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Urban Forest Ecosystem Approaches to Mitigating Urban Heat Island Effects

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ABSTRACT

The urban heat island phenomenon has become a major concern for medium-sized tropical coastal cities, driven by interactions among land-use change, increasing building density, and the effectiveness of spatial planning. This paper examines how urban forest distribution and building density relate to urban heat island intensity using an urban ecology framework, remote sensing-based spatial analysis, including normalized difference vegetation index (NDVI), normalized difference built-up index (NDBI), and land surface temperature (LST), and spatial planning policy evaluation. The study combines Landsat imagery (2015–2023) with spatial planning documents, green space data, and stakeholder interviews. LST was obtained from NDVI-based emissivity-corrected digital number temperature-radiation-brightness conversion, and linear regression was used to determine the impact of NDVI and NDBI on LST. Based on the research findings, the two cities show different LST patterns. In Baubau, the temperature rise is largely influenced by building density, meaning the denser the buildings, the hotter the city becomes. In Kendari, on the other hand, temperature changes are more strongly influenced by vegetation density. Important ecological features, such as urban forests, mangrove forests, and coastal vegetation, remain scattered along the city's outskirts. Their existence has not been fully integrated into the urban spatial planning. As a follow-up to these findings, we emphasize the need for ecosystem-based measures to tackle the urban heat island effect. This includes tightening regulations on building density and green open spaces through permitting systems, as well as preserving remaining vegetation while developing well-integrated green corridors.

1. Introduction

The urban heat island effect (UHI) is a condition in which urban areas experience significantly higher temperatures than surrounding rural areas. This phenomenon arises in response to critical global environmental conditions. The dynamics of growing anthropogenic activity, land-cover changes, and climate change are driving an increase in the UHI, leading to increased energy consumption, air pollution, and heightened risks to public health and the sustainability of urban development worldwide. (Fajary et al. 2024; Mirzaei 2015; Wang et al.

2016a; Yadav and Singh 2024). Various studies have been conducted, but they have mostly focused on large metropolitan cities, while research in medium-sized cities remains limited. Studies of medium-sized cities are important because these areas are experiencing rapid urbanization. In particular, the coastal regions of eastern Indonesia have rarely been studied, creating a knowledge gap that needs to be addressed (Asfiya and Indah 2024; Husen et al. 2016; Ishak et al. 2025; Santamouris et al. 2019).

Various scientific communities and urban planners have proposed nature-based urban planning as a response to the growing threat of the urban heat island effect, which is worsening each year. Nature-based approaches, such as urban forest ecosystems, offer a promising strategy for climate regulation. Urban forests have a highly complex vegetation system, making them a multifunctional solution that provides shade, lowers city temperatures, absorbs carbon emissions, and improves urban air quality, thereby simultaneously cooling the city's thermal environment (Masoudi et al. 2021; Rizki et al. 2024; Sanju 2025). Current research is no longer limited to just the benefits of urban forests. Instead, it focuses on how the spatial patterns and distribution of urban forests interact with urban morphology, including building density, to model the city's surface environment at a local scale (Estoque et al. 2017; Yilmaz and Ozturk 2024).

This study focuses on Kendari and Baubau, two cities in Southeast Sulawesi Province, Indonesia. Both are medium-sized tropical coastal cities under environmental pressure from urban growth and rising human activity. Since 2015, the urbanization rate of 4.2% has led to changes in land use, particularly in green open space. Green open space in Kendari has shrunk by 28% (Otto et al. 2024). These results are supported by spatial-temporal analysis of Landsat 8 imagery, which shows a significant increase in land surface temperature (LST) in the Bau-Bau region, with an average increase of 2.8°C from 2015 to 2023 (Aldiansyah and Risna 2024; Alwi et al. 2022). The increase in urban temperatures is caused by the low proportion of green open space, which ranges from 11% to 12% in the cities of Kendari and Bau-Bau, far from the mandatory spatial planning regulations requiring at least 30% of the total area (Arifin 2020; Husen et al. 2023). In addition to the area that remains far from the target, the distribution of green open space remains uneven. In the city's growth centers, green cover accounts for less than 5% of the area, while the rest is distributed on the outskirts. As a result, the function of urban forests becomes fragmented and ineffective (Husen et al. 2023). This phenomenon of uneven spatial distribution, combined with increasing urbanization, creates the UHI effect, with significant consequences. These include a 15–20% increase in energy demand for air conditioning, higher air emissions, and an increased risk of diseases related to extreme climate conditions (Santamouris et al. 2019; Wang et al. 2016b).

Empirically, urban forests can reduce urban surface temperatures. However, there remains a gap between scientific understanding and policy implementation. Although empirical evidence and regulations have positioned urban forest ecosystems as strategic infrastructure for mitigating the UHI effect, their implementation has not yet been adopted in the current spatial planning of Kendari and Baubau. Current research on UHI mitigation is exploring the use of green roofs and cool pavements (Santamouris and Yun 2020; Wang et al. 2016b). However, implementing urban forest ecosystem strategies is considered a suitable approach to take in the early stages of planning and policy in urban areas. Topography and a humid tropical climate interact in complex ways; these factors support the formation of different heat center patterns that cannot be addressed with general mitigation plans (Du et al. 2024).

The purpose of this study is to provide a holistic assessment of the potential of urban forest ecosystems to mitigate UHI in cities in Southeast Sulawesi Province. The methodology integrates urban forest ecology, geospatial analysis, and evaluation of government policy (Latifah et al. 2025; Utomo et al. 2025). The objectives of this study are: (1) to understand the relationship between urban forest distribution, building density, and UHI intensity; (2) to evaluate the implementation of spatial planning policies (Darmawan and Santoso 2024; Kiswanto et al. 2025); and (3) to formulate ecosystem-based management strategies in the context of urban forests. Urban forests serve as green infrastructure, mitigating the UHI and providing ecosystem services. This study provides empirical evidence to encourage the sustainable development of climate-resilient cities in medium-sized tropical cities in Indonesia (Ng et al. 2021; Pratomo et al. 2024; Rushayati et al. 2025).

2. Materials and Methods

2.1. Research Location

The research was conducted in the cities of Kendari and Bau-Bau in Southeast Sulawesi Province. These two cities, located on the coast, enjoy strategic positions and serve as regional centers with distinct geographic and socio-economic characteristics (**Fig. 1)**.

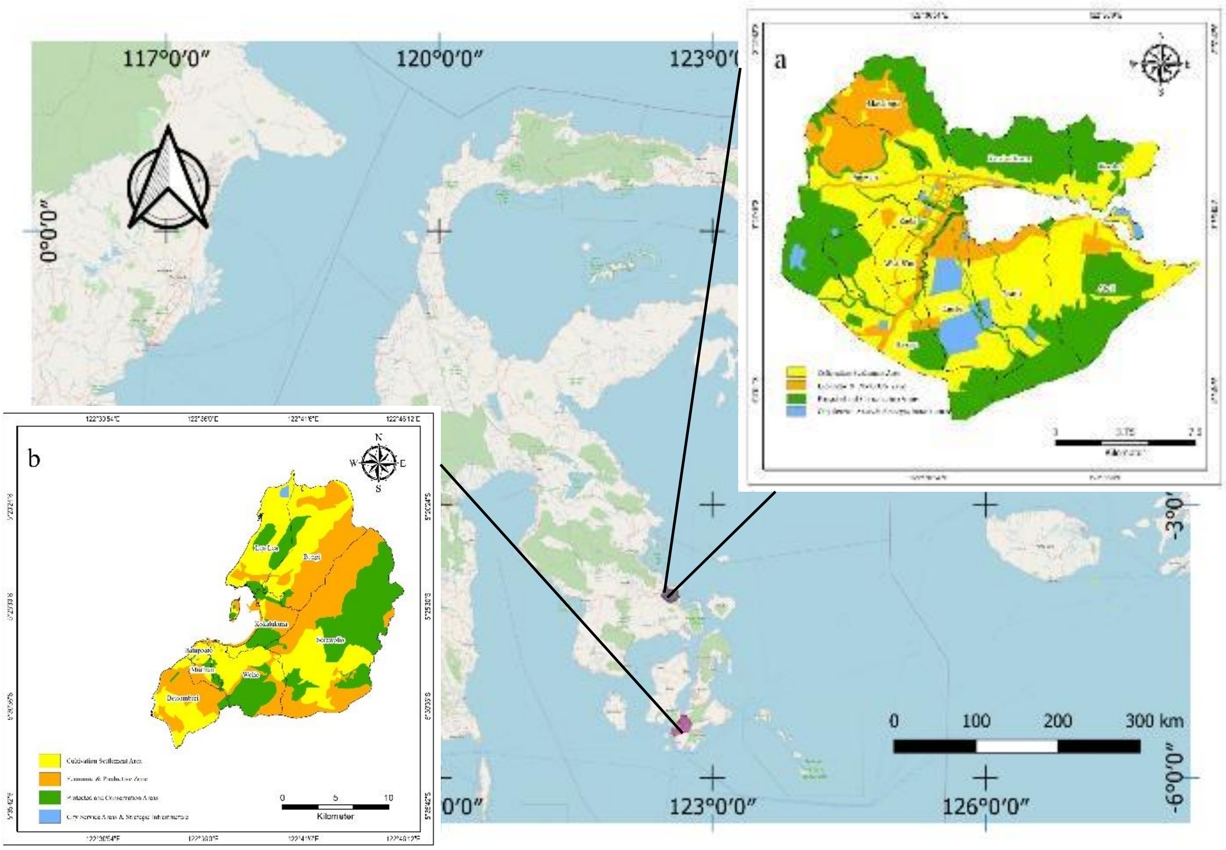


Fig. 1. Sulawesi Island: (a) Kendari City and (b) Baubau City.

Kendari, the capital city of the province, is situated at approximately 3°58′20″ S and 122°30′54″ E (−3.9722°, 122.5149°), and it has an area of roughly 270 km^2 (**Fig. 1a**). The city is on the east coast of Sulawesi Island, adjacent to Kendari Bay. The city's coastal area is mainly lowlands, mangrove forests, and hills reaching 450 meters in height. Baubau is at about 5°28′37″ S and 122°36′60″ E (−5.4770°, 122.6166°), and the city is on the southwest coast of Buton Island (**Fig. 1b**). Its area is close to 295 km^2, of which nearly 30 km^2 is sea, and the city is next to the

Buton Strait. The city is characterized by a mixture of coastal plains and hills that turn into low mountains. Baubau is the economic center of Buton Island. It is evolving into a maritime hub, with port facilities that are continuously expanding and offer sea connections to the eastern part of Indonesia that are very convenient and efficient.

2.2. Data and Variables

The research employs three principal variable groups to examine the urban heat island (UHI) effect in the locality. The initial variable is the earth's surface temperature (SST/LST), which serves as a unit of measure for UHI intensity. In fact, this variable has been widely used, and its validity has been confirmed in numerous studies on urban heating (Bisht et al. 2024; Çetin et al. 2024; Li and Jiang 2017; Wang et al. 2016a).

The normalized difference vegetation index (NDVI) is a measure of the distribution of urban forests and green open spaces. The vegetation density index is a key component in vegetation mapping and UHI mitigation studies in urban areas (Degerli and Çetin 2022; Estoque et al. 2017; Lin and Li 2025). The next variable is the normalized difference built-up index (NDBI), which measures the density distribution of buildings or built-up areas. Building density also empirically influences surface temperature due to different albedo types (Nasrul et al. 2025a; Nasrul et al. 2025b).

The topographic imagery was obtained from Landsat 7 and Landsat 8/9, covering the period from 2015 to 2023. Secondary data includes spatial planning documents, green open space availability and other policy documents. The variables were created based on the studies; thus, they can be used in instrument testing to confirm the validity and reliability of the research results (Alwi et al. 2022; Bhaskara and Pratomo 2023; Hasyim et al. 2025).

2.3. Land Surface Temperature (LST) Measurement

Land surface temperature (LST) is an essential factor in understanding exchanges between the surface and the atmosphere and the UHI effect. The LST mapping is based on Landsat thermal data (10.40–12.50 µm for Landsat 7; 10.60–11.19 µm for Landsat 8/9). The LST calculation method comprises various stages (Li and Jiang 2017).

Digital number (DN) values were converted to spectral radiance using Equation 1.

$$L_\lambda = M_L . Q_{cal} + A_L \quad (1)$$

where L_λ is the spectral radiance (W·m^{-2}·sr^{-1}·µm^{-1}), M_L and A_L are multiplicative and additive rescaling factors, and Q_{cal} is the calibrated DN.

Spectral radiance was converted to brightness temperature (T_b) using Equation 2.

$$T_b = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)} \quad (2)$$

where K_1 and K_2 are band-specific thermal constants.

The LST correction using land surface emissivity (LSE) based on vegetation fraction was performed using Equation 3 (Wang et al. 2016a).

$$LST = \frac{T_b}{1+\left(\frac{XT_b}{\rho}\right) \ln \varepsilon} - 273.15 \quad (3)$$

where λ is the effective wavelength of thermal infrared sensor (TIRS) Band 10 (10.8 µm), $\rho = \frac{h.c}{\sigma}$ $=1.438\times10^{-2}$ mK is a constant derived from Planck's law (h: Planck constant, c: speed of light, σ: Boltzmann constant), and ε is land surface emissivity.

Emissivity (ε) is typically estimated from vegetation fraction, using the NDVI-based approach proposed by Wang et al. (2016a) (Equation 4).

$$\varepsilon = m.\, P_v + n \tag{4}$$

where *m* is the soil emissivity (0.004), *n* is the vegetation emissivity (0.986), and *Pv* is the proportion of vegetation cover, given by Equation 5.

$$P_v = \left(\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}\right)^2 \tag{5}$$

The NDVI is calculated from Landsat OLI bands using Equation 6.

$$NDVI = \frac{\rho_{NIR} - \rho red}{\rho_{NIR} + \rho red} \tag{6}$$

where ρNIR and ρred correspond to surface reflectance in the near-infrared (Band 5) and red (Band 4) bands, respectively.

Essentially, the LST getting back the data stage is associated with the following operations: Thermal DN → Spectral radiance → Brightness temperature → Emissivity correction → LST (°C). This NIR-based emissivity method has been consistently used in urban heat research and has been verified to improve retrieval precision beyond that of the conventional mono-window and single-channel methods (Bisht et al. 2024; Yin et al. 2020).

2.4. Normalized Difference Built-up Index (NDBI)

Normalized difference built-up index (NDBI) is designed to highlight built-up and impervious surfaces by exploiting the spectral difference between shortwave infrared (SWIR) and near-infrared (NIR) reflectance and is computed using Equation 7.

$$NDBI = \frac{\rho SWIR - \rho NIR}{\rho SWIR + \rho NIR} \tag{7}$$

where $\rho SWIR$ is the reflectance in the shortwave infrared band (Band 6, Landsat 8/9 OLI), and ρNIR is the reflectance in the near-infrared band (Band 5, Landsat 8/9 OLI). Positive NDBI values generally correspond to impervious or built-up areas, while negative values correspond to vegetated or water-covered surfaces.

2.5. Regression Analysis between Vegetation and Building Density on LST

The relationships among vegetation density, building density, and surface thermal patterns are quantitatively analyzed using a multiple linear regression model. This model assesses the contribution of independent variables to the dependent variable. This method is also widely used in urban climate research to model the contribution of land-cover indicators to changes in urban surface temperatures.

The regression model is formulated using Equation 8 (Degerli and Çetin 2022).

$$LST = \beta_0 + \beta_1\, x\, NDVI + \beta_2\, x\, NDBI \tag{8}$$

where *LST* is the land surface temperature (°C), $\beta 0$ is the intercept term, and $\beta 1$ and $\beta 2$ are the regression coefficients for NDVI and NDBI, respectively.

A regression analysis aimed at determining the relationships among NDVI, NDBI, and LST used a random sample of 100 points to ensure the data reflected the characteristics of the two cities. The sampling technique used a grid system. The sample points were distributed proportionally across land cover types, including open land, vegetation, and urban built-up areas, to capture the full spectrum of urban temperature variability. The research sample uses a 30 m × 30 m grid based on Landsat 8/9 imagery to minimize spatial autocorrelation; sample points are spaced at least 150 meters apart to ensure statistical independence of each observation. This resolution can identify building blocks and vegetation data maps by maintaining the derived indices NDVI, NDBI, and LST. The sampling technique can better illustrate the influence of vegetation cover (NDVI) and building density (NDBI) on surface temperature (LST) at the local scale. Furthermore, a sample size of 100 points per city is sufficient for multiple linear regression, as it meets the recommended minimum of 15–20 observations per predictor variable.

2.6. Spatial Planning and Green Open Space Policy Analysis

To achieve the second research objective, this study conducted a comprehensive policy evaluation using a mixed-methods approach, combining document analysis with semi-structured interviews. These include: a) Regional spatial plans or *Rencana Tata Ruang Wilayah* (RTRW) for both Kendari and Baubau, along with local regulations concerning green open space or *Ruang Terbuka Hijau* (RTH) implementation, which were systematically reviewed. The analysis focused on: (i) alignment with national mandates (Law Number 26 of 2007 requiring 30% green open space); (ii) spatial distribution targets for green space; (iii) building density regulations (building coverage ratio/KDB); and (iv) integration of ecological indicators in planning instruments.); b) Semi-structured interviews were conducted with 15 key informants purposively selected based on their direct involvement in urban planning and green space management. The informants comprised: five city planning officials from the Development Planning Agency (*Bappeda*) and Public Works Agency (*Dinas Pekerjaan Umum*) in each city (Kendari and Baubau); three environmental agency staff responsible for green space maintenance; four academic experts in urban ecology and regional planning from local universities (Halu Oleo University and Muhammadiyah University of Buton); and three community representatives from neighborhood associations in areas with varying green space coverage.

Interviews were conducted in Kendari and Baubau from August to September 2025, with each session lasting 45–60 minutes. The interviews used a semi-structured method, structured around several key themes, including challenges in policy implementation, obstacles to achieving green open space targets, enforcement of regulations on building density, and the level of understanding of the UHI phenomenon in planning decision-making. All interviews were recorded with the respondents' consent and then transcribed verbatim. Data analysis was then conducted using a gap analysis approach, comparing the policy objectives stated in the RTRW documents and regulations with the field implementation conditions, derived from spatial analysis and interview results. Interview transcripts were analyzed using thematic analysis, following the Braun and Clarke (2006) framework. This involves several stages: understanding the data through repeated readings, developing initial codes, identifying themes, revisiting themes, defining and naming themes, and producing final interpretations. The coding process was conducted manually, grouping themes by regulatory gaps, law enforcement challenges, and obstacles to implementing evidence-based planning. To increase the reliability of the results, triangulation was conducted by comparing interview findings with document analysis and with spatial data, including NDVI, NDBI, and LST patterns. Furthermore, all findings were synthesized using a SWOT analysis framework to identify strategic positions for UHI mitigation efforts, as described in Section 3.3.

2.7. Developing an Ecosystem-Based Strategy

This research resulted in an urban forest management plan based on an ecosystem approach, utilizing spatial analysis results (NDVI, NDBI, LST) and evaluation of existing policies. The focus of the study was to a) Identify priority locations for tree planting and increase green cover, particularly in areas most in need, such as the city center and points with high UHI intensity; b) Linking green open spaces and city vegetation with spatial planning norms to make the best use of ecosystem services (micro-cooling, carbon sequestration, and air quality); and c) Suggestions for local UHI abatement scenarios for Kendari and Baubau by considering the topographic features, tropical climate, and built-up density. This method combines quantitative and qualitative analysis to identify empirically grounded urban forest management strategies for sustainable urban development and climate resilience.

3. Results and Discussion

3.1. Configuration and Distribution of Green Open Spaces

The geographical conditions of Kendari and Baubau differ significantly in their effects on urban heat island (UHI) dynamics. Kendari City, located on the mainland of Sulawesi Island, has a hilly topography and extensive land connectivity. This connectivity encourages urban development to spread to the city's outskirts (Nurgiantoro et al. 2025). The second city research location, Baubau, is on Buton Island, with a relatively limited land area and an archipelagic character that limits horizontal development. Consequently, urban activity and development are more concentrated, especially in city centers such as Wolio, Merhum, and Betoambari Regencies (Aldiansyah and Risna 2024).

Kendari and Baubau exhibit distinct spatial patterns due to their respective geographical conditions. Kendari has a diffuse pattern, while Baubau has a centralized pattern, resulting in different UHI distributions. Research conducted by Nurgiantoro et al. (2025) revealed that UHI changes in Kendari City spread to the west and south, following the expansion of built-up land. In contrast, in Baubau City, they were relatively concentrated in the city's activity centers. This finding is supported by Aldiansyah and Risna (2024), who reported that UHI distribution and intensity in Baubau were concentrated in the city center, with UHI intensity increasing by up to 2°C between 2018 and 2023.

Southeast Sulawesi is characterized by hilly topography and a humid tropical climate, which tends to exacerbate the uneven distribution of heat across the two cities (Husen et al. 2026). Kendari's varied topography results in heat centers of varying intensity. Meanwhile, in Baubau, the island's limited land area causes heat to accumulate in the city center. These differences in characteristics indicate that UHI mitigation efforts through an urban forest ecosystem approach cannot be implemented uniformly. Instead, the strategies implemented need to be tailored to each city’s geographic conditions and spatial configuration.

Based on a spatial analysis of green open space (RTH) in Baubau City, it was revealed that its ecological structure is largely composed of natural forest vegetation. Green open space in

Baubau covers an area of 11,300.22 ha, or 38.30% of the city's total area (29,507 ha). Public RTH accounts for the majority, at 11,073 ha (97.99%), of which primary and secondary forests make up the largest share, covering 9,617.52 ha (85.11%). The next significant components are certified urban forests (441.75 ha; 3.91%), riversides (413.81 ha; 3.66%), and coastal/mangrove areas (197.13 ha; 1.74%) (Hasddin 2023).

By comparison, the coverage of managed RTH, e.g., city parks (148.03 ha; 1.31%) and village parks (37.21 ha; 0.33%), is just a fraction of the area of natural forest. The private green space portion is only 227.25 ha (2.01%), mainly residential yards (180.25 ha; 1.60%), indicating a very low level of household-based vegetation. **Table 1** shows the complete breakdown of the green area in Baubau City.

Table 1. Composition of green open space in Baubau City

Type of green open space (RTH)	Area (ha)	RTH area (%)
City parks	148.03	1.31
Sub-district parks	37.21	0.33
Designated urban forest	441.75	3.91
Primary–secondary forest	9,617.52	85.11
Green belts	144.59	1.28
Roadside green strips	0.63	0.01
Pedestrian green strips	1.26	0.01
Public cemeteries (TPU)	6.71	0.06
Archaeological park areas	24.29	0.21
River buffer zones	413.81	3.66
Coastal buffers (include mangroves)	197.13	1.74
Raw water buffer zones	40.06	0.35
Office yards	34.70	0.31
Commercial/business yards	12.28	0.11
Residential yards	180.25	1.60
Total RTH in Baubau City	11,300.22	38.30
Total area of Baubau City	29,507	

Note: The 38.30% represents the proportion of RTH relative to Baubau City's total administrative area.

The spatial distribution indicates that green open space is largely concentrated in the city's forest-dominated areas, in both the central and northern parts, and along the coastal corridor. On the other hand, densely populated residential areas, especially those in the southwest sector, have low green open space coverage and high levels of fragmentation. This configuration aligns with the higher NDBI and LST values in these areas, and the lack of green open space is cited as a contributing factor to increased surface temperatures. Consequently, densely populated residential areas with a shortage of green open space were pinpointed as the primary target areas for the intervention of tree planting, the creation of neighborhood parks, and the development of green corridors.

At the same time, Kendari City has a green space composition that is not only more extensive but also more structurally diverse than that of Baubau. The total green area amounts to 13,558.71 ha, which is 49.89% of the city's total area of 27,176 ha. The most significant part is the primary and secondary forests, which cover 11,020 ha (81.28%) and, by definition, make them the city's ecological core. The green belts along the streets, on the other hand, make up 1,341 ha (9.89%), and after that, the mangrove forest is at 525 ha (3.87%) and hence plays a crucial role in both the stabilization of the shore and in the reduction of the surface temperatures of the coastal zone.

Managed green spaces additionally include botanical gardens (118 ha; 0.87%), nature tourism parks (65.20 ha; 0.48%), river green belts (168.89 ha; 1.25%), and coastal green belts (102.85 ha; 0.76%). At the city level, green open spaces, such as city parks (6.16 ha; 0.05%) and village parks (0.64 ha; 0.00%), make a quite limited contribution compared to the ecological benefits of greened areas. The private components, such as institutional yards and other non-formal green spaces, account for 56.02 ha (0.41%), indicating that community involvement in green spaces remains quite minimal across the city.

This spatial pattern reveals two main ecological clusters. First, the coastal green belt, consisting of mangrove forests and other coastal vegetation. Second, the forest complex in the north-central region forms the backbone of the city's ecological network. Part of these areas has also been urbanized and is surrounded by fragmented green space, with high LNDVI and LST values. The distant sub-districts have plenty of green space but are mostly low-lying, with mostly low-growing vegetation such as shrubs and grass. The temperature reduction is lower than in areas with mature canopy forests. The complete distribution of green space by typology in Kendari City is depicted in **Table 2**.

Table 2. Composition of green open space in Kendari City

Type of green open space (RTH)	Area (ha)	RTH area (%)
Urban forest	74.62	0.55
Mangrove forest	525.00	3.87
Primary-secondary forest	11,020.00	81.28
City park	6.16	0.05
Nature tourism park	65.20	0.48
Botanical garden	118.00	0.87
Roadside green strips	1,341.00	9.89
Coastal green strips	102.85	0.76
River green strips	168.89	1.25
Sports fields	56.78	0.42
Cemeteries	23.55	0.17
Sub-district Park	0.64	0.00
Other private RTH	56.02	0.41
Total RTH in Kendari City	13,558.71	49.89
Total area of Kendari City	27,176	

Note: The 49.89% represents the proportion of RTH relative to Kendari City's total administrative area.

Taking into consideration these spatial patterns, Kendari's foremost strategies are (i) bolstering the conservation of mangroves, (ii) improving the quality of vegetation in the residential areas with high population density, and (iii) interlinking the green islands in the different districts into ecological corridors to strengthen the control of the urban heat island effect.

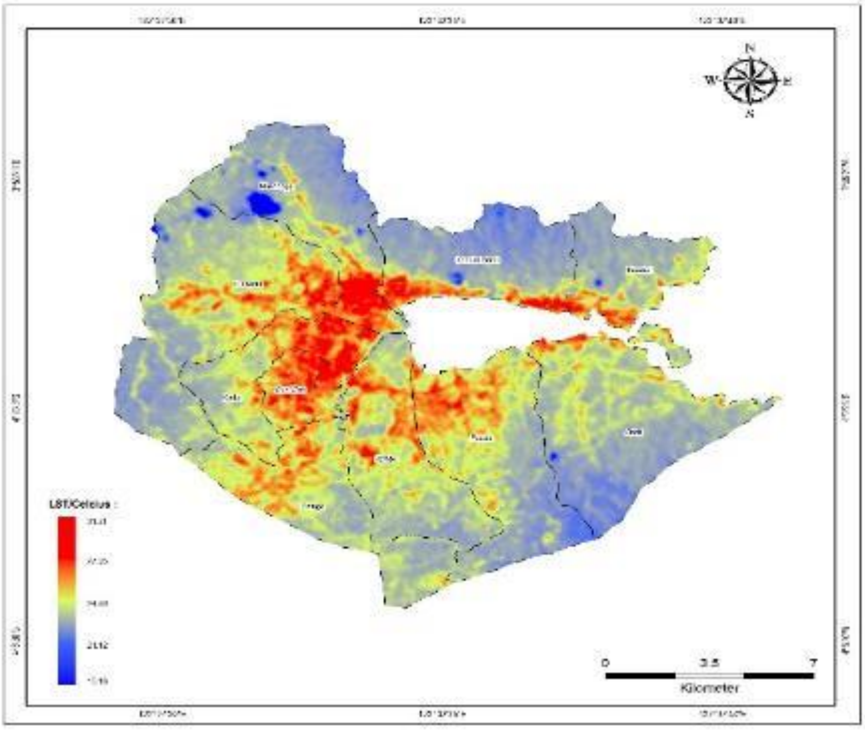
Baubau and Kendari similarly rely on natural forests to meet their green space needs; however, the arrangements and operational effectiveness vary. Built-up residential areas of Baubau exhibit even greater fragmentation of green space. However, Kendari has a more integrated ecological network within the coastal zone and northern forest complex (Agil et al. 2025; Iskandar et al. 2024; Zulkarnain et al. 2025). These differences result in varied LST sensitivities to NDVI and NDBI across the two cities, as corroborated by the following regression analysis. The results demonstrate that to mitigate UHI effectively, cities need more than adequate green space. The green space must be organized in a specific spatial pattern and of high ecological quality (Ulfa and Fazriyas 2020; Zulkarnaen et al. 2021).

The study of green space composition and spatial distribution in Baubau and Kendari has shown that changes in vegetation cover and the degree of green space fragmentation strongly influence urban surface temperature patterns. The variations in tree canopy density, ecological corridor continuity, and built-up area size across districts are evident in NDVI and NDBI values, which directly affect LST changes (Amru et al. 2022; Salsabila et al. 2021; Zulkarnaen et al. 2021). Consequently, the green space layout not only helps identify the level of ecological sustainability but also serves as a principal factor in urban thermal behavior (Massiri 2023). Hence, to determine the extent to which these biophysical factors contribute to the rise of the UHI, the next chapter elucidates the spatial patterns of LST, UHI intensity, and the quantitative relationships among the variables that determine these factors through statistical analysis and thematic mapping (Tarmizi and Rizwan 2024).

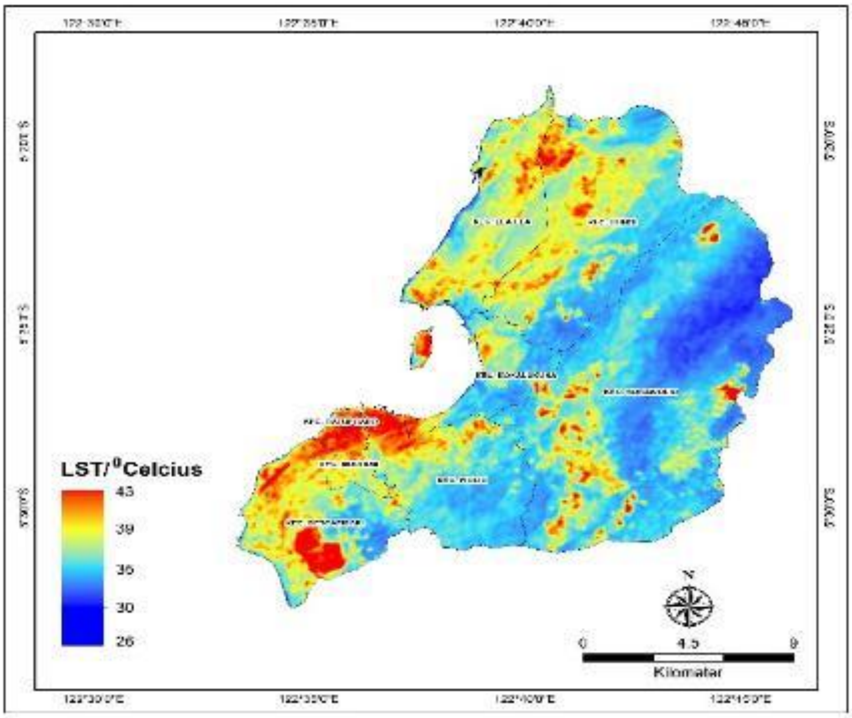
3.2. Land Surface Temperature (LST) Patterns and UHI Intensity

The results of the LST distribution analysis in both cities are shown in **Fig. 2**. The LST analyses in Kendari and Baubau indicate that the thermal patterns differ, which aligns with the distinct urban land cover in the two cities. The city centers in both cities show higher LST than the suburban areas, indicating that heat concentration is in the most densely populated areas. The downtown area of Baubau has a high population density and a high LST, indicating that heat has been concentrated by building materials that absorb and store heat. Meanwhile, in Kendari City, the increase in LST occurs in new growth areas, driven by urbanization that requires commercial housing, which spreads outside the city center and puts pressure on suburban areas, leading to vegetation loss. Therefore, according to research conducted by Isnanto and Priyana (2024), the arrangement of LST depends on building density and vegetation distribution. This shows that the land's physical characteristics are the main factors determining air temperature in urban areas.

To determine the statistical relationship between LST and land cover, multiple linear regression analyses were conducted for NDBI and NDVI. The findings showed that each city showed a different pattern of relationship. In Baubau, LST was significantly affected by NDBI; a 1-unit increase in NDBI was associated with a 9.51°C increase in LST. On the other hand, NDVI did not have a significant effect, possibly because secondary forests and large open areas still reduce thermal differences. In Kendari, LST was more strongly influenced by vegetation density; a 1-unit increase in NDVI resulted in a 4.75°C decrease in LST, while the impact of NDBI was not significant, indicating that the UHI phenomenon in Kendari is significant if there is vegetation loss and land conversion in new areas caused by land use change. Then, the R^2 values of the regressions (0.14 for Baubau and 0.29 for Kendari) indicate that other factors, such as urban morphology, surface material, energy consumption and anthropogenic factors, still influence LST variations (Song et al. 2025).



(a)



(b)

Fig. 2. Spatial distribution of LST: (a) Kendari City and (b) Baubau City.

These findings indicate that the UHI phenomenon is highly complex and cannot be explained by two land-cover indicators alone. Therefore, further research needs to consider additional variables. Factors such as urban morphology, the three-dimensional configuration of buildings and open spaces—including the street canyon aspect ratio and skyview factor play a significant role in influencing radiation trapping and radiative cooling (Morakinyo et al. 2020; Voogt and Oke 2003).

In this context, Baubau, with its high density and relatively narrow street canyons, may experience a stronger radiation-trapping effect, thereby strengthening the influence of the NDBI on LST. On the other hand, the NDBI itself has limitations: it represents buildings in two dimensions and cannot capture their height or volume. High-rise buildings can provide shading during the day but also trap heat at night, while low-rise buildings with high-thermal capacity materials tend to retain heat longer (Yang et al. 2019). In fact, studies show that dense, low-lying residential areas can have ambient temperatures up to 1.3°C higher than those with other spatial patterns (Chen et al. 2022). Urban heat sources from human activities, such as motor vehicles, industry, and air conditioning, also contribute to urban heat, especially in city centers like Baubau and along the main transportation routes in Kendari City. Research in Guangzhou shows that anthropogenic heat emissions increase air temperatures by up to 2.3°C and contribute up to 54% to the intensity of urban heating, especially in the morning (Chen et al. 2022; Santamouris and Yun 2020).

Surface material composition, along with urban morphology, plays a significant role in determining how much heat is absorbed and released through thermal properties such as albedo, heat capacity, and thermal conductivity. Low-albedo materials, such as dark asphalt and metal roofs common in downtown Baubau, absorb and retain more heat than reflective materials or vegetation. Research has shown that increasing albedo from 0.12 to 0.50 can reduce surface temperatures by up to 12°C (Li et al. 2020). Further research in Greece in July 2023 found that asphalt temperatures reached 58.9°C, while grass surfaces were only around 38.3°C, underscoring the importance of material selection for temperature control (Giannaros et al. 2024). In addition to material composition and local climate, land-sea winds, which are common in coastal cities, also influence spatial heat distribution. Areas with limited ventilation, such as valleys in Kendari or dense road canyons in Baubau, tend to trap heat and form local hotspots (Yu et al. 2025). On the other hand, the analysis's low coefficient of determination (R^2) values may also reflect nonlinear relationships between the variables, which multiple linear regression models cannot capture. For example, the link between NDVI and LST often shows a cooling effect that becomes less important after a certain level of vegetation cover is reached. At very high building densities, the effect of NDVI on LST can reach saturation (Estoque et al. 2017; Li and Jiang 2017). This means that strategies to reduce UHI cannot rely on a single method; they need to use a combination of methods that account for the city's shape, material choices, how to manage heat from people, and how to protect natural ventilation corridors. Ecosystem approaches remain important, but they must be combined with urban design that responds to climate change and with building codes that require high thermal performance. The complete regression statistics are available in **Table 3**.

Table 3. LST regression statistics against NDVI and NDBI

City	Multiple R	R^2	Adjusted R^2	Std. error	Observations
Baubau	0.38	0.14	0.12	1.94	100
Kendari	0.54	0.29	0.27	1.36	100

Note: Multiple R, R^2, and Adjusted R^2 show the combined contribution of NDVI and NDBI variables to LST variation in each city.

Moreover, the changes in the dependent variable based on independent variables reveal the way and the extent of the impact of NDVI and NDBI on LST (**Table 4**). In Baubau, LST was positively affected by NDBI at a high level of significance, whereas NDVI was not. In Kendari, a significant negative effect was observed for NDVI, while NDBI remained insignificant. These findings are consistent with the statement of Husen et al. (2026) that the density of buildings mainly dominates the UHI intensity in Baubau, whereas in Kendari, it is a distribution of vegetation that has a greater influence.

Table 4. Regression coefficients of LST (°C) on NDVI and NDBI

City	Variable	Coefficient (B)	Significance (p-value)
Baubau	NDVI	−2.06	0.338 (not significant)
Baubau	NDBI	9.51	0.003 (significant)
Kendari	NDVI	−4.75	0.000 (significant)
Kendari	NDBI	0.56	0.717 (not significant)

Note: The B coefficient indicates the expected LST change due to a one-unit change in NDVI or NDBI. Significance was tested at $p<0.05$.

In fact, the UHI hotspots might be singled out through the characteristics of a city from the regression outcomes. It can be said that Baubau's compact city center made a major contribution to the UHI hotspot, most likely due to its high building density, whereas the urbanized area of Kendari, which is still new, became a hotspot because of its very low vegetation coverage (NDVI). **Table 5** shows these hotspot indicators.

Table 5. UHI hotspot indications based on LST analysis

City	UHI Hotspot	Dominant Factor
Baubau	Dense city center	High building density (NDBI)
Kendari	New urban area	Loss of vegetation (low NDVI)

Note: Shows hotspot locations and dominant factors causing UHI in each city.

Such results offer precise recommendations for UHI mitigation at the level of a single city. For instance, in Baubau, the implementation of mitigation measures should primarily focus on regulating building density, maximizing green open space and applying high-albedo materials. In Kendari, on the other hand, mitigation would be better achieved by focusing on conserving vegetation and urban reforestation to reduce extremely hot areas resulting from urban expansion. This strategy emphasizes the interplay of natural and anthropogenic factors as determinants of urban thermal conditions; consequently, UHI mitigation measures must be customized to the characteristics of urbanization and the distribution of vegetation in each city (Fajary et al. 2024; Syeda et al. 2025).

The findings from spatial analysis and LST regression in the cities of Kendari and Baubau demonstrate that each city's unique characteristics influence the intensity of the urban heat island (UHI) in distinct ways. The high LST in Baubau is due to many buildings in the city center. On the other hand, in Kendari, the LST rises more often in new areas where the vegetation cover is changing. This difference in patterns shows that the UHI phenomenon does not occur in the same way everywhere; instead, it is influenced by a mix of built-up areas and vegetation. In this case, NDBI is a more dominant factor in Baubau, while NDVI plays a larger role in explaining LST variations in Kendari. The somewhat moderate R^2 values indicate that other factors, such as urban morphology, surface materials, and anthropogenic heat emissions, may be contributing to the observed thermal variations (Akbari et al. 2016; Aldiansyah and Risna 2024; Lin and Li 2025).

Such results call for different local UHI mitigation measures. In Baubau, the measures should primarily focus on managing building density, developing green open space and using materials with high albedo to prevent heat storage. On the other hand, Kendari could be more advantageous through urban reforestation, vegetation protection, and the planning of interventions to mitigate the thermal effects of urban expansion (Alwi et al. 2022; Hasyim et al. 2025; Rushayati et al. 2025). The city-specific evidence is that successful UHI mitigation depends on considering not only natural but also anthropogenic factors in urban planning, thereby making the measures compatible with cities' spatial and developmental characteristics.

3.3. Relationships between Vegetation, Built-up Density, and UHI

The first step was to evaluate the effect of vegetation cover (NDVI) and building density (NDBI) on land surface temperature (LST) through separate multivariate regression analyses for the cities of Baubau and Kendari. The total regression model for each city was statistically significant (F test, $p < 0.005$), showing that NDVI and NDBI together affect LST. The coefficient of determination (R^2) was not very high: 0.14 for Baubau and 0.29 for Kendari. This means that the model's variables cannot fully explain the changes in LST. In other words, other factors could have a bigger effect, such as the city's shape, the properties of the surface material, and the heat generated by people, which were not included in the analysis. This finding is consistent with the research outcomes of Nurgiantoro et al. (2025) and Li et al. (2019).

The regression results for Baubau City (**Table 6**) show that building density (NDBI) is the most important factor affecting LST. For every unit increase in NDBI, LST goes up by 9.51°C. This shows that heat is building up and being released in the dense city core. On the other hand, NDVI did not have a statistically significant effect ($B = -2.06$; $p = 0.338$). This is probably because there are secondary forests, plantations, and large, fairly saturated open areas, which make vegetation less important in shaping thermal patterns. These results show that in cities like Baubau, where population density is high, managing urban heat is more effective when it focuses on controlling building density and using high-albedo materials rather than simply increasing the number of plants (Husen et al. 2026; Rajasekar and Weng 2009).

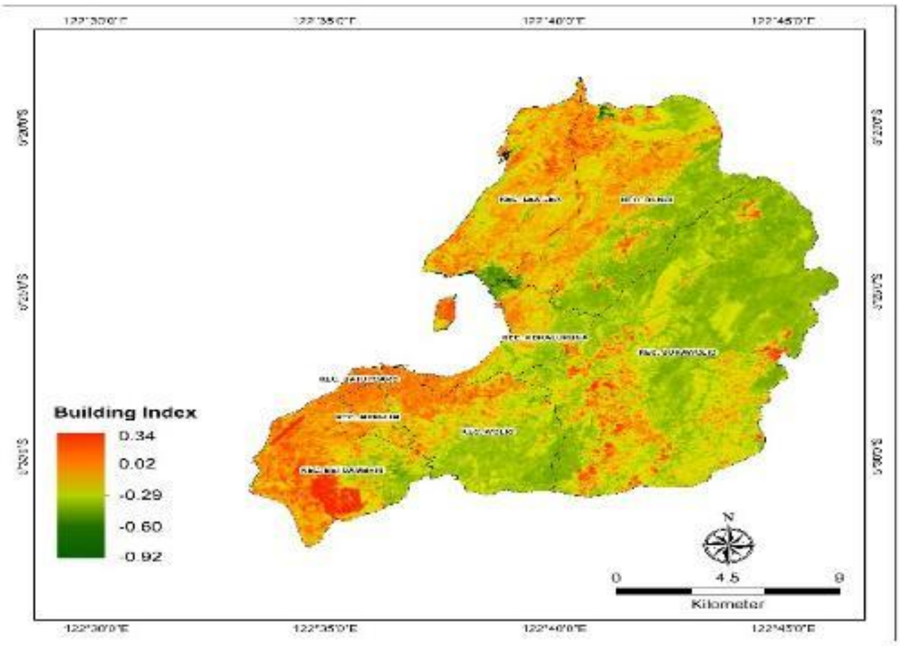
Table 6. Coefficients Regression of NDVI and NDBI on LST in Baubau City

Variable	Coefficient (B)	Std. error	t stat	P-value	95% CI Lower	95% CI upper
Intercept	36.16	0.98	37.11	0.000	34.23	38.09
NDVI	−2.06	2.14	-0.96	0.338	-6.31	2.19
NDBI	9.51	3.11	3.06	0.003	3.35	15.68

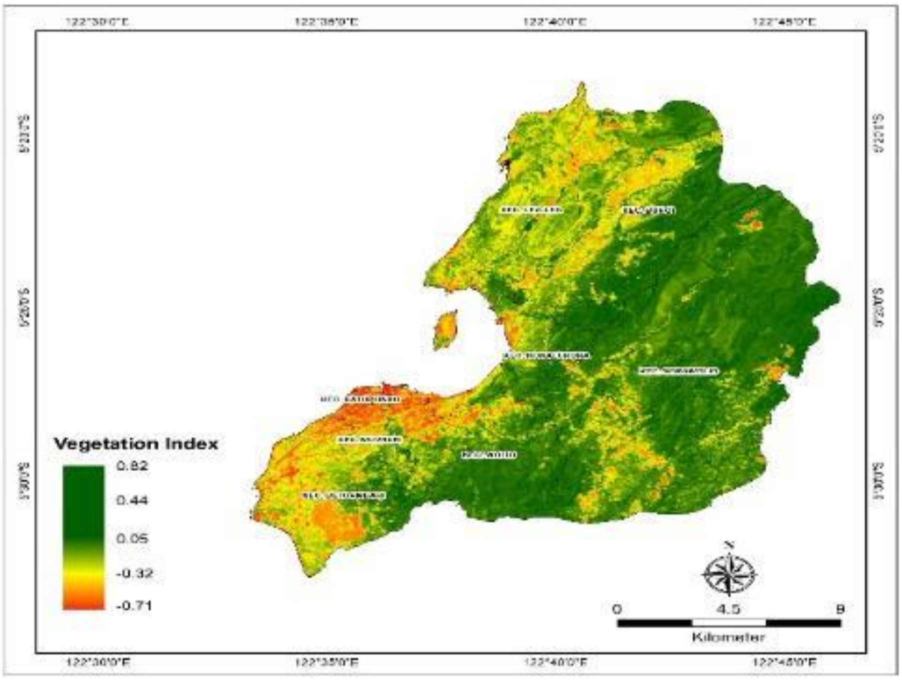
Note: NDBI significantly increases LST, whereas NDVI shows no significant effect, reflecting the influence of dense urban cores on heat accumulation.

The spatial representation of NDVI, NDBI, and LST values in Baubau City, as seen in **Fig. 3**, is a complete depiction of how the cellular nature of the earth's surface regulates the temperature of the city. A stark difference is evident on this map between the forested areas in the north and east that are characterized by high NDVI values and the densely populated residential areas and the city center that show high NDBI values and warmer LST. This spatial representation confirms the regression analysis's quantitative results.

The distribution maps in **Fig. 3** support the findings of the regressions, which show that building density (NDBI) is the main factor of LST in Baubau, while the effect of vegetation (NDVI) is quite limited because of the prevalence of secondary forests and open areas. This picture makes it clear that UHI mitigation strategies in Baubau should not only focus on managing built-up intensity, re-districting dense areas, and applying high-albedo surface materials, but also on greening areas most exposed to heat (Husen et al. 2026; Yadav and Singh 2024).



(a)



(b)

Fig. 3. (a) NDBI and (b) NDVI BauBau City.

Besides this, the regression coefficients for Kendari City (**Table 7**) reveal the contrary, with LST in Kendari being much more dependent on vegetation distribution. The NDVI coefficient (B = −4.75, $p < 0.001$) indicates that a 1-unit increase in vegetation cover can lower LST by about 4.75°C. The impact of NDBI on Kendari was insignificant (B = 0.56, p = 0.717), indicating that building density has not become the main factor in newly urbanized areas. This situation indicates that rapid urban expansion, accompanied by vegetation loss, is the primary cause of UHI in Kendari. Hence, the most effective mitigation strategy will be to implement urban greening and prevent the disappearance of green open spaces to avoid the formation of hotspots (Alwan et al. 2025; Kumar et al. 2024; Kuncoro and Sari 2026).

Table 7. Regression coefficients of NDVI and NDBI on LST in Kendari City

Variable	Coefficient (B)	Std. error	t stat	P-value	95% CI lower	95% CI upper
Intercept	28.04	0.50	56.20	0.000	27.05	29.03
NDVI	−4.75	0.79	−5.99	0.000	−6.32	−3.18
NDBI	0.56	1.55	0.36	0.717	−2.51	3.64

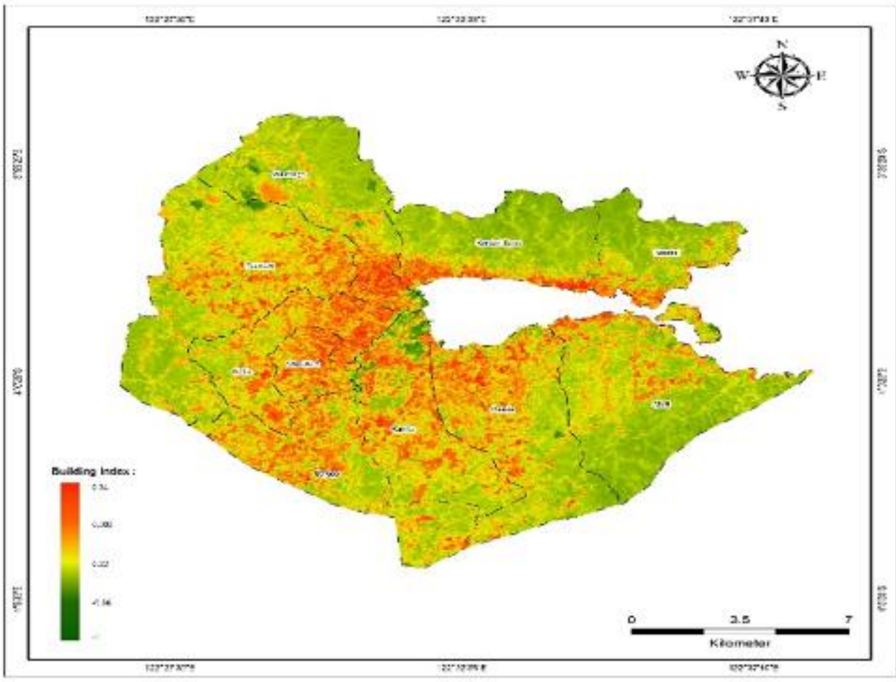
Note: NDVI significantly reduces LST in Kendari, emphasizing the critical role of vegetation in mitigating UHI in rapidly urbanizing areas.

The visualization of the NDVI and NDBI regression coefficients against LST in Kendari City, illustrated in **Fig. 3**, reveals the surface temperature sensitivity to the changes in land cover of the city, which is growing rapidly. This diagram explains the differences in the impacts of vegetation and building density on temperature, particularly given the spatial transformation resulting from the growth of new settlements and the conversion of green areas (Gherraz et al. 2020; Kumar et al. 2024; Kuncoro and Sari 2026; Maheng et al. 2024). **Fig. 4** is an intermediate stage between the spatial patterns of NDVI–NDBI and the numerical results in **Table 5**, as well as a visual representation of which variables are the primary drivers of thermal dynamics in Kendari.

The coefficient pattern in **Fig. 4** identifies vegetation as the dominant element in the regulation of LST in Kendari, which is very well illustrated by the most significant and negative NDVI coefficient. On the other hand, the minimal effect of NDBI indicates that densification has not been a significant contributor to warming; thus, the loss of vegetation cover due to urban expansion is the main cause of hotspots. The results here are an excellent demonstration of the necessity of UHI abatement measures fuelled by urban greening, green space conservation, and the protection of existing vegetation in the progression of urban growth in Kendari (Frosini et al. 2024; Husen et al. 2026; Yu et al. 2025).

Urban forests and green open areas are vital for lowering surface temperatures through evapotranspiration; they also provide shading and alter surface albedo. In Kendari, the very strong negative correlation between NDVI and LST shows that vegetation can lower surface temperature to a very large extent, thus giving a clear signal of the necessity of the conservation of the already existing green spaces and the combining of the reforestation or urban greening programs in the city (Alwi et al. 2022; Huang et al. 2025; Rushayati et al. 2025). Consequently, these policies align with extensive research indicating that green urban areas are a potent tool for dissipating the heat that builds up in cities, especially those undergoing rapid expansion and urbanization (Fajary et al. 2024; Nurgiantoro et al. 2025; Yadav and Singh 2024).

In Baubau, the green open spaces identified by NDVI did not have a direct, statistically significant effect on LST; however, they still served as thermal buffers by reducing local heat peaks, especially in the outskirts (Aldiansyah and Risna 2024; Arifin 2020). The predominance of NDBI in determining LST indicates that plant-based solutions alone are not enough in tightly packed urban cores; thus, alongside building density control and the use of reflective or high-albedo materials, the application of these methods is equally necessary to alleviate urban heat (Atianta et al. 2025; Husen et al. 2025; Pratomo et al. 2024).



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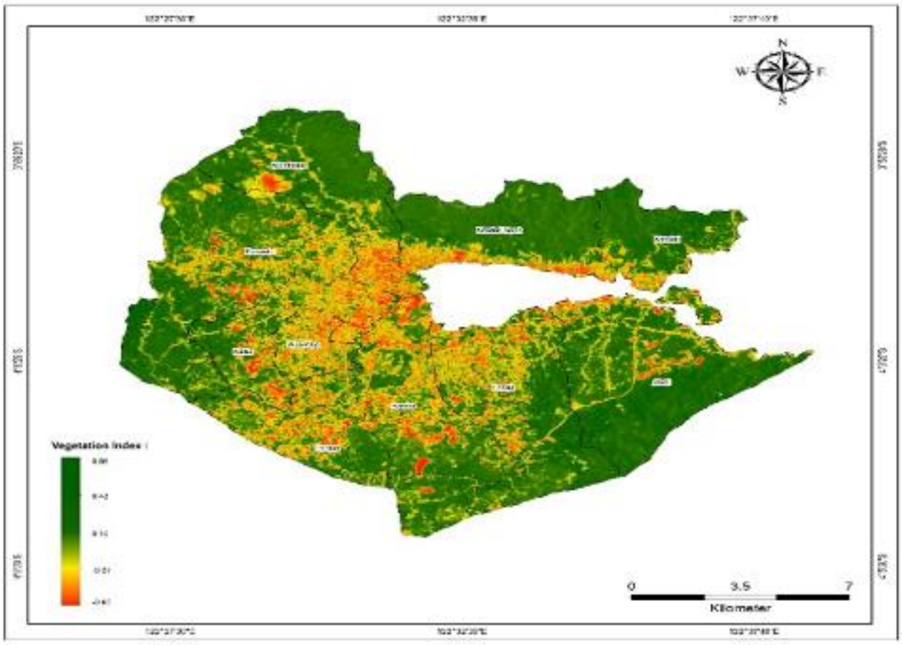

(b)

Fig. 4. (a) NDBI and (b) NDVI Kendari City.

These results highlight the highly local character of the UHI problem across cities, requiring distinct solutions. In Baubau, interventions need to focus heavily on the control of building density and the upgrading of urban infrastructure to the extent that heat retention in dense cores is reduced, while Kendari gains most from the planting and conserving of urban trees to neutralize the effects of fast land-use change (Bhaskara and Pratomo 2023; Hasyim et al. 2025). By putting into practice locally relevant, nature-based measures, both cities will be able to adaptively handle the problem of urban heat while giving back to nature and making their areas more attractive.

3.4. Evaluation of Spatial Planning Policies and Green Open Space Regulations

The evaluation of the Regional Spatial Planning (RTRW) documents and regulations regarding green open space in Kendari and Baubau reveals a discrepancy between the defined policy objectives and the prevailing conditions. According to Law No. 26 of 2007, both cities must set aside at least 30% of their urban areas for green open spaces. However, the actual achievements of Kendari and Baubau are only 11.81% and 12.30%, respectively. Moreover, these areas are located in the outskirts, so the city center, with its high population density and economic activities, has less than 5% vegetation, although the cooling effect of urban green spaces is well known (Rizki et al. 2024).

The enforcement of rules covering building density is also not very strong. The downtown area of Kendari regularly exceeds the building coverage ratio or *rasio koefisien bangunan* (RKB) of 70%, resulting in the disappearance of green spaces, while Baubau is witnessing unchecked overdevelopment of its city core. The results of spatial regression confirm these conclusions: NDVI in Kendari substantially lowered land surface temperature (–4.75°C), whereas NDBI in Baubau significantly increased LST (+9.51°C). Nevertheless, these indicators have not been officially recognized as part of planning instruments (Ariani et al. 2021). The complete table summarizing the comparison of local policies with UN-Habitat standards and empirical gaps is presented in **Table 8**.

Table 8. Comparison of green open space policies and urban planning implementation in Kendari and Baubau Cities

Policy aspect	**Kendari City**	**Baubau City**	**UN-habitat standards**	**Empirical gaps**
Proportion of green open space (RTH)	11.81%; target 30%	12.30%; target 30%	Minimum 45% open space; 15–20% public green space	Both cities fail to meet national and international targets
Distribution and Accessibility	Peripheral; <5% in the city center	Symbolic, uneven; low inclusivity	Access within 400 m of residence	Severely limited access, below global standards
Building density (BCR)	Core zones >70% BCR; vegetation loss	Overbuilding; uncontrolled high density	Density control + green infrastructure	Local policies fail to regulate land-use intensity
Evidence-based policy	Normative; NDVI reduces LST	Normative; NDBI increases LST	Policy informed by spatial data (NDVI, LST)	Regulations ignore available scientific evidence

A SWOT-based assessment detailed in the SWOT matrix in **Fig. 5** helps to understand the strategic positioning of Baubau and Kendari for the reduction of urban heat and the management of green spaces. The cities internally reflect a balance between strengths, for instance, established regulatory frameworks and institutional support, and weaknesses, such as the low achievement of RTH targets and the weak enforcement of building density controls, which have led to a neutral internal score. On the other hand, the threats posed by increasing urbanization, unplanned land-use conversion, and intensifying UHI effects outweigh the opportunities offered by UN-Habitat guidelines and urban innovation initiatives, resulting in a negative external score of –0.80. As a result, the two cities are in a strategic position between the WO (turnaround) and ST (defensive) quadrants of the SWOT matrix, indicating that integrated strategies are needed that simultaneously leverage opportunities to address internal weaknesses and strengthen existing strengths to resist external threats. WO strategies that embrace technology might include redistributing RTH to densely populated areas of the city through vertical gardens, green corridors, and optimized private yards, all facilitated by spatially explicit data. The strength-threat (ST) strategy, on the other hand, could mean stricter enforcement of building density rules, more supervision of KDB/KLB, and making city parks more useful for people and the environment. This integrated approach ensures that UHI mitigation efforts are data-driven and account for conditions in each area. Therefore, Kendari City's recommendation focuses on preserving vegetation and strengthening urban greening, while Baubau focuses more on controlling building density and on stricter regulatory enforcement (Pratomo et al. 2024; Rushayati et al. 2025).

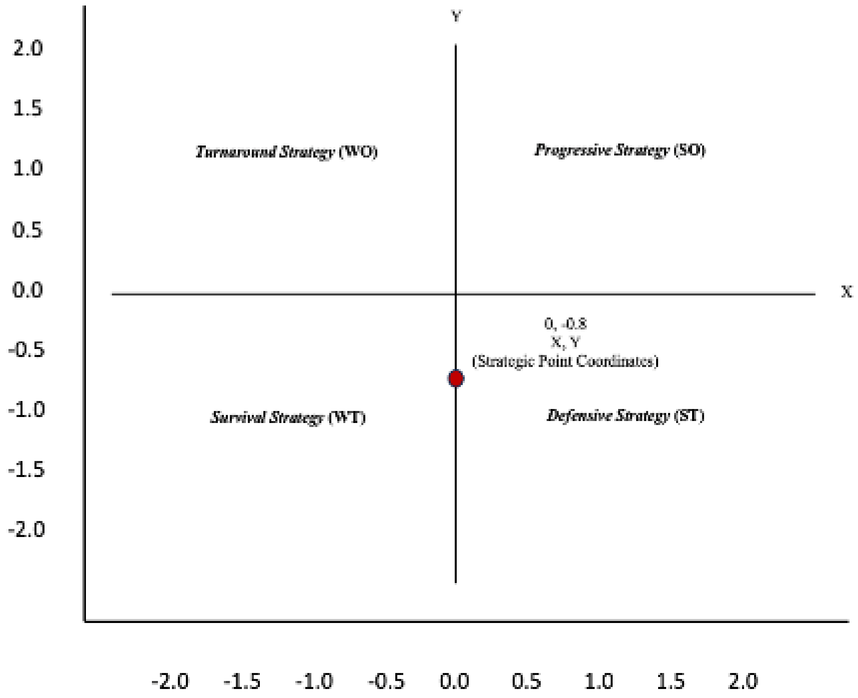

Fig. 5. SWOT quadrant analysis.

The present results are consistent with earlier studies that point to the significant contribution of urban green spaces to reducing surface urban heat. Akbari et al. (2016) argued that urban vegetation is the most effective means of local climate regulation, and Rizki et al. (2024), as well as Lin and Li (2025), went on to show that greening based on NDVI leads to a considerable decrease in land surface temperatures in highly populated urban areas. In the same vein, Aldiansyah and Risna (2024) and Alwi et al. (2022) found that insufficient green coverage intensifies the UHI problem in Indonesian cities, thereby calling for a planning process grounded in solid spatial evidence. On the whole, these pieces of research provide strong backing for the current advice to embed scientific indicators such as NDVI and LST into policy instruments, allowing both Kendari and Baubau to not only put urban thermal management on a sustainable track but also to lessen the negative impacts of rapid urbanization.

3.5. Ecosystem-Based Urban Forest Management Opportunities

The spatial and regression analyses of land surface temperature (LST), vegetation cover (NDVI), and built-up density (NDBI) have provided a quantitative basis for identifying priority areas for ecosystem-based urban forest interventions in Baubau and Kendari. In Baubau, the dense city center shows the highest LST, and LST is highly correlated with building density (NDBI = 9.51, $p = 0.003$), whereas NDVI has an insignificant effect ($B = -2.06$, $p = 0.338$). It implies that thermal relief in Baubau is a matter of increasing plant cover through interventions such as green roofs, vertical gardens, urban green corridors, and pocket parks, especially in the densest core areas where natural green spaces are scarce.

Newly urbanized areas in Kendari are the primary sources of the local UHI, with very low vegetation cover (NDVI coefficient = −4.75, $p < 0.001$). Consequently, building density does not have a significant effect on surface temperature ($B = 0.56$, $p = 0.717$). The statement above emphasizes the heat problem, which can be addressed by preserving nature and using trees for urban greening in rapidly expanding urban districts. Solutions may consist of tree planting, development of pocket parks, and retention of existing vegetated areas to facilitate evapotranspiration and shading.

Assessing local spatial planning documents (RTRW) and green open space (RTH) rules has revealed that the existing urban greenery is mainly in the outskirts, leaving the city centers very hot. In Baubau, the vegetated area in the city center is less than 5%, and the new urban areas of Kendari have lost significant vegetation due to rapid development. The results highlight the need to embed such strategies in the forest, as a natural source of the urban ecosystem, into planning instruments, so that interventions can be geographically targeted to the most deprived areas (Biella et al. 2025; Khan and Shahid 2024).

Table 9 summarizes these priority areas and corresponding city mitigation strategies based on the spatial distribution of LST, NDVI, and NDBI. Such an evidence-based method provides a transparent basis for implementing locally relevant urban forest interventions directly targeted at UHI hotspots.

Table 9. Priority areas and ecosystem-based mitigation strategies for UHI

City	UHI hotspot	Dominant factor	Suggested ecosystem-based interventions
Baubau	City center	High building density (NDBI)	Green roofs, vertical gardens, urban green corridors, pocket parks
Kendari	New urban area	Low vegetation (NDVI)	Tree planting, pocket parks, preservation of remnant vegetation, urban reforestation

Note: Interventions are based on spatial and regression analyses of LST, NDVI, and NDBI to target mitigation of urban heat in areas with the highest thermal risk.

The integration of spatial and regression analyses constitutes compelling evidence for Baubau and Kendari's ecosystem-based urban forest management. The results clearly show that UHI conditions differ between these two cities: the thermal stress in Baubau is driven by the densely built, high-rise city center, whereas the newly urbanized zones of Kendari are most affected by vegetation loss. Therefore, the goal of any intervention is to use a variety of measures—from green roofs and vertical gardens in dense cores to tree planting and remnant vegetation preservation in expanding areas—to eliminate the heat efficiently. This approach not only directly targets UHI hotspots but also aligns with broader goals for urban sustainability, such as improving green infrastructure, enhancing microclimates, and making ecosystems more resilient. Incorporating specific, context-specific actions into spatial planning tools will be an important step toward ensuring that urban greening efforts are focused and useful, so that both the community and the urban environment can get the most out of them.

4. Conclusions

This study verifies that the dynamics of the urban heat island (UHI) phenomenon in Baubau and Kendari are influenced by unique interactions among ecological conditions, land cover attributes, and spatial planning governance. These findings also meet the research goals, which were to measure the relationships among these variables, assess the effectiveness of policies, and identify ways to reduce the impact of urban forest ecosystems. The results of the spatial analysis show that both cities have abundant green resources, including primary and secondary forests, coastal areas, and mangroves. However, they are still mostly found in areas on the outskirts of the city that are not well connected to the center. Because of this, the urban core has very little vegetation cover (<5%) and is highly fragmented, making it harder for the urban landscape to withstand heat stress. Statistically, the factors that affect surface temperature (LST) in the two cities are also very different. In Baubau, building density had a greater effect on LST (NDBI coefficient = +9.51°C; $p < 0.003$), whereas in Kendari, vegetation cover had a greater effect. This confirms that strategies to reduce UHI cannot be applied the same way across all cities; they must be tailored to each city's unique ecological features and layout. This study identified substantial implementation deficiencies from a policy standpoint. Neither city has met the national goal of 30% green open space. Kendari has 11.81%, and Baubau has 12.30%. Also, there is still an uneven distribution of green open space, and planners rarely use spatial data such as NDVI, NDBI, and LST. The SWOT analysis also shows that both cities are in the WO and ST quadrants. This means they need to make the most of their internal resources and manage their strategies to address external pressures, especially uncontrolled land conversion. This research scientifically advances understanding of UHI in tropical secondary cities by illustrating the impact of land-cover changes on urban thermal conditions and emphasizing the need to incorporate remote-sensing-derived ecological indicators into spatial planning. The findings of this study suggest distinct strategies for each city. Baubau should focus on controlling building density, raising surface albedo, and targeted reforestation in areas that need it most. At the same time, Kendari should focus on protecting mangroves, preserving plants, and building green corridors that follow the path of urban growth. Additional research is advised to amalgamate terrestrial microclimate measurements, multi-temporal satellite imagery analysis, predictive modeling, and assessments of anthropogenic and socio-economic vulnerability. This method will enable more thorough monitoring of thermal dynamics, simulation of different mitigation scenarios, and the development of more focused adaptation strategies. Thus, both cities can direct their urbanization toward more climate-conscious, sustainable development through an ecosystem-based approach supported by spatial evidence.

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Author Contributions

O.O.H.: Conceptualization, Methodology, Resources, Writing – Original Draft Preparation, Writing – Review and Editing, Supervision; H.: Conceptualization, Methodology, Writing – Original Draft Preparation, Writing – Review and Editing, Supervision; A.I.: Conceptualization; A.H.T.: Software; J.H.: Software; D.N.Y.F.S.: Investigation; J.A.: Data Curation.

Conflict of Interest

The authors declare no conflict of interest.

Declaration of Generative AI And AI-Assisted Technologies in the Manuscript Preparation

The use of AI in the preparation of this manuscript was limited to basic tools for checking grammar, spelling, referencing, and formatting. No generative or AI-assisted AI technology was used in the writing, analysis, or interpretation of this research.

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