Urban Heat Island Effect

A Project Report submitted by

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in partial fulfillment of the requirements for the award of the degree of

Masters of Technology in Data and Computational Sciences.

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Indian Institute of Technology Jodhpur

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Declaration

I hereby declare that the work presented in this Project Report titled Urban Heat Island Effect submitted to the Indian Institute of Technology Jodhpur in partial fulfillment of the requirements for the award of the degree of M.Tech is a bonafide record of the research work carried out under the supervision of Professor Dr. Saran Aadhar and Dr. Deepak Mishra. The contents of this Project Report, in full or in parts, have not been submitted to and will not be submitted by me to any other Institute or University in India or abroad for the award of any degree or diploma.

Signature

Ruturaj Uday Borkar
M22AI618

Certificate

This is to certify that the Project Report Urban Heat Island eEffect, submitted by Ruturaj Uday Borkar (m22ai618) to the Indian Institute of Technology Jodhpur for the award of the degree of M.Tech. is a bonafide record of the research work done by him under my supervision. To the best of my knowledge, the contents of this report, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

10/9/2024

Signature

Dr SaranAadhar

Signature

Dr Deepak Mishra

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Ruturaj Uday Borkar

Abstract

Urban heat islands (UHIs) are a growing concern for cities worldwide. These areas experience significantly higher temperatures than surrounding rural areas due to the combined effects of urban infrastructure, human activities, and reduced vegetation cover. UHIs exacerbate existing heat stress, air pollution, and energy consumption, posing significant challenges to public health, environmental quality, and urban livability.

This project aims to investigate the UHI phenomenon in detail, focusing on region of interest. The specific objectives are to:

- Analyze the spatial distribution and intensity of the UHI effect within the city/region.
- Identify the key factors contributing to UHI formation, such as building materials, land use patterns, and anthropogenic heat sources.
- Evaluate the impacts of UHIs on public health, air quality, and energy consumption.
- Develop and assess potential mitigation strategies and adaptation measures to reduce the UHI effect and improve urban resilience.

Introduction

Urban Heat Island Effect is a phenomenon where urban areas experience higher temperatures than their surrounding rural areas. This is primarily caused by the removal of natural plant species and increase in urbanization, which is necessary for the development of the urban infrastructure, such as buildings, roads, and sidewalks. The purpose of this project is to examine exactly how the infrastructure of an urban area contributes to significant temperature increases, to describe the impacts this effect has on these areas, and to determine solutions for this widespread problem.

Heatwaves are a big deal globally and are expected to get worse. Urban heat islands (UHIs) make heatwaves even worse, but we don't know much about how they affect heatwaves in Indian cities. Some recent research used on-site measurements, satellite data, and computer models to check this out. Surprisingly, it turns out that Indian cities don't actually make heatwaves more intense. Instead, there are more hot days in cities from 1951 to 2016, and hot nights have gone up in most cities, except those in the Indo-Gangetic Plain.

Interestingly, there's a decrease in hot nights in the Indo-Gangetic Plain during the same period, and this seems to be because of a lot of irrigation happening there. Computer simulations from the Community Land Model back this up. The results show that in major Indian cities, the heat island effect during heatwaves actually goes down both during the day and night compared to normal. During heatwaves, the areas around cities without much greenery are hotter than the cities themselves. This has important implications for health policies during heatwaves

DATA COLLECTION

According to Kumar et al. (2017), the study utilized a 56-meter resolution Land Use Land Cover (LULC) dataset from the National Remote Sensing Center (NRSC) for the year 2011. Additionally, an urban extent map derived from Moderate Resolution Imaging Spectroradiometer (MODIS) 500 meters land cover data (Schneider et al., 2010) was employed to identify densely built-up areas in 89 major urban regions in India. The overlapping built-up regions from both datasets were considered as the urban core areas.

For estimating Land Surface Temperature (LST), 1 km resolution MODIS 8-day data from Aqua and Terra satellites spanning from 2003 to 2016 were used. The LST data were derived based on emissivity in different spectral bands observed from satellites under clear sky conditions. To enhance reliability, quality control flags provided by MODIS products were used.

In the study, observed daily near Surface Air Temperature (SAT) data at a 2-meter height from the India Meteorological Department (IMD) covering the period 2003–2016 were acquired. The gridded dataset was developed using 395 stations from 1951 to the present, employing Shepherd's angular distance weighting algorithm. To match spatial resolution, the IMD data was regridded from 1° to 0.25° using bilinear interpolation. The daily gridded dataset from IMD was utilized to identify hot days, hot nights, and heatwaves. A hot day was defined as a day with a maximum SAT surpassing the 95th percentile of summer (April, May, and June) daily maximum SAT (Tmax) during the reference period of 1970–2010. Similarly, a hot night was identified when the daily minimum SAT (Tmin) exceeded the 95th percentile of Tmin during the summer reference period.

Methods Used

- Urban and non-urban temperature contrast can be quantified using Surface Urban Heat Island (SUHI) intensity. SUHI can be defined as the difference of urban and surrounding non-urban weighted average LST. Where LST_U and LST_{NU} represents weighted average LST for urban and surrounding non-urban region, respectively.
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$$SUHI = LST_U - LST_{NU}$$

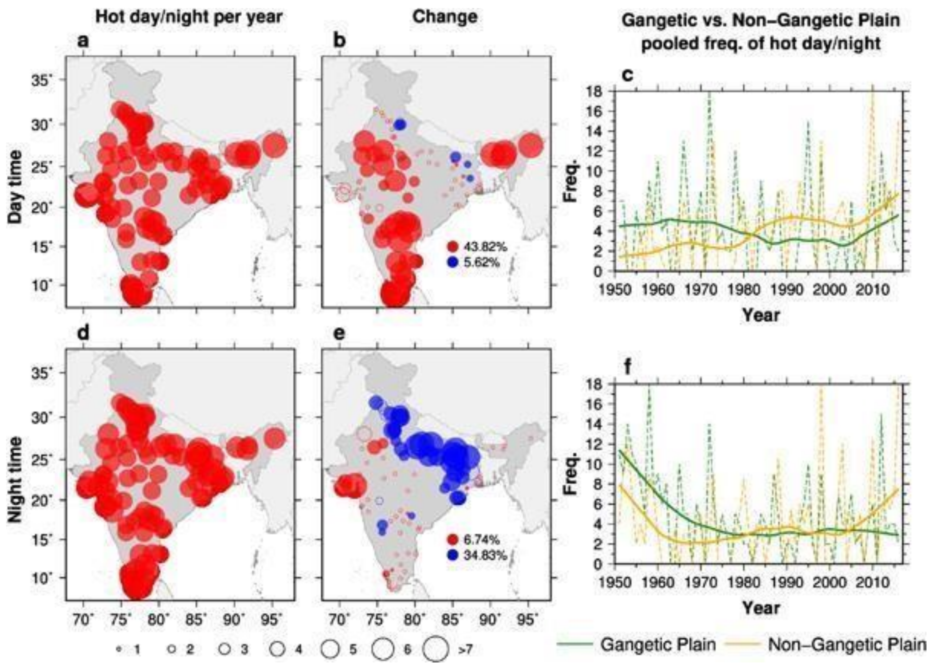
- The weighted areal average of a region (LST) can be determined as, Where, w_p and LST_p are weights and LST of pth pixel respectively.

$$\mathrm{LST} = \frac{\sum_1^n w_p LST_p}{\sum_1^n w_p}$$

$$w_p = \begin{cases} 3, \textit{ good quality LST} \\ 2, \textit{ fair quality LST} \\ 1, \textit{ poor quality LST} \end{cases}$$

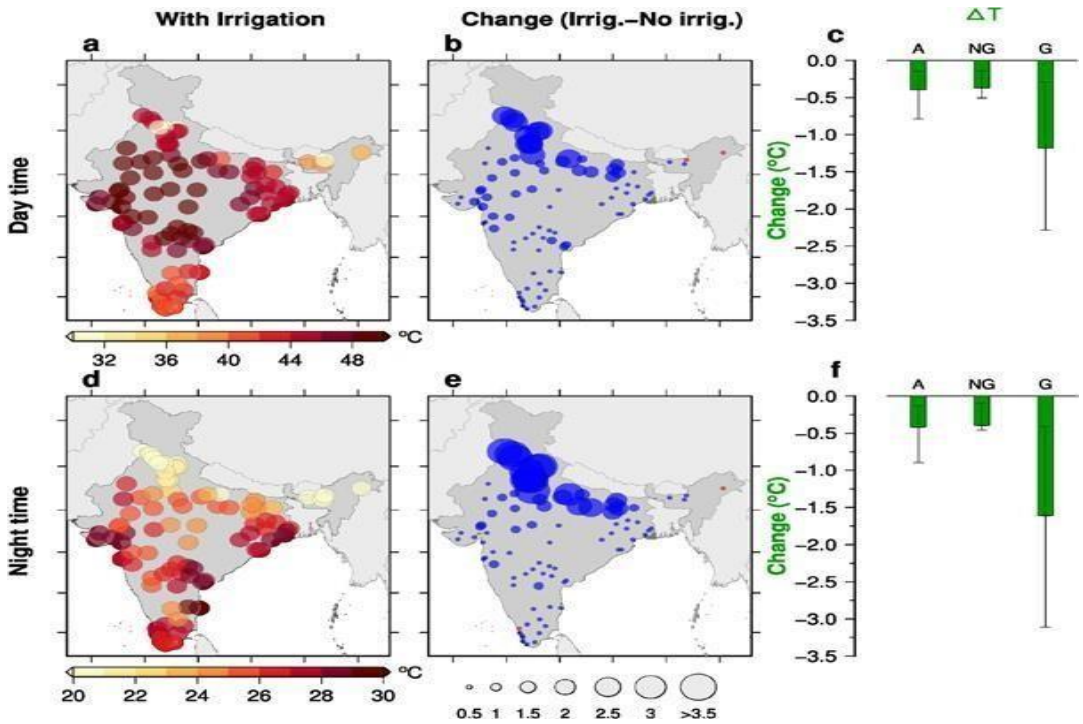
Results and Discussions

In their examination of urban climate trends spanning from 1951 to 2016, researchers discovered significant shifts in the occurrence of hot-days and hotnights across various urban areas. The majority of these locations experienced approximately five such events annually, with 44% witnessing an increase in hotdays, while 34.8% faced a notable decline in hot-nights.Before 1980, non-Gangetic plain regions (NGR) reported fewer hot-days and nights, but post-1980, a decline in hot-days occurred in IGP. Notably, urban areas in NGR exhibited a higher frequency of hot-nights. The variations observed were attributed to intensive irrigation practices, highlighting the impact of human activities on regional climate dynamics. These findings contribute to a deeper understanding of the complex interplay of factors shaping urban heat trends, with implications for climate adaptation strategies in diverse regions.

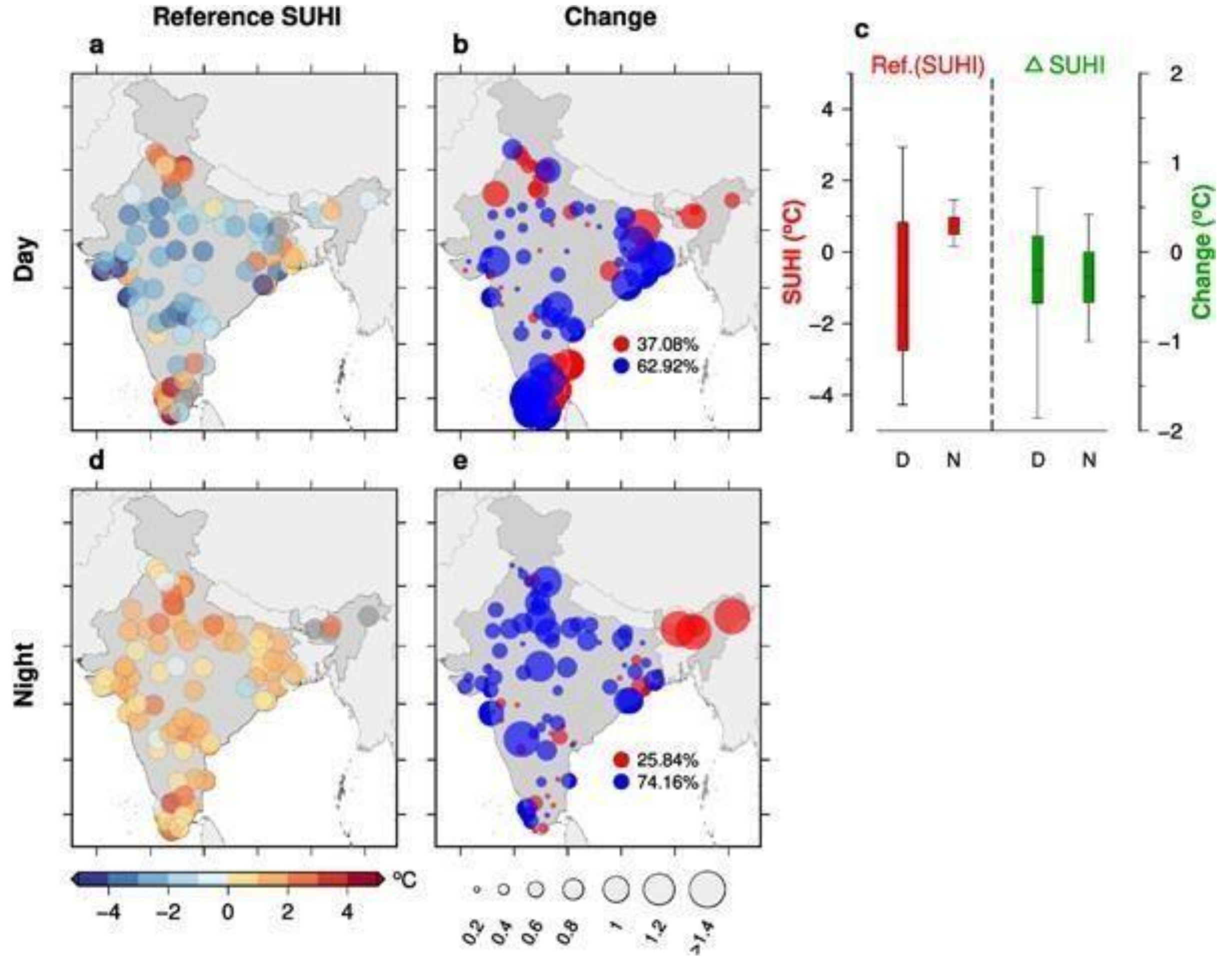


In their investigation into the impact of irrigation on Land Surface

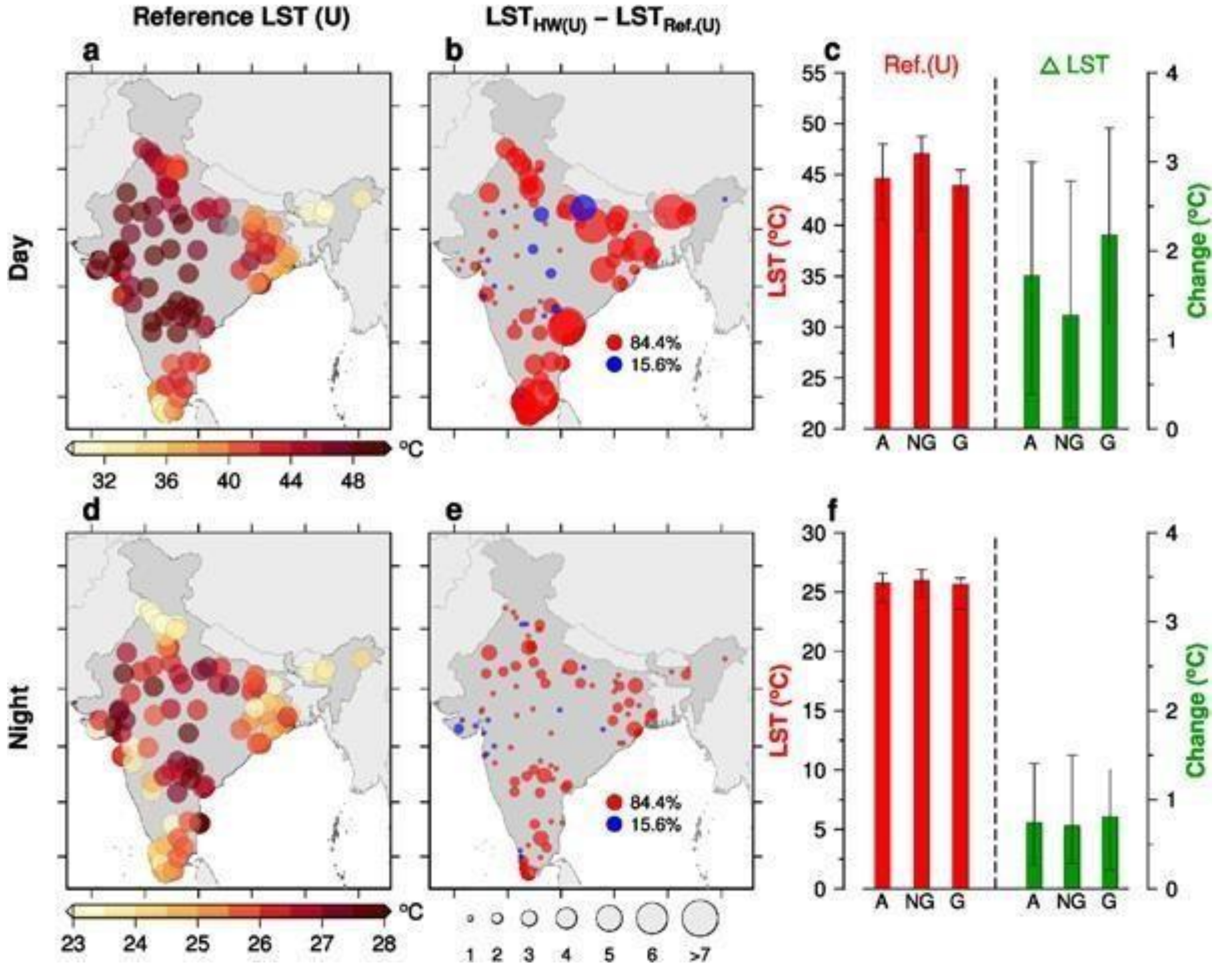
Temperature (LST), the researchers employed simulations from the Community Land Model (CLM) with both irrigation-enabled and irrigation-disabled scenarios. The results revealed a summer median cooling effect attributed to irrigation, with a decrease of 1.2 °C during the day and 1.6 °C during nighttime in the Indus-Gangetic Plain (IGP) region. In contrast, for locations in the less intensively irrigated Non-Gangetic Plain Region (NGR), the cooling effect was notably lower, measuring 0.37 °C during the day and 0.4 °C during nighttime. These findings underscore the substantial influence of irrigation on surface temperature, with observed cooling trends particularly evident in regions like India.



In their assessment of Surface Urban Heat Island (SUHI) intensity variations in major urban areas during heatwaves, the researchers utilized Land Surface Temperature (LST) data from MODIS satellites. The study focused on 89 urban areas in India, estimating changes in SUHI intensity during heatwaves compared to reference SUHI levels at both day and night. The findings revealed that, during heatwaves, most urban areas exhibited a daytime Surface Urban CooIsland(SUCI)as nonurban areas were hotter than their urban surroundings.



The results indicate that Surface Urban Heat Island (SUHI) intensity remains stable during heatwaves in Indian urban areas. To further delve into urban Land Surface Temperature (LST) variations during heatwaves, the researchers assessed absolute LST amplification in both urban and non-urban regions. Daytime reference LST for non-urban areas was notably higher than that of urban areas, with mean amplification during heatwaves higher in non-urban areas (1.9 °C) compared to urban areas (0.14 °C). Median daytime LST amplification in NonGangetic Plain Region (NGR) was 2.3 °C for non-urban areas and 2.1 °C for urban areas. Night-time analysis revealed higher reference LST in urban areas compared to non-urban surroundings.



Reference LST (U)
$LST_{HW(U)} - LST_{Ref.(U)}$
a
b
c
Ref.(U)
△ LST
Day
84.4%
15.6%
LST (ºC)
Change (ºC)
A NG G A NG G
32 36 40 44 48 ºC
d
e
f
Night
84.4%
15.6%
23 24 25 26 27 28 ºC
1 2 3 4 5 6 >7

Conclusion

- It was observed that majority (44%) of the selected locations show significant rise in extreme hot-day frequency in the period of 1951–2016. While 35% of the urban locations experienced a decline in extreme hot-nights frequency in the same period. Our results show a significant decline in change in frequency of hot-nights concentrated in the IGP. Using CLM simulations we show that the intensive irrigation is associated with significant cooling in IGP, which can be attributed to the decline in frequency of extreme hot-nights as compared to the rest of India.
- It was also shown that majority of the urban locations (63% and 74%, respectively) show decline in SUHI intensities during heatwaves both at day and night times.

- The effect of urbanization can be explained by disentangling the urban and non-urban responses during heatwaves. We find that during heatwaves the day-time LST amplification in non-urban regions was significantly higher (1.94 °C) than the amplification in the urban areas (0.14 °C) for all selected locations (on top of higher non-urban base temperature than urban areas). Our results show that heatwaves do not amplify SUHI intensity in India have implications for urban planning in India.

Further Enhancements and Problem Solving

Developing UHI(URBAN HEAT ISLAND) predictive Models.

Common approaches to developing Urban Heat Island (UHI) predictive models often involve conventional regression methods. Researchers such as Chun and Guldmann utilized regression analysis and spatial data derived from 2D- and 3Daerial satellite images to explore UHI determinants. Su et al. demonstrated relations among land-cover types using weighted-regression modeling. However, conventional regression methods may struggle with capturing complex nonlinear and spatially heterogeneous relations between UHI determinants and UHI. To address this limitation, advanced non-linear analysis techniques like artificial neural networks (ANNs) have gained prominence in UHI studies. For instance, Mihalakakou et al. applied a backpropagation ANN model to estimate diurnal and nocturnal UHI intensity fluctuations in Athens, highlighting the importance of urban air temperature and synoptic-scale atmospheric circulation. Gobakis et al. compared different ANN architectures for UHI prediction, identifying Elman ANN as optimal.

While ANNs offer improved modeling capabilities, studies have predominantly employed shallow ANNs, potentially facing issues of overfitting and limited generalizability. To overcome this, the current study proposes the development of two types of deep neural network (DNN) models for UHI prediction in Seoul: a temporal and a spatial model. The spatial UHI-model focuses on geographic indicators, explaining how urban factors influence UHI manifestation in urban areas. In contrast, the temporal UHI-model employs meteorological indicators to elucidate how weather elements affect UHI in urban areas. This approach aims to enhance the understanding of UHI dynamics through a comprehensive exploration of both spatial and temporal factors.

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