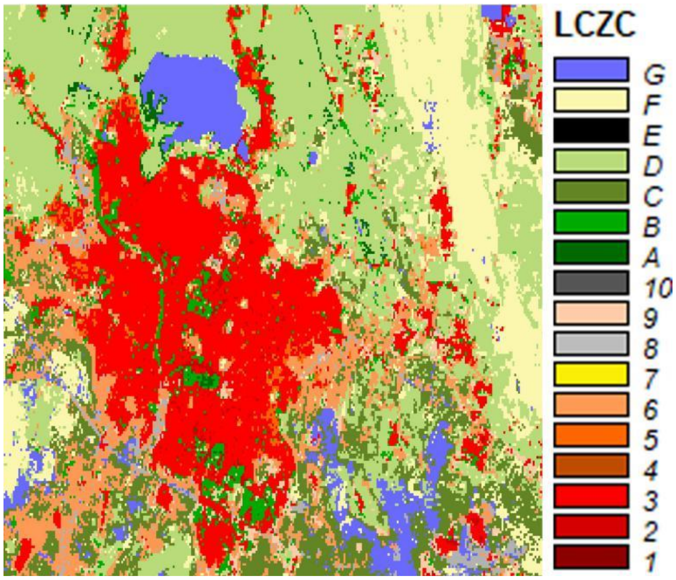


*Figure 7 - Local climate zone classification for Kadapa*

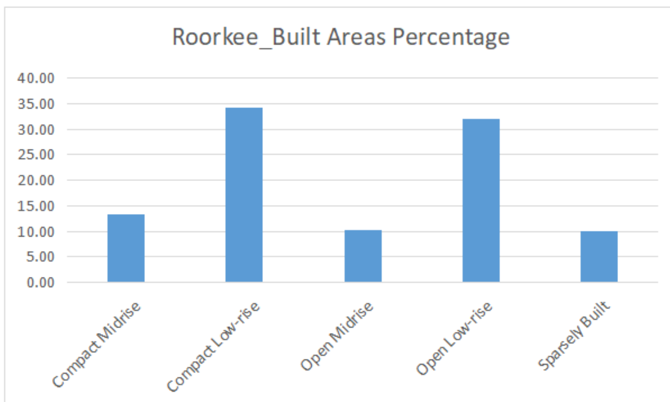


*Figure 8 - Built type percentage asper LCZC for Roorkee*

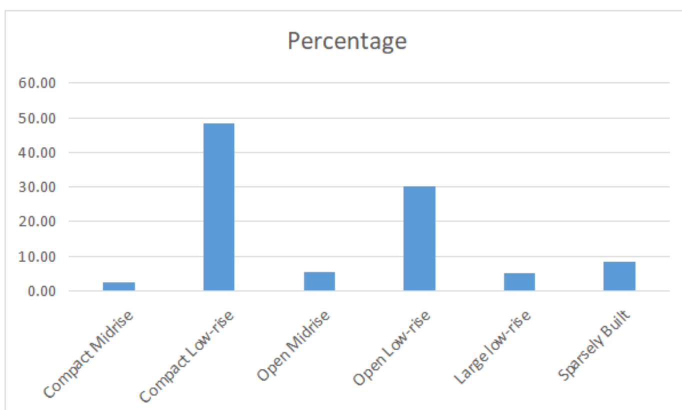


*Figure 9 - Built type percentage asper LCZC for Kadapa*

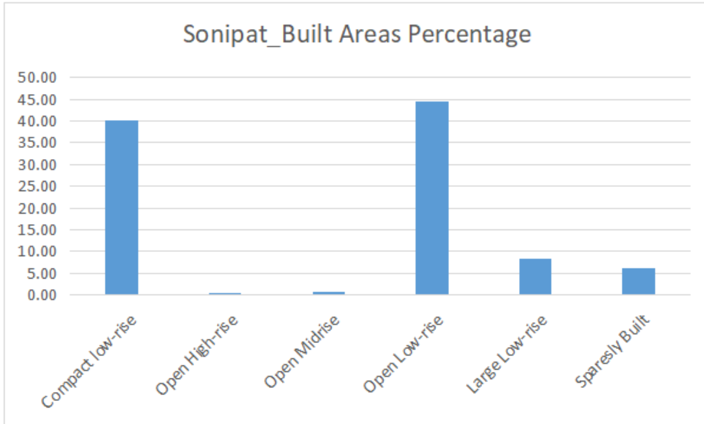


*Figure 10 - Built type percentage asper LCZC for Sonipat*

Immediate observations show us that

- Roorkee has 34% Compact low-rise and 32% Open low-rise making a total of 66% low-rise construction in the city.
- Kadapa has 48% Compact low-rise and 30% Open low-rise making a total of 78% low-rise construction in the city.
- Sonipat has 40% Compact low-rise and 44% Open low-rise making a total of 74% low-rise construction in the city.

## Results & Discussion

In terms of LCZ classification, It is imperative for the researcher to be mindful of arterial road network even if it is in the same LCZ zone as it has significant impact on the temperature readings. In our case, a difference of about 1-0.5 deg, Celcius (Segment 1 and Segment 4) was observed.

The survey results show us that the areas with low-rise profile in a category Z city have about 2 deg. Celsius increase in temperature over the fringes. Further, from the LCZ mapping of the cities we have observed a homogeneity in the building morphology. Morphology is predominantly low rise. And over period of time open low rise is transforming into compact low rise or compact mid rise. This homogeneity is not ideal and research has pointed towards mixing of morphological types. In the short term, the Urban Heat Island effect within the areas with open low-rise profile can be reduced provided there are enough open spaces where blue-green infrastructure interventions can be introduced. The compact low-rise profile areas may require certain policy interventions apart from direct physical blue-green infrastructure interventions wherever possible to be achieve heterogeneous nature over time. The policy interventions may be used to either create more open spaces where blue-green infrastructure can be introduced and development plans should also promote mixed use. Further developmental bye-laws have to be analyzed as some of the homogeneity is driven by them

*Table 2- Results of the traverse survey in Roorkee*

| Representative Temperature at 11:30pm - March 28th, March 29th, April 1st | | | |
|---|---|---|---|
| Node | LCZ Zone | Ta - Air Temperature (Celsius) | Inter LCZ Air difference (reference Node A) |
| Node A | Low Plants LCZ D | 20.93 | 0 |
| Node B | Compact Low-rise surrounded with Low Plants LCZ 3d | 21.38 | 0.45 |
| Node C | Compact Low-rise LCZ 3 | 23.86 | 2.93 |
| Node D | Open Midrise and Open Low-rise LCZ 56 | 22.43 | 1.5 |

*Table 3- Results of the traverse survey in LCZ3 zone in Roorkee*

| Representative Temperature at 11:30pm - March 28th, March 29th, April 1st | | |
|---|---|---|
| Segment | Ta - Air Temperature (Celsius) | Air temperature Difference (reference Segment 4) |
| Segment 1 | 23.4 | 0.5 |
| Segment 2 | 23.97 | 1.07 |
| Segment 3 | 23.86 | 0.96 |
| Segment 4 | 22.9 | 0 |

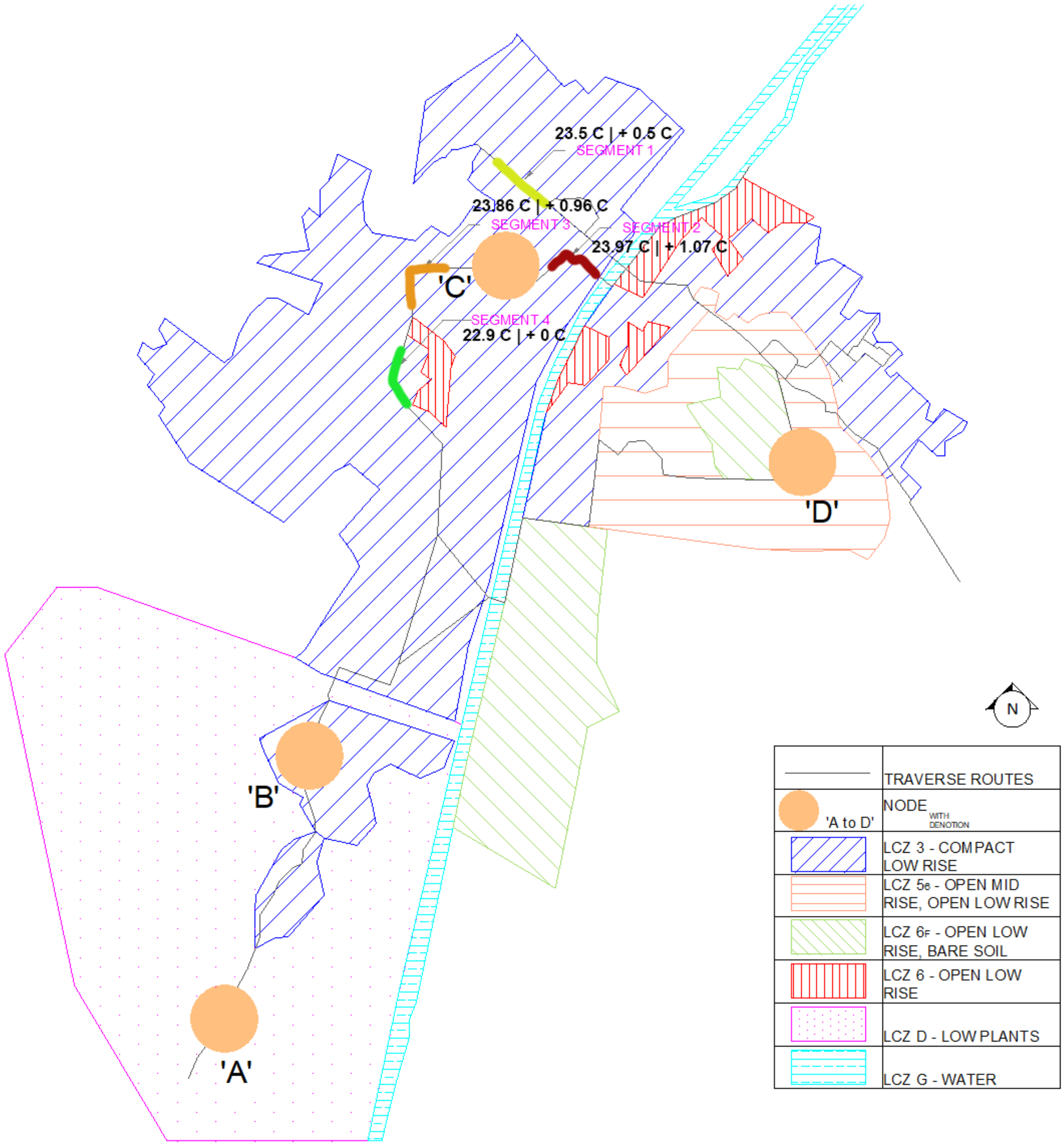


*Figure 11- The nodes and Segments within the respective local climate zones are marked out on the drawing*

## References

Bhagat, R. B. (2014) ‘Urban Policies and Programmes in India: Retrospect and Prospect’, *Urban Planning, Yojana*, 58(January), pp. 4–8.

Census of India (2011) ‘Census of India 2011’, in *Census of India*. Available at: http://censusindia.gov.in/2011-prov-results/paper2/data_files/India2/1. Data Highlight.pdf (Accessed: 14 June 2018).

Ching, J. *et al.* (2018) ‘WUDAPT: An Urban Weather, Climate, and Environmental Modeling Infrastructure for the Anthropocene’, *Bulletin of the American Meteorological Society*, 99(9), pp. 1907–1924. doi: 10.1175/BAMS-D-16-

0236.1.

Government of India (2008) ‘Sixth Central Pay Commission Report (No. 1/1/2008-I C)’, *The Gazette of India*, pp. 28–57. Available at: https://doe.gov.in/sites/default/files/6cpcdecision %281%29.pdf.

Govindarajulu, D. (2014) ‘Urban green space planning for climate adaptation in Indian cities’, *Urban Climate*. Elsevier B.V., 10(P1), pp. 35–41. doi: 10.1016/j.uclim.2014.09.006.

Kotharkar, R. and Bagade, A. (2018) ‘Evaluating urban heat island in the critical local climate zones of an Indian city’, *Landscape and Urban Planning*. Elsevier, 169, pp. 92–104. doi: 10.1016/J.LANDURBPLAN.2017.08.009.

Mathew, A., Khandelwal, S. and Kaul, N. (2016) ‘Spatial and temporal variations of urban heat island effect and the effect of percentage impervious surface area and elevation on land surface temperature: Study of Chandigarh city, India’, *Sustainable Cities and Society*. Elsevier, 26, pp. 264–277. doi: 10.1016/J.SCS.2016.06.018.

Ministry of Finance (2008) ‘Decision of the Government on the recommendations of the Sixth Central Pay Commission (No.1 (3)/2008-E-II(B))’, *The Gazette of India*. Available at: http://dispur.nic.in/sixthpay/sixth-pay-allowances.pdf.

Ministry of Urban Development Government of India (2010) *National Mission on Sustainable Habitat*. Available at: http://www.indiawaterportal.org/sites/indiawaterportal.org/files/National-mission-on-sustainable-habitat-A-document-prepared-by-Ministry-of-Urban-Development %282011%29.pdf (Accessed: 19 July 2018).

Mohan, M. *et al.* (2009) ‘Assessment of urban heat islands intensities over Delhi’, *The Seventh International Conference on Urban Climate*, 3(July), pp. 3–6.

Oke, T. R. *et al.* (2017) *Urban climates*. Available at: https://www.barnesandnoble.com/w/urban-climates-dr-t-r-oke/1125125146 (Accessed: 15 May 2019).

Pandey, A. K. *et al.* (2014) ‘Spatio – temporal variations of urban heat island over Delhi’, *Urban Climate*. Elsevier, 10, pp. 119–133. doi: 10.1016/J.UCLIM.2014.10.005.

Stewart, I. D. *et al.* (2012) ‘Local Climate Zones for Urban Temperature Studies’, *Bulletin of the American Meteorological Society*. American Meteorological Society , 93(12), pp. 1879–1900. doi: 10.1175/BAMS-D-11-00019.1.

Stewart, I. D., Oke, T. R. and Krayenhoff, E. S. (2014) ‘Evaluation of the “local climate zone” scheme using temperature observations and model simulations’, *International Journal of Climatology*. John Wiley & Sons, Ltd, 34(4), pp. 1062–1080. doi: 10.1002/joc.3746.

The Hindu - Special Correspondent (2017) ‘Climate change plan to get new missions’, *The Hindu*, 25 January. Available at: http://www.thehindu.com/news/national/Climate-change-plan-to-get-new-missions/article17090498.ece (Accessed: 28 May 2018).

Thomas, G. *et al.* (2014) ‘Analysis of Urban Heat Island in Kochi, India, Using a Modified Local Climate Zone Classification’, *Procedia Environmental Sciences*. Elsevier, 21, pp. 3–13. doi: 10.1016/J.PROENV.2014.09.002.

United Nations (2014) *World Urbanization Prospects*. Available at: https://population.un.org/wup/Publications/ (Accessed: 15 May 2019).