Urban-rural gradient analysis of land surface temperature and land cover in Surakarta City and its surrounding areas using Landsat 8 Imagery

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Abstract. Urbanisation in Surakarta City, Indonesia is heavily influenced by development and the interaction between the city and surrounding areas This research aims a) to analyse land cover and land surface temperature (LST) and b) to conduct urban-rural gradient analysis of LST and land cover in Surakarta City and its surrounding areas using Landsat 8 image. Land cover was mapped via supervised Support Vector Machine classification (overall accuracy 90.3%), and LST was retrieved from the thermal band with emissivity correction. Concentric 1-km ring buffers were used to profile LST and land cover. The study findings indicate that urban areas, predominantly characterized by built-up surfaces, experience significantly elevated temperatures compared to rural regions with extensive vegetation cover. The gradient shows peak LST at 0–1 km from the Surakarta city centre, a sharp decline to ~7 km, a more gradual decrease to ~13 km, and a secondary local maximum near the Sukoharjo central business district, reflecting the thermal influence of impervious materials and the cooling capacity of vegetation and water body These results underscore the need to conserve and expand urban vegetation and water bodies and to integrate thermal considerations into spatial planning. By identifying spatially explicit LST gradients and heat-intensive urban zones, this study provides evidence to support urban climate adaptation strategies.

1 Introduction

Urbanisation exerts a substantial influence on environmental conditions, with a particular emphasis on the urban heat island (UHI) phenomenon. Research conducted by Shen et al. [1] revealed an increasing trend of heat in Northeast China attributed to urbanization, with urban areas experiencing notably elevated temperatures in comparison to their rural counterparts. Additionally, land cover changes exacerbate the UHI effect. Consequently, there is a need for effective spatial planning to mitigate the impacts of UHI.

One strategy to reduce temperature increases, as indicated by Gherri's research [2], is to incorporate green spaces into urban planning. Moreover, green spaces can serve as cooling agents and improve the liveability and wellbeing of urban populations. The intertwined influences of urbanisation processes and climatic variations on extreme temperatures also

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pose health risks. Therefore, integrating green infrastructure into comprehensive urban planning is crucial for mitigating the adverse temperature effects arising from urbanization processes.

The urban-rural gradient is crucial for examining the spatial dynamics of urbanisation and its influences on the surrounding regions. This gradient elucidates the effects of urbanization on ecological and environmental conditions, significantly influencing changes in biodiversity and habitat quality. Santiago et al. [3] explain that urban areas encroaching on forest fringes contribute to habitat loss, resulting in the decline of endemic species. The urban-rural interface exerts a profound influence on local climatic patterns, exemplified by the urban heat island effect, in which urbanised areas experience notably elevated surface temperatures relative to their rural counterparts. Understanding the urban-rural gradient is crucial for developing effective urban planning strategies and managing environmental conditions.

Studies on land cover and temperature in Surakarta City and its surrounding areas are crucial for understanding environmental dynamics and the implications of urban development. Land use changes in Surakarta's peri-urban areas are influenced by increasing population and accessibility, subsequently affecting environmental quality [4]. Kurnianingsih et al. [5] further demonstrate that population growth in peri-urban regions contributes to land use changes. Güler [6] found that land use changes in peri-urban areas influence species diversity. By analysing the association between land cover and regional temperature characteristics, we can develop more effective management strategies to maintain ecological balance and enhance the quality of life in Surakarta.

Remote sensing data, with its varying spectral bands, allows for the identification and classification of different land cover types [7]. This information is fundamental for analysing transformations in land use patterns, ecosystem dynamics, and biodiversity. In addition, remote sensing methodologies provide the capability to spatially delineate and quantify land surface temperature characteristics with efficient use of time and resources [8]. Remote sensing techniques enable the examination of the connections between land cover and land surface temperature, offering valuable insights into how various land cover classifications influence and regulate surface temperature dynamics. Based on the aforementioned background, this research aims a) to analyse land cover and land surface temperature and b) to conduct urban-rural gradient analysis of land surface temperature and land cover in Surakarta City and its surrounding areas using Landsat 8 image.

2 Literature Review

2.1 Land Cover

Land cover refers to the physical material at the surface of the earth, encompassing a variety of features such as grass, asphalt, trees, bare ground, and water. This is distinct from land use, which describes the arrangements, activities, and inputs that people undertake within a specific land cover type to achieve particular objectives. For instance, a forested land cover may be utilised for purposes such as timber production, biodiversity conservation, or recreational activities. Land cover plays a pivotal role in the climate system, influencing factors such as carbon sequestration, albedo, and evapotranspiration. Land cover is crucial in understanding global environmental change [9].

2.2 Remote Sensing for Extracting Land surface temperature

Remote sensing involves the acquisition of information about an object or phenomenon without making direct physical contact with it [10]. Remote sensing has become an essential methodology for obtaining land surface temperature data, offering significant advantages over traditional ground-based measurements. Satellite-based thermal infrared sensors provide spatially continuous LST information at various scales, enabling comprehensive monitoring of urban heat islands, environmental changes, and other thermal phenomena [11,12]. Various studies have utilized Landsat, MODIS, and other satellite data to retrieve LST, employing algorithms that account for atmospheric effects and land surface emissivity. Wang and Murayama [13] describes LST derivation from Landsat imagery, including equations for calculating emissivity and LST.

These remotely sensed land surface temperature data offer valuable insights for informing urban planning strategies, climate change research, and natural resource management by elucidating the intricate relationships between land cover characteristics and surface temperature dynamics. Siswanto et al. [14] analyzes the spatial and temporal characteristics of the urban heat island phenomenon in Jakarta, leveraging remote sensing data to derive land surface temperature insights. Further research focuses on improving LST retrieval accuracy and integrating remotely sensed data with other environmental variables for enhanced analysis and modeling.

3 Methodology

3.1 Research Location

The study was conducted in Surakarta City, located between 110°45'15"E and 110°45'35"E, and between 7°36'00" and 7°56'00"S, as well as the surrounding regions within a 20 km radius of the city centre (Figure 1). Although Surakarta's area is only 44.04 km2, which is much smaller than the surrounding regencies, it serves as the centre of Greater Surakarta and exerts significant influence on the neighbouring districts. Given the city's limited geographical size, the examination of the urban-rural gradient analysis of Land Surface Temperature and Land Cover must also encompass the surrounding regencies, which experience substantial spatial interactions with Surakarta. This is crucial as Surakarta's influence extends beyond its administrative boundaries and into the neighbouring areas, necessitating a broader regional perspective for the analysis.

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Fig. 1. Surakarta City and surrounding areas (within a 20 km radius of the city center) as research locations.

3.2 Data and Materials

This study utilised Landsat 8 OLI/TIRS (from https://earthexplorer. usgs.gov/) and Google Earth imagery in 2020 to collect and analyse the data required for the research. The Landsat 8 satellite data, with a 30 m spatial resolution and thermal infrared band, enabled the extraction and analysis of land cover and surface temperature characteristics across the study area. In addition, the administrative boundary data for Surakarta City was obtained from the Indonesian Geospatial Information Agency to provide the geographical context for the analysis.

3.3 Workflow

Radiometric and atmospheric corrections were applied to the reflectance bands of the Landsat 8 images. Atmospheric correction was conducted using the dark object subtraction algorithm to obtain the at-surface reflectance value. As the Landsat 8 data were at the L1TP level, which had already undergone geometric correction with high accuracy, no further geometric correction was performed. For the thermal pre-processing, only radiometric correction was applied to derive the at-sensor radiance value.

Land cover classification was performed using reflectance bands that had undergone atmospheric correction to obtain the at-surface reflectance values. In this study, a supervised classification approach was employed, allowing the operator to guide the computer in classifying land cover classes based on the defined training areas. The support vector machine algorithm was utilized for this purpose. During the post-classification stage, a 3x3 filtering window was applied, and pixels smaller than 900 m^2 were eliminated to mitigate the salt-and-pepper effect in the classification results. The accuracy assessment was conducted using satellite imagery from Google Earth, with a test sample of 100 points for each land cover class. A sample location was deemed accurately classified if there was a minimum agreement of 50% within a 15 m radius around the sample point.

Land surface temperature extraction was conducted by converting the value of the thermal band from at-sensor radiance to at-sensor brightness temperature. The land surface temperature was derived from the at-sensor brightness temperature using the following formula: $LST = BT / (1 + (BT * \lambda / \rho) * \ln(\varepsilon))$, where BT is the at-sensor brightness temperature, λ is the wavelength of the emitted radiance, ρ is 1.438×10^{-2} mk, and ε is the surface emissivity.

An urban-rural gradient analysis was conducted to determine the trends in land cover and land surface temperature from the city centre to the rural areas. This involved creating multiple ring buffers at 1 km intervals, from the city centre out to a 20 km radius, resulting in a total of 20 zones that captured the urban-rural variations. For each zone, the proportion of each land cover class and the average LST were calculated. The proportions of land cover and average LST in each zone were then plotted on a single graph to facilitate the urban-rural gradient analysis of LST and land cover.

4 Results and Discussion

4.1 Land Cover and Land Surface Temperature Analysis

The land cover types identified from the Landsat 8 satellite imagery in the study area encompass water, built-up land with soil roofs, and built-up land with metal roofs, high-density non-tree vegetation, low-density non-tree vegetation, and tree vegetation (Figure 2). The SVM algorithm applied for land cover classification has an overall accuracy of 90.3%, which is suitable for further analysis. The predominant land cover in Surakarta City consists primarily of built-up areas with soil-based roofing, which are commonly utilised for residential, commercial, and service-oriented purposes. Other land cover types such as tree and non-tree vegetation are relatively evenly distributed in the regencies surrounding Surakarta City. Tree vegetation is mainly located to the north and east of Surakarta City.

Each land cover type has a distinct land surface temperature. The objects with the lowest average land surface temperatures are water, high-density non-tree vegetation, and tree vegetation. Built-up land exhibits the highest land surface temperature compared to other land cover types in the study area. This elevated temperature is observed predominantly within Surakarta City, which is largely characterised by built-up environments. Conversely, the surrounding regencies experience relatively lower temperatures due to a reduced proportion of built-up land and a greater prevalence of vegetated areas.

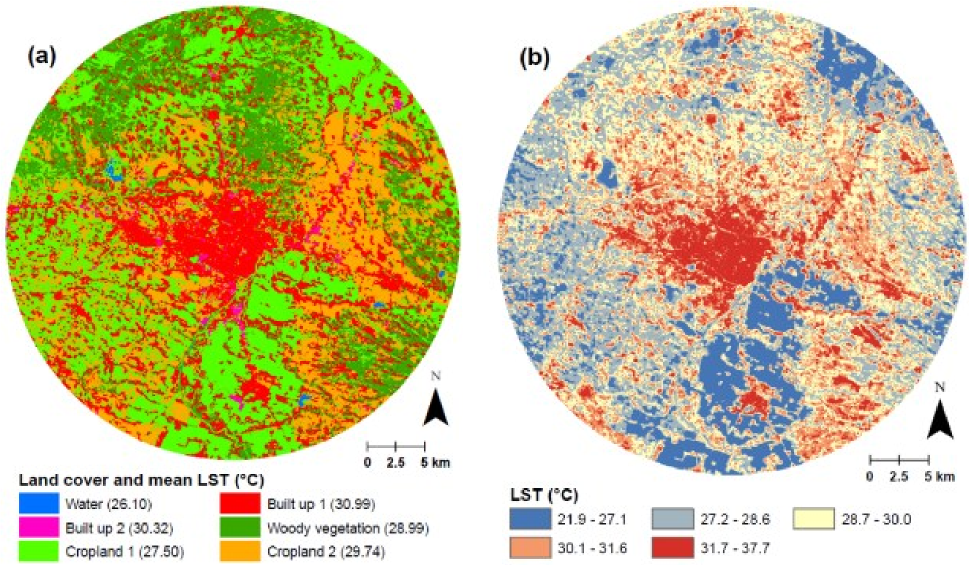

Fig. 2. (a) Land cover and average land surface temperature values in each land cover class. Land cover classes consist of water, built-up land with a roof made of earth (built up 1), built-up land with a roof made of metal (built up 2), high-density non-standing vegetation (cropland 1), low-density non-standing vegetation (cropland 2), and standing vegetation (woody vegetation). (b) Land surface temperature at the research location

Water temperatures are relatively low due to several factors, primarily heat capacity and evaporation. Water exhibits a high thermal heat capacity, necessitating a significant amount of energy input to increase its temperature. Conversely, water also releases a large amount of energy when its temperature decreases. This makes the temperature of water relatively stable and less prone to dramatic fluctuations like air or soil temperatures. The vaporisation of water is an energy-intensive process. As the liquid water transitions to a gaseous state, it extracts thermal energy from its surrounding environment [15], including the remaining water. This causes a cooling effect and helps maintain relatively low water temperatures. The cause of high surface temperatures on built-up land is due to the building materials that absorb and emit a lot of heat, resulting in high land temperatures as well [14].

4.2 Urban-rural gradient analysis of land surface temperature and land cover

Figure 3 illustrates the impact of the varying proportions of land cover classes on the average land surface temperature across the urban-rural gradient. The city of Surakarta covers zone 1 (its area is 1 km from the centre of Surakarta) to zone 6 (its area covers the boundary between 5 km from the centre of Surakarta to 6 km from the centre of Surakarta). In general, the highest LST value was located in zone 1 and decreased significantly to zone 7. From zone 7 to zone 13, the LST decline was more gradual than the decline in LST from zone 1 to zone 7. Between zone 13 and zone 14 which is the centre of government and the CBD of Sukoharjo Regency, there is an increase in LST. The relationship between land surface temperature and the urban-rural gradient is strongly influenced by the variation in the proportions of different land cover types. As one moves from the urban core to the rural periphery, the abundance of built-up areas tends to decrease, while the prevalence of vegetated land cover increases. However, LST 2020 in zones 4 to zone 11 experienced a more significant decrease than the decline in LST between zones 4 to zone 11 in 2008.

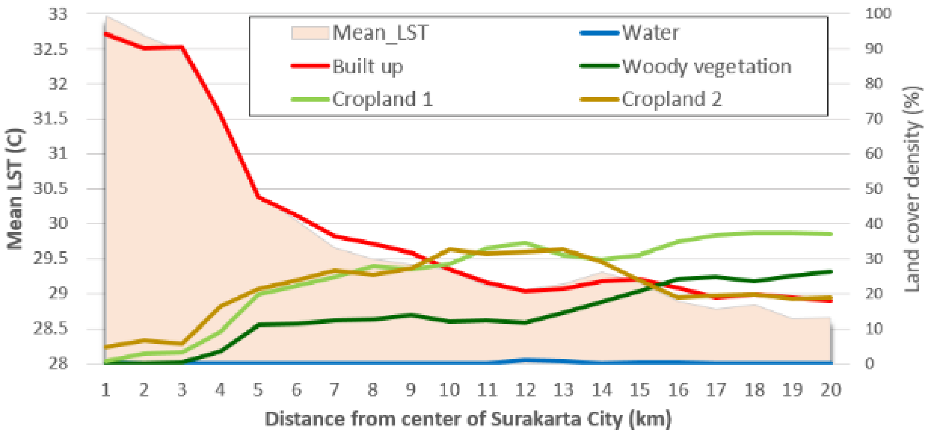

Fig. 3. Variation in average land surface temperature (LST) and the proportion of area of each land cover class at various distances from the center of Surakarta City.

The urban cores possess a greater density of built-up land relative to suburban and rural zones due to the agglomeration of human activities. They function as hubs for commerce, industry, and administration, drawing in sizable populations and necessitating substantial infrastructure. This results in a dense web of buildings, roads, and paved surfaces that constitute the built environment. Urban environments are characterized by extensive impervious surfaces, such as concrete and asphalt, which have a propensity to absorb and retain substantially greater amounts of solar radiation compared to the vegetation and soil predominant in rural areas, thereby elevating surface temperatures [13].

5 Conclusion and Recommendation

The study establishes the pronounced correlation between land cover composition and land surface temperature variations along the urban-rural gradient within the Surakarta region and its surrounding areas. The results reveal that urban zones, which are predominantly covered by built-up land, experience significantly higher temperatures compared to rural areas with extensive vegetation. The urban-rural gradient analysis underscores the crucial role of green infrastructure, comprising green spaces and water bodies, in mitigating the urban heat island phenomenon. These natural features act to lower surface temperatures within the built environment.

To address the growing challenges of rising temperatures driven by urban expansion, urban planners should prioritize the integration of sustainable green infrastructure within cities. Efforts to expand green spaces, protect existing vegetation, and create green corridors can play a crucial function in mitigating urban heat and enhancing overall environmental conditions. Moreover, the utilisation of remote sensing methodologies, as employed in this research, should be promoted to enable the regular monitoring of land surface temperature and land cover transformations, enabling data-driven decision-making in urban planning. Future research endeavours could build upon the current study by undertaking a more in-depth exploration of the social and economic consequences associated with urban-rural gradients. Additionally, an assessment of the effectiveness of green infrastructure interventions across varying climatic and geographic settings would provide valuable insights to inform urban planning and policy decisions.

References

1. X. Shen, Y. Liu, and B. Liu, Urbanization effect on the observed changes of surface air temperature in Northeast China. Terrestrial, Atmospheric and Oceanic Sciences. **31**, 3 (2020). https://doi.org/10.3319/TAO.2019.11.27.01
2. B. Gherri, The Role of Urban Vegetation in Counteracting Overheating in Different Urban Textures. Land. **12**, 12 (2023). https://doi.org/10.3390/land12122100
3. G. D. S. Santiago, B. R. F. Campos, and C. R. Ribas, How does landscape anthropization affect the myrmecofauna of urban forest fragments? Sociobiology. **65**, 3 (2018). https://doi.org/10.13102/sociobiology.v65i3.3042
4. R. Noviani, Ahmad, and I. N. Marfu'ah, Spatial patterns analysis of land use changes using spatial metrics in the peri-urban area of Surakarta City 2023. IOP Conference Series: Earth and Environmental Science. **1314**, 1 (2024). https://doi.org/10.1088/1755-1315/1314/1/012089
5. N. A. Kurnianingsih, M. Pratami, and M. B. Putri, Karakteristik Pertumbuhan Penduduk Perdesaan pada Perkembangan Wilayah Peri-urban di Perbatasan Kota Surakarta. Journal of Science and Applicative Technology. **5**, 1 (2021). https://doi.org/10.35472/jsat.v5i1.420
6. B. Güler, Plant species diversity and vegetation in urban grasslands depending on disturbance levels. Biologia. **75**, 9 (2020). https://doi.org/10.2478/s11756-020-00484-0
7. P. Widayani, A. Fadilah, I. Z. Irawan, and K. Ghosh, Implementing Support Vector Machine Algorithm for Early Slum Identification in Yogyakarta City, Indonesia Using Pleiades Images. Forum Geografi. **37**, 1 (2023). https://doi.org/10.23917/forgeo.v37i1.15248
8. A. Ayanlade, Remote sensing approaches for land use and land surface temperature assessment: a review of methods. International Journal of Image and Data Fusion. (2017). https://doi.org/10.1080/19479832.2017.1299802
9. N. Yacine Barry, M. Lamine Ndiaye, C. Hauhouot, and B. Sambou, Using Remote Sensing Technics for Land Use Land Cover Changes Analyses from 1950s to 2000s in Somone Tropical Coastal Lagoon, Senegal. American Journal of Remote Sensing. **7**, 2 (2019). https://doi.org/10.11648/j.ajrs.20190702.12
10. D. Surachman, A. Saputra, D. Darnardono, A. A. Wibowo, M. Yoshida, C. A. Tanti Noermartanto, N. Z. Annibras, D. A. Maulida, M. F. Rizky, and F. T. Alhakim, Ecological Evaluation of Urban Heat Island at Tegal Regency, Central Java Province, Indonesia. EnvironmentAsia. **18**, 1 (2025)
11. H. Z. Hadibasyir, N. S. Firdaus, V. N. Fikriyah, and D. N. Sari, Assessing Performance of Modified Spectral Indices as Land Surface Temperature Indicators in Tropical Urban Areas. IOP Conference Series: Earth and Environmental Science. **1190**, 1 (2023). https://doi.org/10.1088/1755-1315/1190/1/012005
12. H. Z. Hadibasyir, S. S. Rijal, and D. R. Sari, Comparison of Land Surface Temperature During and Before the Emergence of Covid-19 using Modis Imagery in Wuhan City, China. Forum Geografi. **34**, 1 (2020). https://doi.org/10.23917/forgeo.v34i1.10862
13. R. Wang and Y. Murayama, Geo-simulation of land use/cover scenarios and impacts on land surface temperature in Sapporo, Japan. Sustainable Cities and Society. **63**, (2020). https://doi.org/10.1016/j.scs.2020.102432
14. S. Siswanto, D. E. Nuryanto, M. R. Ferdiansyah, A. D. Prastiwi, O. C. Dewi, A.

Gamal, and M. Dimyati, Spatio-temporal characteristics of urban heat Island of Jakarta metropolitan. Remote Sensing Applications: Society and Environment. **32**, (2023). https://doi.org/10.1016/j.rsase.2023.101062

15. T. Nakayama, Effect of evapotranspiration on hydrothermal changes in regional scale. Evapotranspiration: An Overview. (2013)