

# Impact of Land Use types on the Spatial Heterogeneity of Extreme Heat Environments in Jaipur City, Rajasthan, India

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OIDA International Journal of Sustainable Development, Ontario International Development Agency, Canada.

ISSN 1923-6654 (print) ISSN 1923-6662 (online) [www.oidaijsd.com](http://www.oidaijsd.com)

Also available at <https://www.ssrn.com/index.cfm/en/oida-intl-journal-sustainable-dev/>

**Abstract:** Rapid urbanization has been accompanied by the construction of large amounts of impervious surfaces, artificially built environments, and transportation systems and has further resulted in extreme heat events in urban core areas, which are much warmer than the surrounding areas. Urbanization strongly correlates with land use land cover (LULC) dynamics, which further links to changes in land surface temperature (LST) and urban heat island (UHI) intensity. Each LULC type influences UHI differently with changing climate, therefore knowing this impact and connection is critical. Local climate changes due to urbanization are epitomized by the UHI, which is characterized by temperature differences between urban and rural areas. The UHI is a critical factor for energy consumption and air quality, resulting in higher peak electricity demand in summer because of air conditioning, increased emissions of primary pollutants associated to power production, and increased generation of ozone. However, planners need a better understanding of the relationship between the UHI and land-use patterns to reduce the UHI and promote more sustainable urban development. Keeping the aforesaid knowledge in mind, Jaipur City, Rajasthan State has been chosen as study region for further detailed investigation. The study has been carried out on two levels viz., one is City level and another at Planning zone level to get better understanding of the existing scenario of the study region. At City level, Spatial Autocorrelation followed by multiple regressions using ArcGIS software has been established. Multiple regressions using geographically weighted regression tool gave a mix of parameters which are affecting the temperature and thermal comfort of the study city. On the other hand, at planning zone level, the land uses considered are commercial, residential, and industrial level which had a dominant land use among the different land use compositions. Fishnet analysis with grid size of 250m by 250m was run leading to different sets of factors contributing to UHI in the Jaipur Municipal Corporation. The findings of this research also provide important insights for city planners, urbanist and policy makers to examine urban climate resilience through the lens of land use dynamics and UHI intensity in the system. Based on the results and findings, recommendations were made at city level as well as at the planning zone level. This research study demonstrate that it is possible to reduce temperatures in residential and urban areas through judicious siting of green areas to navigate towards sustainable urban development.

**Keywords:** UHI; Land Surface Temperature; Urban Energy; Land Use Planning; Sustainable Development.

## Introduction

Today, more than 50 percent of the population lives in urban areas, leading to urbanization and thus causing changes in the built environment. Urbanization is occurring because of large-scale commercial development, transportation areas and manufacturing leading to the development of the urban heat island (UHI) phenomenon in the urban systems. As a consequence of change in regional landscapes across the globe due to urban sprawl and urbanization the main contributing factors leading to alterations are changes in physical characteristics of the surface (albedo, thermal capacity, heat conductivity) owing to replacement of vegetation by asphalt and concrete;

decrease of surface moisture available for evapotranspiration; changes in radiative fluxes and in near surface flow, owing to complicated geometry of streets and tall buildings, and anthropogenic heat. As a consequence, there is a significant increase in mean surface temperature which is one of the main contributors of Global Warming.

UHI is a micro-climatic phenomenon which occurs within urban areas and consists of generally warmer temperatures than rural surroundings. It occurs when cities replace natural land cover with dense concentrations of pavement, buildings, and other surfaces that absorb and retain heat. Climate change will likely lead to more frequent, more severe, and longer heat waves during summer months. The impact of Urban Heat Island includes increased energy consumption, elevated greenhouse gas emissions and air pollution, danger to aquatic system, animals, discomfort, and danger to human health as well as impact on climate. The modified land surface in cities affects storage, radiative and turbulent transfers of heat and its partition into sensible and latent components. The UHI effect arises from these changes and may also be affected by changes in water runoff, pollution, and aerosols. UHI effects are often very localized and depend on local climate factors such as windiness and cloudiness (which in turn depend on season), and on proximity to the sea. Higher Thermal content land uses, which include commercial areas, central business district (CBD), and dense housing, are substituting green spaces, which have lower temperatures. Increased heat in cities necessitates a rise in the energy consumption load resulting in poor air quality and bad health consequences. Higher temperatures, for example, boost the production of ozone (O<sub>3</sub>) pollution. Despite the significant costs of urban warming, no city has attempted to build comprehensive plans to minimize it. A little research has been done on the relationship between a city's design and its physical properties for heat absorption.

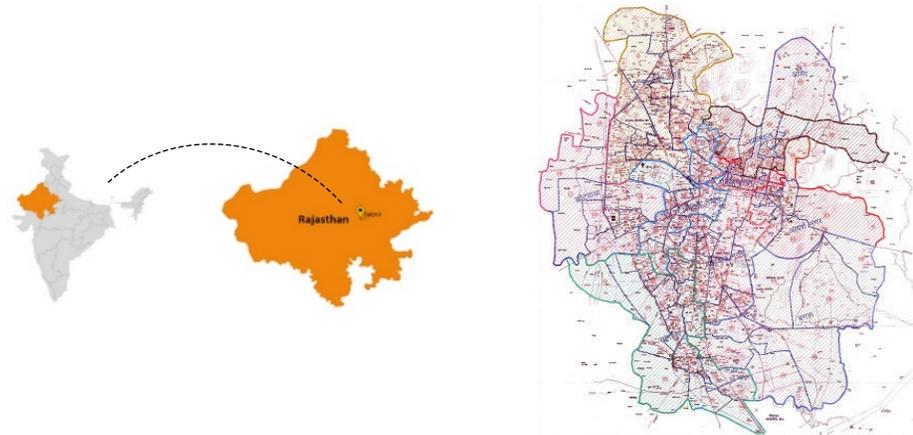
Land use and prospective UHI studies has been carried out for the Jaipur Region. The research covers 444.72 sq. km of Jaipur Municipal Corporation area. Jaipur city is the capital and administrative headquarter of Rajasthan, the largest state of India. The city has witnessed high population growth especially in the past decade. Consequently, there has been a remarkable acceleration in construction activities for industries, institutional infrastructure, and residential colonies etc. Although several research have studied urban expansion of the city and associated LULC changes but there has hitherto been no study on the impact of change in land use on thermal environment of the city as well how land use regulates the surface temperature of an area. The integrated application of remote sensing, geographic information system (GIS) and quantitative analytical modelling can provide scientific and effective methods for monitoring and studying urban land surface thermal environment. Land surface temperature (LST) is a key factor in physical processing of land surface at a regional and global scale, and it generalizes the results of the interaction between land surface and atmosphere, exchange of matter and energy. Surface Urban Heat Island (SUHI) can be measured with the engagement of remote sensing and GIS. Satellite imagery is used to derive the maps. Among the potential applications, the SUHI maps derived from spaceborne sensors supply a scientific support for the urban planning policy aimed to integrate urban development and landscape ecosystems. For instance, the widespread presence of impervious surfaces is a significant urbanization factor increasing the SUHI effects, whilst vegetation and green spaces in the urban texture are one of the fundamental strategies to decrease the urban warming intensity. The research aims to explore the functional interaction between land use and UHI effect in Jaipur City and potentials for minimising the sectoral end use CO<sub>2</sub> emission to mitigate the impact of UHI. The cardinal objectives of the study are (i) To study and understand the functional interaction between land use and urban heat island effect; (ii) To identify the influential factors and their spatial relationship affecting urban heat island effect; (iii) To quantify the sectoral end use energy consumption and its associated CO<sub>2</sub> emissions and (iv) To evolve comprehensive operational model and to recommend optimal planning guidelines for minimizing energy consumption to mitigate UHI effect in the study region.

### **Study Region**

Jaipur city is the capital city of the Indian state of Rajasthan. Location and extent of study area is shown in Figure 1. The study region is in Rajasthan's eastern semi-arid region, between 26°54' north latitude and 75°45' east longitude. It is India's tenth largest city (According to Census, 2011).

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**Figure 1: Geographical Location and Ward Map of Jaipur Study Region**



Jaipur comes among the country’s million plus cities and Rajasthan's only one of this size and one of the fastest-growing populations. In terms of groundwater depletion, trees, soil erosion, flora and wildlife, and climate change, the entire city has undergone an environmental disaster. Nahargarh hills is in the North and Jhalana hills in the East side which are part of Aravalli ranges runs in the city. The study region surrounded by isolated and discontinuous hillocks in the South and West. Jaipur region is located on the eastern edge of the Thar Desert, a semi-arid region. Summers in Jaipur are tremendously hot, while winters are bitterly cold. During the month of May, maximum temperatures range from 40 to 47 degrees Celsius. For a few days of the season, a heat wave occurs, with daytime temperatures rising to 4–6 ° Celsius above usual. Winter minimum temperatures range from 4 to 9 degrees Celsius and drops below 0 degrees. In the earlier 50 years, the population of Jaipur has expanded by more than tenfold. The city's population was only 1.6 lakh in 1900. The population of the Jaipur Municipal Corporation increased from 23.22 lakh in 2001 to 30.46 lakh in 2011. In comparison to the national urban average, the average yearly growth rate is 2.38 percent. The pace of growth was around 2%. The main cause of the urban heat island effect is from the modification of land surfaces. As a population centre grows, it tends to expand its area and increase its average temperature.

**Figure 2: Decadal Population Growth**

Years	Total Population	Growth rate (%)	Annual average growth rate (%)
1941	175,800	---	---
1951	291,000	39.59	3.96
1961	403,400	27.86	2.79
1971	636,800	36.65	3.67
1981	1,015,567	37.30	3.73
1991	1,518,743	33.13	3.31
2001	2,322,575	34.61	3.46
2011	3,046,163	23.75	2.38

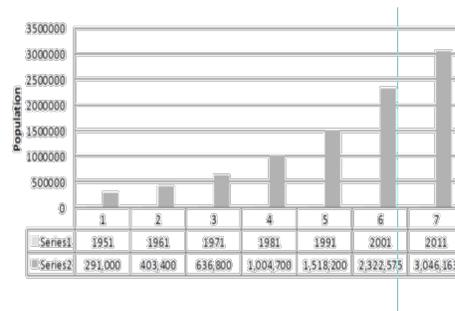
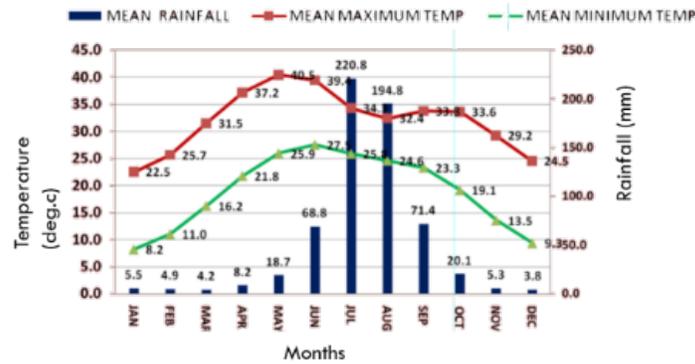


Figure 3: Climate Data -Temperature and Rainfall



The research study was conducted in two levels viz., City level and Planning Zone level. The total city area with reference to existing land use as per the master plan 2025, the study region confined with boundary of 467 sq.km. The land use plan of Jaipur city has various land uses which includes residential, commercial, industrial, mixed use, recreational, army area, special area. Each land use has its own characteristics. Jaipur Municipal corporation has 10 planning zones in which development happens. Each zone has a predominate land use based on its usage of land. The Jaipur Planning Region is formulated into zones to enable each zone to have a certain character and promoting its self-sufficiency. Jaipur Development Authority prepares detailed Development Plan of each zone aiming to achieve equitable distribution of social and physical infrastructure. With interdependency of various facilities amongst these planning zones existing gaps are bridged. Jaipur Municipal Corporation or Jaipur Nagar Nigam is municipal corporation of Jaipur city in Rajasthan state in India. There are 250 wards of which Jaipur Heritage Wards are 100 and Jaipur Greater Wards are 150.

Figure 4: Jaipur Municipal Corporation Planning Zones

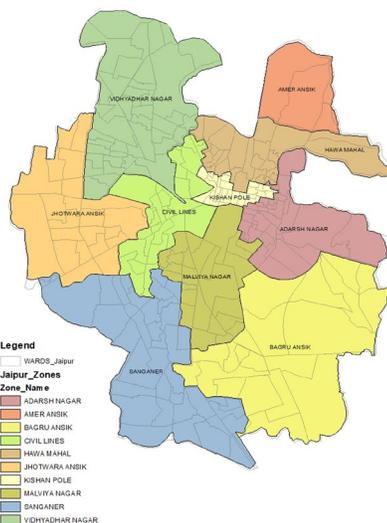
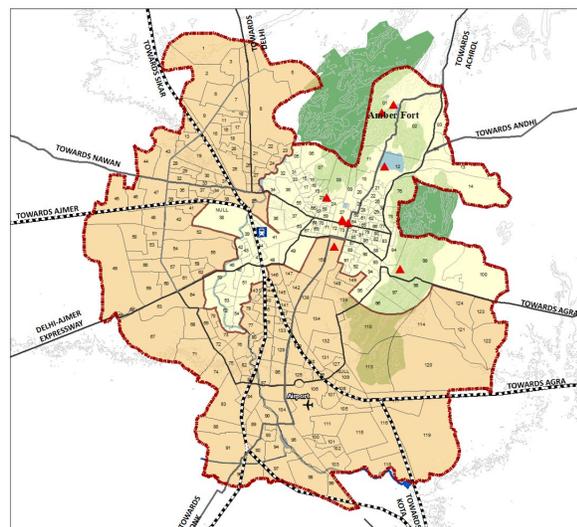
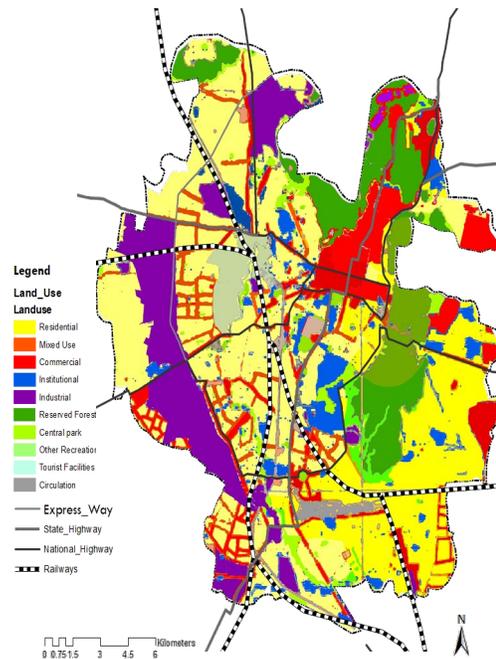


Figure 5: Administrative Divisions of Jaipur Municipal Corporation Ward Map.



**Figure 6: Jaipur Region Land Use Map 2025**

The decadal population growth and Climate Data -Temperature and Rainfall of the study region are presented in the Figure 2 and 3. The various Administrative Divisions of Jaipur Municipal Corporation, Jaipur Municipal Corporation Planning Zones and Jaipur Region Land Use Map 2025 are presented in Figure 4,5 and 6 respectively.

### Research Methodology

The detailed research methodology and data analysis carried out in this research work are as presented in the sequel:

### Data Analysis

The study incorporates the following indicators to establish link between land use and UHI in the system: (i) Land use concentration zones having residential area, Commercial, Mobility, Recreational, Public Semi Public, Agriculture, Industrial and Mixed Use as parameters; (ii). Built up characteristics has built area and population density as parameters; (iii) Land Use characteristics have energy consumption as parameter; (iv) Land use classification has built to open (paved/ circulation) ratio, built to green ratio, built to water ratio and (v) Land use and UHI relationship indicator has LST, NDVI, NDBI, LULC and NDWI considered as control parameters. The city level investigation has been carried out of the relation with the analysis; viz., The land use plan 2025 was used for the study which has designated land use zones depicted in the map. A set of cloud free imagery of summer season, Landsat-8 Enhanced Thematic Mapper Plus (ETM+) image acquired on 23<sup>rd</sup> March 2021 have been employed in the analysis. These Landsat images have been utilised for LULC classification and analysing LST. Landsat images are also considered for quantifying the parameters such as, NDVI, NDBI, NDWI for the Jaipur Municipal Corporation Area. Further, the other secondary data related to population, electricity consumption, land use zones collected from the Government agencies viz., Jaipur Municipal Corporation, Jaipur Development Authority and Jaipur Vidyut Vitran Nigam Limited (JVVNL).

### Land Use and Land Cover Classification

The LULC map has been generated for JMC for which four broad classes namely built up, water body, vegetation and barren land have been considered for classification of study area. These classes have been selected based on the pre-existing knowledge of the study area, as well as land use classes used in the city's master plan 2025 land use map. Band 1 -7 used for LULC map have been combined in one band as band composite. From this composite a false colour composite bands (5, 4, 3) created. Supervised classification carried out for which approximately 100

samples selected for classes considered for the classification. Further maximum likelihood algorithm was used to generate LULC map of the study region (Figure 16) for the year 2021. It has been observed that Land Use Land Cover of Jaipur city have changed drastically with green spaces being turned into different land uses.

### Land Surface Temperature

Thermal band 10 and 11 from satellite image retrieved from Landsat 8 was used to derive land surface temperature of the study area. Every object on the earth's surface emits electromagnetic thermal energy when its temperature above Absolute Zero (Kelvin). The satellite sensors receive this electromagnetic thermal energy using the thermal sensors and store them as Digital Numbers (DNs). Using the radiance rescaling factor, Thermal Infra-Red Digital Numbers can be converted to top of Atmosphere Spectral Radiance. The details of the calculations are furnished below:

$$L\lambda = ML * Q_{cal} + AL$$

Where:  $L\lambda$  = TOA spectral radiance (Watts/ (m<sup>2</sup> \* sr \*  $\mu$ m))

ML = Radiance multiplicative Band (No.)

AL = Radiance Add Band (No.)

$Q_{cal}$  = Quantized and calibrated standard product pixel values (DN)

Further, at spectral Radiance is converted to Brightness Temperature (TB).

Spectral radiance data can be converted to top of atmosphere brightness temperature using the thermal constant Values in Meta data file.

$$BT = K2 / \ln(k1 / L\lambda + 1) - 272.15.$$

Where BT = Top of atmosphere brightness temperature (°C)

$L\lambda$  = TOA spectral radiance (Watts/( m<sup>2</sup> \* sr \*  $\mu$ m))

K1 = K1 Constant Band (No.) and K2 = K2 Constant Band (No.)

After which NDVI using band 4 and 5 is done for the study area. Using the equation as mentioned, in the next step LST in kelvin has been estimated using the equation

$$E = 0.004 * PV + 0.986$$

Where, E = Land Surface Emissivity

PV = Proportion of Vegetation

PV is calculated using the formula:

$$PV = [(NDVI - NDVI_{min}) / (NDVI_{max} + NDVI_{min})]^2$$

Where, NDVI = DN values from NDVI Image

NDVI min = Minimum DN values from NDVI Image

NDVI max = Maximum DN values from NDVI Image

The *Land Surface Temperature* (LST) (Figure 9) is the radiative temperature derived using Top of atmosphere brightness temperature, Wavelength of emitted radiance, Land Surface Emissivity.

$$LST = (BT / 1) + W * (BT / 14380) * \ln(E)$$

Where, BT = Top of atmosphere brightness temperature (°C)

W = Wavelength of emitted radiance

E = Land Surface Emissivity

The map shows temperature range from 24°C to 39°C. Maximum area experiences higher temperature i.e., around 33°C to 39°C for maximum time of the year. Jaipur has very less waterbodies and green spaces leading to higher temperature in city core and peripheral areas.

#### *Normalized Difference Vegetation Index (NDVI)*

For Landsat 8 data NDVI calculation is done using band 4 and band 5. The values range from -1 to 1, where value in negative means barren or land with less vegetation and positive value means relatively good presence of vegetation (Figure 9).

For Landsat 8 data,  $NDVI = \frac{(Band\ 5 - Band\ 4)}{(Band\ 5 + Band\ 4)}$

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

#### *Normalized Difference Water Index (NDWI)*

The index uses Green and

Near infra-red bands of remote sensing images

The index uses Green and Near infra-red bands of remote sensing images. For Landsat 8 data NDWI calculation is done using band 5 and band 6 (Figure 16).

$NDWI = \frac{(Band\ 5 - Band\ 6)}{(Band\ 5 + Band\ 6)}$

#### *Normalized Difference Built Up Index (NDBI)*

The index uses Green and

Near infra-red bands of remote sensing images

The Normalize Difference Built-up Index value lies between -1 to +1. Negative value of NDBI represent water bodies whereas higher value represents build-up areas. For Landsat 8 data NDWI calculation is done using band 5 and band 6 (Figure 9).

$NDBI = \frac{(Band\ 6 - Band\ 5)}{(Band\ 6 + Band\ 5)}$

#### *Population density*

Map depicting population density is prepared with the ward wise data regarding population and area retrieved from JMC. The map (Figure 9) would talk about the major activities happening in which part of the city.

#### *Electricity Consumption and Carbon Emission*

Data from JVVNL, electricity board of Jaipur is collected in form of electricity of various electricity circles of the city. The data was then converted to ward wise data to generate map of electricity consumption. Carbon Emissions are retrieved from energy consumption by using the equation. Spatially the maps are shown in Figure 9.

Input value (in KWh/Yr) X 0.85 (Emission Factor) = Output value in (Kg of CO<sub>2</sub>)

Anthropogenic activities contribute to the Urban Heat Island (UHI) effect, resulting in increased energy usage for buildings due to rising temperatures, which necessitates greater reliance on cooling appliances. This heightened energy demand leads to elevated surface temperatures. As a result, the Jaipur city witnesses a yearly rise in energy consumption. Maximum energy Consumption is spotted in domestic use and least in mixed use. City level and land use energy consumption is shown in Figure 7 and 8 respectively. Higher carbon emission is seen in planning zone 'Bagru' which is majorly residential area.

Figure 7: City Level Energy Consumption

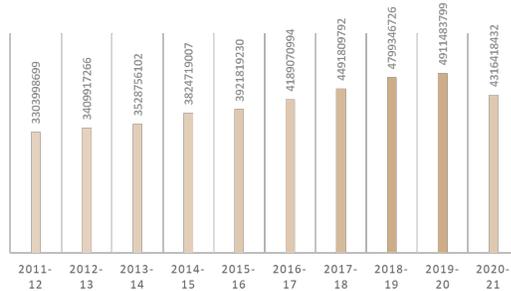
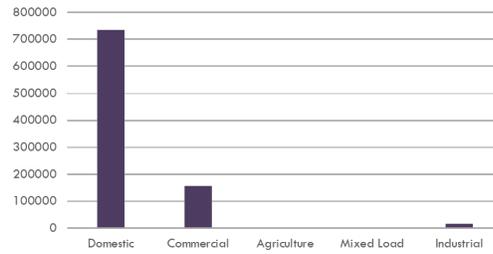
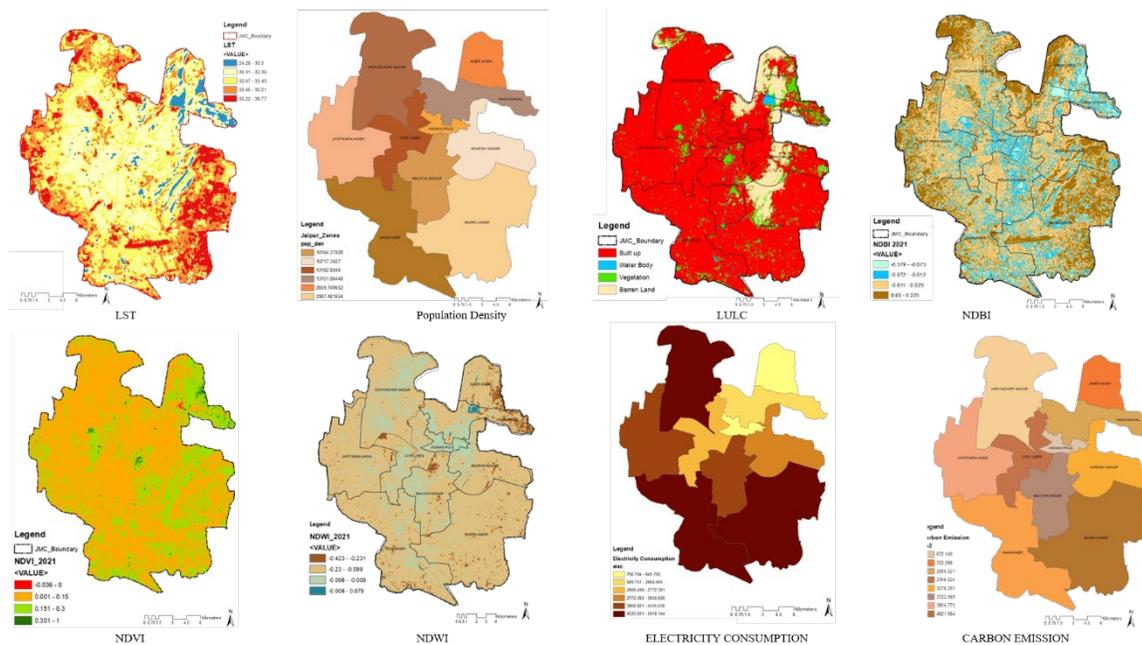


Figure 8: Land Use Energy Consumption



All the control parameters have been transformed spatially and are Spatial distribution and temporal dynamics Maps with Control Parameters in the study region as presented in the Figure 9.

Figure 9: Spatial distribution and temporal dynamics Maps Control Parameters in the study region.



**Temporal trend and correlation analysis for LST, UHI area and land use indices**

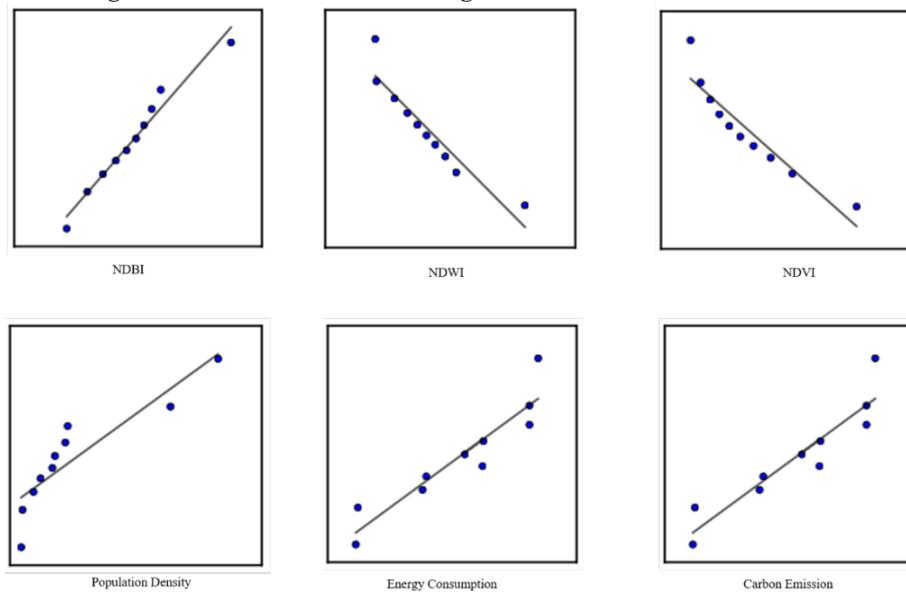
Correlation analysis is a statistical approach for establishing the link between two variables and measuring the strength of the linear relationship associated with them. A high correlation indicates a strong association between the two variables, whereas a low correlation indicates a poor relationship between the variables. Based on the direction, the degree of correlative measure can be categorised as Positive, Zero or Negative correlation. If the trend of a variable is positive and almost similar to another variable, there may be possibility to have positive association of each other and such association can provide positive correlation coefficient; and if the trend of a variable is positive and almost negative to another variable, there may be possibility to have negative association of each other and such association can result in negative correlation coefficient. To derive the relationship between dependent and independent variables, performed a line diagram and correlation study using the mean value of data of the parameters for the year 2021.

To derive the relationship between dependent and independent variables, performed a line diagram and correlation study using the mean value of those data for 2011 to 2020.

The parameters of the study are quantitative in nature which would make it easy to understand the results. At city level spatial relation was established between the land use parameters and land surface temperature to understand the nature of association. The relationship between LST and individually with each parameter namely population density, NDVI, NDWI, NDBI, Electricity Consumption, Carbon Emission was captured through correlation analysis. Population density and land surface temperature has *Positive Correlation of  $R^2 = 0.78$* . Residential area, Industrial Area in the city having maximum population density confirms higher surface temperature. With more human activities in any region, it will lead to anthropogenic heat leading to rise in surface temperature in the system. Spatial variations in LST occur due to complexity of land surface—combination of impervious surface materials, vegetation, exposed soils as well as water surfaces. The increase in built up leading to high surface temperature. Even the topography, hilly region also give rise to surface temperature as it piles heat in daytime and radiates in nighttime. Quantifying and analysing the patterns and effects of building density on LST can help urban planners to understand the effects of climatic factors on urban development, design reasonable thermal environments to mitigate the effects of UHI on climate change and formulate global climate change mitigation strategies. *Positive Correlation of  $R^2 = 0.96$*  between built density and land surface temperature was witnessed in study region. The city has major built up in areas which comes under residential, commercial, institutional land use zones and depicting higher temperatures.

The *Negative Correlation  $R^2 = 0.87$*  between vegetation index and land surface temperature was observed. Green spaces help in absorbing the heat as well as long radiation avoided because the ray gets deflected and doesn't get absorbed. Hilly regions also giving rise to UHI, as the surface of rock will absorb heat in daytime and radiate in nighttime. With the green spaces being replaced by built mass due to urbanization, city experiencing rise in temperature. Water bodies, though have a little thermal response are known to be best radiation absorber and provide evaporative cooling in which the water vaporizes, as the solar radiation reaches the water surface and remove the heat, thereby cooling the surrounding features. The water bodies are drying or are being replaced by built mass due to urbanization, city experiencing rise in temperature. There is Negative correlation between water index and land surface temperature. Energy consumption and land surface temperature demonstrates *Positive Correlation of  $R^2 = 0.86$* . Land use zones having Residential area, Commercial has more surface temperature and as well as high energy consumption. It can be argued that land use plays vital role in controlling surface temperature, thereby regulating the UHI effect in each area. Change in landscape due to urbanization replaces open land and vegetation in the form of permeable surfaces with concrete surfaces which are impermeable and dry in nature which leads to the formation of urban heat islands whereby urban regions experience warmer temperatures than their adjacent rural surroundings. The heat island effect increases energy consumption in urban areas along with other negative impacts. *Positive Correlation of  $R^2 = 0.86$*  between Carbon Emission and land surface temperature has been observed. The residential zone has higher carbon emission. Carbon emission concentration led to greenhouse gas emission rising the surface temperature of the surrounding and thus leading to increase UHI effect in the region. The urban space is also responsible for the increase in the anthropogenic carbon dioxide emissions, generated due to the burning of fossil fuels for heating and cooling effects, due to certain industrial processes and, also because of vehicular transportations. A correlation matrix was generated using analysis tool in Microsoft Excel to get relation amongst all the parameters. Since energy consumption and carbon emission are strongly correlated one of the parameters is not used for the matrix. Results of the analysis reveals that there is a correlation between the parameters. At city level all the parameters have strong association with land surface temperature. It can be implied that changing the values of any of the parameters would change the land surface temperature in the city. The Correlation among the Control Parameters with LST is as presented in the Figure 10 and Table 1 respectively.

**Figure 10: The Correlation among the Control Parameters with LST**



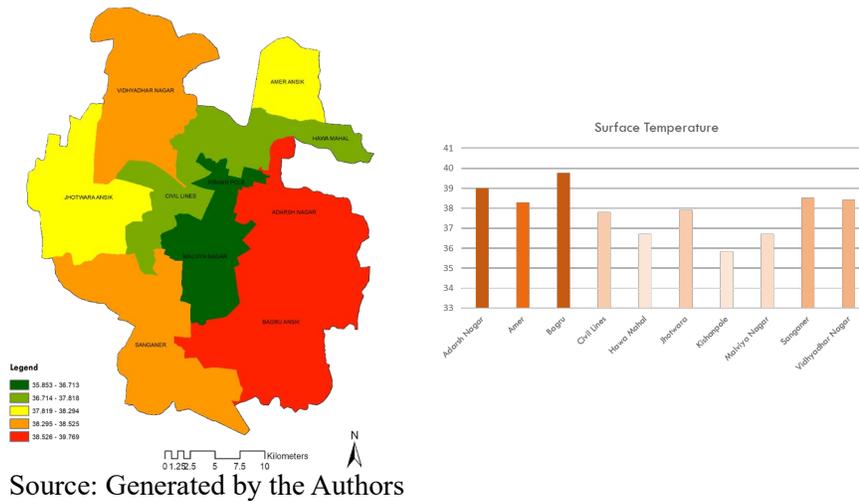
**Table 1: Correlation among Control Parameters**

	LST	NDVI	NDWI	NDBI	ELECTRICITY	CARBON EMISSION	POPULATION DENSITY	CIRCULATION
LST	1							
NDVI	-0.875	1						
NDWI	-0.893	1	1					
NDBI	0.964	-0.150	0.444	1				
ELECTRICITY	0.864	0.281	0.250	0.704	1			
CARBON EMISSION	0.864	0.019	0.250	0.704	1	1		
POPULATION DENSITY	0.780	0.0198	-0.398	0	0.501	0.501	1	
CIRCULATION	0.727	0.0890	0.596	0.479	0.540	0.540	0.151	1

Source: Compiled by the Authors.

The average surface temperature in Jaipur Municipal corporation ranges from 35°c to 39° c. Hotspot lies in Adarsh Nagar and Bagru area. Temperature and Hotspot Zones in the Study Region is shown in Figure 11.

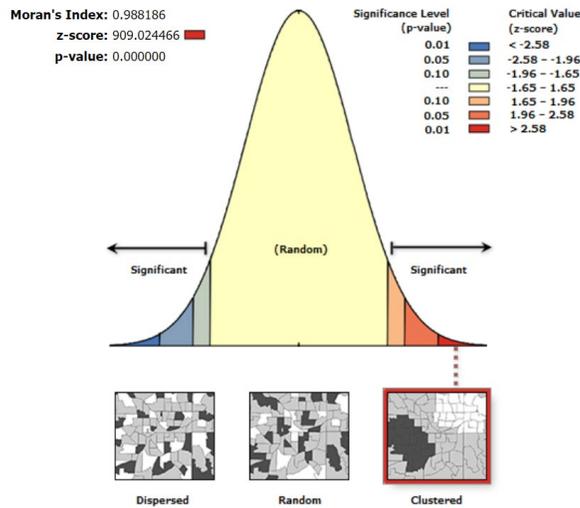
**Figure 11: Temperature and Hotspot Zones in the Study Region**



**Spatial Autocorrelation**

Spatial Auto correlation was carried out for land surface temperature to find its impact on nearby areas. The Moran’s *I* statistic is the correlation coefficient for the relationship between a variable (like income) and its neighbouring values. *Y* coefficient of the equation is land surface temperature. Spatial Auto correlation as shown in Figure 12 was run using the land surface temperature values by making it into points. It shows clustered value which means it would affect the neighboring values and would form a cluster. The outcomes revealed that there is a relation between land surface temperature of one area with land surface temperature of another area. It could be inferred that regulating the temperature in one region and maintaining it might help to achieve lower temperature in neighbouring areas as well. Subsequently, geographically weighted regression was performed to perform Multiple Regression.

**Figure 12: LST Spatial Auto Correlation**



### Geographically Weighted Regression (GWR)

GWR is a local spatial statistical technique used to analyse spatial non-stationarity when the input variable differs from location to location. It provides a local model to predict an independent variable or process by fitting a regression equation to the available datasets of dependent variables. In the study, the researcher utilized the Geographic Information System (GIS) tool's GWR command to examine the correlations between different parameters. Values are normalizing to get results with same units as the data has different unit sets and the result would not come correct. Electricity Consumption is not used for geographically weighted regression as its highly correlated with carbon emission in the system.

**Table 2: Values of Control Parameters which decide the functions of the system**

	Units	1	2	3	4
NDVI	Index	0.303 -1	0.151 - 0.3	0.001-0.15	(-0.036) - 0
NDBI	Index	(-0.379- (-0.073))	(-0.072 -(-0.012))	(-0.011 -(-0.029))	0.03-0.225
NDWI	Index	(-0.111) – (0.079)	(-0.156) – (-0.112)	(-0.209) – (-0.157)	(-0.423) – (-0.21)
Electricity Consumption	KWH	0-1510	1511-3020	3021-4530	4530-6040
Carbon Emission	Kg/KWH	0-1320	1320-2640	2640-3960	3961-5280
Population Density	Persons per sqkm	0-216502	216503-279755	279756-345058	345059-2174139
Circulation	sqm	0-1697204	1697204-3394408	3394408 - 5091612	5091612 - 6788816
LST	Index	24.28-30.78	30.79-32.72	32.73-34.73	34.74-39.77

**Table 3: Normalised Control Parameters Value at Planning Zone level**

Planning Zones	LST	NDVI	NDWI	NDBI	ELECTRICITY	CARBON EMISSION	POPULATION DENSITY	CIRCULATION
Adarsh Nagar	3	2	3	3	3	3	3	3
Amer	2	2	4	2	1	1	1	1
Bagru	4	3	4	4	4	4	2	4
Civil Lines	2	3	2	2	2	2	3	1
Hawa Mahal	2	3	2	2	2	2	4	2

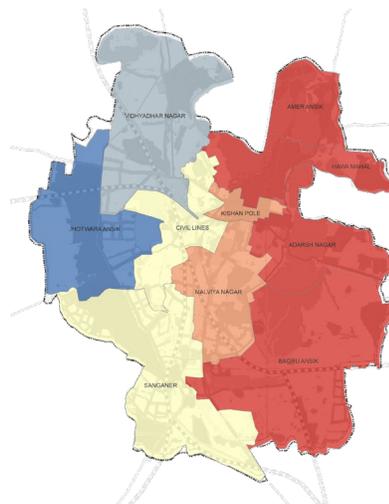
Jhotwara	3	3	3		4	3	3	2	1
Kishanpole	2	3	2		3	1	1	2	1
Malviya Nagar	2	3	2		3	3	3	3	1
Sanganer	3	3	4		4	4	4	4	3
Vidhyadhar Nagar	3	2	2		3	4	4	4	1

The values of Control Parameters which decide the functions of the system are presented in Table 2 and 3. The GWR results are finished in Table 4 and 5 and Regression shown in Figure 11 depicts higher correlation between the variables in the Planning Zones which are indicated in red colour. Change in any one of the parameters i.e., independent parameter will have considerable impact on the dependent parameters in the system.

**Table 4: Multiple Regression R Square Values**

Regression Statistics	
Multiple R	0.95966492
R Square	0.920956759
Adjusted R Square	0.429536942
Standard Error	0.340485077
Observations	10

**Figure 13: GWR Map, Geographically Weighted Regression**



**Table 5: Results of Multiple Regression Analysis**

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept (a)	2.229513109	1.060672199	2.101981282	0.126326743	-1.146019213	5.60504543
NDVI (x1)	-0.24772	0.289961266	-0.854304986	0.455728805	-1.170501517	0.675070805
NDWI (x2)	-0.12202	0.21327512	-0.572136458	0.607291391	-0.800759091	0.556714147
NDBI (x3)	0.208539	0.284687292	0.732520669	0.516893468	-0.697462695	1.114541347
ELECTRICITY (x4)	0.379101	0.229740624	1.650126637	0.197480803	-0.352036077	1.110238324
Carbon Emission	0	0	65535	#NUM!	0	0
Population Density (x5)	-0.27064	0.195848905	-1.381864778	#NUM!	-0.893915329	0.352641921
CIRCULATION (x6)	0.271985	0.155178798	1.752720231	0.177936535	-0.221863174	0.765833211

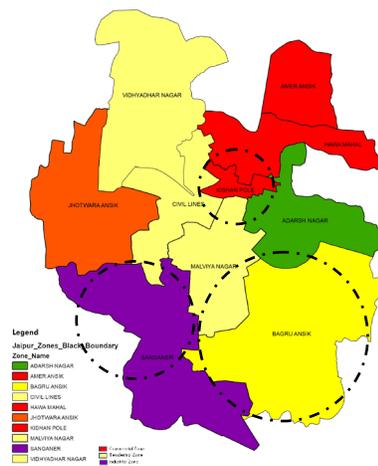
Bagru, Adarsh Nagar, Hawa Mahal, Amer Ansik all these areas have higher correlation.

$$Y = a + (-0.94)x_1 + (-0.82)x_2 + (0.60)x_3 + (0.77)x_4 + (0.67)x_5 + (0.77)x_6$$

Y is the dependent parameter i.e., land surface temperature X values are the independent parameter changing which would affect the y value.

### Land Use Zones

For the study at grassroot level, which is done on planning zones of Jaipur city dominant land uses from the land use map 2025 having commercial, residential, and industrial characteristics have been selected for detailed investigation. Table 6 represents the percentage of land uses. Land use having maximum dominate character based on the percentage of land use area selected for further research to understand role of land use on UHI effect which is earmarked in Figure 14.

**Figure 14: Selection Planning Zone in the Study Region**

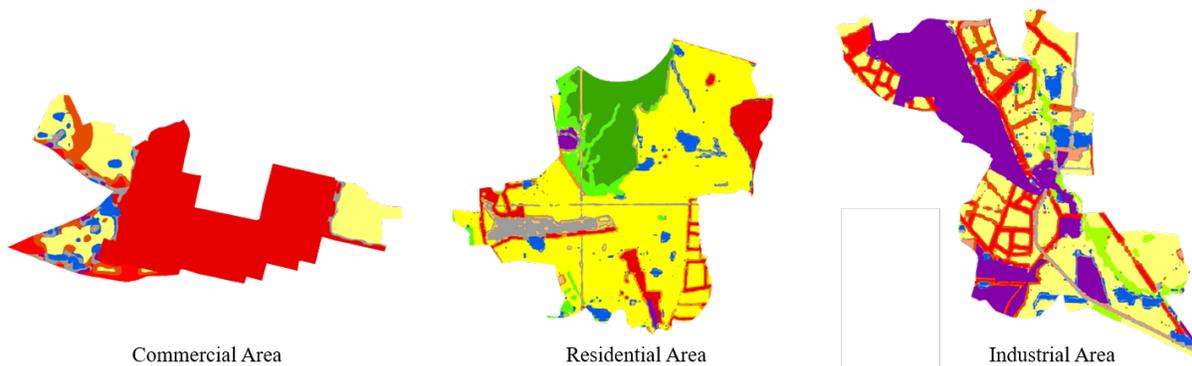
**Table 6: Planning Zone Land Use distribution in Percentage**

Commercial	Percentage	Residential	Percentage	Industrial	Percentage
Hawa Mahal	29%	Bagru	59%	Sanganer	33%
Kishanpole	46%	Civil Lines	52%		
		Vidhyadhar	52%		

For Commercial Land Use Zone Kishanpole located in walled city of Jaipur was selected as it has predominated land use zone of commercial. Looking at how the parameters are behaving in the zone from the table, circulation area, green space accounts for low percentage and parameters such as population density is on higher side. Majorly the population density is because of the floating population which comes there for shopping or as tourists. The energy consumption of the area is also less in comparison to other places in the study region. For Residential Land Use Zone Bagru was selected, located near hill on East side which will also has an impact on UHI effect. Good percentage of reserved forest area and recreational space is present helping in lowering the surface temperature. High population and high built density are observed in the zone.

Sanganer is the major industrial area in Jaipur city. It has wider roads for transportation of materials and goods. Use of heavy machineries lead to high energy consumption and thus more carbon emissions in the system. Land Use Maps of the selected Planning Zones in the study region is presented in Figure 15.

**Figure 15: Land Use Maps of the selected Planning Zones**



**RESULTS AND DISCUSSION**

**Contribution of Land use factors to LST dynamics**

Grassroot level analysis taking into consideration the planning zones was carried out. Identification of correct set of parameters to regulate the surface temperature can be established using the fishnet analysis in ArcGIS Fishnet grid of 250m by 250m was generated for 3 land use zones i.e. residential zone, commercial zone, and industrial zone. Feature class created with a net of rectangular cells using the create Fishnet tool. To make a fishnet, it requires three

**Table: 7 Land Use Zone Percentage**

Army Area	6%
Circulation	1%
Commercial	46%
Industrial	0%
Institutional	2%
Mixed Use	6%
Other Recrea	1%
Reserved For	0%
Residential	37%

Commercial Area

Circulation	8%
Commercial	8%
Industrial	1%
Institutional	4%
Mixed Use	4%
Other Recreational	6%
Reserved Forest	12%
Residential	59%

Residential Area

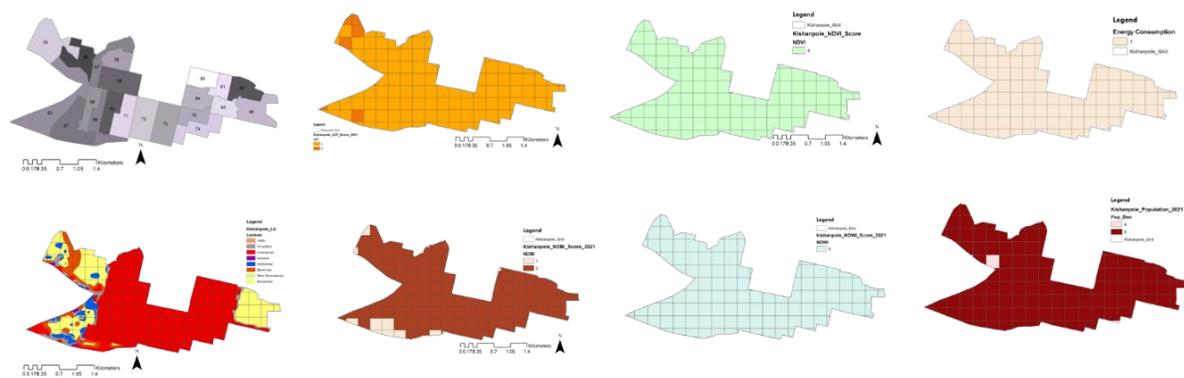
Circulation	5%
Commercial	25%
Industrial	32%
Institutional	4%
Mixed Use	4%
Other Recreational	4%
Reserved Forest	0%
Residential	26%

Industrial Area

pieces of information: *the fishnet's geographic extent, the number of rows and columns, and the degree of rotation.* Analysing through grids would give better understanding of the situation and will help in concluding most suitable mix of parameters which could be used to regulate the temperature. Values are normalised based on respective standards for the parameters to get all the values in same unit. These values are used to run the fishnet analysis using ArcGIS. For each land use maps are extracted with grids to better understand the results.

The land surface temperature of the Kishangarh planning zone ranges from 31°C to 34°C, which comes under moderate and less comfort level. The Grid Shows rise in temperature for the area as the vegetation cover is very less. The NDVI index lies between 0.00 to 0.14. The NDBI index lies between -0.02 to 0.03. Higher temperature is observed where built density is more as compared to other area. The NDWI index lies between -0.17 to -0.05. It has been observed that there is less energy consumption in the area. Positive correlation is there in energy consumption and land surface temperature. It has score of 1 which concludes the planning zone has very less energy consumption and temperature because of which is very comfortable. Circulation space is 6% which is adding to the UHI effect because of the impermeable surface. Green accounts for only 1% which is main cause of surface temperature as there is strong negative correlation between the parameters.

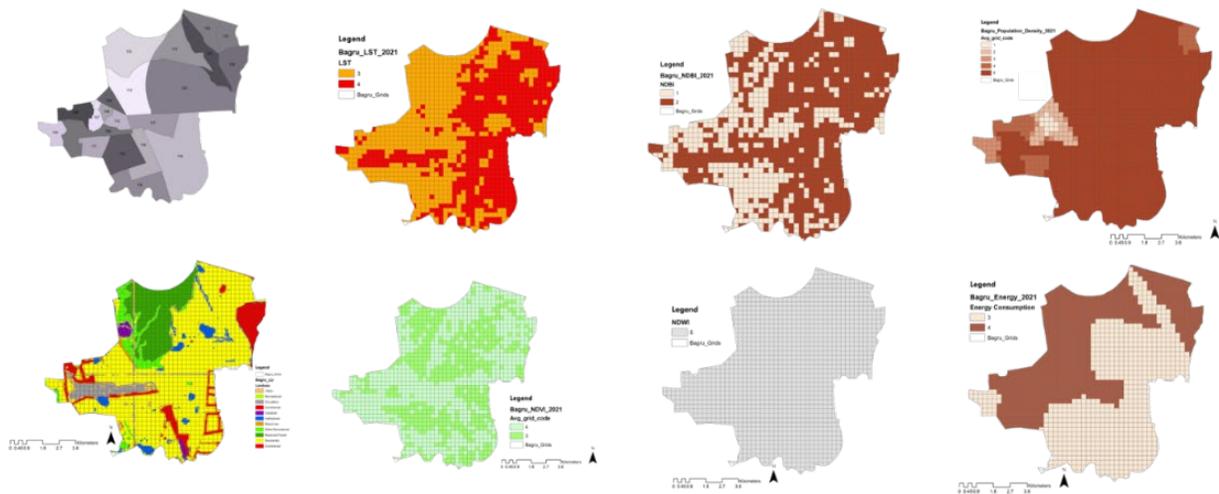
**Figure 16: Commercial Zone Fishnet Analysis Maps**



The land surface temperature of the Bagru planning zone ranges from 29°C to 38°C, which comes under moderate and less comfort level. Serving as the residential zone in the Jaipur Municipal Corporation, Bagru has small scale industries as well. It has reserved forest area in the North direction, but the area also has high residential zone. The NDBI, NDVI & NDWI index lies between -0.09 to 0.06, 0.05 to 0.24, -0.27 to -0.05 respectively. The Grid Shows rise in temperature for the area where built density is more as compared to other area. The surface temperature in the North direction is less as compared to other areas as there is reserved forest area. Population density is more because of residential land use dominant in the planning zone. The area which is under reserved forest also has higher population density because of slum encroachment in the area. But even though the population density is higher in that part, it still has less temperature in comparison to other areas. The green reserved forest areas and the green spaces in the planning zone are regulating the temperature. Energy consumption of the planning zone lies between 225KWH – 340KWH.

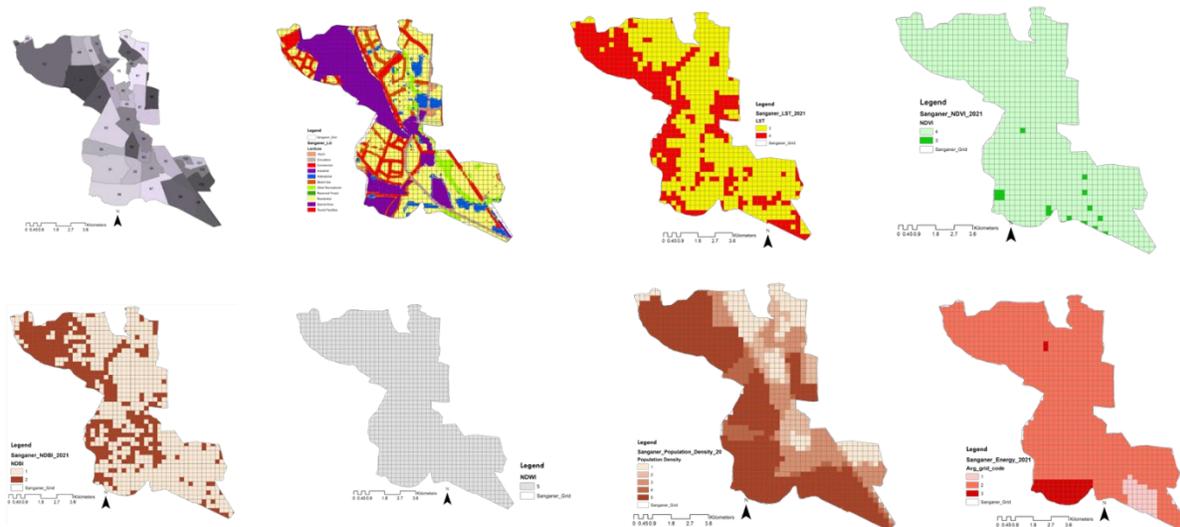
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**Figure 17: Residential Zone Fishnet Analysis Maps**



Sanganer planning zone has dominant industry land use zone and serves as the one of the major industrial areas of the city. Circulation space will be more in industrial area as it must carry heavy vehicles. Energy consumption will be majorly from industrial equipment and residential areas. Industrial area shows more land surface temperature around 33°C to 37°C which comes under uncomfortable thermal zone. The NDVI, NDBI & NDWI index lies between 0.03 to 0.24, -0.11 to 0.07, -0.26 to -0.03 respectively. There is scarcity of water bodies in the area and because of which the surface temperature is rising. The score of population density lies between 1 to 5 which means higher persons per hectare. Energy consumption of the planning zone lies between 98KWH – 290KWH. It has been assigned score as 1, 2 and 3 based on the normalized logic. As the area has dominant industrial land use zone, it would have more surface area of the buildings exposed to the heat. This would absorb the heat and radiate in form of long wave radiation in the nighttime. The zone has very less green cover and thus short-wave radiation would not happen.

**Figure 18: Industrial Zone Fishnet Analysis Map**

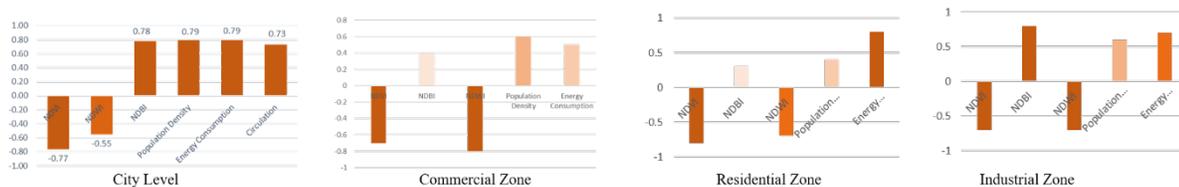


The Fishnet Analysis has been carryout and Maps generated through, Commercial, Residential and Industrial Land Use Zones have been compiled and as presented in Figure 16, 17 and 18 respectively. Land Use Zone Percentage furnished in Table 7. The results obtained from various analysis it can be inferred that land use affects the surface temperature of any area leading to UHI effect. At city level all the parameters value of correlation lies above 0.7, for the parameters including vegetation index, water index, built density, population density, energy consumption, circulation area indicating great association with the land surface temperature.

At *Planning Zone level*, surface temperature varies for different land uses for each land use zone which is commercial, residential, and Industrial. Vegetation Index and Water index have strong negative correlation with land surface temperature. Whereas built density and energy consumption have positive correlation but are not that much correlated. Interventions in these parameters might not affect the much of surface temperature. Population density has positive correlation. Energy Consumption is high in the planning zone, as this is residential zone where home appliances would be consuming more energy for cooling or heating. The suggested interventions could be recommended for the green cover and water body of the planning zones. Planning zone or Wards level interventions can be suggested where detailed planning could be done to regulate the microclimate of the planning zone.

The Planning Zone– Sanganer has strong correlation with all the parameters. Vegetation Index and Water index have strong negative correlation with land surface temperature. Other parameters such as built density, population density, energy consumption are positively correlated. It indicates changing these parameter values with interventions in each would help in altering the temperature. The zone is industrial zone and confirms higher surface temperature which could be regulated with effective recommendations. Correlation of Land Use Indices are presented in Figure 19.

**Figure 19: Correlation of Land Use Indices**



At City Level long-term strategic approach to the physical greening of urban should be adopted which would provide an opportunity of a holistic vision for the whole city. Developing the riverfront or the present water bodies so that it would help in regulating the temperature in the city as it runs throughout the city.

At Planning Zone level, in the commercial area circulation space can be reduced to get space for introducing green belt. Light vehicle on streets or pedestrian friendly streets should be proposed so as control the impervious surface as well as this would reduce the carbon emissions from heavy vehicles. Pervious and high albedo surfaces should be incorporated which would help in easy heat transfer and thus at night the surfaces would not radiate heat in the surrounding giving rise to Urban Heat Island Effect in the zone. In the residential zone more trees can be planted which regulate the temperature and thus less load on the electrical appliances. Proposing city level or ward level parks and gardens will help in regulating the heat in the land use zone. With reduction in surface temperature by incorporating green and blue infrastructure, the load on electrical consumption would be less as less energy would be required for cooling the buildings. As the residential zone will have more surface area of the buildings where heat could be stored, majorly green areas and use of material which radiates back heat will be strong modification which could be done to ease out the surface heating condition. Along with this reduction in energy consumption will lead to less carbon emissions and thus contributing to lowering the temperature.

In the industrial zone majorly, the heavy machineries require more energy to function, this give rise to high energy consumption and in turn will lead to carbon emissions rising in the area. With plantation of more trees and introducing water bodies along with preserving the city level present water bodies can regulate the temperature and thus less load on the electrical appliances. The circulation space should be so designed that there are trees or soft landscape areas incorporated in the design to help in reducing heat absorption in the daytime and thus mitigating the heat island effect in the zone.

### **Linear relationship analysis of land cover indices and LST**

The urban-suburban surface temperature differences vary for different urban areas based on their surface characteristics and fabric type. It is crucial to evaluate and understand the temperature trend and land cover variability within the urban area, to assess urban overheating and planning corresponding mitigation strategies. The presence of vegetation impacts the balance between latent and sensible heat fluxes, contributing to cooling effect on LST through transpiration. However, our linear regression analysis reveals a weak correlation between NDVI and LST, contrary to the expected strong association of higher vegetation cover with lower temperatures, as linear regression may not effectively capture the complex non-linear interactions present in the data. In contrast, the more flexible and adaptive GB model, reveals a negative relationship between NDVI and LST in this case-study. This suggests that as NDVI exceeds a certain threshold, LST tends to decrease. Factors such as vegetation types, vegetation stress, or heterogeneous land cover within the study area can contribute to these non-linear patterns. The relationship between vegetation and temperature highlights the crucial role of moisture availability and healthy vegetation in controlling surface heating and cooling effects. In the absence of urban vegetation and irrigation, cities can become a source of sensible heat.

Urban areas exhibit distinct characteristics that contribute to higher daytime surface heat storage. Factors such as lower surface albedo and emissivity, greater heat conductivity, and larger heat capacity play a role in this phenomenon. The intensity of radiation trapping increases with the density of built-up structures. NDBI values serve as a useful indicator for identifying densely built urban regions. There is a significant positive correlation between NDBI and LST. However, the temporal pattern of NDBI aligns with that of NDVI in the system. This implies a negative relationship between vegetation-induced cooling effects and spatial variations in built-up areas, consistent with findings from other studies.

### **Land cover indices and their cumulative impact on LST.**

The analysis, using the GBR model, showed that the examined parameters collectively accounted for changes in LST. The impact of land cover variables on surface temperature differs with the changing climate. While NDBI was the main contributor to surface temperature in most years, NDVI became the most significant variable in certain years. Even though NDVI has a relatively lower influence on surface temperature in urban settings, it still plays a crucial role. This study differs from previous ones that relied on linear regression, or focused on urban-suburban differences instead of intra-urban variability over a long period. The findings are consistent for the summer season, and further research can explore seasonal variability. The study confirms that NDBI and NDVI are significant factors contributing to surface temperature in urban areas with similar settings and climate, aligning with previous studies. This highlights the importance of land management decisions, such as urban greening initiatives and limiting built-up areas, to mitigate urban heat impacts in Imola and cities with a similar climate.

This study examines urban land cover characteristics and their response to heat during summer months over a long period. The findings have implications for assessing urban overheating and implementing land cover planning to enhance urban thermal environments in similar climate regions. However, the study has limitations, including its focus solely on daytime surface temperatures and lack of consideration for diurnal variability. To expand the study's scope, a global time-series analysis could be conducted to understand the influence of different land variables on temperature across various climate zones and seasons within a climate change scenario. Additionally, future research could explore advanced machine learning techniques to address missing data and employ multiple regression to assess the relationship between temperature, UHI, and independent variables within complex urban environments.

### **Conclusion**

Urbanization greatly correlates with land use land cover (LULC) dynamics, which further associated to changes in land surface temperature (LST) and urban heat island (UHI) intensity, in the system. We aimed to enhance the understanding of the impact of land cover changes on LST dynamics during the summer season in complex urban settings with a temperate and subhumid climate. The transformation of land cover classes reveals a clear relationship between increasing temperature and the shift from permanent crops and green areas to agricultural arable land and ultimately to built-up areas, leading to an expansion of the UHI effect. For estimating localized surface UHI in urban areas, it is crucial to have detailed LULC map in addition to temperature data. However, if the main objective is to compare UHI magnitudes across different locations without considering the underlying physical mechanisms, computing the SUHII based on temperature thresholds is more appropriate. The study captures the complex relationship between land cover indices and LST, demonstrating the quantitative and qualitative contributions of these indices to LST variability. The results highlight the significant role of NDBI in LST dynamics during the

summer season in changing climate scenario, while also acknowledging the considerable importance of NDVI. Thus, the land use-UHI nexus varies over time, influenced by the rate of urbanization and the green-blue to grey ratio of the area.

The analysis of the control parameters including vegetation index, water index, built density index, energy consumption, land use land cover and carbon emissions useful instrument to enable the urban planners in analysis the surface heat conditions. The research study incidental to Land Use planning, and plays vital role, in regulating the surface heat towards minimising the UHI effect. Urban Planners could utilise these aspects, controlling major development happening within one part of the city, giving emphasis to green and blue infrastructure as well as rethinking about the bylaws to regulate the build density in the system. Policies to conserve the water bodies and provide a network of water bodies can help in promoting conducive to temperature of the zones, by regulating microclimatic conditions. The study revealed that the activities characterise the land use in the city, thus, the solutions also lies in the characteristics of the particular zone. For example, commercial area certain set of parameters would work and for industrial and residential area different parameters associated with functions. The scale of investigation at city level the combination of parameters would be varying from the planning zone level.

The study is significant for small municipality's settings at grassroots level, where urban planning decisions impact the local climate and residents' well-being. The findings offer insights for urban planners, policymakers, and municipal development authorities to guide future development strategies. Maintaining a balance of natural vegetation is crucial in mitigating urban heat. Underutilized land areas can be transformed into green public parks with ponds and wetlands. Emphasizing and promoting policies for conserving natural vegetation, including community forests and water bodies, will contribute to a healthier and safer urban environment, enhancing residents' quality of life.

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