INVESTIGATING THE RELATIONSHIP OF URBAN FORM AND FUNCTION WITH SURFACE TEMPERATURE PATTERNS: A CASE STUDY OF CHANDIGARH

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ABSTRACT

Urban microclimate refers to climatic conditions in an urban area that differ from neighbouring rural areas, and are attributable to urban development. The urban precincts and their microclimates are influenced by several factors such as urban morphology and density, the properties of urban surfaces and vegetation cover. The urban built-form due to its dense development, high-rise character and increase in impervious, absorptive surfaces is responsible for the trapping of heat and reduction in evaporative cooling due to decrease in vegetated, soft, pervious surfaces in urban areas. The resultant temperature is higher in cities than the surrounding rural areas, which is popularly manifested as Urban Heat Island (UHI). The Local Climate Zonation presented by Stewart and Oke, 2012 defines various urban built-form classes based on urban form and function and are derived from logical division of the landscape into a hierarchy of sub-classes, differentiated based on urban surface cover, geometry, fabric and metabolism. In this study, local climate zonation of Chandigarh city was prepared for the year 2008 and 2013 and it was compared with Land Surface Temperature (LST) maps derived using Landsat thermal band of corresponding dates. It was found that land uses such as industrial areas exhibited higher LST. The heavy industries exhibited maximum LST in both the years (2008 and 2015) followed by high-rise compact urban development whereas water has lowest temperature in both the years. The study demonstrates the distinct relationship between urban built-form, function and corresponding temperature regimes.

KEYWORDS: Urban Built form, LST, WUDAPT, Local climate zonation

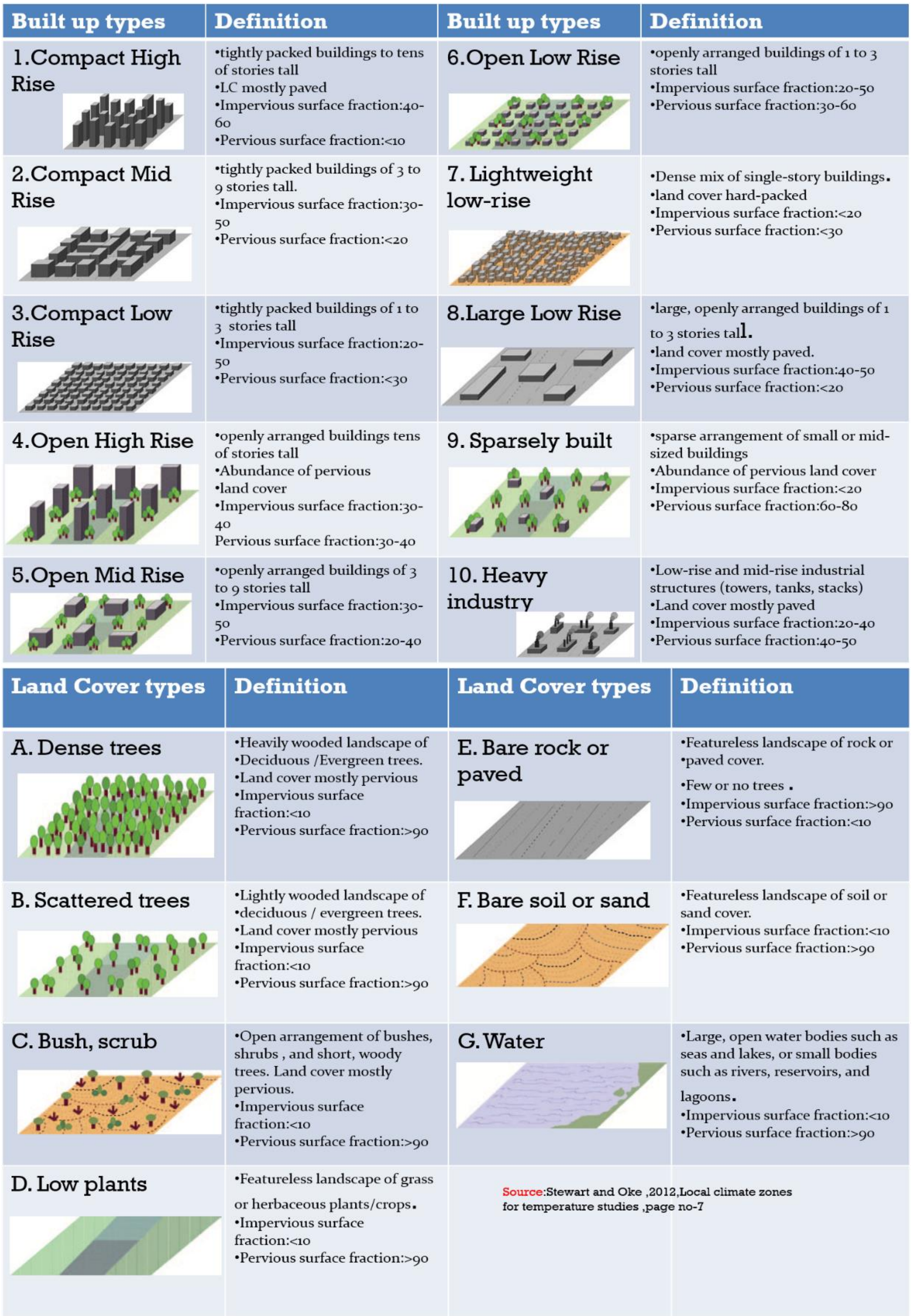
1.0 INTRODUCTION

Growing urbanization has led to modified urban climate with increasing temperature (Oke 1987), a phenomenon popularly known as Urban Heat Island (UHI) phenomenon. This increase in temperature can locally exaggerate the impact of heat waves, air pollution etc. Hence, it is a concern for public health issues (Johnson and Wilson 2009), energy consumption for cooling (Ohashi et al., 2007) and urban planners and administrators. Earlier, the intra-city understanding of urban climate could be obtained through in-situ measurements only. However, now with the availability of satellite and air-borne sensors at multiple resolutions have opened a new dimension to study spatial variation of urban-rural climate. Remote sensing data especially thermal remote sensing data of Landsat mission have been used extensively for deriving the Land Surface Temperature (LST) of entire landscape. It assisted in understanding the UHI phenomenon as well as the spatio-temporal temperature variation across various land covers. Initially, the whole urban built-up was defined as single built up, however, researchers worldwide attempted to develop landscape classification adapted to urban areas and oriented for climatic studies. One such classification of local climate zones were given by Stewart and Oke 2012, which is based on urban form and function.

World Urban Database Access Portal Tool (WUDAPT) adapted this classification system to fill the gap on availability of detailed information on urban surfaces which can be utilized as an input parameters in various urban meteorology and chemistry models. The need for detailed urban information is highlighted in IPCC'S fifth assessment report as well. WUDAPT outlines a methodology to generate Local Climate Zone (LCZ) map of cities of world using open source remotely sensed data and software tools (Bechtal et al., 2015a). In this study a local climate zone map of Chandigarh Greater region was generated by following the methodology outlined by WUDAPT and then further analysed to understand the relationship between urban form and function with surface temperature.

2.0 LOCAL CLIMATE ZONE CLASSIFICATION

Local climate zones were introduced by Stewart and Oke, 2012 to standardize the classification of urban and rural field sites for studying UHI phenomenon. Traditionally, UHI is defined as the temperature difference between urban and rural sites, however different studies have shown tremendous variety in the definition of urban and rural sites. Hence, this classification system was introduced to overcome this ambiguity and defined 17 LCZ classes as given in Figure 1. Local climate zones derive its name from logical division of the landscape "universe" into a hierarchy of sub-classes, each differentiated on the principles of surface cover (built fraction, soil moisture, albedo), surface structure (sky view factor, roughness height), and cultural activity (anthropogenic heat flux) (Stewart and Oke, 2009). Individually, the “zones” are local in horizontal scale (10^2 to 10^4 m) and represent homogeneous urban climate regions.

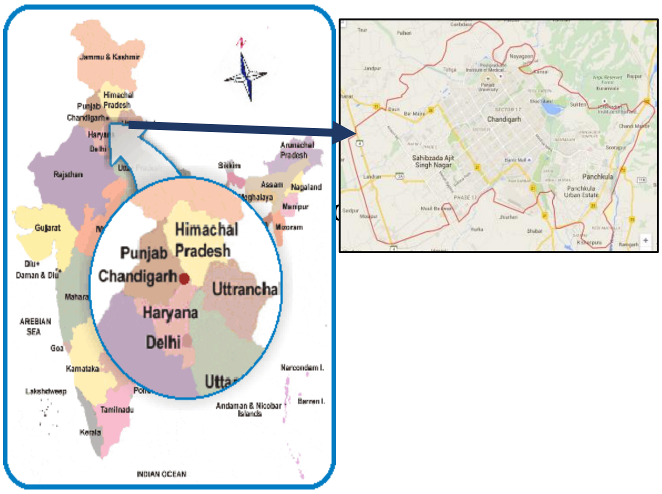


Built up types	Definition	Built up types	Definition
1.Compact High Rise	•tightly packed buildings to tens of stories tall •LC mostly paved •Impervious surface fraction:40-60 •Pervious surface fraction:<10	6.Open Low Rise	•openly arranged buildings of 1 to 3 stories tall •Impervious surface fraction:20-50 •Pervious surface fraction:30-60
2.Compact Mid Rise	•tightly packed buildings of 3 to 9 stories tall. •Impervious surface fraction:30-50 •Pervious surface fraction:<20	7. Lightweight low-rise	•Dense mix of single-story buildings. •land cover hard-packed •Impervious surface fraction:<20 •Pervious surface fraction:<30
3.Compact Low Rise	•tightly packed buildings of 1 to 3 stories tall •Impervious surface fraction:20-50 •Pervious surface fraction:<30	8.Large Low Rise	•large, openly arranged buildings of 1 to 3 stories tall. •land cover mostly paved. •Impervious surface fraction:40-50 •Pervious surface fraction:<20
4.Open High Rise	•openly arranged buildings tens of stories tall •Abundance of pervious •land cover •Impervious surface fraction:30-40 Pervious surface fraction:30-40	9. Sparsely built	•sparse arrangement of small or mid-sized buildings •Abundance of pervious land cover •Impervious surface fraction:<20 •Pervious surface fraction:60-80
5.Open Mid Rise	•openly arranged buildings of 3 to 9 stories tall •Impervious surface fraction:30-50 •Pervious surface fraction:20-40	10. Heavy industry	•Low-rise and mid-rise industrial structures (towers, tanks, stacks) •Land cover mostly paved •Impervious surface fraction:20-40 •Pervious surface fraction:40-50

Land Cover types	Definition	Land Cover types	Definition
A. Dense trees	•Heavily wooded landscape of •Deciduous /Evergreen trees. •Land cover mostly pervious •Impervious surface fraction:<10 •Pervious surface fraction:>90	E. Bare rock or paved	•Featureless landscape of rock or •paved cover. •Few or no trees . •Impervious surface fraction:>90 •Pervious surface fraction:<10
B. Scattered trees	•Lightly wooded landscape of •deciduous / evergreen trees. •Land cover mostly pervious •Impervious surface fraction:<10 •Pervious surface fraction:>90	F. Bare soil or sand	•Featureless landscape of soil or sand cover. •Impervious surface fraction:<10 •Pervious surface fraction:>90
C. Bush, scrub	•Open arrangement of bushes, shrubs , and short, woody trees. Land cover mostly pervious. •Impervious surface fraction:<10 •Pervious surface fraction:>90	G. Water	•Large, open water bodies such as seas and lakes, or small bodies such as rivers, reservoirs, and lagoons. •Impervious surface fraction:<10 •Pervious surface fraction:>90
D. Low plants	•Featureless landscape of grass or herbaceous plants/crops. •Impervious surface fraction:<10 •Pervious surface fraction:>90	Source:Stewart and Oke ,2012,Local climate zones for temperature studies ,page no-7	

Figure 1: Local Climate Zone Classification (adapted from Stewart and Oke, 2012)

3.0 STUDY AREA AND DATA USED



Chandigarh lies within the surrounding states of Punjab and Haryana (Figure 2). While Punjab lies to its north, west and south, the state of Haryana surrounds its periphery from north-east to east and south east. Further to the north of Punjab and Haryana lies the state of Himachal Pradesh. The districts of SAS Nagar and Panchkula are in its immediate neighbourhood. The region around Chandigarh has Shivalik hill ranges in the north, which form a fragile Himalayan ecosystem. It is occupied by Kandi (Bhabar) in the north east and Sirowal (Tarai) and alluvial plains in the remaining part. The area is drained by two seasonal rivulets, viz., Sukhna Choe in the east and Patiala ki Rao in the west. The central part forms a surface water divide and has two minor streams. Located at the foothills of the Shivalik range, a large part of the area is designated as an environmentally sensitive zone. The region has a relatively flat topography, with moderately gentle slopes towards south western part of the area, where all the rivers and streams drain through the GCR.
Landsat 8 TIRS (Thermal Infrared Sensor), Band 10 and 11 and OLI (Operational Land Imaginer) sensor Band (1-9) of Chandigarh region of October 1, 2015 and Landsat 5 Thematic Mapper data of October 13, 2008 was used for generating the LST and urban built-form (LCZ) maps. Thermal constant K_1 and K_2 and other image statistics were obtained from metadata of the image file.

4.0 METHODOLOGY

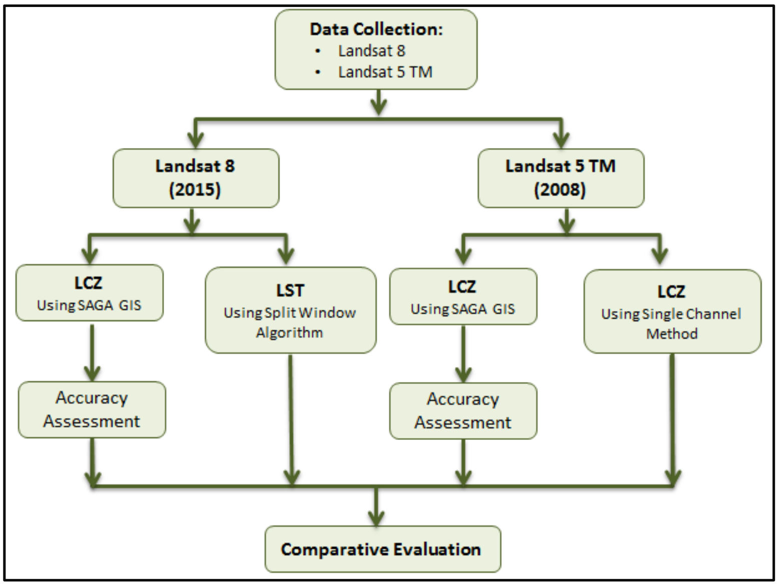


Figure 3: Chandigarh Capital Region (CCR)

The broad methodology (Figure 3) involves the processing of Landsat 8 data and Landsat 5 TM data following the methodology outlined by WUDAPT. The processing steps involved collection of training areas in Google Earth for all 17 LCZ classes in the region of interest. It was suggested to define minimum 5-15 training areas per class with minimum size of 1 sq. km (Bechtal et al., 2015b). The Landsat data can be easily acquired from Earth Explorer site with a resolution of 30m. Instead of computing the NDVI and LST separately, all the bands were considered directly. The digitized training areas and Landsat Top of Atmosphere (TOA) data were ingested into SAGA GIS in a predefined LCZ classification tool. SAGA GIS is an open platform with rich spatial library hence, serves as a framework for the development and implementation of geoscientific methods and models. It provides an easily approachable user interface with many visualization options and can be scripted from the command line, using python or R. For LCZ classification, random forest classifier were trained using training areas digitized in Google Earth and mode of the class was assigned to the pixel value. Further, LST maps of the year 2015 and 2008 were also generated using same Landsat data by applying Split Window and Single Channel algorithm, respectively. The generated LCZ and LST maps were further analysed to judge the relationship between temperature and LCZ classes, especially the urban built-up classes.

5.0 RESULTS AND DISCUSSIONS

Figure 4 and 5 presents the LCZ map of Chandigarh region for the year 2008 and 2015, respectively. Similarly, the Figure 6 and 7 presents the area covered by different LCZ classes for the year 2008 and 2015, respectively.

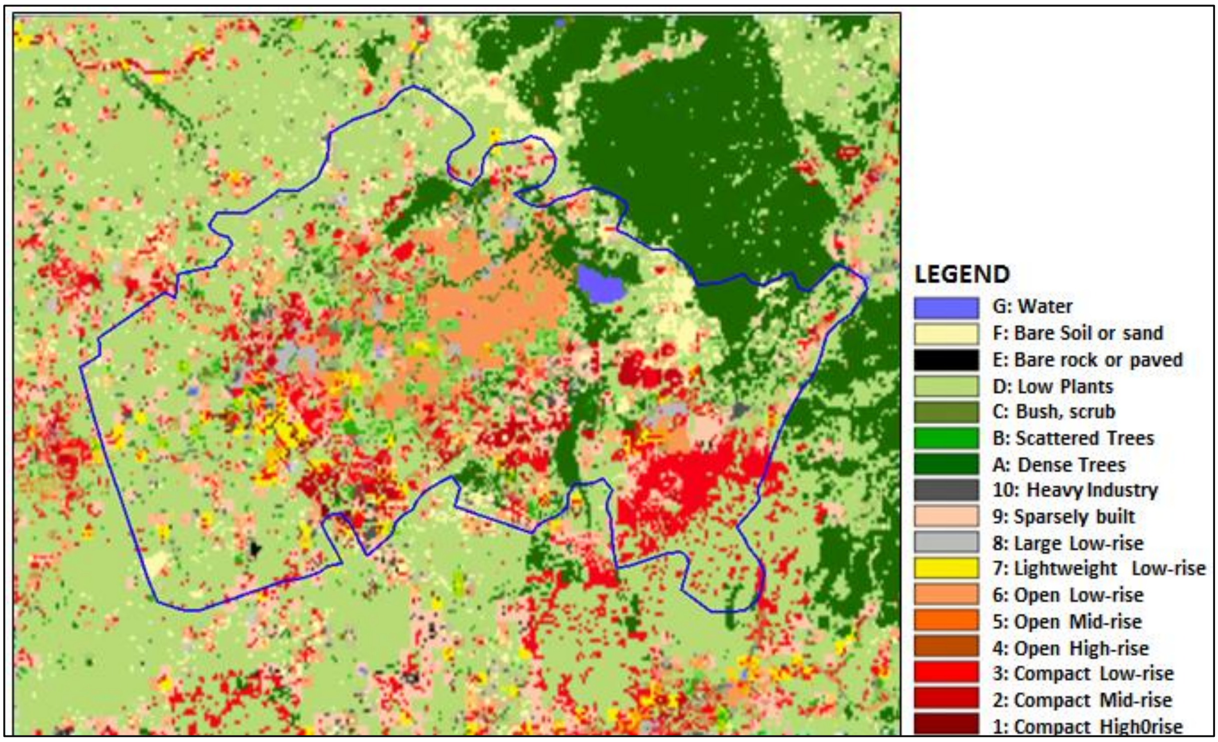


Figure 4: LCZ map of Chandigarh Capital Region (CCR) (October' 2008)

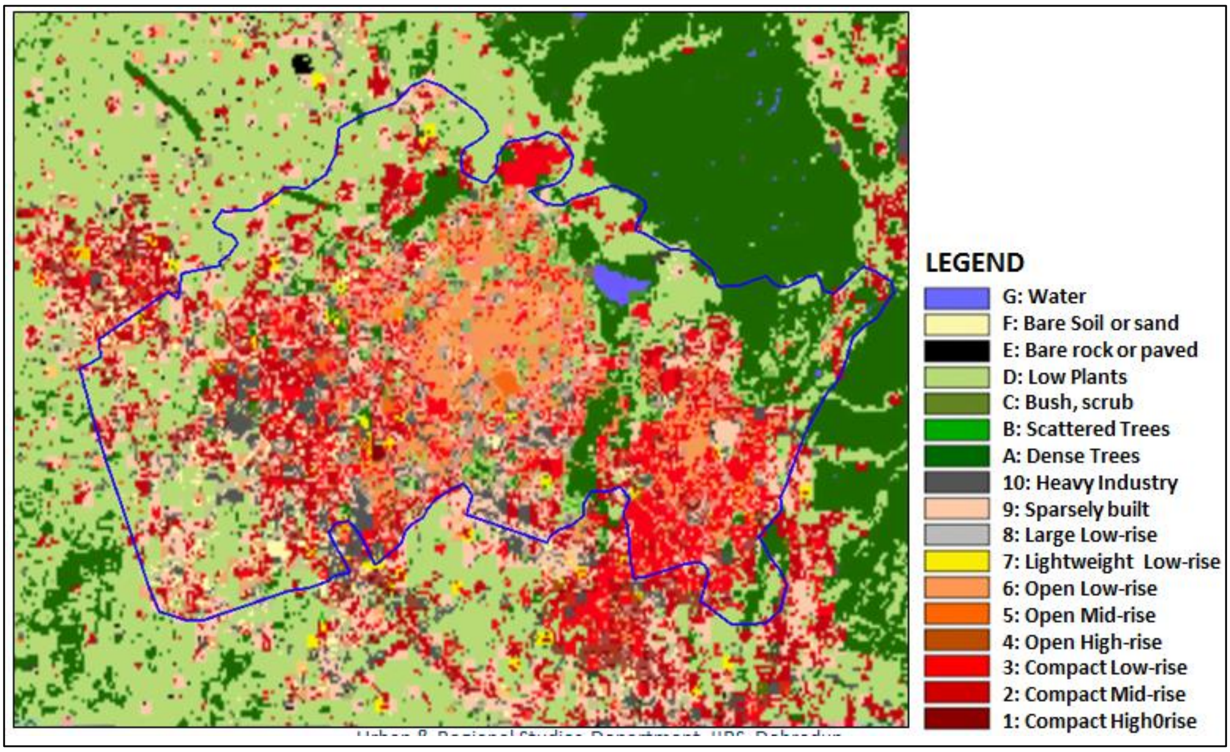


Figure 5: LCZ map of Chandigarh Capital Region (CCR) (October' 2015)

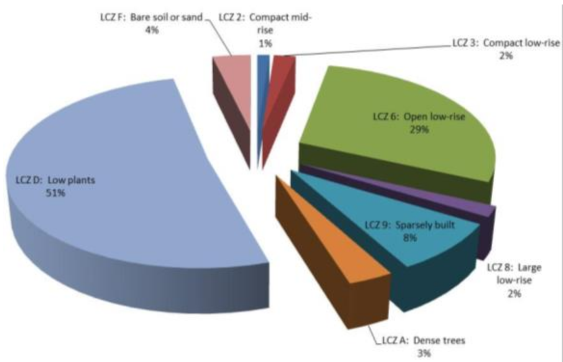


Figure 6: Area covered by different LCZs in 2008

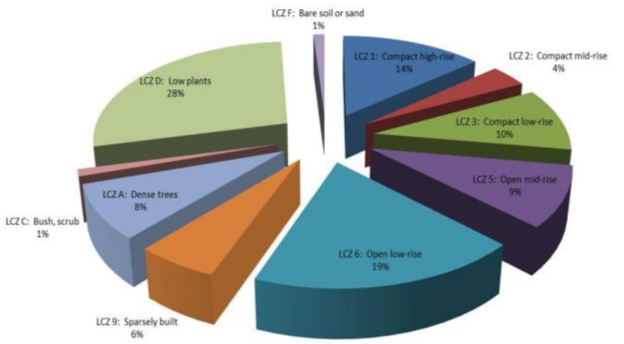


Figure 7: Area covered by different LCZs in 2015

LCZ- D (Low Plants) covers the maximum area as compared to other classes in both the years 2008 (51%) and 2015 (28%). Approximately, 30% of the total area is covered by open low-rise built-up in 2008 whereas it was decreased to 19% in 2015 due to the development of compact high-rise, compact mid-rise and compact low-rise. Bush scrub, bare soil and sand cover the minimum area in the region of interest. There is a 13% increase in the area covered by compact high-rise and decrease in open low-rise by 9.7%. Significant increase in built-up and heavy industry has been observed from 2008 to 2015. Industries are found near Mohali and Panchkula area. There is increase in the area covered by heavy industry (7.1%), Open mid-rise (9.1%), Compact low-rise (7.9%), and Compact high-rise (10.3%). Though, decrease in the area covered by low plants and open low-rise is observed by 13% and 10% respectively.

Figure 8 presents the LST maps of the study region for the years 2008 and 2015. It can be seen that LST of October 2008 is showing minimum temperature as 22^{o}C and maximum temperature as 30^{o}C. Whereas LST of October 2015 is showing 19^{o}C as minimum temperature and 37^o C as maximum temperature. The overall mean temperature has been changed from 22.6^o C (2008) to 24.5^o C (2015).

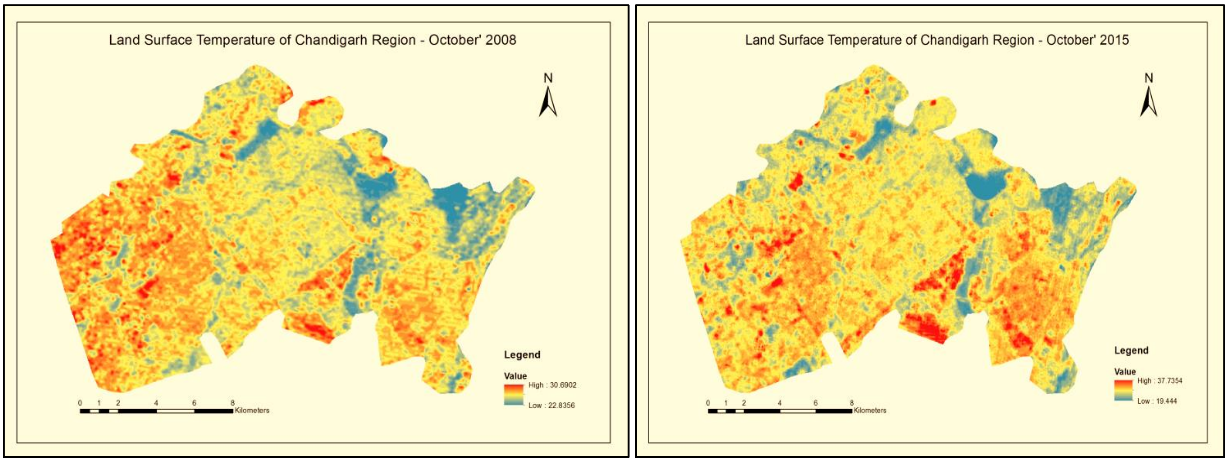


Figure 1 Comparison of Land Surface Temperature of 2008 and 2015

In urban areas, building materials are non-reflective and therefore they absorb heat. Also, the road surfaces such as concrete have a high thermal capacity and therefore absorb a large amount of heat due to their dark color. Compact high rise and heavy industries are showing the highest temperature (24.1^{o}C) because of the compactness and impervious materials. LCZ- G (Water) has the lowest temperature i.e. 20.5^{o}C followed by the second lowest temperature of Dense Trees i.e. 21.1^{o}C. Panchkula district has the highest temperature in the CCR region due to the presence of heavy industries. Water and dense trees are showing the same scenario in both the years. Water has the lowest temperature i.e. 20.8 ^{o}C followed by the second lowest temperature of dense trees i.e. 22.6 ^{o}C.

The comparison between LCZ classes and LST map (Figure 9) shows that the Heavy industry LCZ has maximum mean LST in both the years which ranges between 25 ^{o}C to 27 ^{o}C because of the maximum anthropogenic heat output (>300) as compared with the other Local Climate Zones. Whereas, water shows the minimum LST in both the years 2008 and 2015 due to zero anthropogenic heat output.

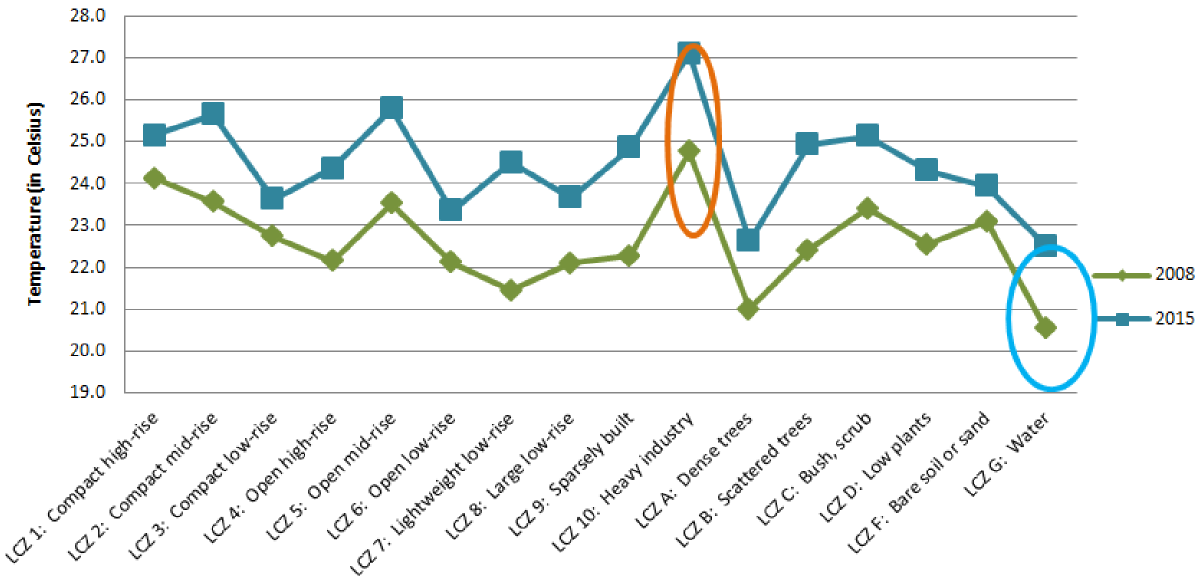


Figure 9: Graph showing variations in the Temperature from 2008 to 2015

6.0 CONCLUSION

There is significant increase in Compact high rise (10.3%), Open Mid-rise (9.1%) and Heavy Industry (7.1%) from 2008 to 2015. 12.7% of low plants and 9.7% of Open low-rise have decreased due to increase in high-rise development. Overall, average temperature has changed from 22.6 ^{o}C (2008) to 24.5 ^{o}C (2015). Heavy industries and compact high rise has the highest temperature in both the years 2008 and 2015 which ranges between 25 ^{o}C to 27 ^{o}C because of the height and packing of roughness feature and also because of the high anthropogenic heat output. The generated LCZ can be used for defining UHI magnitude, Climate modeling, weather forecasting, and historical temperature analysis, architecture, city planning, and landscape ecology.

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