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Utilization of the Terra-MODIS Satellite for Analysis of the Urban Heat Island Phenomenon in Balikpapan City as a Non-Military Defense Effort

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A B S T R A C T

Cities act as centers of activity that make them attractive for people to migrate. This increases the productivity of built-up land. However, the impact of this expansion is the increase of temperature in urban areas and the decrease of temperature around them, which is known as Urban Heat Island (UHI) phenomenon. Therefore, this research aims to analyze the UHI phenomenon in Balikpapan City by using remote sensing technology through Terra-MODIS satellite. Terra-MODIS satellite images are used to measure Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI). The urban area studied is Balikpapan City. The data used includes images from 2000 to 2023. The results show the existence of UHI phenomenon in Balikpapan City. This emphasizes the need for non-military defense strategy in vegetation improvement and preservation to reduce the risk of UHI.

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INTRODUCTION

Urban areas serve as centers for social, economic, and governmental activities, making them attractive hubs for migration and infrastructural development. As cities grow, the expansion of built-up areas often comes at the cost of reduced green spaces, altering the local climate and leading to the Urban Heat Island (UHI) phenomenon. UHI refers to a condition where urban areas experience higher temperatures than surrounding rural areas due to increased heat absorption by artificial surfaces, reduced vegetation, and elevated anthropogenic heat emissions.

This phenomenon has significant implications for local climate patterns, air quality, and public health. Higher temperatures exacerbate the risk of heat-related illnesses, reduce air quality through increased ground-level ozone production, and strain energy resources due to higher cooling demands. In addition, UHI can disrupt local ecosystems, intensify weather events, and contribute to global climate change.

Balikpapan, a rapidly developing city in East Kalimantan, Indonesia, is an example of a growing urban area where UHI is becoming increasingly evident. The city's strategic role, particularly following its proximity to the planned new capital city of Indonesia, has led to accelerated urbanization, characterized by the transformation of natural land into infrastructure. This transformation, involving vegetation loss and the proliferation of impervious surfaces, significantly impacts surface temperature dynamics.

To address these challenges, the integration of remote sensing technology offers a robust solution for analyzing and mitigating UHI impacts. This study employs Terra-MODIS satellite imagery to analyze surface temperature and vegetation distribution in Balikpapan over a 23-year period (2000–2023). By focusing on Land Surface Temperature (LST) and the Normalized Difference Vegetation Index (NDVI), this research aims to provide a comprehensive understanding of UHI dynamics and their correlation with vegetation changes.

The findings are expected to support the development of sustainable urban planning strategies, emphasizing non-military defense approaches, such as increasing urban green spaces and promoting environmental resilience. These strategies aim to mitigate the adverse effects of UHI, enhance urban livability, and contribute to broader climate change adaptation efforts.

LITERATURE REVIEW

The Urban Heat Island (UHI) phenomenon describes a condition where urban areas exhibit significantly higher temperatures than their surrounding rural areas. This temperature difference arises primarily due to land-use changes, such as the replacement of vegetative surfaces with impervious materials like asphalt and concrete. These artificial surfaces have a higher heat absorption capacity and lower albedo, leading to increased surface and air temperatures in urban areas (Tursilowati et al., 2023).

Vegetation plays a crucial role in mitigating UHI effects through processes such as transpiration and increased reflectivity, which reduce heat accumulation. Vegetative areas lower surface and air temperatures by absorbing sunlight for photosynthesis and releasing moisture into the atmosphere. The reduction of

vegetative cover in urban areas, therefore, directly contributes to the intensification of UHI effects (Naigolan, Sasmito, & Sukmono, 2020).

Remote sensing technology has emerged as a vital tool for studying UHI. Satellite imagery, such as that provided by Terra-MODIS, enables the monitoring of environmental parameters like Land Surface Temperature (LST) and the Normalized Difference Vegetation Index (NDVI). These metrics are essential for understanding the spatial distribution and temporal dynamics of UHI (Bagyaraj et al., 2023). Terra-MODIS imagery, with its high spectral resolution and frequent observations, provides detailed data suitable for analyzing urban temperature patterns and vegetation changes over time (Sabarati, Aminuddin, & Toersilowati, 2022).

Data processing for remote sensing applications has been significantly enhanced by cloud-based platforms like Google Earth Engine (GEE). GEE allows large-scale spatial analysis by leveraging powerful computational resources and algorithms. It also enables efficient data extraction and processing without the need for downloading large datasets, making it a preferred tool for UHI studies (Gorelick et al., 2022).

Past research has highlighted the negative correlation between NDVI and LST, where areas with higher vegetation coverage tend to have lower surface temperatures (Putra, Sukmono, & Sasmito, 2018). This relationship underscores the importance of maintaining and restoring urban green spaces as a strategy for mitigating UHI impacts. Additionally, strategies such as urban reforestation and sustainable land use planning have been proposed as effective measures to counter UHI effects (Octarino, 2022).

In the context of Balikpapan, the rapid urbanization and the associated land-use changes have led to significant UHI effects. This study leverages Terra-MODIS data to examine the relationship between vegetation cover and surface temperatures over a 23-year period. The findings aim to inform urban planning strategies that prioritize environmental sustainability and resilience.

METHODOLOGY

This research focuses on analyzing the Urban Heat Island (UHI) phenomenon in Balikpapan City using remote sensing data. The study utilizes Terra-MODIS satellite imagery from 2000 to 2023 to evaluate two key environmental parameters: Land Surface Temperature (LST) and the Normalized Difference Vegetation Index (NDVI). Terra-MODIS was selected for its high spectral resolution, spatial detail, and frequent observation capabilities, which are essential for long-term monitoring and analysis of urban environmental changes.

The data acquisition process was conducted using the cloud-based Google Earth Engine (GEE) platform, which offers significant advantages in processing efficiency and accessibility. GEE enables the extraction and analysis of large-scale spatial datasets without the need for local storage, leveraging powerful computational resources to perform complex algorithms directly on the platform. For this study, algorithms available in GEE were used to extract LST and NDVI values from Terra-MODIS imagery.

The processing workflow began with data pre-processing to ensure quality and consistency across the temporal dataset. This step included filtering images by cloud cover and selecting the relevant bands for LST and NDVI calculations. The LST was derived from the MOD11_L2 product using band 31 and 32, while NDVI was calculated based on the near-infrared and red reflectance values provided by the satellite.

After extraction, the data were visualized using the Grid Analysis and Display System (GrADS) software, which facilitated the generation of clear and informative maps. These visualizations provided a spatial representation of LST and NDVI distributions over the study period, highlighting trends and patterns in surface temperature and vegetation coverage.

Finally, a statistical analysis was performed to investigate the relationship between NDVI and LST. Regression analysis was employed to assess the correlation between vegetation density and surface temperature. The results were presented in tables and graphs to enable a comprehensive interpretation of the findings. By combining remote sensing technology with advanced data analysis tools, this study aimed to provide actionable insights into the impacts of vegetation changes on urban surface temperatures.

RESEARCH RESULTS

The analysis of the Urban Heat Island (UHI) phenomenon in Balikpapan City was conducted using Terra-MODIS data from 2000 to 2023. The findings are presented below:

1. *Normalized Difference Vegetation Index (NDVI) in Balikpapan (2000–2023)*

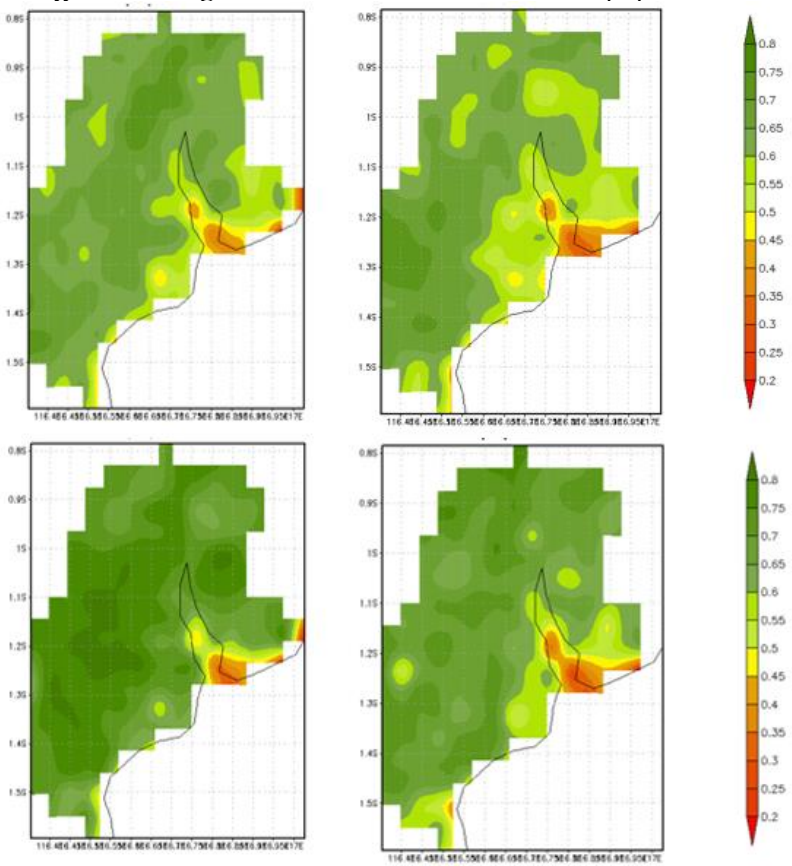

Figure 1. NDVI Distribution in Balikpapan (2000–2023)

The NDVI values ranged from 0 (indicating no vegetation) to 1 (indicating maximum vegetation). The analysis revealed a significant decline in NDVI values in the city center, highlighting the reduction of green spaces due to urbanization. The areas with lower NDVI values were predominantly urban zones with limited vegetation cover, as illustrated in Figure 1.

2. *Land Surface Temperature (LST) in Balikpapan (2000–2023)*

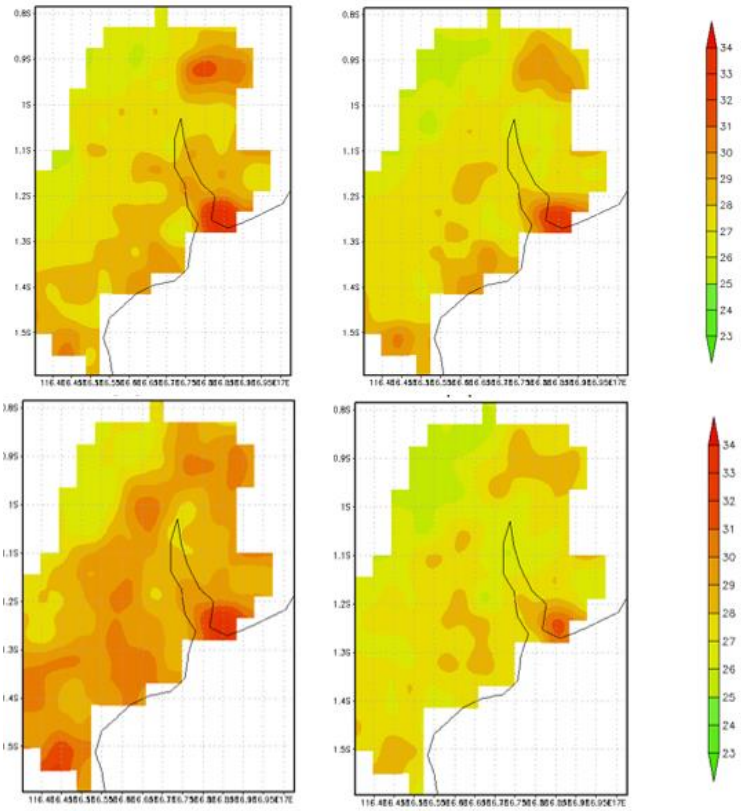

Figure 2. LST Distribution in Balikpapan (2000–2023)

The average LST in Balikpapan ranged from 26.14°C to 28.59°C during the study period. A notable temperature spike was observed in 2015, attributed to the El Nino phenomenon, which caused higher-than-average temperatures globally. The urban center consistently exhibited higher temperatures compared to the outskirts, as shown in Figure 2.

3. *Relationship Between NDVI and LST*

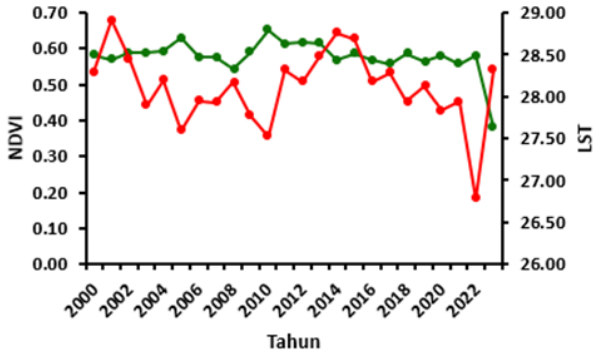

Figure 3. Relationship Between NDVI and LST in Balikpapan (2000–2023)

Regression analysis demonstrated a negative correlation between NDVI and LST. Regions with higher vegetation coverage (high NDVI) showed lower surface temperatures, while areas with reduced vegetation had elevated temperatures. This relationship underscores the critical role of vegetation in moderating urban temperatures. The regression plot depicting this relationship is presented in Figure 3.

DISCUSSION

The findings of this study highlight the significant influence of urbanization on environmental parameters, particularly vegetation cover and surface temperature, in Balikpapan City. The decrease in Normalized Difference Vegetation Index (NDVI) values in urban areas emphasizes the impact of reduced green spaces due to the expansion of built-up land. This reduction directly contributes to the Urban Heat Island (UHI) phenomenon, where higher temperatures are recorded in urban centers compared to surrounding rural areas. Vegetation plays a critical role in moderating surface temperatures through processes like transpiration and increasing surface albedo, which reduces heat absorption (Putra, Sukmono, & Sasmito, 2018). The observed negative correlation between NDVI and Land Surface Temperature (LST) further substantiates the importance of maintaining vegetation cover to mitigate urban heat effects.

The analysis of LST data revealed consistent temperature variations, with urban areas showing higher temperatures than peripheral zones. This disparity is attributed to the dominance of impervious surfaces in urban settings, which absorb and retain more heat than natural surfaces. The spike in surface temperatures during 2015, linked to the El Nino phenomenon, underscores the combined impact of global climatic events and local urbanization on temperature dynamics (GGWeather, 2023). This finding indicates that climatic anomalies can exacerbate existing urban heat issues, making the mitigation of UHI effects even more critical.

The regression analysis demonstrated a clear relationship between vegetation density and surface temperature, where areas with higher NDVI values exhibited lower LST. This relationship aligns with previous studies that have emphasized the cooling effect of vegetation, particularly in dense urban environments (Naigolan, Sasmito, & Sukmono, 2020). Green spaces not only reduce heat but also provide ecosystem services, such as improving air quality, enhancing biodiversity, and mitigating climate change impacts. These findings highlight the need for urban planning strategies that prioritize the preservation and expansion of vegetation cover to counteract the adverse effects of urbanization.

From a non-military defense perspective, the implications of UHI extend beyond environmental concerns. The increase in urban temperatures can disrupt local water cycles, as higher surface temperatures lead to increased evaporation rates. This poses risks to water availability, particularly during dry seasons, and can strain resources needed for urban and defense operations (Danga, Yusuf, & Prakoso, 2023). Additionally, elevated temperatures may negatively impact agricultural productivity, altering planting cycles and reducing crop yields. These outcomes underscore the importance of integrating environmental resilience into

defense strategies, emphasizing sustainable resource management and climate adaptation measures.

The study's findings reinforce the urgency of implementing policies aimed at mitigating UHI effects in Balikpapan. Strategies such as urban reforestation, the creation of green corridors, and sustainable land-use planning can serve as effective measures to reduce surface temperatures and enhance urban resilience. Furthermore, leveraging remote sensing technologies like Terra-MODIS and platforms like Google Earth Engine (GEE) can provide valuable insights for continuous monitoring and evaluation of urban environmental changes (Gorelick et al., 2022).

By addressing the UHI phenomenon through strategic interventions, urban planners and policymakers can contribute to the broader goals of sustainable urban development and environmental conservation. These efforts will not only improve urban liability but also strengthen the city's capacity to adapt to future climatic and environmental challenges, ensuring the long-term sustainability of Balikpapan and its role in national resilience.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This study highlights the significant impact of urbanization on the Urban Heat Island (UHI) phenomenon in Balikpapan City. The findings demonstrate a negative correlation between vegetation coverage (NDVI) and surface temperature (LST), emphasizing the critical role of green spaces in moderating urban heat. Urban areas with reduced vegetation consistently exhibited higher temperatures, underlining the need for sustainable urban planning to mitigate UHI effects. The use of Terra-MODIS data and advanced processing platforms like Google Earth Engine proved effective in analyzing long-term environmental changes.

Recommendations

1. Urban Planning Policies**:** Prioritize the preservation and expansion of green spaces through urban reforestation and green infrastructure development.
2. Monitoring Systems: Implement continuous monitoring of UHI-related parameters using remote sensing technologies to inform data-driven decision-making.
3. Community Engagement: Encourage public participation in urban greening initiatives, such as community-based urban farming and tree-planting programs.
4. Sustainable Development: Integrate environmental resilience into urban development projects to balance growth with ecological sustainability.

These measures will help mitigate UHI effects, improve urban livability, and strengthen Balikpapan's role in contributing to national environmental and defense strategies.

ADVANCED RESEARCH

This study has limitations that should be addressed in future research. Firstly, the reliance on satellite data, while effective for large-scale analysis, may

lack the resolution needed for localized studies. Future investigations could integrate in-situ measurements with remote sensing data to improve accuracy and provide a more comprehensive understanding of UHI dynamics.

Secondly, this research focused on the relationship between vegetation and surface temperature without exploring other contributing factors such as urban material properties or anthropogenic heat sources. Further studies should include these variables to develop a holistic model of UHI impacts.

Lastly, this study was limited to a single urban area. Comparative studies across different cities with varying climates, urbanization patterns, and vegetation types would offer broader insights into effective UHI mitigation strategies. Expanding research to include socio-economic impacts and community responses could also enhance the applicability of findings in urban planning and policy-making.

By addressing these areas, future research can build on the findings of this study to develop more targeted and effective solutions for mitigating UHI effects.

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