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Local Climate Zone Classification and Seasonal Variation by using Land Surface Temperature: A case of National Capital Territory, Delhi, India

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ABSTRACT

Local Climate Zones (LCZ) are a well-established concept in cities of the developed world and is beneficial for quantification of both spread and backwash effects in the system, forecasting the future under different scenarios and simulating the mitigation strategies for climate change adaptation. Temperature differentiation in LCZ classification (ΔT_{LCZ}) is considered a more appropriate, reliable and robust measure to analyze the magnitude of spatial temperature variations than temperature differentiation of urban and rural (ΔT_{u-r}). The seasonal behaviour of ΔT_{LCZ} is still to be established. Urban morphology of Indian cities is quite different from European and American cities due to non-uniform geometric and surface cover properties. The present work investigates the ΔT_{LCZ} based on the LCZ classification system and the seasonal behaviour of Land surface temperature (LST) for the National Capital Territory (NCT) Delhi, India. The Landsat 8 imageries of NCT Delhi are analyzed for the year 2016 and 2017, downloaded from USGS earth explorer, for the purpose of LST retrieval by using well-established single-window LST algorithm. A sample of 91 subsets, nearly uniform shape and size of 1 km^2 are classified by considering built-up, vegetation, water, and other classes, and are further categorized based on land-cover, built-up density, average building height and their closely matching LCZ. The spatial distribution of sample subsets is kept uniform for all classes to represent the entire study area. Variations of ΔT_{LCZ} and LST in the same LCZs ($\Delta T_{LCZ-LST}$) for all the subsets are quantified and comparative analysis is done a season-wise comparison between ΔT_{LCZ} and $\Delta T_{LCZ-LST}$ for all present climates in the study area. A seasonal variation of intensity ranging from 1.15^{o}C (airport site) to 4.78^{o}C (agricultural sample sites) with an average variation of 2.14^{o}C is observed in $\Delta T_{LCZ-LST}$. The paper concludes with the significance of seasonal $\Delta T_{LCZ-LST}$ in urban planning.

Keywords: *Local Climate Zone (LCZ) classification; Land Surface Temperature (LST); Seasonal Temperature Differentiation; Delhi*

INTRODUCTION

The temperature of a specific location is a function of energy exchanges over that space. Land-use land-cover, morphology and anthropogenic activity of that location affect the intensity

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of the energy exchanges. Urban Heat Island (UHI) is being measured as a temperature (energy exchange) difference between urban and rural settings (Tim R. Oke, 1987). Urbanization is a dynamic process over space. These urban and rural spaces have different degrees of dynamism associated with them both in space and time. The boundaries and intensity of land-uses land-covers and anthropogenic activities change over a period. The process of urbanization engulfs spaces, which were rural at one point in time. In addition, there remains high variability in urban and rural sites of reference. So, the temperature differentiation, among different land-use land-covers, and different compositions within a single type, across the world, has yielded better results in a dynamic situation of urbanism as compared to temperature differentiation of urban and rural (ΔT_{u-r}). There have been regular attempts to classify local climates in different zones (Cahndler, 1965) (T. R. Oke, 2004); (Bechtel, 2011); (Bechtel & Daneke, 2012); (Stewart & Oke, 2012); (Perera, Emmanuel, & Mahanama, 2012) (Quan, Dutt, Woodworth, Yamagata, & Yang, 2017); (Kotharkar & Bagade, 2017); (Perera & Emmanuel, 2018) . The LCZ classification proposed by Stewart & Oke (2012) is widely accepted latest and has been very well adopted by different researchers across the world including World Urban Database and Access Portal Tools (WUDAPT) project, which is further used in numerous studies for LCZ classification. Classification of the urban morphology of urban areas in developing and underdeveloped countries is not very clear, so, Kotharkar & Bagade (2017); Perera & Emmanuel (2018) have suggested the development of detailed separate LCZ classification scheme. The UHI intensity varies with the change in the season due to variations in wind speed and water content available in different surfaces and atmosphere (Panwar, Agarwal, & Devadas, 2018). The authors have not come across any study on temperature differentiation behaviour of LCZ classes over different seasons. Therefore, the present investigation presents spatial and seasonal Inter & Infra-LCZ temperature variability as per LCZ and LST derived from Landsat 8.

BRIEF ABOUT STUDY AREA

The National Capital Territory (NCT) of Delhi, one of the seven Union Territories of India, has been selected for the study. Delhi, the capital city of India, is part of the study area. The study area under consideration is located at 28.7041° N 77.1025° E (Fig. 1 a & b). It has a geographical area of 1484 sq. km, surrounded by the States of Haryana and Uttar Pradesh. Delhi attracts in-migration from the entire nation for employment opportunities, as it is the political centre and major economic hub of India. Delhi is growing in almost all aspects because of the aforementioned reason.

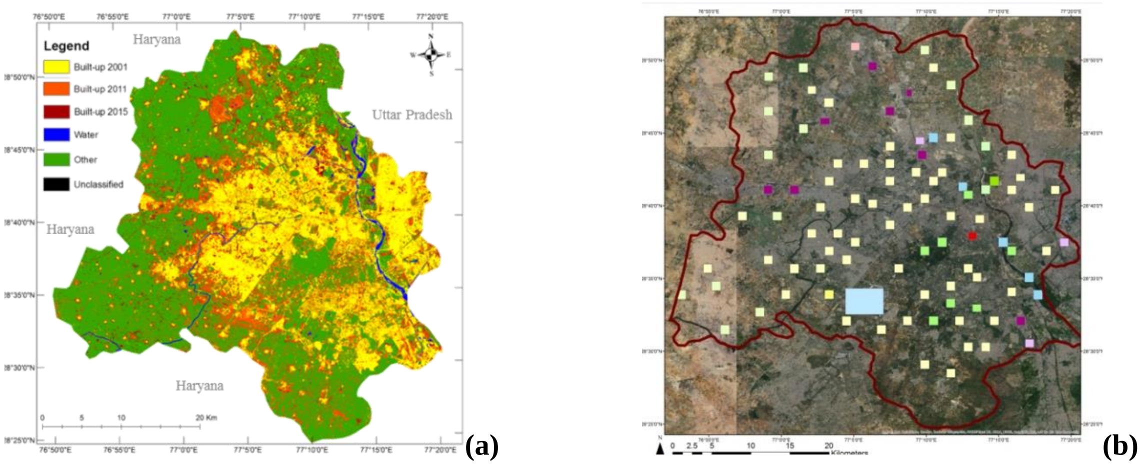

Fig. 1: (a) Spatial growth of urbanization in the NCT of Delhi. (b) Study area showing all the subsets used in the present investigation.

The built-up area & density, and energy consumed by different sectors are increasing at an exponential rate, and haphazard growth is adding to a vicious cycle. In accordance with Köppen climate classification, Delhi has climate overlapping humid subtropical (Cwa) and Semi-arid (BSh) climates. The study area is blessed with summer, monsoon, autumn, winter and spring seasons. The spatial sprawl and type of sprawl make Delhi the ideal case for analyzing the $\Delta T_{LCZ\text{-}LST}$.

CURRENT INVESTIGATION

Landsat 8 Imagery downloaded from https://earthexplorer.usgs.gov/ provide by NASA are used for this present study. Since, the objective of the research is to analyze the seasonal variations over LCZ, two year time period i.e. two years (2016 and 2017) kept is very short (so that the development within this period remains very little) and enough to capture all the seasons. Less than one per cent cloud cover criterion is used for selection of imagery for path 146 row 40 scene of Landsat 8 encompassing the study is for the previously mentioned period. Weather data, matching overpass time of Landsat 8, has been obtained from NCDC of NASA website https://www.ncdc.noaa.gov/ for weather station no. 421810 for Safdarjung Airport, New Delhi. The details of the data used for this research is presented in table 1. The methodology adopted for the present investigation is presented in Fig. 2. Authors are well versed with the study area. Land-use Map for the period 2011-12 is available in BHUVAN portal. However, the preliminary earmarking of the subsets has been done on Google earth (Fig. 1b) using the author's knowledge representing different land-cover land-use and morphology within single land-use representing entire Delhi. The 3D maps of the sub-sets are prepared to analyze rise and compactness (the generated data will be further used as training data set for LCZ mapping of entire NCT Delhi in near future). Google earth data is used for preparing the base map for the physical survey to analyze the LCZ of different subsets.

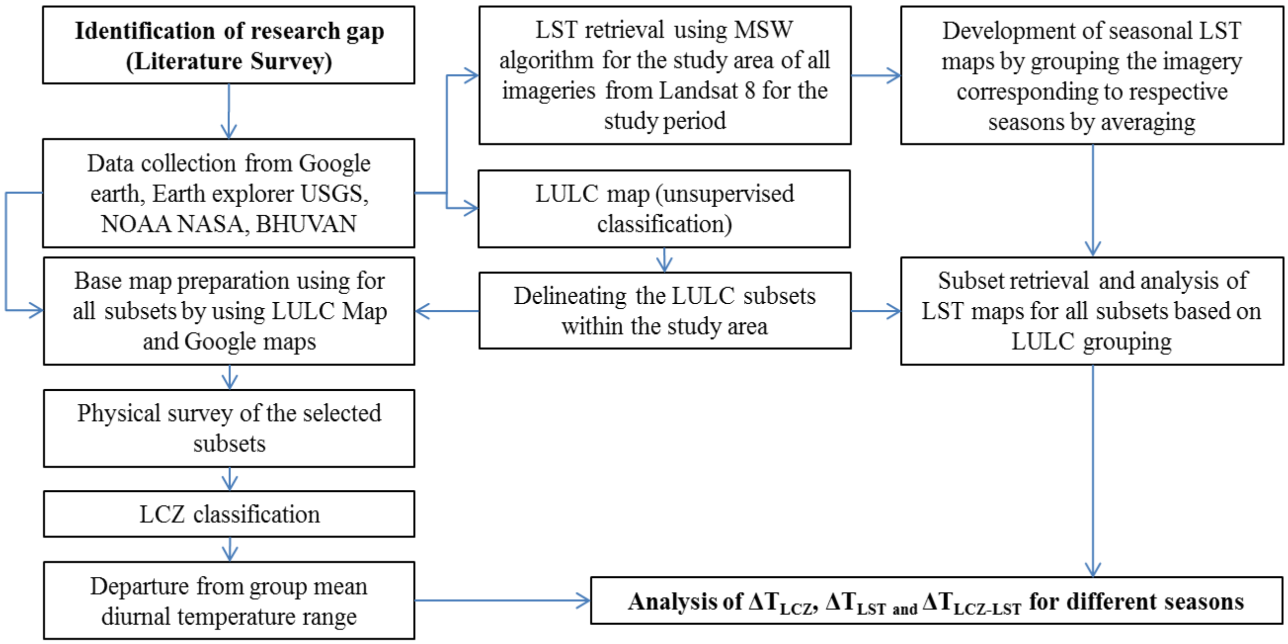

Fig. 2: Methodology used in the present investigation

Table 1. Data used for the study

Sl. No.	Landsat 8 Imagery Acquisition Date *	Seasonal classification for calculation of LST@	Actual classification #	Temperature (ºK) at 11:00 AM $	Humidity (RH) $
1	30.01.2016	Winter	Winter	299.3	40.4
2	21.05.2016	Summer	Summer	315.4	16.1
3	12.10.2016	Winter	Autumn	307.0	27.5
4	28.10.2016	Winter	Autumn	304.8	18.5
5	13.11.2016	Winter	Autumn	302.0	28.2
6	21.03.2017	Summer	Spring	306.5	20.5
7	06.04.2017	Summer	Summer	310.9	17.9
8	24.05.2017	Summer	Summer	314.3	23.1
9	25.06.2017	Summer	Summer	313.2	35.0
10	29.09.2017	Summer	Monsoon	309.3	43.1
11	15.10.2017	Winter	Autumn	309.3	27.7
12	02.12.2017	Winter	Winter	297.6	28.6

Source: *USGS Earth Explorer; @ Classification used for various calculations in IMW algorithm; # (Delhi Tourism Department, 2018); $NCDC NASA

LST retrieval

Improved Mono Window (IMW) algorithm (Eq. 1 – Eq. 11) is proposed by Wang et al. (2015). Authors have adopted this algorithm for retrieval of LST for the NCT of Delhi. The study area has been considered as a flat surface for the calculation of LST. The atmosphere for the study area is considered as the mid-latitude atmosphere. All imagery has been classified in summer and winter seasons for applying respective effective mean atmospheric temperature equation for the mid-latitude atmosphere of the study area. Air density and saturation of water vapour to air is calculated by using the respective air temperature given in Table 1. The values of constants and rescaling factors to be used for the analysis of LST from Landsat8 imagery by using the IMW algorithm as given by USGS, and are presented in table 2.

Table 2: Values of constants, rescaling factors used in IMW algorithm

Temperature Range	constants to an approximate derivative of the Planck radiance function for the TIRS Band 10		Multiplicative rescaling factor for TIRS Band 10	Additive rescaling factor for TIRS Band 10	Thermal conversion constants for Band 10	
	a_{10}	b_{10}	M_{10}	A_{10}	K_1	K_2
0ºC - 50ºC	-62.7182	0.4339	3.342×10^{-4}	0.1	774.89	1321.08

Source: https://earthexplorer.usgs.gov/ metadata file

Improved Mono Window (IMW) algorithm

$$T_s = [a_{10}(1 - C_{10} - D_{10}) + (b_{10}(1 - C_{10} - D_{10}) + C_{10} + D_{10})T_{10} - D_{10}T_a]/C_{10} \quad (1)$$

T_s is LST in degree Kelvin from Landsat 8 band 10; T_a is effective mean atmospheric temperature; T_{10} is brightness temperature band 10 of Landsat 8; C_{10} and D_{10} are internal parameters based on atmospheric parameters and ground emissivity;

$$C_{10} = \tau_{10}\varepsilon_{10} \quad (2)$$

$$D_{10} = (1 - \tau_{10})[1 + (1 - \varepsilon_{10})\tau_{10}] \quad (3)$$

τ_{10} and ε_{10} are atmospheric transmittance and ground emissivity

$$R_{10} = M_{10}Q_{10} + A_{10} \quad (4)$$

R_{10} is the spectral radiance of band 10 for Landsat 8 and Q_{10} is the DN value for pixels of band 10

$$T_{10} = \frac{K_2}{\ln(1+(K_1/R_{10})} \quad (5)$$

$$E = 3.7096\, e^{0.0663\, T_o} \qquad \{-20C^o \leq T_o \leq 45C^o\} \quad (6)$$

$$A = -0.0042\, T_o + 1.2936 \quad \{-20C^o \leq T_o \leq 45C^o\} \tag{7}$$

$$w(0) = E * A * H/1000 \tag{8}$$

w is total water vapour content; E is the saturation mix ratio of water vapour and air at a specific temperature; A is air density at specific air temperature and H is the air humidity at the ground.

$$w = \frac{w(0)}{Rw(0)} \; (The\ value\ of\ Rw(0)\ considered\ for\ mid\ latitude\ winter\ is\ 0.6365) \tag{9}$$

$$\tau_{10} = 0.9228 - 0.0735\, w \tag{10}$$

The effective mean atmospheric temperature is calculated using Eq. 11.

$$T_a = 19.2704 + 0.9112\, T_o \tag{11}$$

Global values for Normalized Difference Vegetation Index (NDVI) for soil and vegetation ($NDVI_s$=0.2 and $NDVI_v$= 0.5) are used for emissivity calculation.

Deviation in LST for different land-uses and LCZ

The $\Delta T_{LCZ\text{-}LST}$ has been derived by analyzing the mean ΔT_{LST} for individual subsets and then aggregating the $\Delta T_{LCZ\text{-}LST}$ for subsets belonging to same LCZ class within a particular land-use (Eq. 12 & Eq. 13). The iterations have been done for all imageries used for summer, monsoon, autumn, winter and spring seasons.

$$\Delta_{LST} = LST_i - LST_{Min} \tag{12}$$

$$\Delta_{LCZ-LST_{ijk}} = \sum_{i=0}^{n} \frac{\frac{\sum_{j=0}^{m} \Delta_{LCZ-LST}}{m}}{n} - \sum_{i=0}^{n} \frac{\Delta_{LCZ-LST}}{n} \tag{13}$$

i - *No. of same LCZ classes belonging to k^{th} land-use*
j - *No. of images used for LST analysis*
k - *Land-uses considered in different subsets*

RESULTS AND DISCUSSION

The authors have done an extensive literature survey, reviewed the literature and observed the findings. However, the findings observed in the present investigation are very different from the findings, which were earlier observed. The findings of the present investigation revealed an additional component to the existing research, which was not investigated earlier. The major findings observed are presented below:

The variations in intensities of LST are clearly visible both with the change in land use land cover and with the change in season. The surfaces with lower moisture content show a higher temperature. Highest intensities are observed in built-up land cover followed by subsets having a mix of soft and hard land covers and then finally in unbuilt land covers. The land covers those show lower variations in ephemeral properties with seasonal changes observed fewer ΔT_{LST} variations with the change in season. The evapotranspiration from atmospheric moisture comes into play after the surface moisture. The availability of vegetation, which has the capability of shading the surfaces, i.e. high moisture content atmospheric zones shows lower temperature both surface and atmosphere. The order of intensity of LST in built-up, mix and unbuilt land covers are governed by land use. The planned urban residential subsets show lower LST due to the presence of higher tree and forest cover in those subsets. Subsets with water and dense vegetation, i.e., LCZ B and LCZ G (both urban forest and urban green) show the lowest temperature during all seasons. The observed LST (^{o}C) intensities and standard deviation for different land use land covers in winter, spring, summer, autumn and monsoon are presented in table 3.

The subsets having landfill sites, airport and industries observed consistently higher LST intensities in comparison with the average LST intensity. The LST intensities for landfill sites are 32.31 ^{o}C, 31.74 ^{o}C, 35.54 ^{o}C, 22.56 ^{o}C, and 30.16 ^{o}C for Autumn, Monsoon, Summer, Winter, and Spring season respectively. The observed LST for landfill sites is contributed by the burning of solid waste and availability of methane below the top surface of landfill. The LST intensities for airport are 32.50 ^{o}C, 32.32 ^{o}C, 36.73 ^{o}C, 23.56 ^{o}C, and 30.03 ^{o}C for Autumn, Monsoon, Summer, Winter, and Spring season respectively. The large hard paved surfaces contribute to the consistent high LST intensity at airport. The LST intensities at industrial sites are due to anthropogenic activities and high energy consumption leading to heat, and the mean intensities of LST in industrial sites are 31.84 ^{o}C, 31.95 ^{o}C, 35.35 ^{o}C, 22.65 ^{o}C, and 29.23 ^{o}C for Autumn, Monsoon, Summer, Winter, and Spring season respectively. The LST intensities for roads in the study area has also been observed consistently higher than the average LST intensity. The intensity of anthropogenic activities contributes to higher intensity of LST on roads.

The subsets with agriculture, water, a mix of agriculture and water, forest greens, urban greens, and institutional campus observed intensities of LST consistently lower than the average LST intensities in all seasons except subsets with agriculture land use. The mean intensities of LST in subsets with agriculture land use are 32.12 ^{o}C, 29.13 ^{o}C, 35.32 ^{o}C, 21.51 ^{o}C, and 23.73 ^{o}C for Autumn, Monsoon, Summer, Winter, and Spring season respectively. The variations in the intensity of LST in agriculture land use is due to the variation in surface moisture content. The mean intensities of LST in subsets with water land cover are 27.79 ^{o}C, 26.68 ^{o}C, 29.34 ^{o}C, 19.95 ^{o}C, and 25.09 ^{o}C for Autumn, Monsoon, Summer, Winter, and Spring season respectively. The mean intensities of LST in subsets with mix of water and green land cover are 28.72 ^{o}C, 26.92 ^{o}C, 30.92 ^{o}C, 20.77 ^{o}C, and 23.70 ^{o}C for Autumn, Monsoon, Summer, Winter, and Spring season respectively. The observed lower intensities of LST in land covers as water, agriculture and green, and mix of these, are due to availability of moisture content for evapotranspiration during all seasons.

The detailed analysis of residential land use provides information about intensity of LST as a function of built-up density and availability of greens. The intensity of LST in rural and urban residential land use remain fluctuating in different seasons but intensity of LST in rural subsets always remain lower than urban counterparts. The mean intensities of LST in subsets with rural settlements are 29.58 ^{o}C, 30.15 ^{o}C, 34.06 ^{o}C, 21.18 ^{o}C, and 26.12 ^{o}C for Autumn, Monsoon, Summer, Winter, and Spring season respectively, however, the mean intensities of LST in subsets with residential land use in towns are 30.51 ^{o}C, 31.58 ^{o}C, 34.93 ^{o}C, 21.05 ^{o}C, and 27.69 ^{o}C for Autumn, Monsoon, Summer, Winter, and Spring season respectively. Within residential land use the LST intensities for farmhouses are always lower, however, high-rise apartments have been observed closer to the average intensities of LST for entire study area. The intensities of LST for farmhouses are 29.06 ^{o}C, 28.55 ^{o}C, 32.40 ^{o}C, 19.62 ^{o}C, and 26.37 ^{o}C for Autumn, Monsoon, Summer, Winter, and Spring season respectively.

Table 3. Season-wise Mean LST (^{o}C) and Standard Deviation for all subsets grouped for different LULC

Land use Land cover	Residential (Rural)	Residential (Town)	Residential (Urban - Unplanned)	Residential (Urban Planned) Midrise	Residential (Urban Planned) High-rise	Residential (Urban Planned) Farmhouses	Industrial	Comm-ercial
	1	2	3	4	5	6	7	8
No. of Sites	3	2	10	28	2	4	9	1
Season	LST Mean (SD)	LST Mean (SD)	LST Mean (SD)	LST Mean LST	LST Mean (SD)	LST Mean (SD)	LST Mean (SD)	LST
Autumn	29.58 (0.33)	30.51 (0.30)	30.12 (0.45)	29.37 29.87	29.73 (0.12)	29.06 (0.19)	31.84 (0.43)	29.87
Monsoon	30.15 (0.69)	31.58 (0.86)	30.96 (0.63)	29.64 30.52	29.60 (0.33)	28.55 (0.42)	31.95 (0.53)	30.52
Summer	34.06 (1.22)	34.93 (0.25)	34.55 (0.64)	33.12 33.34	34.26 (0.03)	32.40 (0.38)	35.35 (0.65)	33.34
Winter	21.18 (0.48)	21.05 (0.05)	20.77 (0.41)	20.43 20.52	21.44 (0.11)	19.62 (0.91)	22.65 (0.72)	20.52
Spring	26.12 (0.57)	27.69 (0.17)	27.47 (0.64)	26.85 27.30	27.87 (0.11)	26.37 (0.43)	29.23 (0.91)	27.30

Land use Land cover	Institutional	Air-port	Agriculture	Agriculture + Water	Water	Forest Green	Urban Green	Landfill Sites
	9	10	11	12	13	14	15	16

No. of Sites	1	1	2	10	28	2	4	9
Season	LST	LST	LST Mean (SD)	LST Mean (SD)	LST Mean (SD)	LST Mean (SD)	LST Mean (SD)	LST Mean (SD)
Autumn	28.89	32.50	32.12 (3.28)	28.72 (0.77)	27.79 (0.32)	27.56 (0.67)	27.68 (0.49)	32.31 (0.47)
Monsoon	28.56	32.32	29.13 (2.83)	26.92 (0.16)	26.68 (0.72)	25.97 (0.86)	26.81 (0.54)	31.74 (0.41)
Summer	32.78	36.73	35.32 (1.96)	30.92 (0.39)	29.34 (1.03)	32.25 (1.73)	31.07 (1.27)	35.54 (0.22)
Winter	20.09	23.56	21.51 (0.94)	20.77 (0.45)	19.95 (0.60)	21.07 (0.73)	20.30 (1.01)	22.56 (0.14)
Spring	26.80	30.03	23.73 (1.63)	23.70 (2.11)	25.09 (0.84)	26.75 (1.26)	25.91 (2.07)	30.16 (0.56)

The results of $\Delta T_{LCZ\text{-}LST}$ after averaging the subsets pertaining to different LCZ classes and in comparison with the ΔUHI_{LCZ} recorded by Stewart & Oke (2012) and Perera & Emmanuel (2018) in Table 4. The seasonal variation of intensity 1.58°C and 3.07°C are observed in ΔT_{LST} over built-up and counterparts area in the study area. A seasonal variation of intensity ranging from 1.15°C (over fully paved airport site) to 4.78°C (average over agricultural sample sites) with an average variation of 2.14°C is observed in temperature differentiation over different land-cover land-uses. This difference is due to continuous burning on landfill sites, use of concrete surfaces without shade at airport and use of high albedo CGI sheets in industrial areas but the variation in the intensity of ΔT_{LCZ} is low due to very little changes in the ephemeral properties of the surface. The subsets over agricultural land have high variability, which is because of the variations in vegetation cover and soil moisture content. Subsets showing LST over institutional and commercial land-uses show lower LST values. The institutional subsets have good tree cover, whereas the commercial has a central grass surface. The numbers of subsets analyzed are less in number, so further investigation is required.

Table 4: Season-wise ΔTLCZ-LST in the present investigation and UHILCZ presented in the literature

				Departure from Average (°C)					Departure using LCZ classification (°C)	
Sr. No.	LCZ Classification	LULC	No. of Samples	Autumn	Monsoon	Summer	Winter	Spring	(Stewart & Oke, 2012)	(Perera & Emmanuel , 2018)
1a	LCZ 7C	Residential (Rural)	3	-0.86	0.70	-0.02	-0.06	-0.70	1.50	0.31
1b	LCZ 3F	Residential (Town)	2	0.06	2.13	0.85	-0.20	0.87	0	3.19
1c	LCZ 3E	Residential	10	-0.32	1.51	0.47	-0.48	0.65	-	3.19
1d	LCZ 5	Residential	28	-1.07	0.19	-0.96	-0.82	0.03	4.00	3.71
1e	LCZ4	Residential	2	-0.72	0.15	0.18	0.19	1.05	-	4.35
1f	LCZ9	Residential	4	-1.39	-0.90	-1.68	-1.63	-0.46	0.30	-
2	LCZ10	Industrial	9	1.40	2.50	1.27	1.40	2.41	5.50	-
3	LCZ 8	Commercial	1	-0.57	1.07	-0.74	-0.73	0.48	1.80	1.10
4	LCZ 5	Institutional	1	-1.55	-0.89	-1.30	-1.16	-0.02	4.00	3.71

5	LCZ 8E	Public & semi-public (Airport)	1	2.06	2.87	2.65	2.31	3.21	-	1.04
6	LCZ F	Agriculture	12	1.68	-0.32	1.24	0.26	-3.10	-9.50	-0.90
7	LCZ FG	Agriculture + Water	2	-1.73	-2.53	-3.17	-0.48	-3.13	<-9.5	NA
8	LCZ G	Water	4	-2.65	-2.77	-4.74	-1.30	-1.73	-	0.62
9	LCZ A	Forest Green	5	-2.88	-3.48	-1.83	-0.17	-0.07	-7.20	-0.12
10	LCZ B	Urban Green	4	-2.76	-2.65	-3.02	-0.95	-0.91	-7.20	-0.09
11	LCZ 10	Landfill site	3	1.87	2.29	1.46	1.31	3.33	-	NA

The morphological characteristics of the study area are entirely different from the existing classes of LCZ proposed by Stewart & Oke (2012) or any other scholar due to differences in nature of the economic and spatial development of the settlement. LCZ classification a very good concept for doing the prima-facie analysis for a lot of users need but further development especially for unplanned urban areas as they don't have classes even near matching to existing classes of LCZ proposed by Stewart & Oke (2012) or any other scholar. Furthermore, the LST based temperature departure differentiation is used for the first time in the LCZ study. The relationship between $\Delta T_{LCZ\text{-}LST}$ and ΔT_{LCZ} couldn't be established due to the non-matching of LCZ classes and lack of $\Delta T_{LCZ\text{-}LST}$ data of the existing published research. The observed seasonal variation in $\Delta T_{LCZ\text{-}LST}$ offered research question for the scholars in this field of study and need for addressing such issue. Season wise ΔT_{LST} for studied land use land covers are presented in Fig. 3.

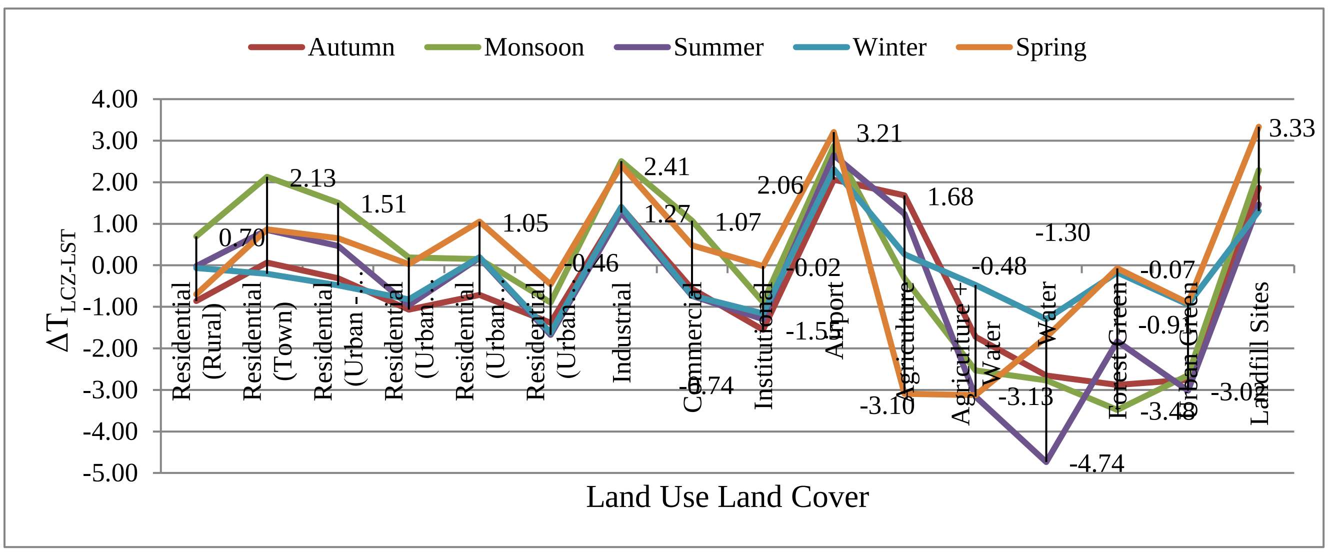

Figure 3. Season-wise LST departure from average LST for different Land Use Land Covers

Generally, planning for the development of the urban system the authors used to consider physical subsystem, social sub-system to some extent and infrastructure sub-system. The Brundtland Commission published the sustainable development concept in the year 1987, since then environmental sub-system is considered as a pillar of sustainable development along with social and economic. To quantify the environment sub-system and its functions in the urban system, the present research, which is an attempt by the authors, is very much essential. The present research focuses on the quantifying the variations in the LST in different seasons along with land-use land-cover and its comparison to LCZ based temperature differentiation. The land-use in the urban system varies based on the functional character of the urban system. It may be observed that the functional character of the urban system will differ from one urban system to another urban system, even within a state, region or country. The LST varies from one area to another area in urban system, which alters the functions of the urban system and impacts the entities of the urban system. The variation in LST differentiation over different seasons will provide boundary conditions for doing sensitivity analysis in seasonal and spatial dimensions in urban planning.

CONCLUSION

The present investigation uses LST retrieved by using IMW algorithm as a tool for the analysis of seasonal temperature differential for the 91 subsets covering different land-use land-cover spread across the study area of NCT Delhi. The temperature differentiation obtained by using the retrieved LST in different LULC is compared with the LCZ based temperature differentiations. The papers conclude that the classification of the urban morphology of unplanned urban areas in developing and underdeveloped countries is not very clear. Different LCZ classes are showing variations in LST differentiation but the quantification of the relationship between LCZ based temperature differentiation and LST temperature differentiation could not be established due to non-matching of LCZ classes and lack of LCZ based temperature differentiation data. LCZ based UHI provides Canopy Layer UHI whereas LST is a surface phenomenon, the development of LCZ for entire NCT Delhi and installation of AWS for analysis of air temperature will unfold relationship between $\Delta UHI_{LCZ,}$ field measurements and $\Delta UHI_{LCZ\text{-}LST}$. The depiction of ΔUHI_{LCZ} in range format is a better option for generalization of the results to be applicable to a larger number of settlements, and also for capturing the season-wise variations in same settlement. Further, a detailed investigation in this field of research is proposed for future work.

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