Assessing the Surface Urban Heat Island Effect in Nueva Ecija, Philippines: A Decadal Analysis Using Landsat 8 Satellite Imagery

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ABSTRACT

This study investigates the Surface Urban Heat Island (SUHI) effect in Nueva Ecija, Philippines, utilizing Landsat 8 satellite imagery from 2013 to 2023 to analyze temperature differences between urban and rural areas. Through remote sensing and thermal analysis, we evaluated mean, maximum, and minimum surface temperatures across selected polygons, revealing substantial temperature disparities associated with urbanization. Results show an average SUHI intensity of 12.42°C, with urban areas reaching peak temperatures of 53.62°C, while rural regions recorded lower maximums at 49.91°C. These findings highlight the significant influence of urban environments on local thermal profiles and underscore the urgent need for sustainable urban planning to mitigate heat-related impacts. Future research should consider seasonal variations in SUHI intensity to better understand the dynamics of temperature changes in response to climate and vegetation shifts. Incorporating socio-economic data could further elucidate the SUHI's effects on public health, energy use, and living conditions. Additionally, integrating ground-based temperature data is recommended to enhance accuracy, offering more detailed insights for urban planners and policymakers working toward resilient and sustainable urban growth.

Keywords: Surface Urban Heat Island (SUHI), Landsat 8, remote sensing, sustainable urban planning

INTRODUCTION

The Urban Heat Island (UHI) phenomenon, characterized by elevated temperatures in urban areas compared to surrounding rural regions, presents a critical environmental and public health challenge in rapidly urbanizing areas (Zhou et al., 2016). This effect is primarily driven by the transformation of land use, where natural surfaces are replaced by impervious ones like concrete and asphalt, amplifying heat absorption and reducing the landscape's natural cooling capacity (Huang et al., 2019). Researchers have increasingly turned to remote sensing technologies, particularly satellite imagery, to monitor and analyze UHI effects. Tools such as the Landsat series, with high-resolution thermal data, have become instrumental in assessing land surface temperature (LST) and quantifying UHI intensity over time (Guo et al., 2020).

Recent studies highlight various methodologies for UHI analysis. For instance, Chen et al. (2020) utilized Landsat thermal data to assess UHI effects in urban centers, applying atmospheric and geometric corrections to enhance accuracy. Lazzarini et al. (2021) explored temporal UHI variations in metropolitan areas using multi-temporal Landsat imagery, while Vancutsem et al. (2018) emphasized the importance of accurate emissivity adjustments in deriving LST values. The current study adopts these foundational methods, integrating advanced cloud-masking techniques and optimized atmospheric correction to produce precise, cloud-free thermal readings. Additionally, the study leverages Google Earth Engine (GEE) to streamline data processing and analysis, enhancing efficiency in handling large datasets. This methodology ensures reliable UHI assessments with a comprehensive decadal perspective, providing insights beyond those typically observed in shorter-term studies.

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Despite these advancements, research gaps remain concerning UHI effects' temporal and spatial characteristics in smaller but rapidly urbanizing regions like Nueva Ecija, Philippines. Limited research has focused on quantifying UHI intensity in regions where urbanization trends deviate from those in larger metropolitan areas. This study aims to address these gaps by conducting a decade-long analysis of surface temperature variations in Nueva Ecija, employing remote sensing techniques to quantify the intensity and impacts of the Surface Urban Heat Island (SUHI) effect.

Objectives/Aims

The main objectives of this study are to (1) analyze surface temperature variations between urban and rural areas in Nueva Ecija over ten years, (2) quantify the SUHI intensity and its temporal trends, and (3) provide insights for sustainable urban planning to mitigate heat-related risks in this rapidly urbanizing region.

METHODOLOGY

Study Area

This study examines Nueva Ecija, located in Central Luzon, Philippines, with coordinates from approximately 15.32° to 15.92° N and 120.64° to 121.30° E. Over the past decade, rapid urbanization has led to notable warming due to land use changes that enhance the Urban Heat Island (UHI) effect (Andres et al., 2021). The province's lowland plains are bordered by the Caraballo and Sierra Madre ranges, with a tropical monsoon climate that brings distinct wet and dry seasons. Average annual temperatures range between 24°C and 34°C, peaking from March to June, the period used for this study (Philippine et al. Administration [PAGASA], 2022).

Urban growth is concentrated in cities such as Palayan, Cabanatuan, and San Jose, where construction and reduced vegetation drive up surface temperatures. Using Landsat 8 satellite imagery and Google Earth Engine, this study quantifies the Surface Urban Heat Island (SUHI) effect over ten years. Figure 1 Map of Nueva Ecija, Philippines, with latitude and longitude coordinates highlighting urban and rural analysis zones.

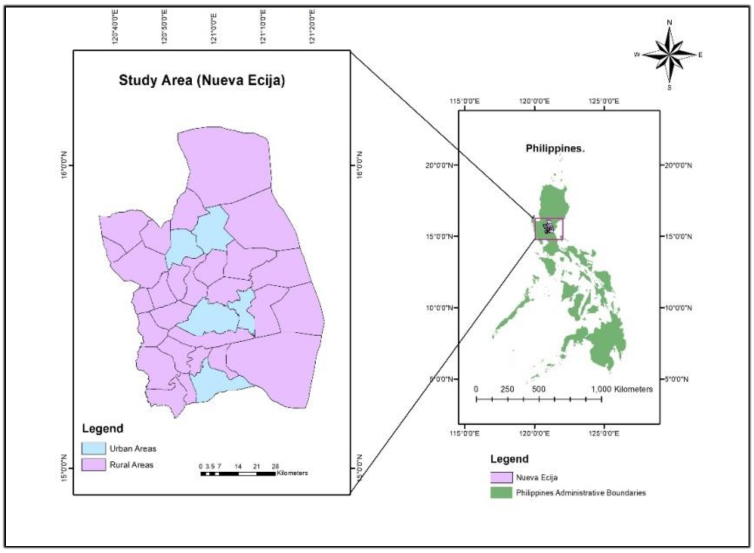

Figure1. Map of Nueva Ecija, Philippines

Satellite Imagery

Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) data will be utilized to obtain land surface temperature (LST) measurements. The selected scenes will be cloud-free and cover different seasons to capture seasonal variations in LST. Data will be processed using Google Earth Engine, which efficiently handles large datasets and cloud computing capabilities. As Zhang et al. (2020) highlighted, Landsat data allows for detailed spatial and temporal analysis of LST and UHI effects. Table 1 presents the property satellite imagery from Landsat 8.

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Table1. LANDSAT/LC08/C02/T1_L2 Property

Property	**Value**
Image Collection ID	LANDSAT/LC08/C02/T1_L2
Number of Images	20
Time Frame	March 2013 - December 2023
Temporal Resolution	16 days
Spatial Resolution	30 meters
Bands Analyzed	ST_B10, QA_PIXEL

The analysis utilized the Landsat 8 Image Collection identified as LANDSAT/LC08/C02/T1_L2, which comprises 20 individual images captured over several years. Each image features two significant bands: ST_B10, representing surface temperature, and QA_PIXEL, providing quality assessment metrics for each pixel. The availability of multiple images allows for a comprehensive temporal analysis of surface temperature variations across the study area in Nueva Ecija, Philippines. Table 2 summarizes the 20 feature collection data.

Table 2. Image Collection LANDSAT/LC08/C02/T1_L2 (20 elements)

1	Image LANDSAT/LC08/C02/T1_L2/LC08_116049_20140530 (2 bands)
2	Image LANDSAT/LC08/C02/T1_L2/LC08_116049_20150501 (2 bands)
3	Image LANDSAT/LC08/C02/T1_L2/LC08_116049_20160417 (2 bands)
4	Image LANDSAT/LC08/C02/T1_L2/LC08_116049_20160503 (2 bands)
5	Image LANDSAT/LC08/C02/T1_L2/LC08_116049_20180525 (2 bands)
6	Image LANDSAT/LC08/C02/T1_L2/LC08_116049_20190410 (2 bands)
7	Image LANDSAT/LC08/C02/T1_L2/LC08_116049_20200530 (2 bands)
8	Image LANDSAT/LC08/C02/T1_L2/LC08_116049_20210501 (2 bands)
9	Image LANDSAT/LC08/C02/T1_L2/LC08_116049_20230507 (2 bands)
10	Image LANDSAT/LC08/C02/T1_L2/LC08_116050_20130425 (2 bands)
11	Image LANDSAT/LC08/C02/T1_L2/LC08_116050_20150501 (2 bands)
12	Image LANDSAT/LC08/C02/T1_L2/LC08_116050_20160417 (2 bands)
13	Image LANDSAT/LC08/C02/T1_L2/LC08_116050_20160503 (2 bands)
14	Image LANDSAT/LC08/C02/T1_L2/LC08_116050_20160519 (2 bands)
15	Image LANDSAT/LC08/C02/T1_L2/LC08_116050_20180509 (2 bands)
16	Image LANDSAT/LC08/C02/T1_L2/LC08_116050_20180525 (2 bands)

17	Image LANDSAT/LC08/C02/T1_L2/LC08_116050_20190410 (2 bands)
18	Image LANDSAT/LC08/C02/T1_L2/LC08_116050_20200530 (2 bands)
19	Image LANDSAT/LC08/C02/T1_L2/LC08_116050_20210501 (2 bands)
20	Image LANDSAT/LC08/C02/T1_L2/LC08_116050_20230421 (2 bands)

Preprocessing of Satellite Imagery

This process involves preparing satellite imagery for analysis, focusing on cloud masking, atmospheric and geometric corrections, and surface temperature derivation. First, a cloud masking function removes clouds and shadows using the QA_PIXEL band from Landsat 8 and 9 images. The images are then filtered to include those with less than 20% cloud cover for more precise data. In the preprocessing stage, atmospheric correction is applied using the Landsat surface reflectance product (Choudhury et al., 2021) to remove atmospheric interference. Geometric correction ensures the images accurately align with the study area's coordinates. Finally, a scale factor function is applied to the thermal band ST_B10 to derive Celsius's surface temperature (ST). The result is cloud-free, corrected images ready for surface temperature analysis.

Mean LST and SUHI Calculation

This study's Land Surface Temperature (LST) calculation uses Google Earth Engine (GEE) and follows a systematic approach to handle Landsat 8 thermal data. The process begins with importing and filtering Landsat images by geographic area, date range, and cloud cover, ensuring high data quality. To improve accuracy, a cloud mask function removes clouds and shadows from the images (Choudhury et al., 2021).

The thermal data is then converted from digital units (called "digital numbers") into brightness temperature values, a necessary step to determine the land's actual surface temperature. Brightness temperature is calculated using a formula that applies thermal calibration constants (K1 and K2) specific to the Landsat 8 satellite:

$$\text{Brightness Temperature (BT)} = \frac{K2}{\ln\left(\frac{K1}{L\lambda}+1\right)}$$

Here:

- Lλ represents the at-sensor radiance (the amount of energy received by the satellite sensor),
- K1 and K2 are constants provided in the Landsat metadata,
- The logarithmic function adjusts for the sensor's response to temperature.

Once the brightness temperature is determined, land surface emissivity (the efficiency with which land emits thermal energy) is adjusted based on land cover types to get a more accurate LST (Vancutsem et al., 2018). This corrected temperature data is averaged across the defined urban and rural areas in Nueva Ecija to provide mean LST values.

The Surface Urban Heat Island (SUHI) intensity is then calculated by subtracting the mean rural LST from the mean urban LST:

$$\text{SUHI Intensity} = LST_{urban} - LST_{rural}$$

This calculation shows the difference in temperature caused by urbanization, helping us understand how changes in human activities and land use impact the local climate.

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RESULTS AND DISCUSSION

This study reveals significant differences in land surface temperature (LST) between urban and rural areas in Nueva Ecija, Philippines, highlighting the impact of urbanization on local thermal environments. The analysis shows that urban areas recorded notably higher surface temperatures, with a maximum of 53.62°C and an average of 46.33°C, compared to rural areas, where maximum and mean temperatures reached 49.91°C and 33.91°C, respectively (see **Table 3** for detailed temperature statistics across urban and rural zones).

Table 3 Summary of temperature statistics for urban and rural areas in Nueva Ecija

Area Type	**Qa Pixel max**	**Qa Pixel mean**	**Qa Pixel min**	**St B10 max**	**St B10 Mean**	**St B10 Min**	**ST max**	**ST mean**	**ST min**
Urban Areas	26542.29	21837.65	21803.33	52009.88	49875.38	47082.29	53.62	46.33	36.78
Rural Areas	25920.50	21825.01	21762.00	50924.22	46241.73	42534.00	49.91	33.91	21.23

Figure 2 visually presents the distribution of mean LST across Nueva Ecija, providing a clear contrast between urban and rural temperature patterns. These differences correspond to an average Surface Urban Heat Island (SUHI) intensity of approximately 12.42°C, emphasizing the pronounced thermal impact of urbanization on the region

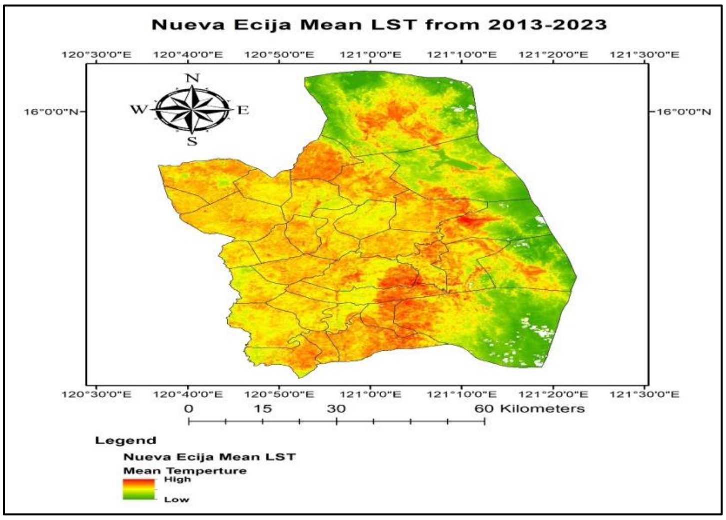

Figure 2. Map of Nueva Ecija displaying the spatial distribution of mean LST from 2013 to 2023

The SUHI intensity observed in Nueva Ecija aligns with findings from other rapidly urbanizing tropical regions. For example, studies in Southeast Asian cities such as Bangkok and Ho Chi Minh City reported similar UHI effects due to dense construction, reduced vegetation, and increased energy use (Sarrat et al., 2019; Chen et al., 2020). However, the intensity recorded in Nueva Ecija exceeds some UHI estimates in larger metropolitan areas, suggesting that rapid, unplanned urbanization in smaller cities can have disproportionate thermal impacts due to the limited presence of mitigating green spaces.

Research in other tropical climates, such as those conducted by Lazzarini et al. (2021) and Tran et al. (2017), highlights regions with reduced tree cover and high building density experience elevated LST levels, like Nueva Ecija. Unlike these studies, the present research focused on a provincial area rather than a major urban center, offering insights into how urban heat dynamics can vary in smaller, rapidly developing locations.

Figure 3 shows a histogram of the frequency distribution of surface temperatures within the analyzed dataset, illustrating how urban areas skew towards higher temperatures compared to rural zones.

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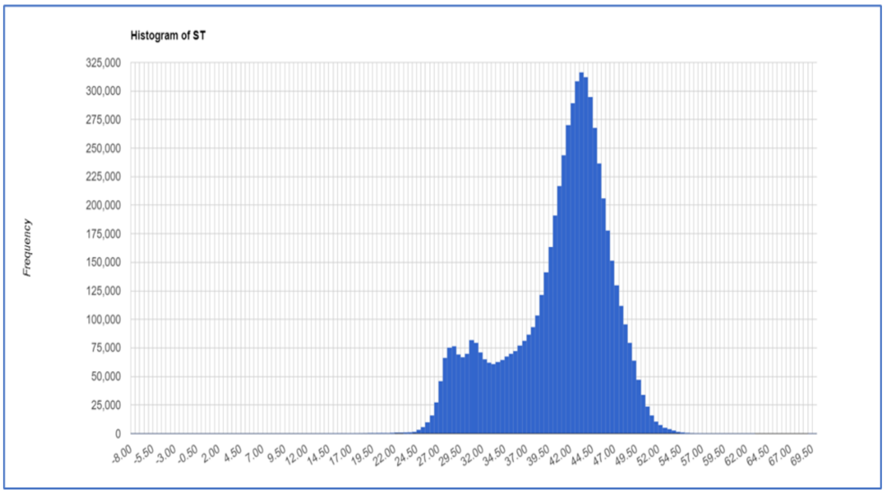

Figure 3. The histogram of surface temperature values for urban and rural areas in Nueva Ecija shows the distribution of temperature frequencies across the study period.

These findings underscore the urgent need for urban planning strategies to address the thermal effects of rapid urbanization. Increasing green spaces, implementing reflective or green roofing materials, and enforcing stricter zoning regulations could help manage the SUHI effect in Nueva Ecija. Enhancing vegetation cover in urban spaces has proven effective in reducing UHI intensities in various tropical cities and could be a viable strategy for Nueva Ecija (Huang et al., 2019).

Future studies could benefit from incorporating seasonal SUHI variations to deepen our understanding of SUHI dynamics, as UHI intensity may fluctuate with seasonal climate changes and vegetation cover. Additionally, integrating local socio-economic data would provide a more comprehensive perspective on how UHI impacts communities, particularly regarding public health, energy use, and housing conditions. Exploring alternative data sources, such as ground-based measurements or meteorological station data, could also enhance the accuracy of LST measurements and contribute to a more nuanced understanding of local thermal profiles (Rajeshwari & Mani, 2018).

CONCLUSION

The findings from this decadal analysis reveal significant SUHI intensity in Nueva Ecija, emphasizing the pressing need for sustainable urban development strategies. While remote sensing offers valuable insights into surface temperature dynamics, future studies should consider integrating socio-economic and seasonal data better to understand the impacts of UHI on local communities. This multi-faceted approach could aid in developing targeted interventions that address both environmental and social dimensions of UHI effects, ultimately enhancing climate resilience in the region.

Ethical Considerations

This study on the Surface Urban Heat Island (SUHI) effect in Nueva Ecija prioritizes privacy, transparency, and social responsibility. Socio-economic or ground-level data must be used carefully to protect community privacy, and informed consent is necessary for any local data collection. Clear methodology documentation and acknowledgment of data limitations ensure accuracy, while findings should support sustainable urban planning with attention to equity, as urban heat impacts marginalized communities disproportionately. Presenting results objectively will guide responsible policy and development decisions.

Conflict of Interest

The authors declare no conflict of interest regarding this study on the Surface Urban Heat Island (SUHI) effect in Nueva Ecija, Philippines. The research was conducted independently, with no financial or personal relationships that could inappropriately influence the study's design, data analysis, results, or interpretation. All findings are presented objectively to support sustainable urban development and inform equitable policy decisions.

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