Qualifying Urban Heat Islands: Advanced Techniques in Land Surface Temperature Analysis using Google Earth Engine

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Abstract. Banjarmasin, often referred to as the city of a thousand rivers, has witnessed significant urban development, leading to an intensification of the Urban Heat Island (UHI) effect. This study leverages Landsat 8 satellite data, combined with Google Earth Engine capabilities, to examine the interplay between Land Surface Temperature (LST) and the Normalized Difference Vegetation Index (NDVI) from 2013 to 2022. Initial observations revealed varying patterns in LST, especially in areas surrounding the rivers, and significant NDVI variations indicative of vegetation conditions. A detailed analysis showed an evident relationship between vegetation cover and urban temperatures, with temperature fluctuations correlating with both changes in vegetation and anthropogenic activities. Particularly, the global COVID-19 pandemic played a role in LST decline during 2020-2021, even when vegetation coverage remained relatively static. The findings underscore the importance of sustainable urban planning, emphasizing the conservation and integration of green spaces to counteract UHI effects and promote environmental balance. This research contributes valuable insights into the dynamics of urban climates, vegetation health, and sustainable development strategies for cities undergoing rapid urbanization.

Keywords: UHI, LST, NDVI, Google Earth Engine, Sustainable Urban Planning

1 Introduction

Banjarmasin is a renowned city in Indonesia, often referred to as the city of a thousand rivers. The community's life, deeply intertwined with the river, stands as evidence of the interplay between urban development and the natural landscape. As the city stretches its boundaries, embracing modernity and infrastructure development, it inadvertently amplifies a global environmental concern - the Urban Heat Island (UHI) effect. The urban heat island (UHI) is a phenomenon where urban areas experience higher temperatures compared to their surrounding rural areas. This is caused by the introduction of artificial surfaces in cities, which alter the aerodynamic, radiative, thermal, and moisture properties of the urban region [1]. The UHI effect is the best-known climatic response to disruptions caused by urban development and can be observed by the characteristic warmth of a settlement compared to its surroundings [2]. Urban heating is primarily due to the excess heat from rapidly heating urban surfaces such as buildings, asphalt, bare soil, and short grasses [3]. The temperature in urban areas can be significantly higher than in suburban areas, and the high-temperature zone continues to expand as urbanization advances [4]. The symptoms of diurnal heating in urban areas can be observed

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by mid-morning and can be about 10 degrees warmer than nearby woodlands in summer [2], [5].

In Banjarmasin, the intertwined canals and rivers have long played a pivotal role in shaping the city's cultural and economic fabric. However, the escalating pressures of urbanization present challenges to its delicate ecological balance, particularly concerning temperature variations and vegetation health. Land Surface Temperature (LST) is an essential parameter for analyzing urban heat islands (UHI) in the context of climate change. The surge in urbanization, human-made activities, and climate change factors contribute to the rising LST in urban zones [6]. Differences in LST between urban and green spaces can be discerned, with urban locales witnessing higher temperatures during summer and cooler readings in winter [7]. The Surface Urban Heat Island (SUHI) quantifies the temperature variance between urban and rural settings, wielding a significant influence on local climate and ecosystems [8]. Remote sensing datasets, combined with satellite thermal readings, facilitate the computation and scrutiny of LST variations in urban domains [9]. Spatiotemporally enhanced LST, extracted from the synergistic employment of coarse- and fine-spatial-resolution thermal infrared (TIR) imagery, bolsters the delineation of SUHI, furnishing crucial insights for urban strategizing and climate resilience initiatives [10].

Alongside the LST, the Normalized Difference Vegetation Index (NDVI) becomes an equally vital metric, reflecting the state of vegetation in the city [11]. NDVI provides a measure of vegetation health, productivity, and coverage, playing a critical role in understanding the interrelation between urban expansion and green spaces. In areas like Banjarmasin, where the aquatic system is deeply intertwined with the urban fabric, NDVI helps in pinpointing regions of vegetation stress or robustness, aiding in informed urban planning. The unique topography and urban sprawl of Banjarmasin offer a compelling case study. It is essential for environmental researchers to utilize advanced platforms such as Google Earth Engine, incorporating both LST and NDVI metrics, to achieve a comprehensive understanding and effective mitigation of UHI phenomena [12].

In this study, we leverage the capabilities of Google Earth Engine to delve deeper into the dynamics of Land Surface Temperature (LST) and the Normalized Difference Vegetation Index (NDVI) within Banjarmasin. Given the city's unique urban structure and geographical characteristics, a combined analysis of LST and NDVI offers a clearer insight into how the Urban Heat Island effect manifests in this region and the vegetation conditions influencing it. The methodology employed in this research not only focuses on identifying temperature and vegetation patterns but also on understanding the factors contributing to these variations. Through this combined approach, we aim to offer a significant contribution to the scientific literature on LST and NDVI analysis in urban environments. Specifically, in the context of Banjarmasin, this study endeavors to provide a comprehensive understanding of how modern urbanization impacts local climates and vegetation conditions, and how cities like Banjarmasin can plan for a sustainable future considering both aspects.

2 Method

This study explores the annual variations in land surface temperature (LST) and the Normalized Difference Vegetation Index (NDVI) in Banjarmasin by integrating LANDSAT-8 satellite imagery and Google Earth Engine (GEE) analysis [13]. The focus is given to the cloud-free infrared spectrum from the thermal sensor in LANDSAT-8 Satellite for LST, as well as the near-infrared and red bands for NDVI [14]. The images were calibrated and processed within the GEE platform. Custom scripts were developed to extract both LST and NDVI, providing real-time visualizations, enabling the identification of areas with significant temperature fluctuations and vegetation density. Initial results highlight diverse LST patterns between urban zones and areas surrounding the rivers, as well as NDVI variations depicting vegetation conditions. The combined analysis offers critical insights for sustainable urban planning in Banjarmasin. For the focal area in analyzing LST and NDVI, we utilize the Region of Interest (ROI) based on the Banjarmasin city's shp file.

To collect data, internet resources were utilized to download LANDSAT-8 data for free from https://earthexplorer.usgs.gov/. The data analysis approach employed spatial analysis techniques, specifically focusing on LST (Land Surface Temperature) and NDVI, with variables such as air temperature, ground surface temperature, air humidity, soil moisture, and vegetation density. The LST and NDVI analysis methods proved effective in providing valuable insights into the ecological and thermal impact within the analyzed Region of Interest (ROI). The software tool used for this analysis was the code from Google Earth Engine (code.earthengine.google.com). We presents the research location and spatial observations with ROI using the shp file from Banjarmasin city displayed below:

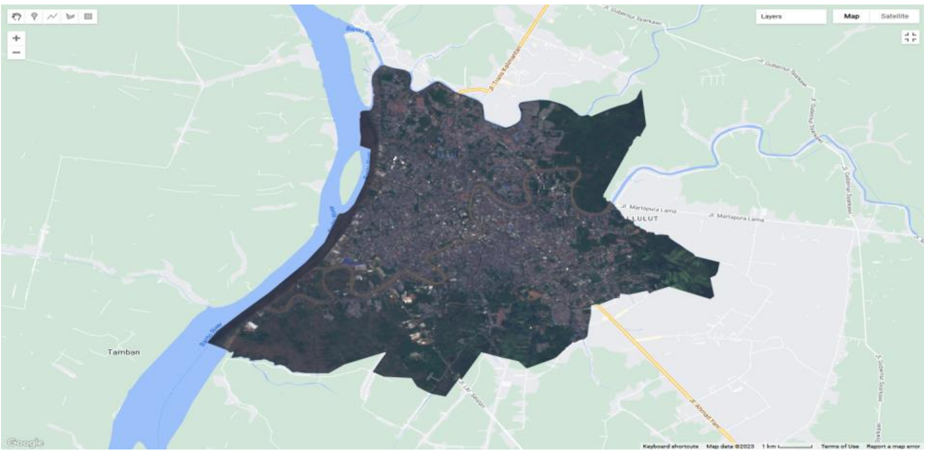

Figure 1. ROI Research location from Banjarmasin City

By understanding the baseline, the research can explain the initial UHI conditions in the Proklim village, examine the temperature differences between urban and non-urban areas, and understand their impact on the quality of life and well-being of the community. The baseline also helps measure and evaluate the impact of the proposed planning and UHI mitigation solutions in this research. The utilization of Google Earth Engine can provide valuable tools and datasets for spatial analysis . It allows for the integration of satellite imagery, remote sensing data, and geospatial analysis techniques to assess UHI patterns and their relationships with various variables, such as land cover, building characteristics, and demographic factors. By leveraging the capabilities of Google Earth Engine, planners and researchers can conduct detailed spatial modeling and analysis to inform effective UHI mitigation strategies. Figure 2 showcases the research location and spatial observations within the Region of Interest (ROI) delineated by the shapefile (.shp) of Banjarmasin city. This figure has been generated through the utilization of Google Earth Engine's code platform (code.earthengine.google.com), which facilitates the analysis of large datasets of geospatial information. The ROI is visually demarcated, providing a clear representation of the urban boundaries and landscape features pertinent to the study. The data visualized in Figure 2 is critical for understanding the spatial distribution and the extent of the urban area under investigation, which in turn is essential for the analysis of environmental parameters such as emisi and serapan karbon within the specified urban context.

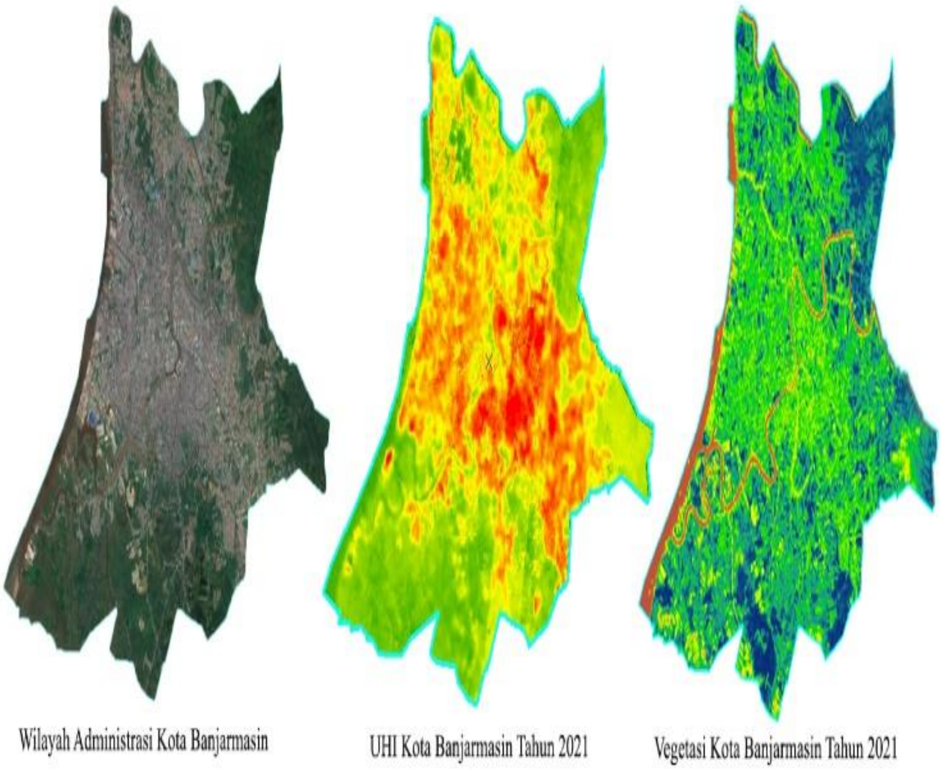

Figure 2. Urban Heat Island (UHI) and vegetation in Banjarmasin City

3 Result and Discussion

In this study, we utilized Landsat 8 satellite imagery data from the Google Earth Engine platform, focusing on Banjarmasin city as our Region of Interest (ROI) and covering the period from 2013 to 2021. This approach, featuring a specific coding script for data processing, including years of observation, targeted ROI analysis, and advanced cloud masking techniques, offers a unique perspective compared to other studies in the field [15][8]. While similar research typically employs satellite data for spatial analysis over extended periods, our study's use of recent Landsat 8 data specifically for Banjarmasin provides a more current and localized insight into urban environmental changes. The application of sophisticated cloud masking, a crucial step in ensuring data quality in remote sensing, further enhances the reliability and accuracy of our analysis. This methodological approach positions our study as a significant contribution to urban environmental studies, particularly in the realm of urban planning and policy-making, by offering an in-depth, technologically advanced examination of urban dynamics and environmental shifts in a rapidly urbanizing region:

```
code_munsyi_disertasi_vhi *   Get Link   Save   Run   Reset   Apps
Imports (2 entries)
  var bjm: Table projects/ee-munsyi/assets/Batas_BJM
  var bjb: Table projects/ee-munsyi/assets/Banjarbaru

//masking awan
var maskL8 = function(image){
  var qa = image.select('BQA');
  var mask = qa.bitwiseAnd(1 << 4).eq(0);
  return image.updateMask(mask);
}

//Fungsi Auto Center Map Objek
Map.centerObject(bjm, 11);

//Dataset NDVI 2020
var datasetndvi = ee.ImageCollection('LANDSAT/LC08/C01/T1_TOA')
  .filterBounds(bjm)
  .filterDate("2013-01-01", "2022-12-31")
  .map(maskL8);

//Dataset LST 2020
var dataset = ee.ImageCollection("LANDSAT/LC08/C01/T1")
  .filterDate("2013-01-01", "2022-12-31")
  .filterBounds(bjm)
  .map(maskL8)
  .select ("B10");
```

Figure 3. Script for Years Analysis

The analysisin this study is focuses on the patterns of urban heat island (UHI) in Banjarmasin City using spatial data from code.earthengine.google.com. The data used for this study were sourced from the Landsat 8 satellite, specifically focusing on the land surface temperature (LST) data. The analysis spans from 2013 to the end of 2021. The distribution patterns of UHI in Banjarmasin City are evident from the following observations:

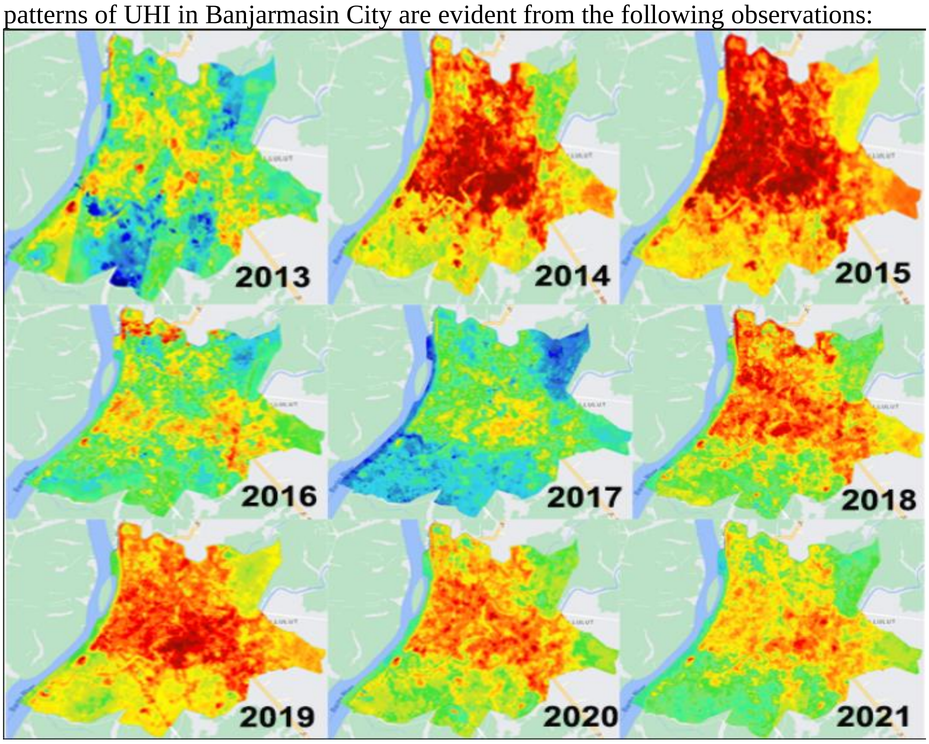

Figure 4. distribution patterns of UHI in Banjarmasin City 2013-2021

From the data above, it was observed that at the beginning of the satellite's orbit, capturing images in 2013, there was a minimal presence of UHI in the Banjarmasin city area. The highest average temperature was 30 degrees Celsius, and the lowest was 16.79 degrees Celsius. In the subsequent year, there was a significant increase in temperature in 2014 and 2015, with an average temperature of 30.2 degrees Celsius and a minimum of 23.97 degrees Celsius. From 2016 to 2017, there was a substantial decline in the LST values captured from the Landsat 8 satellite imagery. The highest temperatures in 2016 and 2017 were 28.04 and 24.83 degrees Celsius, respectively, while the lowest temperatures were 19.64 and 17.51 degrees Celsius. In 2018 and 2019, there was a resurgence in LST data, with the analysis using Google Earth Engine revealing the highest temperatures for 2018 and 2019 as 28.36 and 30.32 degrees Celsius, respectively. From 2020 to 2021, there was another significant decrease in LST, with the highest temperatures being 27.45 and 26.02 degrees Celsius and the lowest being 22.68 and 22.02 degrees Celsius, respectively. The decline from 2020 to 2021 can be attributed to the global COVID-19 pandemic, which also affected Indonesia, especially Banjarmasin City. The Indonesian government imposed lockdowns and restricted community activities, with almost two years of community activities being conducted from home. These restrictions reduced community activity levels. The consequent effect was a significant decrease in temperature, as urban activities significantly diminished. Thus, pollution and other related factors also decreased.

Following this observed trend, it's essential to highlight the intricate relationship between human activities and local climatic changes. The urban heat island (UHI) phenomenon, as depicted by the Landsat 8 satellite data, underscores the vulnerability of urban areas like Banjarmasin to anthropogenic influences. It's evident that external factors, such as a global pandemic, can drastically alter the urban microclimate by limiting human activities, thereby reducing the heat produced from anthropogenic sources. Moreover, the decline in temperature in conjunction with the reduced pollution underscores the significance of sustainable urban planning. Integrating green spaces, promoting eco-friendly transportation, and adopting sustainable construction practices can potentially mitigate UHI effects. Future research should delve deeper into understanding the long-term impacts of reduced human activities on urban environments and exploring sustainable strategies to ensure that cities remain resilient against climatic adversities.

We also analyzed the NDVI data, which will be compared with the temperature increase from the LST data obtained. This NDVI data will be analyzed to determine if there is a correlation to the temperature increase beyond the influence of community activities. The NDVI data from this research is presented in the following figure:

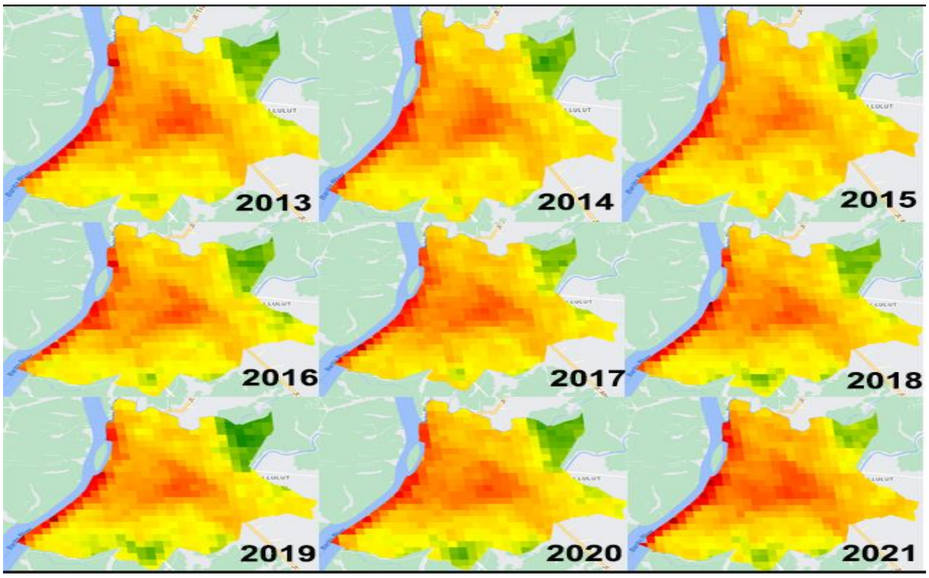

Figure 5. distribution patterns of NDVI in Banjarmasin City

In light of the observed NDVI data, the intricate relationship between vegetation health, urban vegetation cover, and the UHI phenomenon in Banjarmasin is further emphasized. It is widely understood that healthy and expansive vegetation acts as a natural countermeasure against the UHI effects by absorbing solar radiation, offering shade, and promoting evapotranspiration, which subsequently results in localized cooling. The periodic changes in NDVI values, when considered alongside the variations in LST, indicate a profound interplay between the city's vegetative cover and its temperature dynamics. As urban expansion persists, often at the expense of green spaces, the natural ability of vegetation to mitigate UHI effects becomes increasingly limited. This highlights the urgent necessity to integrate urban greenery into city planning initiatives. Grasping the complex relationship between urban structures and ecological elements brings to light the importance of a comprehensive strategy that equally values urban growth and environmental preservation. Future endeavors in urban planning should consider these dynamics, emphasizing a balance between development and the maintenance of green spaces to ensure a sustainable urban environment.

Based on the satellite imagery data we have analyzed, we aimed to discern the trend between LST and NDVI values in relation to the fluctuations in temperature values within the analyzed Region of Interest (ROI). Here is the chart from our analysis :

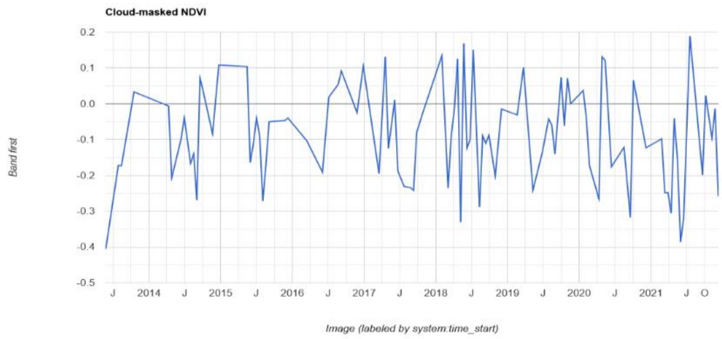

Figure 6. TIme Series Trend NDVI 2013-2021

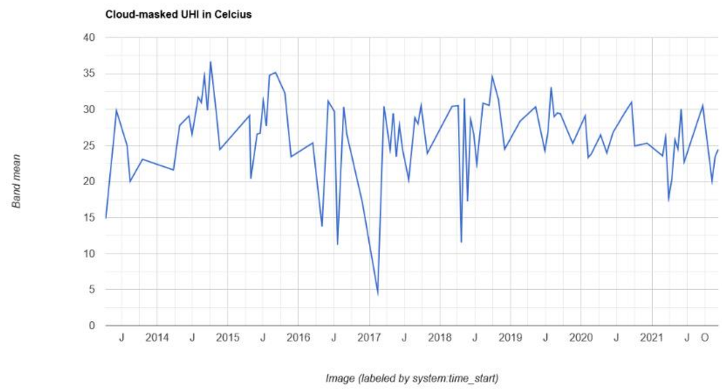

Figure 7. TIme Series Trend LST 2013-2021

Analyzing the provided NDVI (Normalized Difference Vegetation Index) and LST (Land Surface Temperature) datasets from the Landsat 8 satellite offers a comprehensive perspective on Banjarmasin city's environmental dynamics from 2013 to 2022. Starting with the NDVI data, there is evident fluctuation in vegetation health and coverage across the years. Higher NDVI values point towards healthy vegetation, while the lower values suggest stressed vegetation or diminished green cover. In 2013, the moderate NDVI values indicate a reasonable balance in green cover. However, the corresponding LST data for that year reveals moderately high temperatures, suggesting the urban heat island (UHI) effect. This suggests that, while there was significant green coverage, the heat absorption and re-emission by urban infrastructures might have elevated the temperatures. The period of 2014-2015 sees a decline in NDVI values, hinting at a possible decrease in vegetation or an increase in urban activities. This is corroborated by the LST data, which indicates a noticeable uptick in temperatures. The reduction in vegetation might have intensified the UHI effect, leading to these increased temperatures. Between 2016 and 2017, both NDVI and LST charts demonstrate a positive environmental trend. The uptick in NDVI values suggests possible green space initiatives or a natural resurgence in vegetation. Concurrently, the LST values display a cooling trend, underscoring the positive impact of green spaces in tempering urban temperatures. However, 2018-2019 witnesses a dip in NDVI values, hinting at deteriorating vegetation health or reduced green coverage. The LST data confirms this with an upward trend, especially pronounced in 2019. The diminished green cover could have amplified the UHI effect during this period. The years 2020-2021 are particularly noteworthy. While the NDVI doesn't show a significant surge, the LST values register a marked decline, especially in 2021. This anomaly can be attributed to the global COVID-19 pandemic, which led to a downturn in human activities, transportation, and industrial functions. Even if vegetation cover remained static, the drop in anthropogenic heat sources contributed to this decline in LST values. By 2022, both LST values' stabilization and a slight increase in NDVI values suggest a harmony between urban development and green initiatives.

In the result, the combined analysis of NDVI and LST data underscores the symbiotic relationship between vegetation cover and urban temperatures. In years where vegetation was diminished or stressed, urban temperatures surged, emphasizing green spaces' role in climate modulation. Conversely, external factors, like a global pandemic, can also significantly influence urban microclimates. Sustainable urban planning, integrating more green spaces, and preserving the existing vegetation are pivotal in ensuring a balanced and comfortable urban environment.

4 Conclusion

The meticulous examination of the Landsat 8 satellite data for Banjarmasin city from 2013 to 2022 provides profound insights into the dynamic interaction between vegetation cover (as indicated by NDVI values) and urban temperature (as reflected by LST values). This relationship underscores the significance of maintaining adequate green coverage within urban settings. During times when vegetation was compromised, either due to anthropogenic activities or other external factors, a noticeable rise in urban temperatures was observed. This reaffirms the impact of the Urban Heat Island (UHI) phenomenon on urban areas that lack sufficient vegetation. Conversely, periods that saw a decline in temperature, even when NDVI values remained relatively unchanged, were influenced by external events like the global pandemic, highlighting the role of anthropogenic activities in shaping urban climates.

Thus, the data presents a compelling argument for sustainable urban development that emphasizes the integration and conservation of green spaces. Such an approach not only mitigates the adverse impacts of the UHI effect but also contributes to establishing urban environments that are resilient and adaptable to external challenges, such as pandemics. The symbiotic relationship between green spaces and urban climate modulation is pivotal, and future urban planning endeavors should be anchored in these findings to ensure a harmonious balance between urbanization and environmental preservation.

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