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Does High Rise Building Help Mitigate the Urban Thermal Environment? Influence Of Densification of City on Land Surface Temperature- A Case Study of Ahmedabad

Rachita Lal

Ph.D. Student, CEPT University, Ahmedabad

Abstract:
Increased temperature in urban areas brings about various problems and thermal discomfort. Many studies (Imran et al., 2022) (Li et al., 2009) focused on detecting the effects of land cover patterns on Land Surface Temperature (LST) using satellite imagery and remote sensing tools and subjective study (People's perception) of the thermal environment. A very limited number of studies (Wang & Xu, 2021) (Yang et al., 2010) have focused on the different building density groups and their relation with respect to LST at the local level. This study focused on the specific land cover pattern, i.e., built-up and vegetation in different localities of Ahmedabad, to explore the relationship between the LST with building density (High-rise, mid-rise, low-rise) and vegetation ratio (High- more than 30%, low-less than 30%). By using quantitative meteorological data and satellite imagery (Landsat-8 & Landsat 5) an experimental study will be conducted to observe the impact of building density groups and vegetation on the local thermal environment. This study will help prove that high density in combination with high greenery coverage can mitigate the Urban heat island effect at Neighborhood scale. The study will also enhance the understanding of LST at a micro-scale and gives insight into mitigating the urban heat intensity through urban design and vegetation.

Keywords: Land surface Temperature (LST), Thermal environment, building density, Land-use Land-cover (LULC), green space coverage

1. Introduction:

Rapid urbanization is a phase faced by many cities, and creating geographic expansion and sprawl development beyond the administrative boundary; as a result, it generates more carbon footprint, increases unemployment, vehicular traffic, energy demand, and changes the natural landscape of a city to an artificial landscape. Because of sprawl and city expansion. One of the immediate effects of changing a natural environment to an artificial one is an increase in surface and air temperature. The urban heat island (UHI) phenomenon is the common name for elevated temperatures in metropolitan areas. The primary cause of this phenomena include construction material with high heat capacities and low solar reflectivity, such as asphalt; concrete reduces turbulent heat transfer because of the geometry of an area and reduce latent heat loss by evaporation because the natural green surface has been replaced by heart surface and increase human cost heat emission into the atmosphere of the urban area.

UHI has been posing critical problems to the people, as abnormal temperature increases significantly influence the local climate, increase water and energy consumption at the local level, and high heat Stress causes harm to the resident's physical and mental health. The urban environment and the quality of life in urban cities that can achieve a sustainable community is one of the primary goals of urban planning.

Therefore, a discourse related to the sustainable urban form was present among the urban planner, policymakers, environmentalists, and private developers.

During the 1970s and 1980s, urban planning methods were founded on low-density development, and reliance on the automobile and single-use construction were known to encourage Urban sprawl and unplanned development, which created negative consequences such as biodiversity loss, water and air pollution, and social inequality (Gonçalves & Umakoshi, 2010) (Ewing, 1997; Squires, 2002). After the 1990s, the Brundtland Commission was published, promoting sustainable development that works on three pillars, i.e., economic, social and environmental. The Term ``compact city" was first coined in 1973 by George Dantzig and Thomas L. Satty to achieve the more efficient use of resources (Bibri et al., 2020); however, after Brundland Commission, the compact city approach was seen as a sustainable urban planning approach in European countries in the late 1990s(Chen et al., 2008). In essence, compact City Development denotes mixed land use, higher density development, increasing accessibility, and preservation of open and green space. The major factor of a compact city is that it densifies the city area limiting urban sprawl. Research shows that sprawl developments generate more land surface temperature than compact City Development *(Stone et al., 2010) (Garden & Jalaludin, 2009)*.

Transit-oriented development (TOD) approach is part of Compact city development. TOD approach in urban planning focuses on compact mixed-used development and transit corridors such as metro, rail, and BRTS corridor development for better accessibility. Many cities are adopting TOD as a planning measure to create urban development patterns that facilitate public transit, walking, and cycling as primary modes of transport and support vibrant, diverse, and livable communities. Researchers argue that promoting TOD increases mixed land use, preserves open space, and improves public Background transit and street connectivity, which enhances the residence's quality of life, protects the natural environment, and provides an economically resilient surrounding (Mobaraki & Oktay Vehbi, 2022). Although the TOD approach benefits the city, there is a dispute related to the temperature increase.

TOD densifies the city; many studies have proven that if a 1 unit increase in built-up land increases 14 units in the LST (Yuvaraj, 2020). Also, narrow streets and wrong budding orientation increased the LST. As a result, many researchers suggest that limiting the densification of a city is the best way to mitigate the urban heat island effect. So the question arose whether the densification of the Urban Development principle is a better way to achieve urban resilience.

The study, therefore, investigates the extent of urban forms such as building height, density, and ground coverage and their influence on the land surface temperature. To study this, Ahmedabad city was taken, as it is one of the cities where the TOD approach was first implemented.

2. Background

2.1. Compact city development framework

India is experiencing tremendous urbanization, migration, and population increase. As a result, the land use along the motorway, railway line, next to the industrial region, and on the fringes of the city border is changing, and the city is growing daily. Sprawl development refers to this widespread and uncontrolled construction beyond the city limits and along the main transit corridors (Theobald, 2001) (Shawly, 2022). It is typically described as the abrupt, discontinuous, spatially scattered, and fast growth of low-density regions. Urban sprawl is a major problem for many nations since it harms the environment, communities, and wildlife habitat loss. It also lowers water quality by increasing surface runoff, which carries pollutants like oil and other pollutants into the water supply. The significant impact of sprawl development is changes in land use land cover (LULC), and natural landscape changes into the built-up coverage.

In this regard, a compact city development strategy encourages greater density, the preservation of open space, mixed-use development, revitalization of downtown and central business areas, as well as extensive use of public transportation (Deilami & Kamruzzaman, 2017). High density and public transit are two of the traits of compact city development that have received the most attention to date. *To increase built area and residential population densities; to intensify urban economic, social, and cultural activities; and to manipulate urban size, form, structure, and settlement systems in pursuit of the environmental, social, and global sustainability benefits derived from the concentration of urban functions, according to Rod Burgess's provisional definition of the compact city approach.*

Le Corbusier's utopian vision of a city with high-rise structures off the ground and quick mass transit networks, the radiant city, is where the idea of a high-density compact city was first conceived. As per him, the modern city's evil was its development density(Gonçalves & Umakoshi, 2010) (Hall, n.d.). Corbusier's solution is to demolish the existing city and build a new city with high-rise towers consisting of the density of development, and 70-80% of the land can be used as a green city development. The modernist theory for these cities is to develop geometrically with high-rise towers, which will cater to all the density. However, it was criticized by saying it is a product of industrial mass development. The "compact city" was initially proposed by Dantzing and Saaty in 1973 (Gonçalves & Umakoshi, 2010). Additionally, by the end of the 1980s, public transportation was seen as essential to developing dense, livable cities. It contained later ideas in the 1994 concentrated center city concept by Haughton and Hunter. Since 1990, research has supported the compactness and mix-use concept since it is ethically and environmentally sound.

2.1.1. Existing compact city approach

Transit-oriented development (TOD) is considered a part of the compact city development approach. The goal of TOD, a planning and design strategy, is to encourage compact, mixed-use, pedestrian- and bicycle-friendly urban development that is tightly integrated with mass transit by concentrating employment, housing, services, and amenities near public transportation hubs (Source-https://tod.itdp.org/) .

Indian cities are rapidly being urbanized; thus, to make them livable, healthy, and smart, it is crucial to utilize transit corridors effectively and integrate land use with the transportation infrastructure. Because of this, the Union Urban Development Ministry developed the TOD Strategy to deal with the problems caused by urbanization. The goal of the strategy is to encourage residing adjacent to corridors for fast transport systems for cities, such as metros, monorails, and bus rapid transit (BRT). At the same time, the state governments are responsible for implementing a management plan for metropolitan areas (MOHUA, n.d.).

2.1.2. Indian case scenario

India has the world's fastest expanding economy at the country level, with an average growth rate of 7% from 2017-18 to 2018-19 and a steadily increasing percentage of global GDP. The Indian population is likewise expanding rapidly, and it is expected to reach a startling 60 crores by 2030(Source- National Institute of Urban Affairs, 2022) https://nudm.mohua.gov.in/ . According to the 2011 Census, "*53 cities in India had a population of one million or more people. More than half of the country's population is expected to be urban by 2050 (WUP, 2018)*".According to the global scenario, 7 out of 10 people are expected to reside in urban regions by 2050, making our society a fast urbanizing one. According to current predictions, approximately 36% of India's population will be urban by 2050, when there are 800 million people. In the hypothetical Indian situation, throughout the 1990s, cities were planned based on the traditional urban development paradigm, which traps us in congestion, sprawl, and wasteful resource usage (Source-WRI) (WRI, 2021).

Indian cities like Bangalore, Delhi, Mumbai, and Ahmedabad have used this strategy to control densification. Ahmedabad outlines better streets, a better public realm, and infrastructure improvements for planned residential zones in its Development Plan 2021. The TOD concept used as a development approach is a compact city model to densify it and create an environment that reduces residents' ecological footprint while providing fair access to opportunities and basic amenities. The TOD policy in Ahmedabad applies to places 500 meters or less from metro routes. With around 50% of the area for constructed structures, 20% for roads, and the remaining 25% for green open spaces, the corridor promotes diversified land use.

2.2. Potential effect of Compact city development on Land surface Temperature (LST)

A significant study on LST was conducted on how Land uses and land cover change increases the surface temperature (Gupta et al., 2019a) (Tan et al., 2010) . Many researchers have examined urban morphology and how it affects UHI growth (Cai et al., 2018). However, there is a lack of study present with respect to the justification of urban planning "compact city" or "TOD" approach for environmental sustainability related to the LST. As the extensive study related to the land use land cover (LULC) impact on LST is present, it gives key implications for local urban planning, such as restraining horizontal development, controlling sprawl and unplanned development and promoting high-density development.

However, in cities, buildings impact LST by altering the movement of materials and energy in a landscape and directly changing surface properties. Buildings with different heights and densities affect Land surface temperature differently. The primary presumption is that a high rise in a high-density development increases surface temperature; however, research demonstrates that high-rise buildings have a positive impact on reducing heat islands by providing more ground-level space for more vegetation area and wind flow corridors, while low-rise high-density structures raise the temperature of the Land.

Compact communities may unintentionally increase the danger of heat waves by trapping heat and slowing wind speed because they have high densities, narrow streets, high buildings, and few open spaces. Furthermore, earlier research showed that mixed-use commercial and industrial areas with high building densities and little greenery produce higher LST than other types of Land. Yet, applying this can encourage varied Land uses with high densities along it, preserving the green and open space, which can lessen the negative effects of an increase in the Earth's surface temperature. In order to determine if the compact urban form may lessen the negative effects of elevated LST, this study took into account the varied urban form of a city in relation to the TOD method at the neighborhood level. In the study (Stone et al., 2010) (Garden & Jalaludin, 2009) it was studied that in terms of mitigating the impact of climate change and for better health, compact cities play an important role than the sprawling city.

2.3. Land surface temperature rise phenomena

The densification of a city brings fast changes in the natural landscape within the city boundary. As the city developed in a planned manner, the demand for infrastructure increased in the core areas. The need for the city, like infrastructure facilities, residential areas, and built-up places, is increasing, altering the permeable natural surface into artificial impermeable built-up areas. Densification of a city leads to the change in land use land cover, mainly built-up and vegetation cover (Swades Pal S. Z., 2017) (Thakur S, 2017) (Oke, 1973).

Impervious surfaces or hard structures available on land absorb and retain more of the sun’s heat than natural vegetation due to the darker color. Therefore, most of the world’s cities experience higher temperatures in their urban core as it has more hard structures than in the surrounding suburban and rural areas. Increased temperature brings a variety of problems like increased energy consumption, [1]Thermal discomfort (Feng & Myint, 2016). The thermal comfort of city people is impacted both directly and indirectly by urban heat intensity. People have heat stroke when the heat intensity grows, the heat intensity grows, people have heat stroke, and energy consumption by utilizing AC increases, reducing a person's immune level. UHIs not only impact water usage and biodiversity, but they also cause human suffering by increasing the causes of mortality and disease. (Alavipanah et al., 2015).

Chandler (1965) (Oke, 1973) was the first person to study the Urban Heat island phenomena through LST. He classified the city into different zones based on climate, physiographic, and built morphology and calculated the Air temperature. With quantitative evidence (done in London) he found out that the central area where high commercial areas are located has warmer temperatures than the inner suburban and outer areas of high and low-density residential development. However, in the 1990-91, Ellefsen devised a system called “urban terrain” zones (UTZ) based on built morphology, street configuration at the neighborhood scale. To calculate the urban heat island, the city was classified on the basis of their built form(Oke, 1973) (Cardoso & Amorim, 2018) . Apart from the UTZ classification Local climate zone (LCZ) [2]classification (Kim et al., 2021) was also used to study the UHI phenomena. However, in developed countries like China, Tokyo, and Singapore, it was found that high-rise buildings have a positive impact on reducing heat islands by providing more ground-level space for more vegetation area and wind flow corridors. At the same time, low-rise high-density structures raise the temperature of the Land. The extensive study was conducted in Singapore, Shanghai and Hong Kong and found that high density housing with mass transport utilization is available in these cities. Although the city suffers from pollution, noise, a loss of privacy, isolation, a disintegration of identity, etc., 50% of the public housing

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[1] The thermal comfort index is a valid measure index that helps measure a city's thermal environment to determine its suitability for people. However, the thermal comfort index is influenced by several factors, including air temperature, surface temperature, meteorological wind speed, cloud cover, humidity, and solar radiation.

[2]] Local climate zone (LCZ) scheme approach was adopted (Kim et al., 2021) , *“It is basically made up of 17 urban and natural classes based on uniform regions of surface cover (pervious and impervious), surface structure (height and density), building material (heavy and light-weight), and anthropogenic activity (heat output) that span hundreds of meters to kilometers at a horizontal scale, as illustrated in the figure. The LCZ technique will aid in the classification of a city into separate zones on a local scale (source- https://www.wudapt.org/lcz/).”*

there is located in or close to core regions with open space within walking distance (Bibri et al., 2020). As the population is growing, the government opted for a compact city approach so that all the people could live in the core area with all the facilities. The urban development policies in these cities focused on providing efficient infrastructure and recreational spaces within a walkable distance.

The specific case study related to the Building density and LST were taken further to know the factors which affect the LST at neighborhood level. The effects of various building heights, building densities, and sky view factors (SVF) on LST were examined in research on Guangzhou, China (Guo et al., 2016). According to the findings, urban morphology with medium building height and lower density created significantly greater LST variation levels. In contrast, high-rise and dense building arrays provided the lowest LST variation levels. Reason behind this result was that, 1 unit increase in built-up land increased 14 units in the LST (Yuvaraj, 2020) thus high rise buildings take less ground coverage and give more space for green space (Feng & Myint, 2016). Also in (Yang et al., 2010) (Wang & Xu, 2021) (Azhdari et al., 2018) studied the building's density and its relationship with the LST. The experimental study was conducted in Beijing- China, Shiraz- Iran, Ningbo - East China; results show that High-rise buildings generate low LST because they have less ground surface coverage and generate more shadow, while residential areas with moderate and low-rise building density alleviated the surface temperature. It was found out that these cities have a compact city approach and have a policy to build a neighborhood with 70% built-up areas and 30% green space area. These studies were conducted at neighborhood level where only high rise buildings were present, however in Indian context even the FSI is high in the transit corridor, old low rise buildings were already situated there and as the time goes new structures were built whose height is more than the previous buildings. So in these scenarios, where different heights of building are present, This study investigates the built form and its relation the LST.

3. Research Approach

3.1. Aim and Objectives

The aim of this study is to empirically investigate that the urban planning approach in a local context is an ideal development which can mitigate the influence of Urban heat island effect. To achieve this aim, following research question is asked here-

1. Does higher density development (buildings and vegetation) provide a better thermal environment?

To answer this question, study is divided into two objectives, firstly to determine the urban form variables which affect the local temperature. Secondly is to analyze the relationship between the building height and density with land surface temperature at Neighborhood level.

3.2. Methodology

The study mainly investigates the building density and its height impact on LST at the neighborhood level. A quantitative approach is followed in this paper. The study is divided into two parts: a literature study with the keywords: *sustainable urban form, urban heat island, thermal environment, Land surface temperature, and local climate change*. Based on this, major variables were selected which affect the land surface temperature. After identifying those variables, a city-level assessment was done to select a locality at the neighborhood level that was more vulnerable in terms of LST using a weighted overlay method.

Secondly, a primary survey was conducted at the neighborhood level; the localities were studied on three levels, i.e., Building, Land use, and Road. Secondary data- Air temperature, Rainy days, Humidity, and

Wind pressure were collected from the meteorological department to study the climate pattern. Based on the meteorological factors, the month (when the temperature is highest) was selected for the LST study. After that, a temporal study was done from 2010 to 2022 to investigate the relationship between the buildings and LST.

3.2.1. Data Source

Landsat Remote Sensing (RS), a digital elevation model (DEM), and administrative boundaries were the major raster data used in this study. The United States Geological Service (USGS) provided the Landsat Remote sensing images for LST, NDBI, and NDVI retrieval. Apart from this, secondary data-population and meteorological factors (Air maximum and minimum temperature from 1980-2022, Humidity (%), Wind direction, and pressure collected as vector data.

Table 1: Data Source

Data source and description		
Data source	Spatial resolution	Description
Landsat TM	Band 2,3,4,5 (30 m) Band 6 (120 m)	USGS
Landsat OLI	Band 3, 4, 5, 6 (30m) Band 10 (100 m)	USGS https://earthexplorer.usgs.gov/
DEM (Digital Elevation Model)	30 m	Bhuban https://bhuvan app3.nrsc.gov.in/data/download/index.php#
Administrative Boundary		AUDA (Ahmedabad Urban Development Authority)
TOD Map		AUDA
Ward wise population		AMC (Ahmedabad Municipal corporation)
Meteorological Data (Air temperature, Humidity, wind flow)		Meteorological department Ahmedabad

Source- Compiled by Author

4. Materials and Method

4.1. Study area

This study focuses on Ahmedabad city in Gujarat. The city is located at a latitude and longitude of 23.03oN, 72.58oE. The population in the Ahmedabad Municipal Corporation (AMC) limits increased to 35.15 lakh in 2001 from 28.77 lakh in 1991 and 5.5 million in 2011. It is *predicted to host over 10.5 million by 2030* (Census of India, 2011) (Gupta et al., 2019) (Munshi, 2013). The city climate is classed as hot semi-arid by Köppen and Geiger (Gupta et al., 2019). The average annual rainfall in the study region is around 80 cm. Summer (March to July), winter (November to February), and monsoon (with occasional severe rains) are the three primary seasons of the city (July to September) (Gupta et al., 2019). August is the month with the greatest relative humidity (80.09%). April is the month with the lowest relative humidity (30.79 percent) (Gupta et al., 2019b).

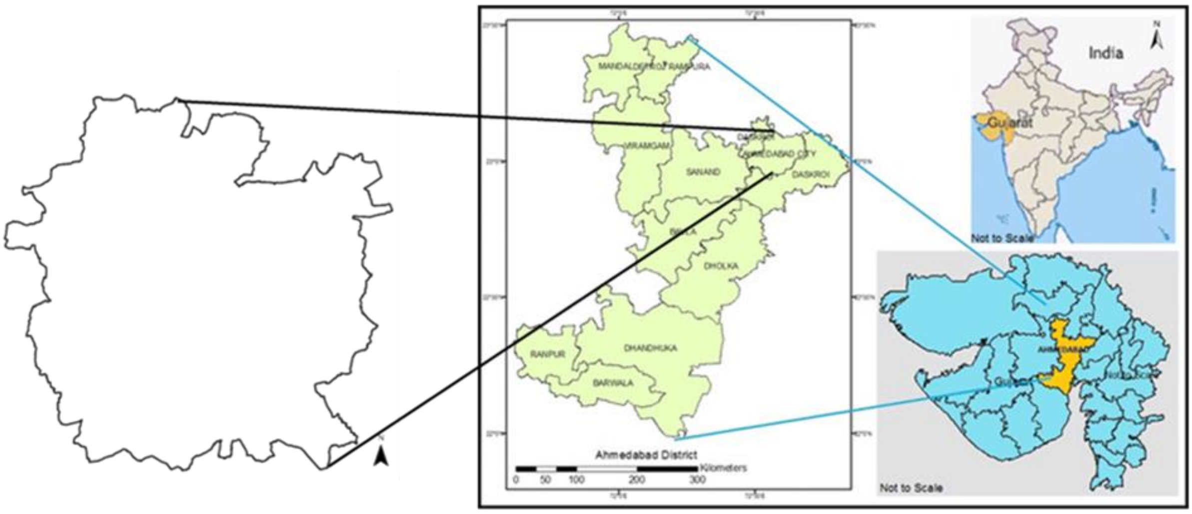

Figure 1: Location Map-Ahmedabad

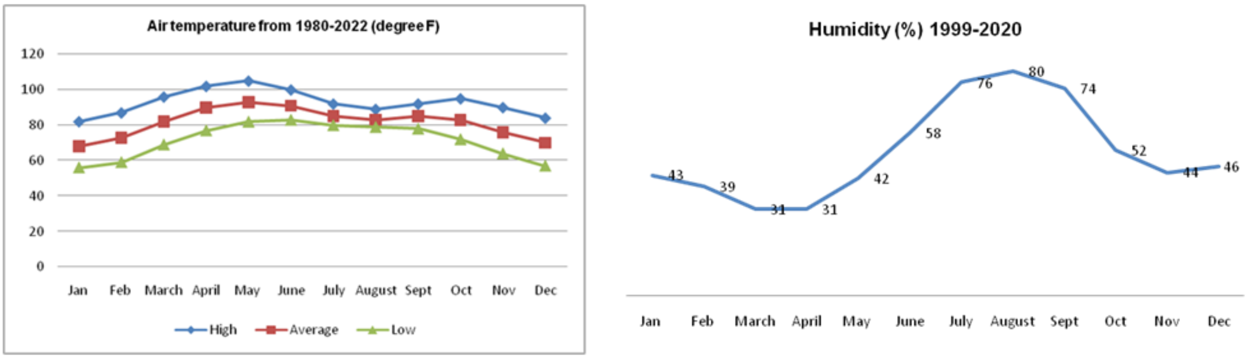

Figure 2: Meteorological data

Source- Indian Meteorological department, Pune, 2010

As per the above picture, it shows that May month is the month when the air temperature is high. Summer days are very hot with mean maximum temperature of 41.30 C while nights are pleasant with mean minimum temperature of 26.30 degree C. The mean maximum and minimum temperatures in winter are 30. 0 degrees C and 15.40 degrees C respectively

4.1.1. City expansion

According to the density pattern shown below, the spatial growth is only occurring in close proximity to the AMC. One of the study area's most densely inhabited locations, the walled city has achieved saturation. Many have preferred to live in the outlying districts where they can take advantage of greater infrastructural amenities, which has led to new outgrowths in the western sections of the city under AUDA control.

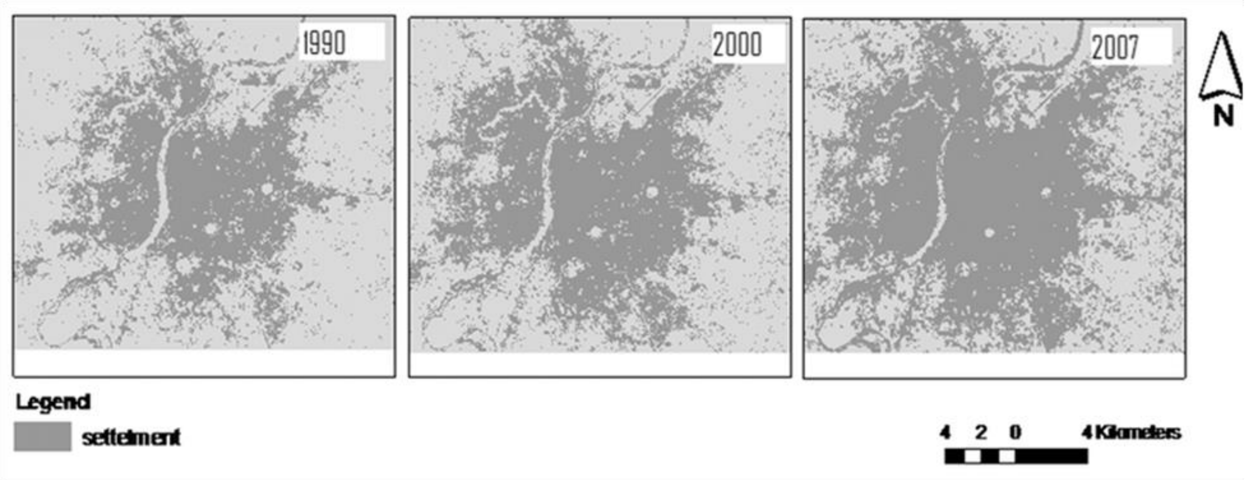

Figure 3: City expansion from 190-2007

Source- (Munshi, 2013)

As the above picture shows, the city is growing beyond the city boundary, and alteration in natural landscape happened rapidly. Until 2007, the city's urban land was expanding at a rate of around 2.6 sq km per ten years. Yet, the expansion of urban land increased by 132% between 2007 and 2017, reaching 6 sq km per decade*(Munshi, 2013)*.

Table 2: Land use changes from 1976-2017

Land Use	1976	1989	1997	2007	2017
Dense Urban	2.8	10.5	39.2	62.5	99.6
Spare Construction	77.3	116.4	112.4	114.7	137.5
Open spaces	37.9	17.9	18	10.1	8.4
Urban vegetation	3.8	16.2	29.7	45.6	35.3
Agricultural vegetation	269.9	264	225.6	192.7	147.2
Water Bodies	23.7	18.4	18.6	17.7	15.6
Total	415.4	443.4	443.5	443.3	443.6

Source- (Munshi, 2013)

The study discovered that although the city's agricultural land, open spaces, and water bodies had severely decreased throughout the study period, densely populated areas had increased by 157 sq km. The elaborate study on Ahmedabad about surface urban heat island (SUHI) temperature captured by satellite and location-based study was done to investigate the land surface temperature fluctuation within the city boundary and outskirts. Surface temperatures in rural regions are 0.63°C higher throughout the summer than in their urban counterparts. Cities' daytime surface temperatures are 0.37 ℃ hotter in the winter. In 2019, 1.7 million people died worldwide from extreme heat and cold. In Ahmedabad, India, 1344 people died from extreme heat in 2010. The recent statistics show that India faced extreme heat during the year 2022, 30th April. Around 56.49 crore people faced 42°c, 74.03 crores, and 57.86 crores faced 40°C and 38°C respectively, which were detrimental to their health. As the study shows, the Ahmedabad city faces heat stress every year. Also, to mitigate the heat stress, the city implemented a Heat wave Action plan in 2019.

4.1.2. Variables which affect LST

The response variables which affect the LST are studied at city level, evaluated based on Landsat 8 satellite imagery.

Table 3: Description of different Variables

No.	Parameter	Explanation
1	LST (Land Surface Temperature)	Land surface temperature of a city will determine which area is generating high LST, that area will be considered more vulnerable to the heat stress.
2	NDBI (Normalized Difference Built-up Index)	It emphasizes manufactured built-up areas. It is useful as it determines the built-up percentage around the city and helps in finding a place which has more built-up coverage than other areas.
3	NDVI (Normalized Difference Vegetation Index)	Since it can adjust for changing illumination conditions, surface slope, and viewing angle, it is especially useful for monitoring vegetation on a continental to global scale. It is critical in this setting to identify places with less vegetation since these areas create more LST.
4	TOD (Transit Oriented Development)	Transit corridors have high FSI [3](Floor Space Index) in comparison to other places, so in future it will have high rise buildings. Within the 250 meter of TOD corridor, FSI is 4.0.
5	Population Density (PD)[4]	Population density plays an important role as it determines which area settlement intensity of that area.
6	Solar irradiance	The energy provided by the Sun in the form of electromagnetic radiation in the measuring device's wavelength range per unit of surface area is known as solar irradiance.

Source- Compiled by Author

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[3] *"FSI refers to the maximum permitted area on a piece of land for construction. The FSI is the ratio of floor area covered to the available land area. FSI, which is usually set based on National Building code, is regulated by the municipal or local authorities of the state government"(Urban Development and Urban Housing Department, 2014).*

[4] *Formula PD= area/ no. of population living in that area*

To evaluate the LST at city level, three criteria was set (1) less than 10% cloud cover (Imran et al., 2022) (2) no scan line error (3) the Landsat satellite image was captured from 2010-2022 (2010-representing past year * TOD policy implemented in the year 2009 at Ahmedabad and 2022 (representing present situation). Above table represents the other variables which were studied to select an area at neighborhood level.

4.2. Locality selection

At city level, five parameters were studied i.e., Solar radiance, Built-up coverage (NDBI) , vegetation coverage (NDVI), TOD corridor (250 meter buffer), Population density and LST.

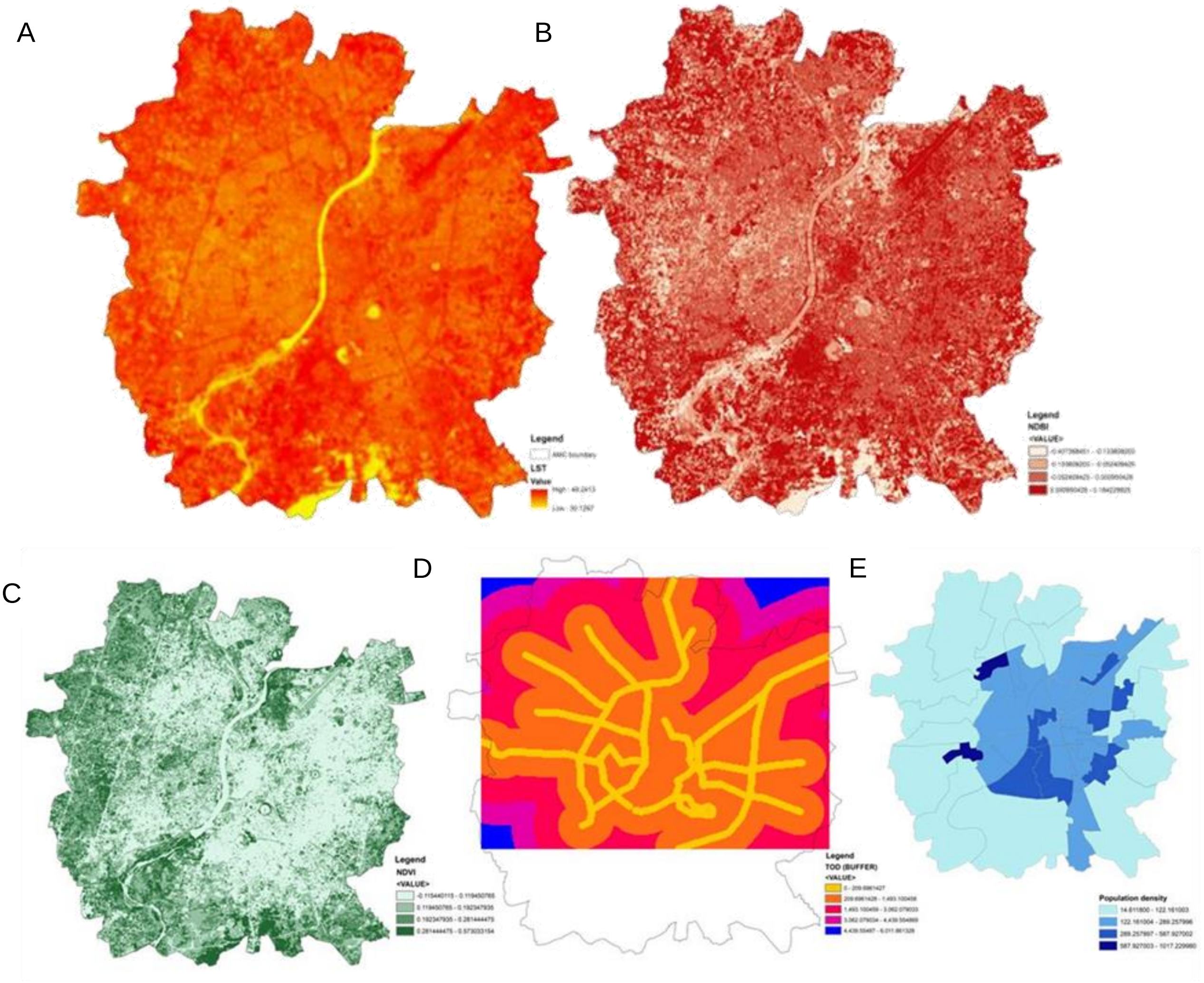

Figure 4: (A) LST Mao, year 2020, season-summer, (B) NDBI Map (C) NDVI map (D) Proximity to TOD corridor (E) Population Density Map

The above spatial mapping is used to determine the vulnerable locality in terms of heat stress by using the weighted overlay method[5]. The site suitability criteria would specify the amount of satisfaction expected of each qualifying location. Similarly, input maps for limitations are created by gathering spatial data and producing standardized maps in GIS software. By assigning a weight to each raster

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[5] One technique for representing suitability is the weighted overlay technique. Arc GIS used the following methods for this analysis. Each raster layer is assigned a weight in the suitability analysis. To categorize the values in the raster, a standard scale is used. (*Source- https://www.esri.com/)*

during the overlay process, you may manage the effect of various factors in the suitability model. Here more weightage is given to the high LST (42-49 degree Celsius), more built-up percentage (0.18), less vegetation coverage, more density, and a High FSI area.

The below picture shows the weightage of each pixel based on their values, and after that, rank was given, like 1 for the most suitable location and 5 for the least suitable location. After overlaying the spatial map of each factor, a suitable location was identified. In suitability modeling, 30*30 meter grid was made to select the area among the many areas.

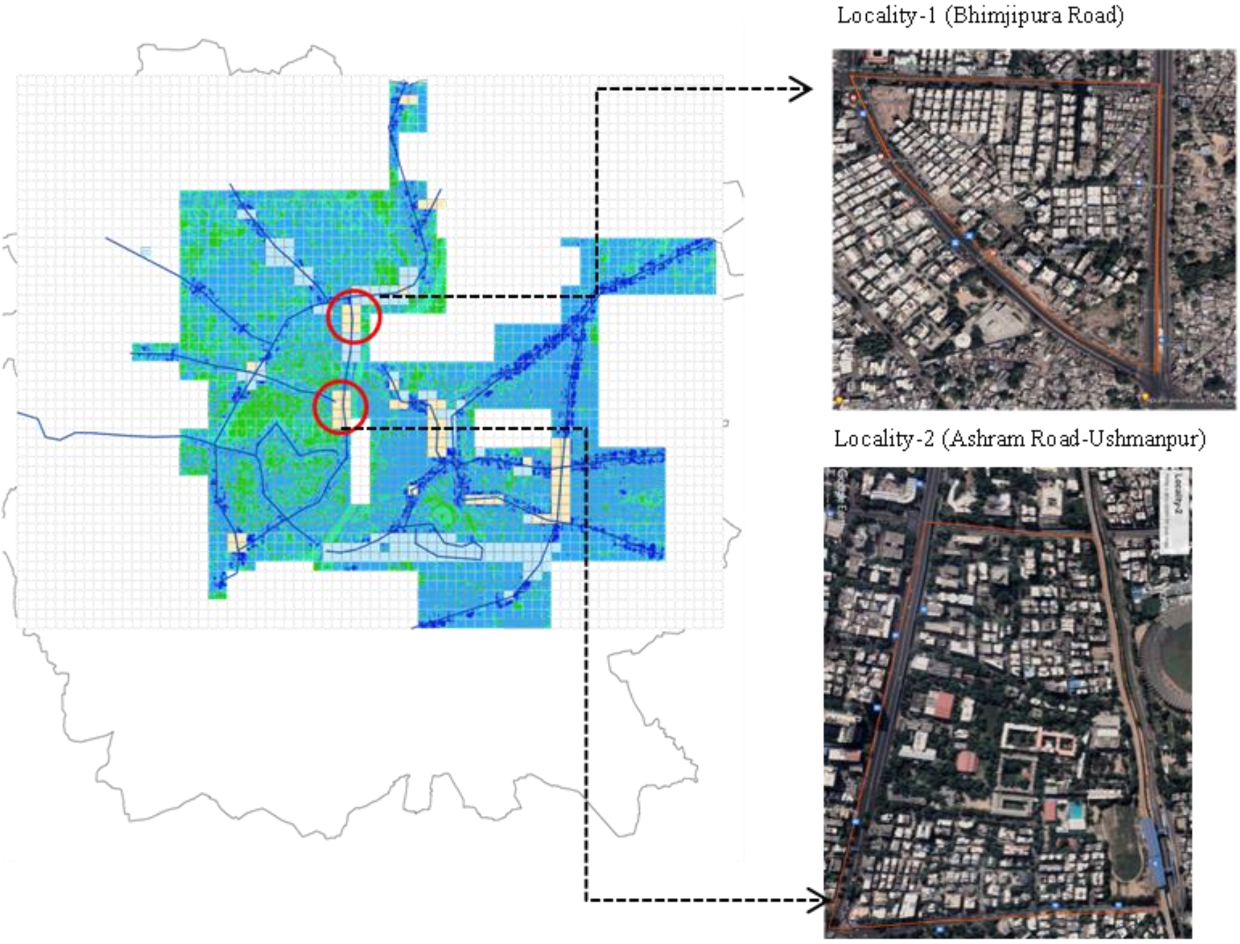


Figure 5: Grid analysis to select Localities

4.3. Field procedure and variables study

In terms of the ‘TOD’ approach, three variables were studied at the neighborhood level. Primary site survey was conducted in both localities where below variables were studied.

4.3.1. Neighborhood scale- Locality study

4.3.1.1. Locality-1

As the below picture shows (A) and (B) which is taken in the year 2010 and 2017 respectively shows similar feature from image (C) year 2022, there are 2 places which is different from its previous images in terms of building number, as it was seen circle indicates area is current on construction for new building however during the last year it has G+1 buildings were present there also the rectangular shape denotes bold building which was demolished and new buildings (G+12) were constructed.

Figure 6: changes in the locality-1 from 2010-2023

Source- Google earth

Figure 7: Locality-1 study as per their Height

Source- Primary Survey

The above picture shows the different typology of buildings as per their height, the buildings were divided into three parts i.e., High rise (>G+6), Mid rise (G+3 to G+6), Low rise (＜G+3).

Table 4: Details about the Building typology locality-1

Area= 10.73 Ha · **Land use= Residential**			
Building Type	**Building footprint count**	**Population**	**Population density**
Low rise (G-g+2)	116	1021	524.47
Mid rise (G+3 to G+6)	73	964	489
High rise (more than G+6)	3	198	1157

Source- Primary Data and Google imagery

The total area of the locality 1 is 10.73 Ha, out of which 96% area have built-up coverage and 4% have vegetation coverage. As the above table shows, this locality has a total 192 buildings, out of which only 3 buildings are coming under the high rise building category.

4.3.1.2. Locality-2

The second locality is situated at Usmanpura, coordinate is 23° 2'49.13"N, 72°33'51.77"E. This locality has mixed land use characteristics, i.e., 43%- recreational, 41%- residential, 3%- commercial, 1%- public and semi public and 12%- institutional.

Figure 8: Locality-2 as per their Height and Images

Source- Primary Survey

Locality 2 has a total area of 33 Ha, of which 27% is covered by vegetation and 73% by built-up areas. According to the table above, there are a total of 243 structures in this area, of which 26 are classified as high rises, 159 as mid-rises, and 58 as low rises.

5. Data Analysis

5.1. LST calculation with respect of Building

Landsat 8 thermal infrared sensor (TIRS) data was used to calculate the LST. It is downloaded from the United States Geological Survey (USGS) (https://earthexplorer.usgs.gov/). The details of the data are shown below.

Table 5: Landsat Data details

Locality-1	Locality-2	Spatial Resolution
Date	Date	
2013/17/5	2013/20/5	100m
2016/15/5	2016/13/5	100m

2019/20/5	2019/15/5	100m
2022/12/5	2022/14/5	100m

Source- Landsat Imagery, USGC

Landsat 8 official website recommends using band 10 to retrieve LST due to the calibration problem of band 11. Therefore, Landsat 8 band 10 was used to retrieve the LST using the USGC algorithm formula (Avdan & Jovanovska, 2016). The formula expressed as-

"Step 1- Calculation of TOA (Top of Atmospheric) spectral radiance.

TOA (L) = $M_L * Q_{cal} + A_L$, *Where:* M_L= *Band-specific multiplicative rescaling factor from the metadata,* Q_{cal} = *corresponds to band 10,* A_L= *Band-specific additive rescaling factor from the metadata*

TOA = 0.0003342 * "Band 10" + 0.1……… (1)

Step 2: OA to Brightness Temperature conversion

$$BT = (K_2 / (\ln (K_1 / L) + 1)) - 273.15$$

Where: K_1= *Band-specific thermal conversion constant from the metadata (K1_CONSTANT_BAND_**x**, where x is the thermal band number).*

K_2= *Band-specific thermal conversion constant from the metadata*

L = TOA, Therefore, to obtain the results in Celsius, the radiant temperature is adjusted by adding the absolute zero (approx. -273.15°C).

BT = (1321.0789 / Ln ((774.8853 / "%TOA %") + 1)) – 273.15…….. (2)

Step3- Calculate the NDVI

NDVI = (Band 5 – Band 4) / (Band 5 + Band 4)………….. (3)

Step 4- Calculate the proportion of vegetation P_v

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

$$P_v = \text{Square} (("NDVI" - 0.216901) / (0.632267 - 0.216901))\ldots\ldots\ldots\ldots\ldots (4)$$

Step 5- Calculate Emissivity ε

$\varepsilon = 0.004 * P_v + 0.986$…………. (5)

Step 6- LST = (BT / (1 + (0.00115 * BT / 1.4388) * Ln(ε)))…………..(6)

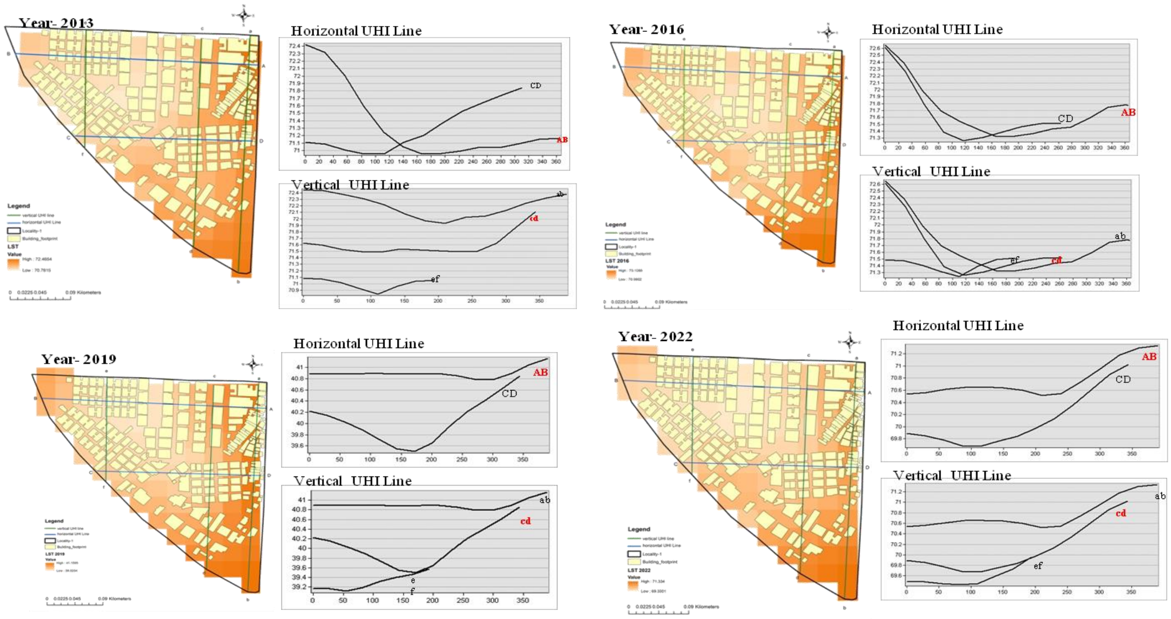


Figure 9: LST (month-May) from 2013-2022

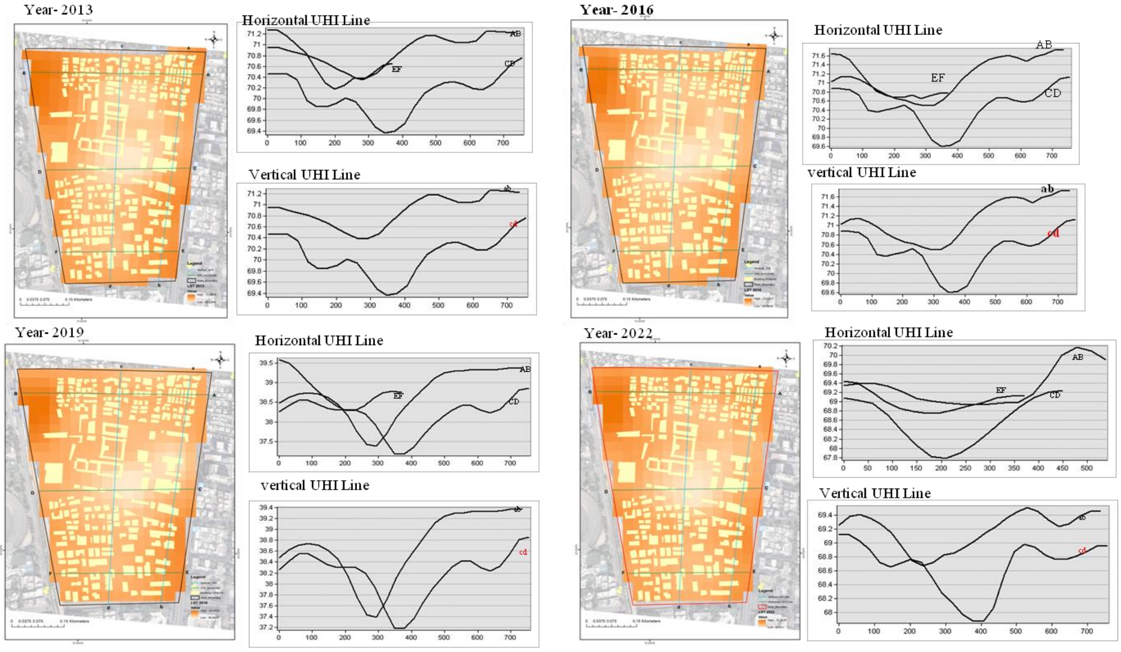
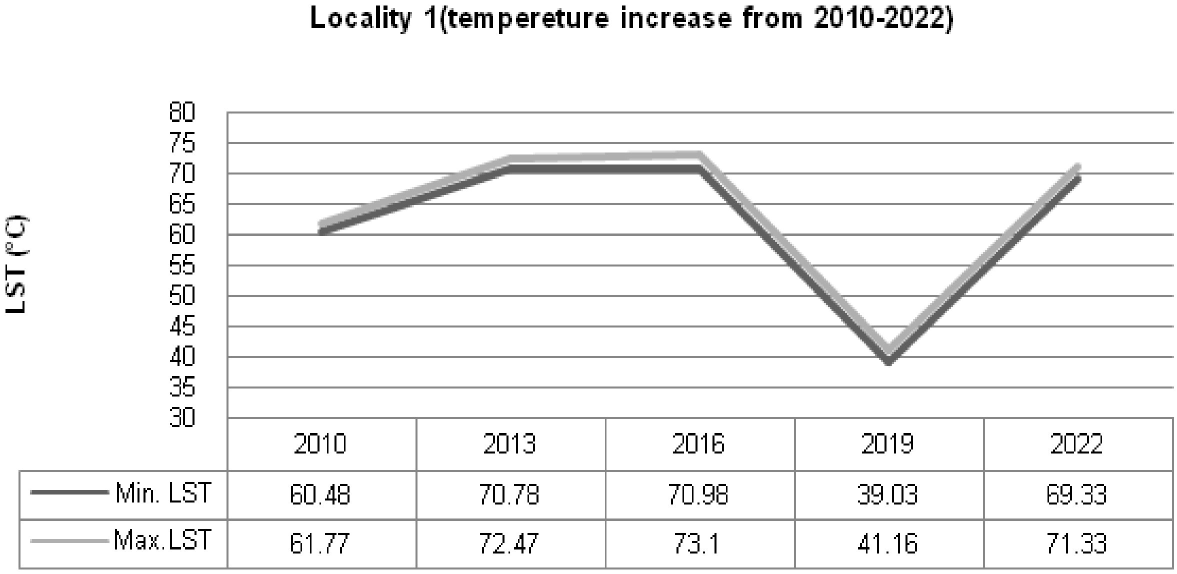


Figure 10: LST (Month-May) from 2013-2022

Figure d) and e) shows the map of Land surface temperature from 2013 to 2022 and the horizontal and vertical line above the LST raster data shows the LST quantity at every point. The minimum LST of locality 1 was 60.48 in 2010, but it grew to 69.33 in the ten years depicted above and the maximum LST was 61.77 °C in 2013, which rose up to 71.33°C. The lowest LST in locality-2 was 59.14 in 2010, and it increased to 67.73 in 2022. With the help of the stack profile tool in ArcGIS, a graph illustrating the profile of line features on LST raster data was produced. This feature was used to determine LST for each structure. The generation of both a horizontal and vertical line was done in order to demonstrate the variation in LST across the various building typologies.



	2010	2013	2016	2019	2022
Min. LST	60.48	70.78	70.98	39.03	69.33
Max.LST	61.77	72.47	73.1	41.16	71.33

Figure 11: Minimum and maximum temperature from 2010-2022

Table 6: Horizontal line Point LST data

Points	1	2	3	4	5	6
Building type (as per height)	low rise	Mid rise	High rise	Mid rise	Mid rise	low rise
2013	**72.4**	72.1	72	71.4	71.1	71.3
2016	**72.6**	72.4	71.9	71.6	71.4	71.6
2019	**40.88**	40.572	39.9	39.32	39.21	39.46
2022	**70.59**	70.39	69.84	69.53	69.39	69.5

Source- LST retrieval from Landsat-8

In location 1, the line began at low-rise structures before moving up to mid-rise, high-rise, mid-rise, mid-rise, and low-rise structures, in that order. According to the temporal study from 2013 to 2022, low-rise structures produced high LST of 72.4 °C, 72.6 °C, 40.88 °C, and 70.59 °C, respectively. Yet, compared to Low rise and High rise buildings, High rise buildings exhibit less LST.

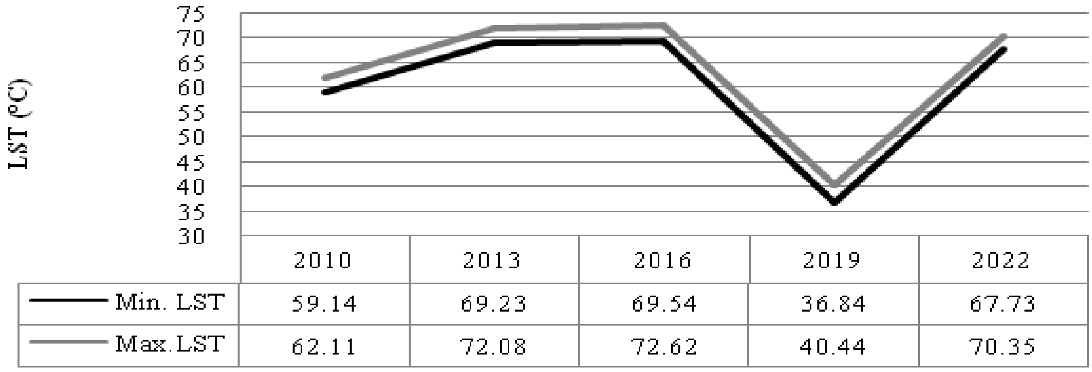


Figure 12: Minimum and maximum temperature from 2010-2022

Table 7: Vertical point data

Locality 2						
Distance	0	50	150	300	450	550
Building Points	1	2	3	4	5	6
typology of building (as per height)	**mid rise**	**high rise**	**greenery**	**greenery-low rise**	**mid rise**	**mid rise**
2013	70.49	70.46	69.84	69.47	69.85	70.32
2016	70.88	70.84	70.45	69.73	70.34	70.67
2019	38.61	38.55	38.3	37.18	37.66	37.91

2022	69.12	69.02	68.64	67.97	68.06	68.93

Source- LST retrieval from Landsat-8

As the above table shows, high rise buildings generate less LST than the mid rise buildings. Greenery areas which are available in this locality generate less LST than any other build structure.

5.2. Shadow extract

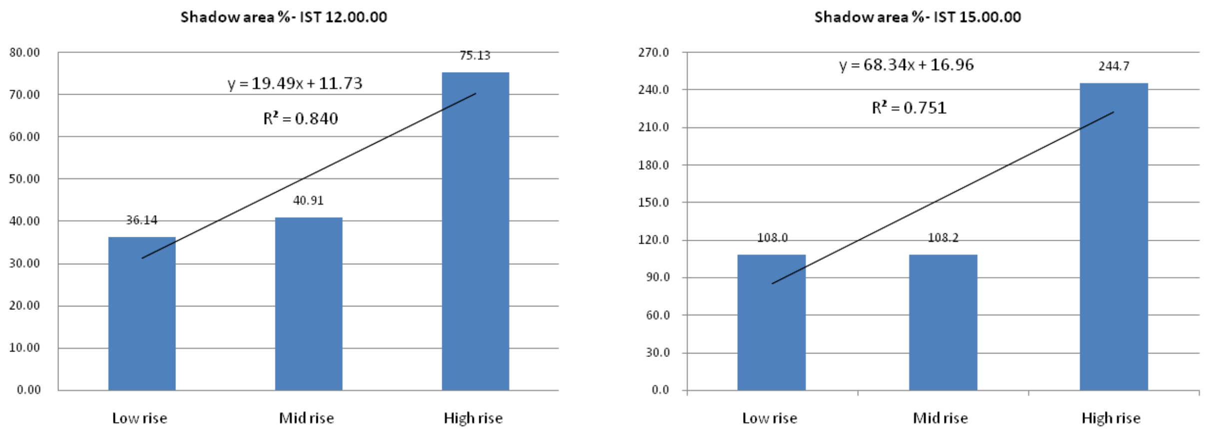
In order to analyze the effects of shadow created by building to LST, automated Water Extraction Index (AWEIsh) is used to effectively extract water and shadow pixels (Wang & Xu, 2021). Then, modified normalized difference water index (MNDWI) is used to remove water pixels from shadow pixels. The formula is expressed as:

$AWEIsh = \rho band2 + 2.5 * \rho band3 - 1.5 * (\rho band5 + \rho band6) - 0.25 * \rho band7$

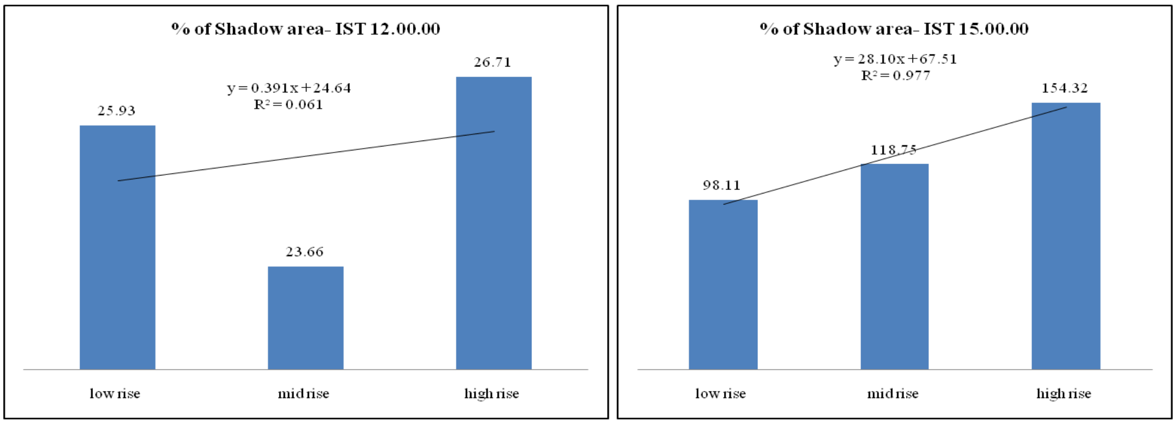
$MNDWI = (\rho band3 - \rho band6) / (\rho band3 + \rho band6)$

Where, ρ is the reflectance value of spectral bands of Landsat 8: band2 (Blue), band 3(Green), band 5(NIR), band 6(SWIR1) and band 7(SWIR2).

For shadow analysis, both sun path orientation and building orientation was considered. Indian time standard IST 12.00.00 and IST 15.00.00, two different times were taken for the analysis.



Locality-1** Shadow area % = increase area % from the original area of the building during IST 12.00.00 & IST 15.00.00



Locality-2** Shadow area % = increase area % from the original area of the building during IST 12.00.00 & IST 15.00.00

At IST 12.00.00 in the afternoon, the sun angle at locality-2 was 160.67. As seen in the following image, mid-rise buildings generate less shadow at that time than low- and high-rise structures. At noon, high-rise structures cast a 26.71% greater shadow than their original area. However, low-rise and high-rise buildings cast a smaller shadow around 15.00 IST compared to mid-rise and high-rise buildings. During peak hour (3.00 pm), the sun angle was 270.26. This study shows that locality-2, an area with both greenery and built-up coverage, generates less LST than Locality-1, which dominates by the more built-up coverage.

6. Discussion and Result:

In locality- by using ArcGIS tool, under random sampling, 50 points were made. However, 15 points were given null values as it was located at the place where LST raster data was not present, like at the corner. By using these data points, LST, NDVI, NDBI and building heights were extracted and after that a regression coefficient analysis was done to show the dependency between the different variables. In Regression analysis, Pearson correlation method was used to calculate the r (correlation) value.

Statistical values	NDVI	NDBI	Building height
Multiple R	0.553926762	0.05087531	0.00107833
R Square	0.306834857	0.002588297	1.1628E-06
Adjusted R Square	0.285829853	-0.0276363	-0.030301832
Standard Error	0.48479216	0.581533128	0.582286843
Observations	35	35	35

Multiple R value is the Pearson’s coefficient correlation. It measures the strength of the linear relationship between the predictor variables and the response variable. A multiple R of 1 indicates a perfect linear relationship while a multiple R of 0 indicates no linear relationship whatsoever. As the above table shows, here LST taken as a dependent variable (Y axis) and NDVI, NDBI and building height taken as an independent variable (X axis). As shown here, NDVI has a strong positive relation with LST however in this case building heights have less positive relation with LST. Different research also shows that LST value mainly depends on vegetation coverage.

ANOVA				
	df	NDVI-Significance F	NDBI-Significance F	Building Height-Significance F

Regression	1	0.000555995	0.771633039	0.995094803
Residual	33			
Total	34			

df= Degree of Freedom

In all the three cases, F- significance value is less than *p* value, which indicates that there is sufficient evidence to conclude that the regression model fits the data better than the model with no predictor variables.

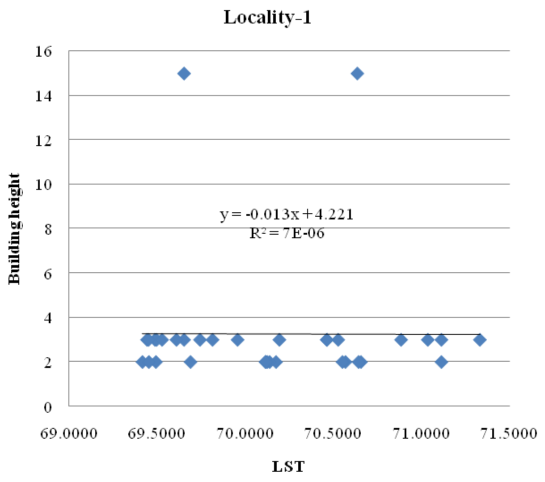
Locality-2 Regression Statistics			
Values	NDVI	NDBI	Height
Multiple R	0.510996848	0.024870483	0.511135219
R Square	0.261117778	0.000618541	0.261259212
Adjusted R Square	0.251644929	-0.012194042	0.248600985
Standard Error	0.48136577	0.559826226	60.60997182
Observations	80	80	80

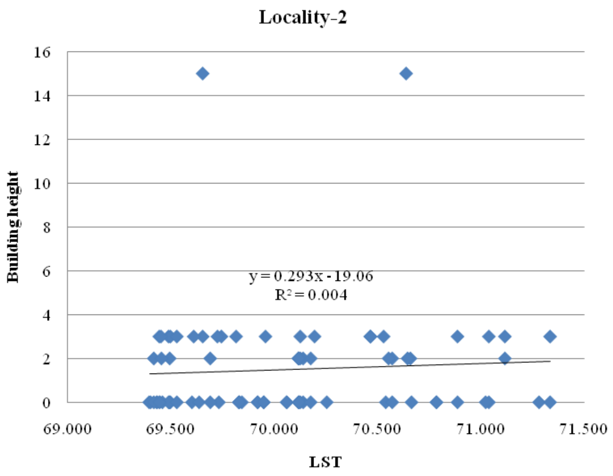
In locality 2, NDVI and LST are giving 0.510- R Value, which means LST is strongly positive related to the NDVI value.

ANOVA Test				
		Significance F		
	df	NDVI	NDBI	Building Height
Regression	1	1.27731E-06	0.826664693	1.10773E-06
Residual	78			
Total	79			

6.1. LST Correlation with NDVI, NDBI and Building height

By using regression analysis, we got NDVI, NDBI and building height Multipple R value with respect to LST i.e. 0.553926762, 0.0508753 and 0.00107833 which means NDVI have strong positive relation with LST so when vegetation coverage will decrease, LST will increase. however, in comparison to NDVI, NDBI and building height showing less positive relation with LST. Even when we take only building height and LST value and plot the graph showing no correlation, the bond between the Buildings height and LST is very weak. By focusing only on building height, a thermal comfortable environment can not be achieved. Even during peak hour building height helps in giving more shadow area, it does not greatly impact the LST amount of that particular place.





As the above image shows the buildings who are coming under low rise and mid rise buildings have no correlation between their heights and LST. However, the buildings which are considered as high rise buildings do not come under the equation. Here in the sampling most of the low rise and mid buildings were taken as in booth locality high rise buildings are limited. So, in this case if we consider only high rise buildings and LST, it is showing a positive linear relationship.

This paper mainly investigates three features i.e, Building height, vegetation coverage and built-up coverage. From the analysis, it was found that in terms of both localitty, locality 1 shows higher LST than the Locality-2. As it was discussed above that Locality-1 has 96% hard concrete surface in comparison to the Locality-2, it has 73% built up coverage. So, as it was proven that vegetation coverage helps in mitigating the Land surface temperature. Also, as it was seen that Building heights create more shadow area at peak hours. So, from the TOD concept, this paper studied 3 aspects so if all the elements are considered at one locality, it can gave a better approach to study the LST at the local level.

7. Limitation and implication

The study has a few significant flaws that need to be discussed. A weekly/fortnightly mean LST from another satellite dataset (i.e., MODIS satellite data) can be utilized better to understand the link between LST and Buildings indices as our study employed Landsat TM/ETM data for specific dates in different years. Also, at the neighborhood level, other variables with the concept of TOD development, like Road infrastructure availability and land use concerning energy consumption be taken as a parameter for further research. Apart from this, humidity, wind flow, wind velocity, and rainfall factor is not considered; however, these factors also play an important role in determining the thermal comfort of human beings.

This study helps in understanding the value of vegetation and green space in the core city area. Not only does it have scenic value but it also helps in mitigating the LST and providing a good thermal environment. Also, the study helps understand the planning measures for TOD and its impact on the environment. The TOD approach increases the efficient transport system and helps preserve the green space and open space at the neighborhood level. As the *"Guide to Urban cooling strategies-2017" shows that in one area by focusing on cool material, urban canopy layer- tree alignment with roads (Street tree canopy can be increased by planting shade trees in footpaths, forecourts and street medians.) and cooling spot will help in providing a good thermal comfort environment.* This study will help contribute to the policy level implementation of how much vegetation coverage should be present at the neighborhood level.

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