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Measuring Urban Heat Islands in Metropolitan City, Pokhara, Using Remote Sensing

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Abstract

This study investigates the Urban Heat Island (UHI) effect in Pokhara Metropolitan City using remote sensing and geographic information systems (GIS). The primary objective is to analyze temporal and spatial variations in UHIs, with secondary objectives including evaluating spatial patterns of Land Surface Temperature (LST) and assessing changes in UHI intensity over time. Landsat 8 imagery from 2013 to 2022 was processed using Google Earth Engine (GEE) to derive LST maps. Data preprocessing involved band selection, cloud masking, and spatial filtering to enhance data quality. Urban and suburban areas were delineated using shapefiles, facilitating the calculation of Surface Urban Heat Island (SUHI) intensity across the city. Results indicate pronounced spatial disparities in LST, with urban areas consistently registering higher temperatures than suburban counterparts. The average LST in urban areas peaked at 39.13°C, compared to 34.43°C in suburban areas. Temporal analysis reveals a steady rise in both LST and SUHI intensity over the study period, with SUHI values increasing from 2.99 in 2013 to 5.85 in 2022, highlighting the escalating impact of urbanization on local climate dynamics. This research contributes crucial insights into the urban thermal environment of Pokhara Metropolitan City, essential for informing sustainable urban planning and climate resilience strategies in rapidly developing regions.

***Keywords*:** Sub-urban; Urban; Island; Hot spots; Land Surface Temperature; Urban Heat Intensity

1. Introduction

Urbanization is a global phenomenon characterized by rapid city and town growth. While cities offer economic opportunities and improved living standards, they also face challenges like the Urban Heat Island (UHI) effect. The UHI phenomenon refers to elevated temperatures observed in urban areas compared to suburban surroundings (Smith, 2016). This effect has profound environmental, societal, and public health implications, including increased energy demand, amplified air conditioning use, higher greenhouse gas emissions, and reduced outdoor comfort (Smith, 2016). Addressing the UHI effect requires a comprehensive understanding of its spatial and temporal patterns and the contributing factors. Remote sensing and geospatial analysis have become indispensable tools for studying and mitigating UHI phenomena. These technologies enable the monitoring of Land Surface Temperature (LST) across urban and non-urban regions, facilitating the identification of UHI hotspots and temperature gradients. This study focuses on Pokhara Metropolitan City, a rapidly urbanizing area in recent decades. The city has experienced significant growth in built-up areas, leading to the conversion of agricultural land, open spaces, and forest covers (Johnson, 2023). This research uses advanced technology such as Google Earth

Engine (GEE) to detect and analyze UHI patterns within Pokhara, offering insights to inform effective urban planning and mitigation strategies. The UHI effect presents critical challenges globally, affecting urban environments with heightened temperatures and associated environmental stressors. As cities expand, understanding UHI dynamics and developing effective mitigation strategies become essential for sustainable urban development (Brown et al., 2024). Recent studies emphasize the importance of localized UHI assessments in understanding spatial variability and designing appropriate mitigation measures (Wang, 2021; Rodriguez et al., 2022). Advancements in remote sensing techniques provide new opportunities to quantify and monitor UHI effects accurately, integrating demographic data to unravel socio-economic implications (Patel et al., 2022; Garcia et al., 2020). The unique geographical and climatic characteristics of Pokhara Metropolitan City necessitate localized research efforts to tailor strategies effectively (Kumar et al., 2019; Sharma et al., 2023) area.

1.1. Surface Urban Heat Island Intensity

Surface Urban Heat Island (SUHI) intensity was calculated using the formula $\Delta T_{u-r} = T_u - T_r$, where Tu represents the average land surface temperature (LST) of urban areas and Tr represents the average LST of suburban areas. This approach quantified the temperature differential between urban and suburban zones over the study period, indicating the magnitude of the urban heat island effect in Pokhara Metropolitan City.

2. Methodology: Analysis

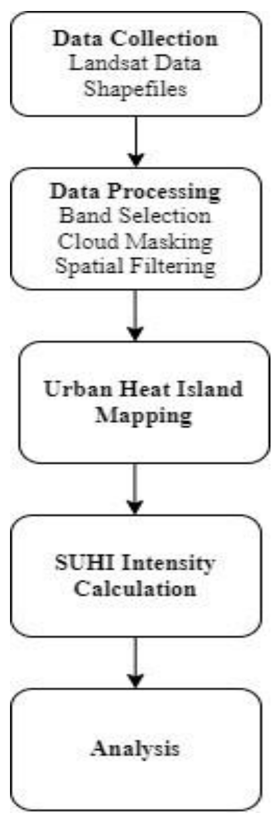

Figure 1: The procedure of SUHI Analysis

The analysis encompassed temporal and spatial assessments of LST trends and SUHI intensity across Pokhara Metropolitan City from 2013 to 2022. The temporal analysis involved examining seasonal and annual variations in LST to discern patterns indicative of urban heat island intensification. Comparative spatial analysis compared LST distributions between urban and suburban areas to highlight localized heat stress and temperature anomalies associated with urbanization.

2.1. Study Area

Pokhara Metropolitan City, located in the Gandaki Province of Nepal, served as the primary study area. With a population of 513,504 and undergoing rapid urbanization (National Population and Housing Census, 2021), Pokhara presented an ideal setting for studying urban heat islands. The average maximum temperature in summer varies between 30˚C and 32˚C and in winter minimum

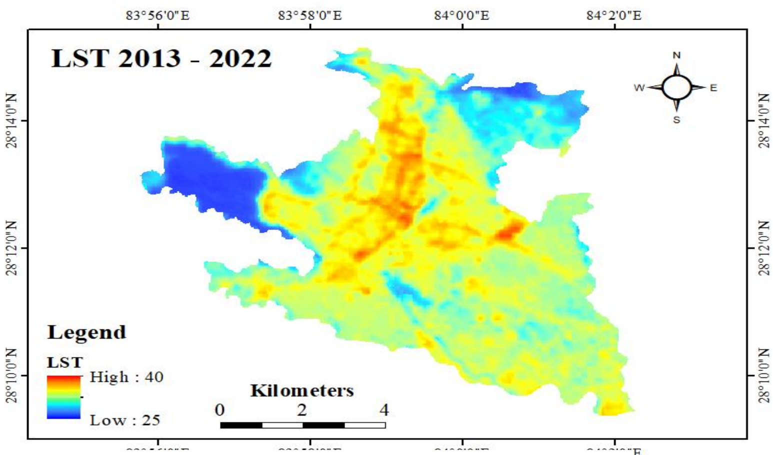

Figure 2: LST Over AOI (average of 2013-2022)

6˚C to 8˚C (WeatherSpark, 2023). Its unique geographic and climatic conditions, including proximity to mountain ranges and prominent lakes, influenced local meteorological patterns and urban heat island dynamics. Understanding these factors was crucial for developing strategies to mitigate the adverse effects of urban heat islands and enhance urban planning efforts in the region.

3. Results and discussion

3.1. LST Map

The analysis, spanning from 2013 to 2022, computed the mean surface temperature for specified months. The average surface temperature for each pixel was clipped to the Area of Interest (AOI) and used to create a histogram, showing the range of land surface temperature (LST) values in degrees Celsius.

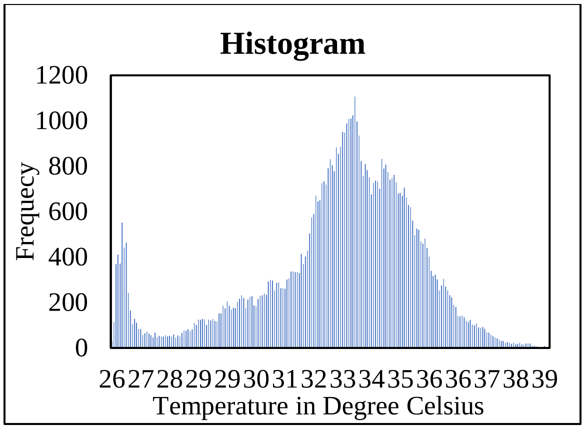

Figure 3: Histogram of LST over AOI (average of 2013-2022)

Figure 3 shows a histogram depicting the spread of LST values (degrees Celsius) over the AOI, ranging from 25.90°C to 39.13°C. The highest frequency of temperature (33.38°C) is observed in the area.

Figure 2 displays the land surface temperature of the study area, highlighting hotter (red) and cooler (blue) areas. The central city area, characterized by impervious surfaces and congested settlements with tin roofs, exhibits higher temperatures compared to the surrounding forested areas.

3.2. Trend of LST

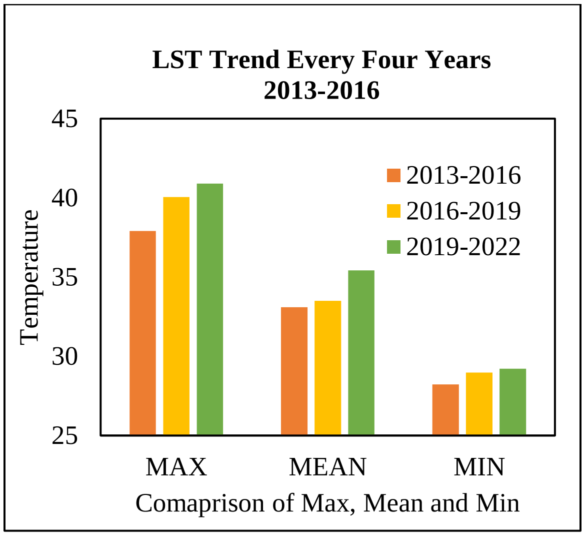

Figure 4: Comparison of LST Averaged Every Five Years From 2013-2023

Land Surface Temperature (LST) maps were generated for distinct five-year intervals (2013-2016, 2016-2019, 2019-2022) to visualize temporal LST trends across the AOI.

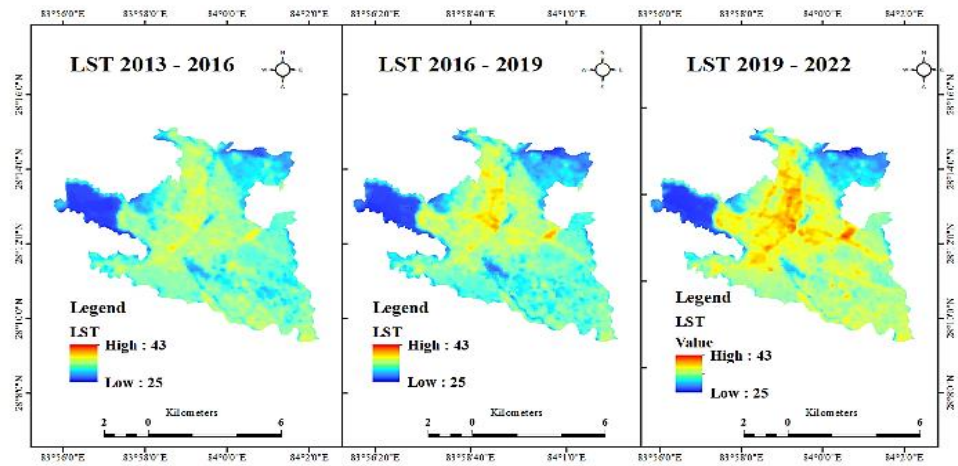

Figure 5 LST Time Series From 2013-2022 For Every Four Years

Figure 5 indicates a gradual increase in LST over Pokhara Metropolitan City from 2013 to 2022. Hotspot areas have visibly expanded, as detailed in Table 1.

Table 1 Comparison of LST averaged every three years from 2013-2023

LST	**2013-2016**	**2016-2019**	**2019-2023**
Max	38°C	40°C	41°C
Mean	33°C	34°C	35°C
Min	28°C	27°C	29°C

3.3. Urban Heat Island (UHI)

Analysis of LST values from urban and suburban points (Figure 4) using data from 2013 to 2022 shows significant temperature differences. A buffer zone of 200m was selected around these points to calculate and average the LST time series separately for urban and suburban areas.

Table 2 Urban vs Suburban Temperature

Land Surface Temperature (Celsius)	**Urban**	**Suburban**
Max	39.13°C	34.43°C
Mean	33.23°C	29.49°C
Minimum	28.48°C	25.90°C

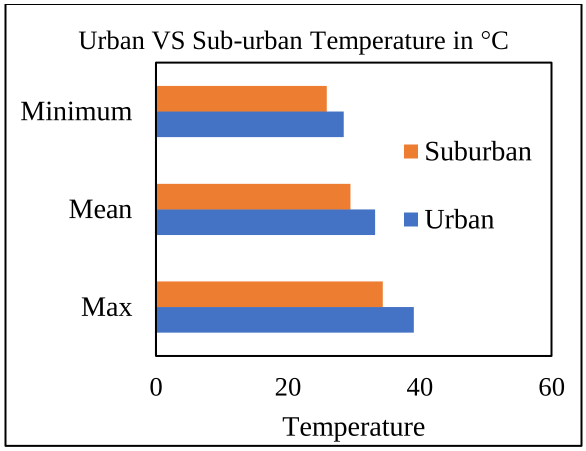

Figure 6: Graph Comparing Urban vs Suburban Temperature

Figure 6 illustrates the temperature disparities between urban and suburban areas, with urban areas consistently exhibiting higher temperatures as compared to suburban areas. The analysis of LST data from 2013 to 2022 underscores the Urban Heat Island (UHI) effect in Pokhara Metropolitan City, where urban areas consistently experience higher temperatures than their suburban counterparts.

3.4. Increasing SUHI Intensity

Table 3: Year and average SUHI of AOI

Year	**SUHI Intensity**
2013	2.99
2014	3.15
2015	3.65
2016	3.48
2017	4.24
2018	4.39
2019	4.19
2020	5.12
2021	5.30
2022	5.85

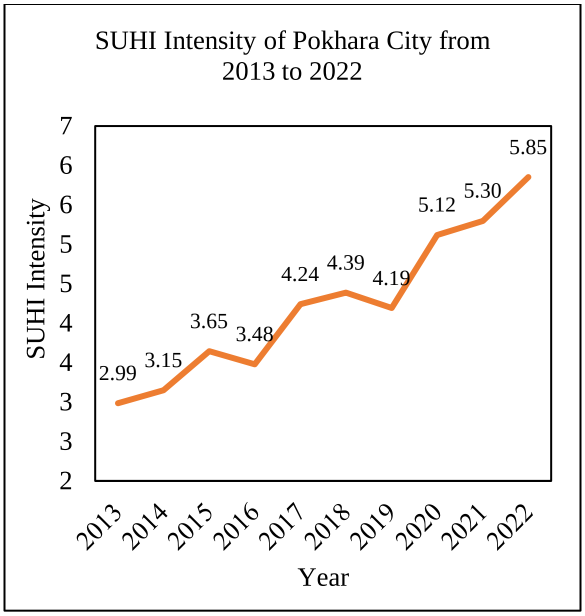

Figure 7: Trend of SUHI from 2013 to 2022

Table 3 and Figure 7 depicts the increasing trend of SUHI from 2013 to 2022 in Pokhara Metropolitan City. The SUHI values indicate a significant rise in temperature differences between urban and suburban areas, emphasizing the growing impact of urbanization on local temperatures. The U.S. Environmental Protection Agency (EPA) Heat Island Index classifies the intensity of the Urban Heat Island (UHI) effect based on temperature differences between urban and suburban areas:

- Slight: < 1°C
- Moderate: 1-3°C
- Severe: 3-5°C
- Extreme: > 5°C

3.5. Discussion

The study reveals significant findings regarding the Urban Heat Island (UHI) effect in Pokhara Metropolitan City. Analysis of Land Surface Temperature (LST) maps from 2013 to 2022 shows a consistent rise in urban temperatures, exacerbated by urbanization and land use changes. The spatial distribution of LST highlights hotter urban cores with dense, impervious surfaces, contrasting with cooler suburban areas rich in vegetation. the increasing trend of SUHI from 2013 to 2022 shows that PMC has reached extreme level of Urban heat island. This phenomenon poses challenges for urban planning and climate resilience, necessitating strategies like green infrastructure and sustainable design to mitigate heat island effects. Future research should focus on refining modeling techniques and exploring socio-economic factors to enhance climate resilience and sustainable urban development in Pokhara.

4. Conclusion

The research on Pokhara Metropolitan City reveals a significant impact of urbanization on local climate, particularly in terms of increasing land surface temperatures (LST) and changing vegetation cover. Analysis spanning from 2013 to 2022 shows a clear rise in LST, reaching extreme levels by 2020. These findings are consistent with global studies on the Urban Heat Island (UHI) effect, highlighting Pokhara's unique urban dynamics. The study fills a crucial gap by offering localized insights into how urbanization has shaped Pokhara's climate over time.

In conclusion, the research underscores the critical need for sustainable urban planning and the preservation of green spaces to counteract the adverse effects of urbanization on local climate. These insights are essential for informing policymakers and urban planners in developing strategies that promote balanced urban growth while ensuring environmental sustainability.

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