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Integration of Remote Sensing and Big Data to Study Spatial Distribution of Urban Heat Island for Cities with Different Terrain

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P A P E R I N F O

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A B S T R A C T

Urban microclimate has posed a detrimental effect on the life of the urban population. This research drives with an aim of identifying environmentally conscious factor vis-a-vis urban planning which leads to the vicious cycle of urban climate change. The vicious cycle is inclusive of many urban dynamics' parameters, which are complicated to understand. This research emphasizes on using Remote Sensing Big Data on Google Earth Engine as an advancement to study Climate Vulnerability leading to Urban Climate Gentrification. Temporal data of Landsat for the past 30 years has been taken into consideration for the study. Three cities with diverse geographical and terrain characteristics have been selected for the study, to understand the modern decisive planning is in coherence with the Sustainable Development Goals. Understanding spatial and temporal information of Urban hotspots using High-Resolution Satellite data is just not enough to suffice the need to decrease the temperature by 2- 3°C. The present study is a toll on how the reasons for microclimate change vary along with the terrain, spatial location, and urban growth pattern of the city.

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1. INTRODUCTION

The current climate issue is wreaking havoc on the world. While growing deforestation and unsustainable industries are easy to criticize; it may come as a shock but the metro cities and urban growth play a significant role and is one of the main causes of the current climate change issue [1]. Nearly, 55% of the world's population resides in urban areas, which is expected to increase vividly and reach 66% worldwide by 2050. The anthropogenic activity in cities is a significant contributor to climate change. These activities are also main source of greenhouse (GHG) emissions [2, 3]. The Climate is fairly different in urban and buildup construction while its different in rural development as a result of the impervious urban fabric, the urban structure and anthropogenic activities [4]. There is a risk of increased depletion of energy and natural resources due to incessant increase in the population in cities. The Urban Heat Island (UHI) effect, which causes cities to be hotter than the nearby rural areas, is a result of this phenomena. The temperature in a heat island may be 1 to 6 degrees Celsius greater than the surrounding surroundings [5].

Urbanization rate is increasing with an increase in anthropogenic activities, which leads to Land use Landcover (LULC) Change. This rate of change impacts the microclimatic condition of the city and leads to heatwaves and extreme flood events [6-8]. The UHI effect, which makes cities generally warmer than the nearby rural areas, cities are more susceptible to heat waves than rural areas [9]. Climate adaptation and mitigation strategies are more crucial in these developing cities [10]. Developing nations are not yet capable enough to deal with the friction caused by climate change. Climate responsive designs needs to applied at everyday practice for comfortable urban spaces [11]. Characterizing and representing the urban environment has become a crucial element in the steps involved in urban planning and design [12]. The metropolis weather is managed with the aid of using many natural elements, each on the macro-scale and on the meso-scale which

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modulate several natural microclimatic parameters. The different essential elements regulating Urban Micro Climate (UMC) consist of nearby ecosystems together with city parks, vegetation, water our bodies and concrete built-up [13]. The trends in UMC varies with different cities.

In the past few years, one of the world's biggest public policy concerns is rising climate change. The Paris Agreement, which came into action in 2015 emphasizes on tackling climate-related activities for developing countries, with a goal of reducing the global temperature by 1.5°C [14]. SDG-11 on sustainable cities and communities requires higher living standards for citizens in every facet while the resilience acts as the pillar. To achieve this global goal and frame policies for mitigating Urban climate (UC) and Urban microclimate (UMC) change it is crucial to understand the Multi-Temporal LULC change and its impact on LST. Several studies have used Remote Sensing and GIS to study LST its impact on UC [15-19]. To carry out Multi Spatio-Temporal study of UMC using Remote Sensing is challenging with the constraints of proprietary software, big data, computer space, and tedious hour of processing data. To address this challenge for large-scale cloud computing, platforms such as Google Earth Engine (GEE) is used for multi-temporal studies, which has extensive archive of open access data from various satellite and sensor.

Recently studies have showcased the potential of GEE for UC studies at city scale. Liang et al. [20] illustrated how GEE can be used to detect spatial and temporal changes in time series of LULC and integrate GEE development tools to post process LULC classification and improve accuracy. Despini et al. [21] investigated the genesis of UHI: Surface Albedo and provided an approach to calculate and improve the albedo for city administrations. Agarwal and Nagendra [22] classified Indian cities using GEE and investigated on how shape of cities plays a role in impacting sustainability outcomes. Ravanelli et al. [23] exploited large scale GEE analysis for US metropolitan area to investigate the temporal variation of UHI. Roy [24] detected urban growth for two decades and estimated LST change with response to that growth [25]. As per Oke [7], there are two major scales to measure UHI (a) Urban Canopy Layer (UCL) and (b) Urban Boundary Layer (UBL) [26]. Intensive studies have been carried out using GEE to combat climate change and understand its relationship with LST at Global and City Scale (UBL). Bherwani et al. [13] in his review, showcased the gaps in research methodology for UMC studies, demonstrated the missing links that besides a lot of progress in UMC research, there are very limited application in the field due to lack of clarity in the targeted outcome and lack of integration between the natural and anthropogenic parameters that affect UMC. Studies carried out at microscale in developed countries are either done using computational fluid dynamics [27-29], Field data [30, 31] or HRS thermal imagery/ DSM [32, 33]. In developing nation like India, performing CFD and in-situ experiments becomes expensive and cannot be performed at a large scale. Majority of the data are not available on open-source platform to carry out research. To address this challenge this study aims on using Open-Source GEE platform for UMC analysis at a micro level for different cities. However, every city has unique characteristic and terrain which demands for unique climate policy respectively.

This study focuses on understanding the co-relation between LST with variables like climate, population density and land use. For the current study 3 cities Surat, Delhi and Ahmedabad are optimized for the experiment. The unique characteristic of these cities are they have different terrain, different direction of river flowing through the cities, varying land use pattern and population density. The objective of this research is (1) Understanding the heat flux dynamics contemporary to Spatial-Temporal change using GEE for 3 different cities at two scales (i) City Scale and (ii) Micro- Scale; (2) Comparative analysis of LST with city characteristic (i.e. Land use, Population Density) to understand the heat flux; (3) Proposing need of unique climate adaptive policy for each city to meet the Paris Agreement.

2. MATERIALS AND METHODS

The study's experimental cities are 1) Surat 2) Ahmedabad and 3) Delhi. These cities have unique geographical condition, population, and socio-economic characteristic. Surat is a coastal city, Ahmedabad and Delhi are landlocked city with river flowing through the city. To understand the influence of cities terrain and land use on land surface temperature, macro level analysis at city scale has been demonstrated and then micro-level analysis for UMC was investigated for the city of Surat, Ahmedabad, and Delhi to understand the effect of land use/ typology on hot spots in the city (see Figure 1).

2. 1. Description of Study Area and Climate

The million plus cities of india as shown in Figure 2 surat, ahmedabad and delhi are investigated for current research. The spatial dynamics, population density, geographical location, terrain, and climate of these cities are studied in correlation to land use to understand the thermal profile of city.

The city of Surat is located at latitude 21°10'N and longitude 72°50'E in the southern state of Gujarat on the west coast of India, with an average elevation of 13 meters. Surat city is located near Tapi river and has tropical savannah (Köppen: Aw) climate. City's wind direction is south-west to north-east, mainly from the sea

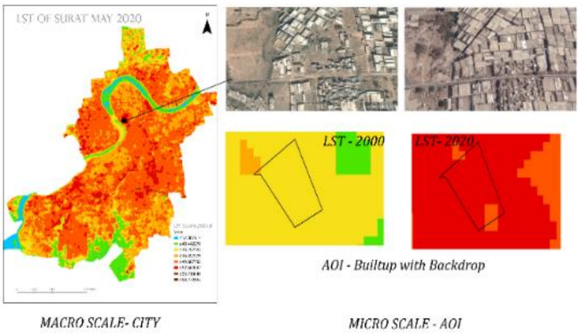

Figure 1. Land Surface Temperature at Macro and Micro Scale

towards the capital. Mostly in Indian cities, summer begins in early March and lasts until June. It is observed that April and May are the hottest months, with average highs of 45°C (99°F). It is one of India's most dynamic cities and the fastest growing with immigrants from Gujarat and other Indian states. The population of Diamond City Surat has grown from 2.8 million in 2001 to 4.5 million in 2011, a staggering increase of 58.68%. Surat is ranked the 4th fastest growing city in a global survey of the fastest growing cities conducted by the city mayors' foundation, international urban affairs think tank. In fact, it is the fastest growing Indian city in terms of economic prosperity.

Ahmedabad is strategically located in the heart of Gujarat in the Sabarmati basin. The Sabarmati River, which divides Ahmedabad in half, runs along both city's sides. In western India's landlocked city of Ahmedabad, the climate is hot and semi-arid (Köppen classification: BSh), with somewhat less precipitation than would be needed for a tropical savannah environment. Due to its topography, the city frequently experiences high temperatures. The highest temperature in the city was 50 °C on May 18-19, 2016. In May 2010, a 46.8 °C (heat wave claimed hundreds of lives. The 2011 census, Ahmedabad had a population of 5,633,927, making it her fifth largest city in India. The urban agglomeration centered on Ahmedabad is now the 7th largest urban agglomeration in India with a population of 6,357,693 estimated at 7,650,000. As of 2011, approximately 66% of the population lives in formal housing. Although Ahmedabad's population has grown, the housing stock has remained essentially constant, with both formal and informal housing concentrated and available space being used more economically. Ahmedabad is considered the financial center of Gujarat. The major climate challenge observed in the pockets of city is overburdened and unsustainable planning and increased emissions from industry and vehicles. Which leads to the urban heat island effect. (UHI) in the large cities [34] bordering a hot semi-arid climate (Köppen BSh).

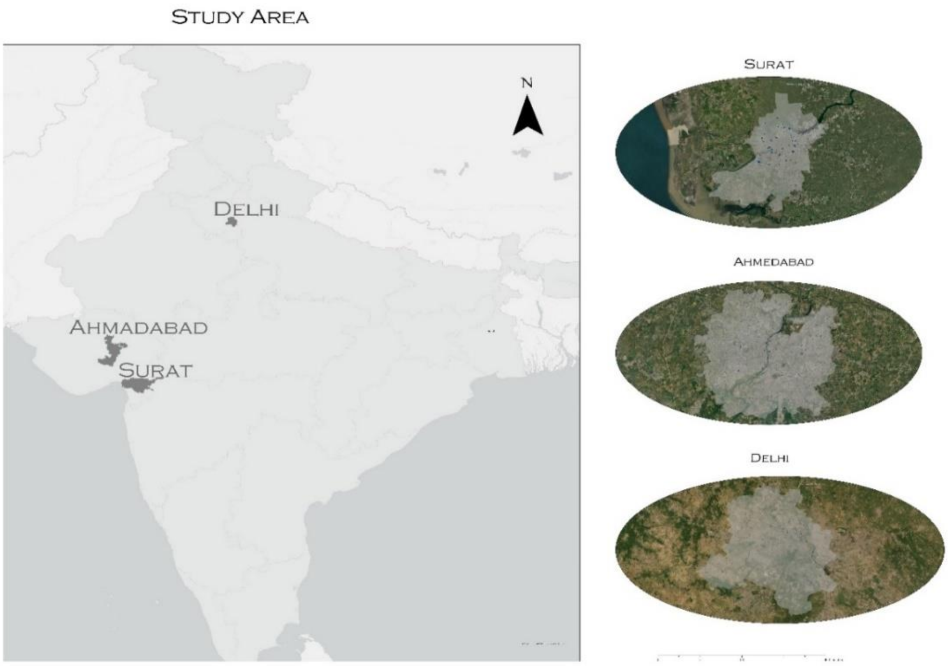

Figure 2. Three study area for the present study are selected on the basis of 1) Terrain and 2) City Location and 3) different location of river flowing through the city. The first city is Surat which is a coastal city, Second city Ahmedabad is a landlocked city , third city Delhi is a National captial with mixed weather conditions

India's National Capital is Delhi. Delhi typically experiences a dry-winter humid subtropical climate that is adjacent to a hot semi-arid climate. The temperature is between 2°C and 47 °C. Delhi's geographical setting provided a distinctive environment. It struggles frequently with issues like pollution and environmental deterioration while having a richness and variety of environmental assets, including as the river Yamuna, the Aravalli Ridge, water bodies, forests, etc. [26, 35].

According to India's 2011 census, Delhi has the second-highest population, with 11 million people. One of the urban areas in the world with the quickest growth rates is Delhi, whose GDP is 7.1%. The National Capital Region's economic hub, Delhi, accounts for about 50% of the region's GDP.

2. 2. Data Used and Pre-Processing In order to study the dynamics of LST due to anthropogenic activities at defined study area at macro and micro scale, remote sensing dataset were used. To demonstrate the densification and city growth dynamics impacts on LST it is crucial to detect the time series of LST change. A comprehensive thermal imagery dataset of Landsat 5, Landsat 7 and Landsat 8 are retrieved as a primary source from Google Earth Engine [27, 28] and are processed using Ermida [29] algorithm to generate LSTs. In the module "Landsat_LST" provided by Ermida, the date range provided for the current time series analysis was from 1982- 2020, for the month of April, May, and June. These datasets are retrieved from the Landsat satellite (4, 5, 7, or 8). City Boundaries are uploaded in the asset, as the region of interest to process. NDVI-based correction is applied to emissivity, which loads the respective collections of Top of Atmosphere (TOA), brightness temperatures (BT) ssand Surface Reflectance (SR). A cloud mask is applied to both using the quality information bands (module cloudmask) and the dataset having cloudcover not more than 10% are selected. Time-series chart is supported in GEE if there are less than 5000 elements in collection. The process is aborted if there are more than 5000 elements, so to prepare the time-series chart date range for 3 years were given as input. The "reducer" function in GEE was used to extract the mosaiced image for the respective timespan, as provided in the input. Temperature obtained from the above collection is mean temperature of the entire city boundary region and measured in kelvin. Temperature conversion from Kelvin to Celsius was performed using python in the pycharm console. These LST datasets are exported in tabular format and time series LST chart is computed for each city.

3. RESULTS

In this study, a comparison of land surface temperature of cities with three different geographical terrains have been investigated for 20 years (two decade) to understand the temporal trend of change in LST. Two decadal big data of Landsat 5, 7, and 8 data were processed to understand the Land Surface Temperature variation over the three cities i.e., Surat, Ahmedabad, Delhi. The heat maps were generated using Google Earth Engine and ArcGIS Pro platforms. The heat maps are analyzed to obtain the relationship between the parameters like - increase of air temperature, geographical location of city, water body, terrain of city corresponding to the urban sprawl and density. Urban Heat Maps were prepared using ArcGIS online platform. The different terrain, geographical location spatial and temporal distribution of values of UHI is as shown in Figure 2.

Figure 2 shows LST of three cities Surat, Ahmedabad and Delhi. The rows indicate the different cities and its temporal variation while the columns provide an insight on the comparative values on the LST due to the terrain and geographical location of the cities. The first row shows the temporal and spatial variation in the temperature of Surat city. Surat city is a coastal city and has river Tapi crossing through the NE_NW of city. The development of city has flourished along the banks of river and then during 2015-2020 Surat city has expanded gradually on the fringes. There is an industrial area which is located on the Southeast side of city. The land use of city of Surat is majorly Residential and Textile Industry on the west side of river. The major commercial activity in Surat city is Diamond Trade and Textiles. There are educational institutes located on the central eastern part of city.

In the second row of Figure 2, city of Ahmedabad is shown. It is a landlocked city with the Sabarmati River flowing through the center of city. On the eastern side of river, the old city of Ahmedabad with very dense urban area is located. The city of Ahmedabad is trade hub of Gujarat state also known as Manchester of Gujarat. It has a lake located on the southeast side. The city of Ahmedabad has observed maximum LST of 51°C.

The direction of wind in India during summers is Southwest while in winters is Northeast. So, there are extreme cold temperature observed in Delhi. While Ahmedabad and Surat observe moderate temperature. Corresponding to it the summers in Ahmedabad are very hot and then in Delhi and Surat. The water body flowing through have different location in all the three cities. In Surat the Tapi river is located on the northwest, The Sabarmati River of Ahmedabad passes through center of city, while in Delhi Yamuna River passes through the northeast of the city which is visually quite evident from Figure 2. The maximum LST that has been observed is 58.8°C in the city of Ahmedabad and Delhi.

The statistical observation of LST from the thematic maps as per Figure 3 is summarized in Table 1. The mean LST temperature for the landlocked cities Ahmedabad and Delhi is more by 2-3°C compared to the coastal city

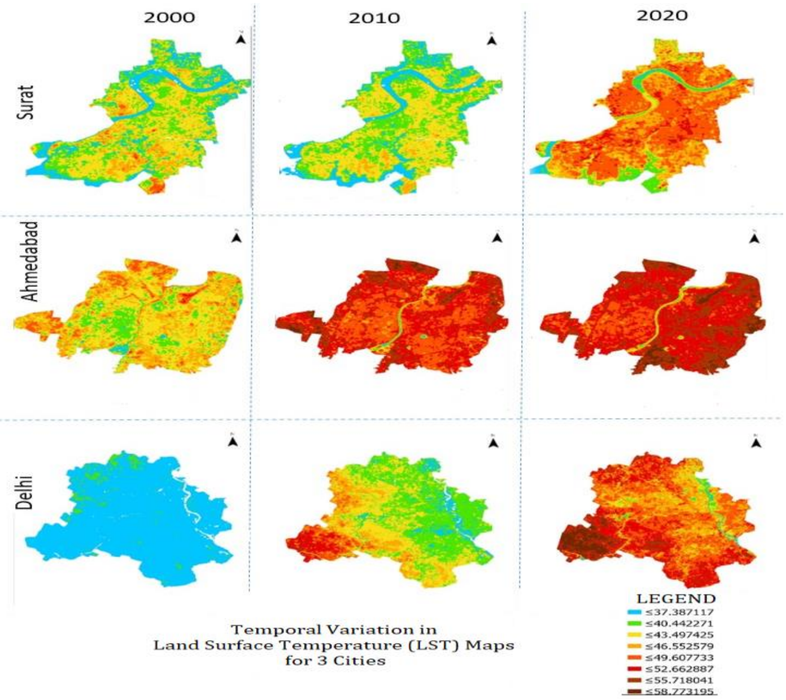

Figure 2. Spatial distribution of Land Surface Temperature (LST) maps of Surat, Ahmedabad, and Delhi City for the year 2000,2010 and 2020. Temporal variation of LST for 20 years of big data is processed using Google Earth Engine for three different city. The maps show a significant rise in temperature from 2010 to 2020 for landlocked city of Delhi and Ahmedabad compared to coastal city of Surat

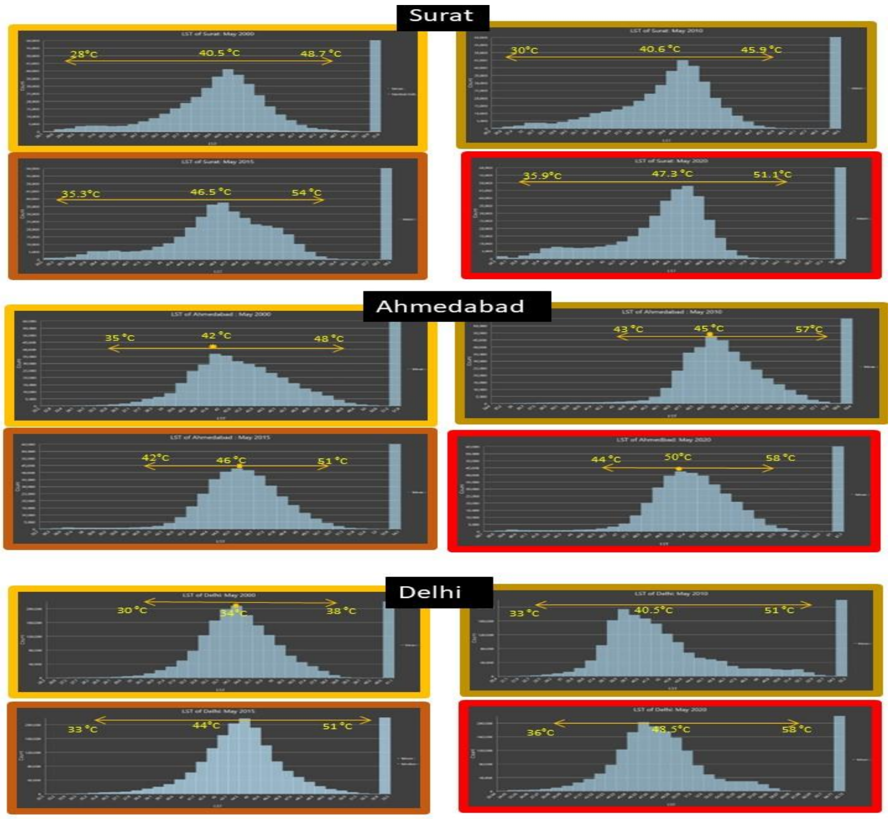

Figure 3. Statistical analysis of the LST image of years 2000, 2010, 2015 and 2020 for the cities of Surat, Ahmedabad, Delhi to investigate the change in temperature peak and its intensity

TABLE 1. Statistical Data of LST for 3 cities

Year	2000			2010			2015			2020		
Temperature in (°C)	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
Surat	28	40.6	48.7	30	40.6	45.9	35.3	46.9	54.6	35.9	47.3	51.1
Ahmedabad	35	42	49	35	49	57.1	42.1	46.1	50.7	38.9	51.4	58.8
Delhi	30	34.6	38.8	33	40.5	52	35.8	44.3	50.9	36	48	58.8

of Surat. For the year 2010, LST of Ahmedabad shows peak temperature of 49°C, which may be due to some error, and it is considered as outlier.

While investigating the mean vertical profile of Gaussian curves it is observed that, there is a shift in peak LST temperature observed in the Landlocked city of Delhi and Ahmedabad. There is a shift in temperature peak by 8°C in the landlocked city .While the coastal city of Surat observes a shift in LST peak by 6°C [9] in their study mentioned that there is 4.5% increase in mortality rates for 1°C increase in heat wave intensity.

Our results provide strong statistical evidence of significant change in the response of city with coastal and landlocked climate.

4. CONCLUSIONS

In this study, three Indian cities with different terrain were investigated using Landsat dataset to understand the effect of Urban Heat Island. The spatial temporal analysis of the study area indicates that the Landlocked city of Ahmedabad shows higher temperature compared to the coastal city of Surat. The statistical analysis and visually interpreted results confirm strong effect of Urban Heat Island in the different medium-dense built-up pocket of the cities. The impervious surface shows a positive correlation with LST while green space shows negative correlation with LST. The Gaussian analysis of three cities indicates that the landlock city of Ahmedabad experiences extreme temperature for a larger span of time, compared to Surat and Delhi. It is also observed, skewness in the temperature variation compared to the past several years. This inferences out there may be possibility of extreme heat and heatwaves. These events of extreme temperature led to loss of human lives and creating thermal discomfort to the vulnerable group of people. Further, from this study it is found that human anthropogenic activities are playing major role in rising temperature. Invariably this rise in temperature is resulting in climate change. The study can be extended for understanding the factors influencing climate change.

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Persian Abstract

چکیده

اقلیم خرد شهری تأثیر مخربی بر زندگی جمعیت شهری گذاشته است. این تحقیق با هدف شناسایی عامل آگاه از محیط زیست در مقابل برنامه ریزی شهری که منجر به چرخه معیوب تغییر اقلیم شهری می شود، انجام می شود. چرخه معیوب شامل بسیاری از پارامترهای پویایی شهری است که درک آنها پیچیده است. این تحقیق بر استفاده از داده های بزرگ سنجش از راه دور در موتور Google Earth به عنوان پیشرفتی برای مطالعه آسیب پذیری آب و هوا که منجر به Gentrification آب و هوای شهری می شود تأکید دارد. داده های زمانی لندست برای ۳۰ سال گذشته برای مطالعه در نظر گرفته شده است. سه شهر با ویژگی‌های جغرافیایی و زمینی متنوع برای مطالعه انتخاب شده‌اند تا بفهمیم برنامه‌ریزی تعیین‌کننده مدرن در انسجام با اهداف توسعه پایدار است. درک اطلاعات مکانی و زمانی نقاط هات اسپات شهری با استفاده از داده های ماهواره ای با وضوح بالا کافی نیست تا نیاز به کاهش دما بین ۲ تا ۳ درجه سانتیگراد را برآورده کند. مطالعه حاضر نشان می دهد که چگونه دلایل تغییر اقلیم کوچک همراه با زمین، موقعیت مکانی و الگوی رشد شهری شهر متفاوت است.