

Identification of Urban Heat Island (UHI) in the City of Padang from 2019-2023 using Multitemporal Images Case Study: Padang City Area, West Sumatra

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ABSTRACT

The increase in population and urban development leads to higher energy consumption, which adversely affects environmental quality. The resulting impacts include a reduction in green open spaces, an increase in air pollution, and a rise in surface temperatures. This leads to the phenomenon known as the Urban Heat Island (UHI), where urban areas experience higher temperatures than their rural surroundings. This research aims to identify the UHI in Padang City using Landsat multitemporal data over a 5-year observation period from 2019 to 2023. The method involves converting digital numbers from Landsat 8 OLI/TIRS and Landsat 9 satellite images in the Thermal Band to generate Land Surface Temperature (LST) data. Subsequent processing is carried out in GIS software, such as QGIS or ArcGIS, to obtain the distribution of UHI. The research findings indicate fluctuations in land surface temperatures, with both increases and decreases observed over the study period. Each year witnesses an expansion of the UHI area, indicating worsening heat conditions in various regions of Padang City. The findings suggest that land surface temperatures will continue to rise with further urban expansion, highlighting the need for proactive measures. Therefore, it is crucial to develop and implement policies to control and mitigate the negative impacts of UHI in urban spatial planning.

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Introduction

Increased land surface temperatures in cities lead to the formation of urban heat islands, a condition in which urban areas exhibit higher surface temperatures than their surrounding areas (Buyantuyev and Wu, 2009). Buildings, concrete, asphalt, and industrial activities in urban areas cause UHI (Wong and Jusuf, 2010; Coutts et al., 2012; Clive et al., 2012). Tall buildings and narrow streets can trap heated air and block airflow, with additional heat generated by vehicles and factories.

Identification of Urban Heat Island (UHI) in the City of Padang from 2019-2023 using Multitemporal Images Case Study: Padang City Area, West Sumatra

Padang City is the capital of West Sumatra Province and one of the most populous cities on the island of Sumatra. Padang City generally has a tropical climate with a fairly high air temperature. According to BPS Padang City (2006), in 2005, the air temperature of Padang City ranged between 22.6°C and 32.1°C. In 2012, the temperature increased, ranging between 22.2°C and 32.7°C (BPS, 2013). The spatial distribution of UHI in Padang City increased every year of observation. The threshold for identifying UHI was set at 29.0°C in 2007 because the maximum temperature recorded by satellite imagery was 30.51°C. In contrast, the threshold was set at 30.0°C in 2013 and 2017 for maximum temperatures reaching 34.35°C (2013) and 35.92°C (2017) (Fajrin and Dwi Marsiska Driputafany, 2019). These thresholds help in consistently identifying and comparing UHIs over time.

The temperature in Padang City does not align with the standard thermal comfort zone in Indonesia, based on the effective temperature recommended by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), where the comfortable temperature limit is between 22°C and 27°C. The mismatch of surface temperature with the recommended temperature standard affects the comfort of the people of Padang City (Irza Annesi Zulfa and Triyatno, 2020).

This study aims to identify UHIs in Padang City and assess their impact on the urban environment and human life. UHIs cannot be identified solely through image processing without incorporating spatial analysis and data from Landsat 8 satellite images in the Thermal Band to produce UHI distribution maps. These results can provide valuable information and suggestions for urban planning and environmental protection in Padang City. The research objective is to identify Urban Heat Islands in Padang City using multitemporal Landsat data from 2019, 2020, 2021, 2022, and 2023. The benefits of this research include providing comprehensive information on the identification of Urban Heat Islands in Padang City.

Methodology

The study area is Padang City, the capital of West Sumatra Province. Padang City has an administrative area of approximately 1,414.96 km² and is located on the west coast of Sumatra, geographically positioned between 00°05'05" East to 100°34'09" East and 00°44'00" South to 01°08'35" South. The topography of Padang City includes highlands, hills, and lowlands, with development more concentrated and denser in the lowlands and along the western coastline. This pattern is influenced by the steep eastern topography. The elevation of Padang City ranges from sea level to over 1,000 meters above sea level.

This research identifies Urban Heat Islands (UHI) in Padang City by using Land Surface Temperature (LST) data over a five-year observation period. The data were obtained from five Landsat image recordings, including Landsat 8 and 9 OLI. UHI identification was performed through the extraction of land surface temperature. Padang City was selected as the study area due to its rapid urbanization and its status as the central city of West Sumatra.

The surface temperature extraction and UHI estimation processes were conducted using QGIS and ArcGIS software, which were chosen for their robust geospatial analysis capabilities.

Steps Involved

1. Download Landsat 8 and 9 Imagery: The images were sourced from the USGS website.
2. Radiometric Correction: Applied to correct the sensor data.
3. Geometric Correction: Ensured the spatial accuracy of the images.
4. Software Utilization:
 - a. QGIS: For preliminary data handling and analysis.
 - b. ArcGIS: For advanced spatial analysis and visualization.

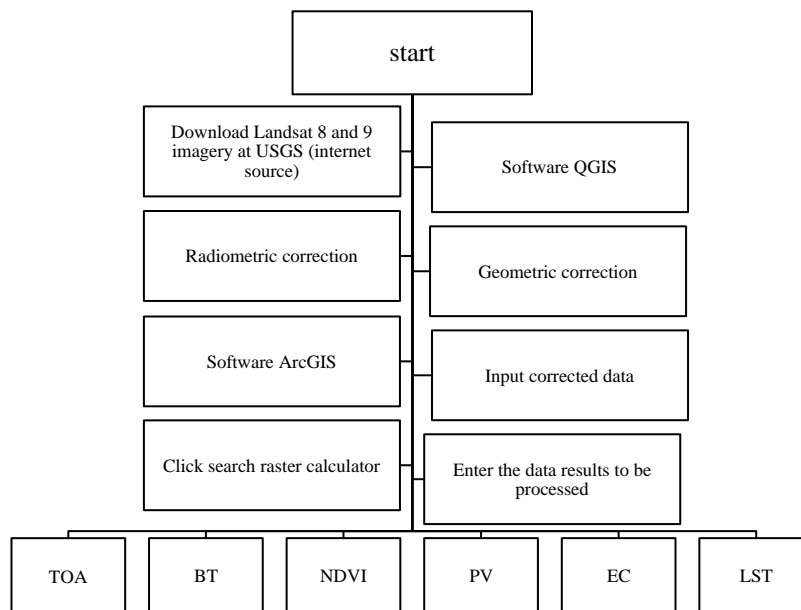
Identification of Urban Heat Island (UHI) in the City of Padang from 2019-2023 using Multitemporal Images Case Study: Padang City Area, West Sumatra

- c. Land Surface Temperature Extraction: Calculated using the thermal bands of Landsat images.
- d. Urban Heat Island Identification: Based on the extracted LST data and visualized using GIS tools.

Data Analysis

The study analyzed LST data for five years (2019-2023) to identify temporal changes in UHI patterns. Each year, the spatial distribution of UHI was mapped to observe trends and variations. The analysis involved calculating the LST from the Landsat images and identifying areas with elevated temperatures, which were then classified as UHIs. The results were visualized through color-coded maps showing temperature variations.

Figure 1. Research Flowchart



Source: Obtained from the researcher's flow chart

Result

The Urban Heat Island (UHI) map uses five colors to indicate temperature levels. Red indicates very high temperatures, typically found in densely populated urban areas with significant human activity. Orange represents rather high temperatures in less active and less densely populated areas. Yellow shows high temperatures in residential or rural land use areas. Green represents low temperatures found in plantation, agricultural, and other similar land uses. Dark green indicates very low temperatures in forested areas far from housing and human activity.

Based on the analysis of Landsat 8 OLI satellite images recorded on May 25, 2019, the land surface temperature values ranged from 22.47°C to 35.78°C, with an average temperature of 27.05°C. In comparison, the analysis of Landsat 8 OLI satellite images recorded on May 11, 2020, showed a range of 14.86°C to 34.74°C, with an average temperature of 24.31°C. This indicates a notable decrease in the average land surface temperature from 2019 to 2020.

In the following years, the land surface temperature analysis continued, highlighting both increases and decreases in different areas:

Identification of Urban Heat Island (UHI) in the City of Padang from 2019-2023 using Multitemporal Images Case Study: Padang City Area, West Sumatra

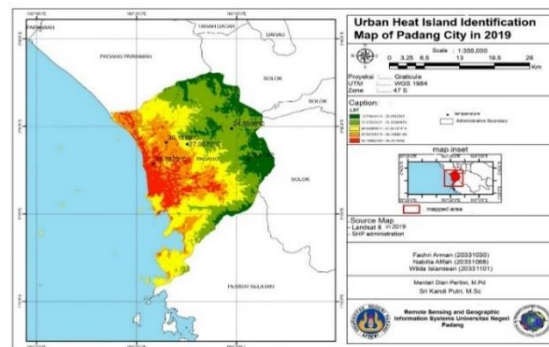
1. 2021: The analysis revealed temperatures ranging from 22.98°C to 38.05°C, with an average of 27.49°C. The maximum temperature increased significantly compared to the previous years.
2. 2022: The temperatures ranged from 11.56°C to 26.97°C, with an average of 18.34°C, indicating a substantial decrease in both maximum and average temperatures.
3. 2023: The analysis showed a temperature range of 11.92°C to 30.47°C, with an average temperature of 19.17°C, which was slightly higher than the previous year but lower than earlier years.

Each year's data was visualized in UHI maps, showing the distribution of temperatures across Padang City. The UHI maps indicated that areas with high human activity and dense populations consistently exhibited higher temperatures, while rural and forested areas maintained lower temperatures. These maps provide valuable insights into the spatial distribution of UHIs and can help inform urban planning and environmental protection efforts in Padang City.

Discussion

Based on the description of the results of the research conducted, it can be described as follows:

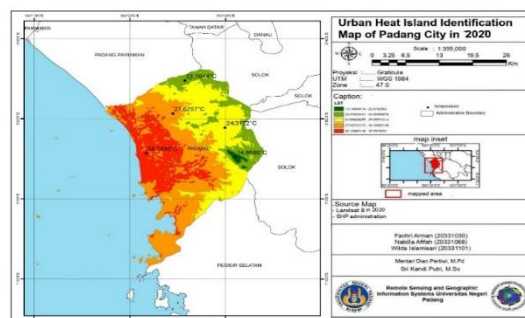
Figure 2. Urban Heat Island Identification Map of Padang City in 2019



Source: Obtained from Primary Data from Image Processing, 2023

Figure 2 shows the Urban Heat Island in Padang city from the extraction of Landsat images in 2019 with a maximum temperature of 35.7870°C and a minimum temperature of 22.4762°C. The temperature in 2019 in Padang city is quite hot in areas with dense settlements and human activities while areas with low temperatures are far from settlements such as in forest areas.

Figure 3. Urban Heat Island Identification Map of Padang City in 2020



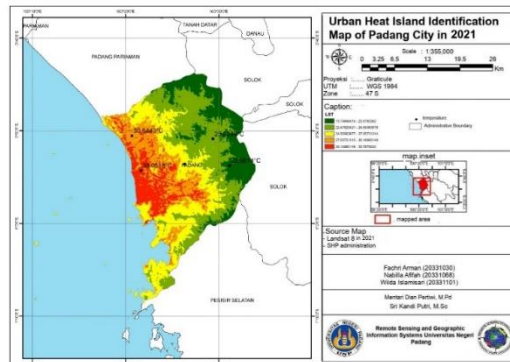
Source: Obtained from Primary Data from Image Processing, 2023

Figure 3 shows the Urban Heat Island in Padang City from the results of Landsat image extraction in 2020 with a maximum temperature of 34.7496°C and a minimum temperature of

Identification of Urban Heat Island (UHI) in the City of Padang from 2019-2023 using Multitemporal Images Case Study: Padang City Area, West Sumatra

14.8689°C. The temperature that occurs in 2020 in Padang city is quite hot in areas with dense settlements and human activities while areas with low temperatures are far from settlements such as in forest areas.

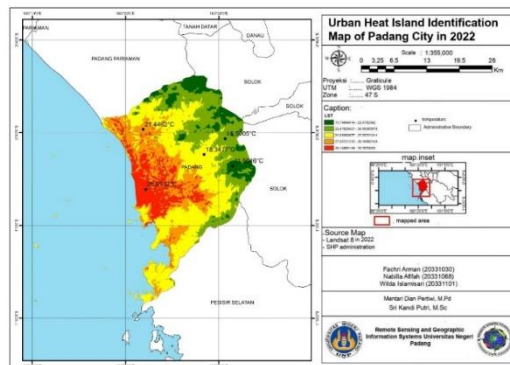
Figure 4: Urban Heat Island Identification Map of Padang City in 2021



Source: Obtained from Primary Data from Image Processing, 2023

Figure 4 shows the Urban Heat Island in Padang city from the extraction of Landsat images in 2021 with a maximum temperature of 38.0518°C and a minimum temperature of 22.9814°C. The temperature that occurs in 2021 in Padang city is very hot because the temperature almost reaches 40 °C in areas with dense settlements and human activities while areas with low temperatures are far from settlements such as in forest areas.

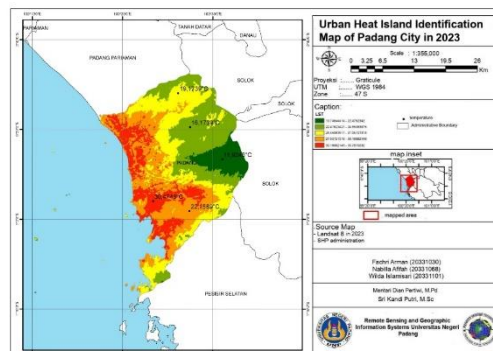
Figure 5: Urban Heat Island Identification Map of Padang City in 2022



Source: Obtained from Primary Data from Image Processing, 2023

Figure 5 shows the Urban Heat Island in Padang city from the extraction of Landsat images in 2022 with a maximum temperature of 26.9732°C and a minimum temperature of 11.5646°C. The temperature that occurs in 2022 in Padang city is not too hot because the maximum temperature does not reach 30 °C in areas with dense settlements and human activities while areas with low temperatures are far from settlements such as in forest areas.

Figure 6: Urban Heat Island Identification Map of Padang City in 2023



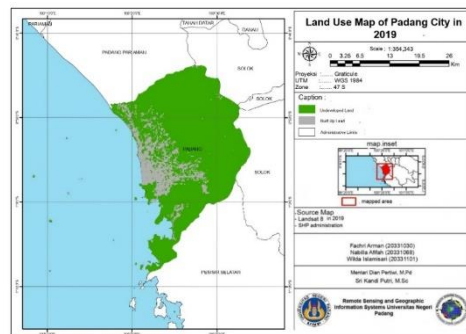
Identification of Urban Heat Island (UHI) in the City of Padang from 2019-2023 using Multitemporal Images Case Study: Padang City Area, West Sumatra

Source: Obtained from Primary Data from Image Processing, 2023

Figure 6 shows the Urban Heat Island in Padang city from the extraction of Landsat images in 2023 with a maximum temperature of 30.4743°C and a minimum temperature of 11.9246°C. The temperature in 2023 in Padang City is quite hot in areas with dense settlements and human activities while areas with low temperatures are far from settlements such as in forest areas.

For the analysis of Landsat 8 OLI satellite image recorded on July 17, 2021, it can be seen that the lowest land surface value is 22.98°C and the highest is 38.05°C, and the average land surface temperature is 27.49°C. Analysis of Landsat 9 OLI satellite image recorded on March 22, 2022, shows that the lowest land surface temperature value is 11.56°C and the highest is 26.97°C, and the average land surface temperature is 18.34°C. And finally, the analysis of Landsat 8 OLI satellite image recorded on January 12, 2023, shows that the lowest land surface temperature is 11.92°C and the highest is 30.47°C, and the average land surface temperature is 19.17°C.

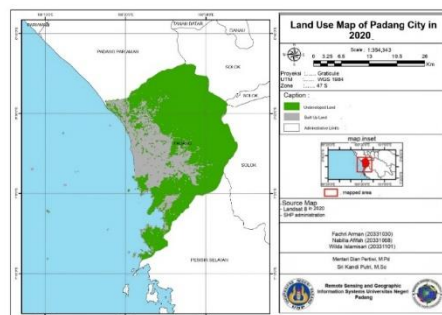
Figure 7: Land Use Map of Padang City in 2019



Source: Obtained from Primary Data from Image Processing, 2023

Figure 7 shows the land use in Padang city from the extraction of Landsat images in 2019 using two land use classes, namely built-up land and undeveloped land. Built-up land is land that has been used or used by humans to live or do other activities such as settlements, industry, and others, while undeveloped land is land used for agriculture, plantations, and others. Unbuilt land has an area of 58590.36 ha and built-up land with an area of 10024.56 ha.

Figure 8: Land Use Map of Padang City in 2020

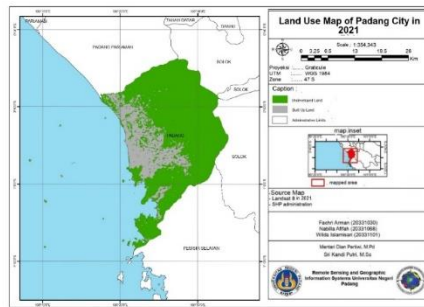


Source: Obtained from Primary Data from Image Processing, 2023

Figure 8 shows the land use in Padang city from the extraction of Landsat images in 2020 using two land use classes, namely built-up land and undeveloped land. Built-up land is land that has been used or used by humans to live or do other activities such as settlements, industry, and others, while undeveloped land is land used for agriculture, plantations, and others. Unbuilt land has an area of 55281.84 ha and built-up land with an area of 12260.36 ha.

Identification of Urban Heat Island (UHI) in the City of Padang from 2019-2023 using Multitemporal Images Case Study: Padang City Area, West Sumatra

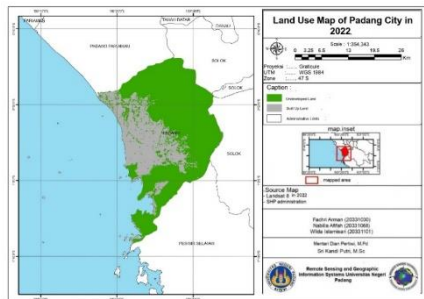
Figure 9. Land Use Map of Padang City in 2021



Source: Obtained from Primary Data from Image Processing, 2023

Figure 9 shows the land use in Padang city from the extraction of Landsat images in 2021 using two land use classes, namely built-up land and undeveloped land. Built-up land is land that has been used or used by humans to live or do other activities such as settlements, industry, and others, while undeveloped land is land used for agriculture, plantations, and others. Unbuilt land has an area of 53410.05 ha and built-up land with an area of 15210.36 ha.

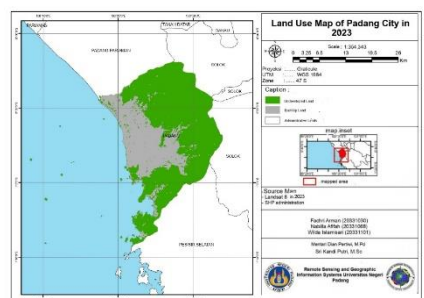
Figure 10: Land Use Map of Padang City in 2022



Source: Obtained from Primary Data from Image Processing, 2023

Figure 10 shows the land use in Padang city from the extraction of Landsat images in 2022 using two land use classes, namely built-up land and undeveloped land. Built-up land is land that has been used or used by humans to live or do other activities such as settlements, industry, and others, while undeveloped land is land used for agriculture, plantations, and others. Unbuilt land has an area of 51880.55 and built-up land with an area of 16463.65 ha.

Figure 11: Land Use Map of Padang City in 2023



Source: Obtained from Primary Data from Image Processing, 2023

Figure 11 shows the land use in Padang city from the extraction of Landsat images in 2023 using two land use classes, namely built-up land and undeveloped land. Built-up land is land that has been used or used by humans to live or do other activities such as settlements, industry, and others, while undeveloped land is land used for agriculture, plantations, and others. Unbuilt land has an area of 50696.79 ha and built-up land with an area of 17072.01 ha.

Conclusion

The purpose of this research was to identify Urban Heat Islands (UHIs) in Padang City using multitemporal Landsat data from 2019, 2020, 2021, 2022, and 2023. The analysis of Landsat images revealed year-to-year variations in UHI patterns. Using an integrated remote sensing and GIS-based approach, the results indicated significant fluctuations in the level and magnitude of UHIs in Padang City from 2019 to 2023. Each year, the UHI area expanded, reflecting the changing conditions in different regions of Padang City. As urbanization continues to expand, it is expected that land surface temperatures will also increase, exacerbating the UHI effect. Therefore, it is crucial to implement policies aimed at controlling and mitigating the negative impacts of UHIs in urban spatial planning.

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