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Urban Thermal Stress Dynamics in a Tropical Coastal City: Insights from Remote Sensing Analysis in Padang City, Indonesia

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ABSTRACT

Introduction. The Urban Heat Island (UHI) phenomenon has emerged as a critical global environmental challenge, significantly undermining the sustainability of urban ecosystems and the well-being of city dwellers. UHI directly impacts human thermal comfort, increases energy demands for cooling, and escalates public health risks. In tropical regions, these challenges are particularly acute due to high baseline temperatures, intense solar radiation, and rapid urbanization. In tropical coastal settings, the complexity of thermal dynamics is further heightened by unique geomorphological features and the degradation of natural buffer zones—such as mangroves and riparian vegetation—and massive land cover transformations, thereby altering the microclimatic balance. This study focuses on Padang City, a tropical coastal city in Indonesia, which has undergone intensive land-use transformation over the past decade. This rapid development has converted extensive non-vegetated areas and agricultural lands into dense residential and commercial zones, leading to the emergence of localized thermal hotspots that threaten the city's long-term ecological resilience.

Data and Method. This research utilized multitemporal Landsat 8 OLI/TIRS satellite imagery (2015–2024) to analyze the spatio-temporal dynamics of the urban environment. The analysis focused on coastal lowlands (built-up and cultivation zones), excluding upland forests to eliminate topographic thermal bias. The Normalized Difference Vegetation Index (NDVI) was employed to quantify vegetation density, while Land Surface Temperature (LST) was retrieved using the thermal infrared bands through a rigorous series of calibration steps, including top-of-atmosphere (TOA) radiance conversion and surface emissivity estimation based on land cover proportions. To evaluate thermal stress, the Urban Thermal Field Variance Index (UTFVI) was modeled, classifying ecological quality into six categories to provide a precise spatial metric for urban environmental health.

Result and Discussion. The findings indicate that the relationship between NDVI and LST in Padang City lowlands consistently exhibits a negative correlation, underscoring the role of vegetation as a key thermal regulator. However, the strength of this relationship has progressively weakened over the study period, with the coefficient of determination declining by 2024. This trend suggests a reduction in the cooling capacity of existing urban vegetation amidst the expansion of impervious surfaces. Interestingly, during the COVID-19 pandemic in 2020, average surface temperatures declined to 28.18°C due to reduced anthropogenic heat emissions. Nevertheless, UTFVI analysis reveals that extreme thermal stress classes, specifically the 'Strongest-Worst' category, continued to expand structurally, particularly in the urban core. This expansion intensified in the post-pandemic period (2022–2024), where the 'Worst' ecological zone reached its peak spatial extent. The persistence of these hotspots reinforces the argument regarding the high thermal inertia of concrete and asphalt materials. This study finds that the thermal ecological quality of Padang City is undergoing structural degradation. Future urban planning must prioritize the integration of blue-green infrastructure with surface material albedo control and optimized morphological designs to enhance the thermal resilience against the escalating pressures of climate change and urbanization.

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1. Introduction

Globally, the Urban Heat Island (UHI) phenomenon has emerged as one of the major environmental issues affecting the sustainability of urban areas. UHI is characterized by elevated surface and air temperatures that directly influence thermal comfort, public health, energy consumption, and urban ecological stability [1-4]. In tropical regions, thermal stress tends to be more intense due to high baseline temperatures, strong solar radiation, and rapid urbanization that accelerates land cover change and alters surface characteristics.

Numerous studies indicate that urban ecological degradation—marked by the reduction of vegetation cover, the expansion of impervious surfaces, and the decline of ecosystem functions—plays a significant role in intensifying UHI effects and disrupting urban microclimatic balance [5, 6]. In tropical coastal settings, these challenges become increasingly complex. Coastal geomorphological characteristics, large-scale coastal development, and the degradation of buffer ecosystems such as mangroves and riparian vegetation substantially increase the thermal vulnerability of coastal cities in Southeast Asia [7-9]. These pressures are further exacerbated by global climate change through the increasing frequency of heatwaves, rising nighttime minimum temperatures, and altered precipitation patterns [10].

Within urban climate studies, the role of vegetation in mitigating surface heat is commonly examined using the Normalized Difference Vegetation Index (NDVI), while surface temperature distribution is represented by Land Surface Temperature (LST). A negative relationship between NDVI and LST has been widely reported [11-14], highlighting the capacity of vegetation to reduce surface temperatures through shading and evapotranspiration processes. However, in urban areas dominated by built-up surfaces, this relationship often exhibits non-linear characteristics and is strongly influenced by urban spatial configuration.

Consequently, reliance on average temperature values alone is insufficient to comprehensively capture urban thermal stress. The Urban Thermal Field Variance Index (UTFVI) was developed to account for the spatial heterogeneity of thermal stress and urban ecological quality, enabling more sensitive identification of zones experiencing high levels of thermal stress [15].

In Indonesia, rapid urban development is frequently not accompanied by adequate environmental quality protection. The reduction of green open spaces, conversion of coastal land

uses, and the expansion of settlements and infrastructure have intensified thermal stress in many large and medium-sized cities [16-21]. This condition is particularly relevant to Padang City, a tropical coastal city on the western coast of Sumatra that has experienced intensive built-up area growth and land-use transformation [22]. Declining vegetation cover, increasing impervious surfaces, and mounting pressure on coastal ecosystems have contributed to the emergence of UHI hotspots, particularly in coastal zones and urban activity centers [23-25].

Nevertheless, studies that integratively combine LST, NDVI, and UTFVI analyses to understand urban thermal dynamics and ecological quality in Padang City remain limited. Furthermore, the influence of changes in human activity including periods of mobility restriction during the COVID-19 pandemic on urban thermal dynamics has received little attention in the context of tropical coastal cities, particularly in Indonesia. Addressing these gaps, this study aims to analyze the spatio-temporal dynamics of surface temperature and vegetation and to evaluate the intensity of urban thermal stress using the UTFVI approach in the lowland areas of Padang City. By employing remote sensing data and geospatial analysis, the findings are expected to provide a scientific basis for climate-adaptive urban planning and UHI mitigation strategies in tropical coastal cities.

2. Materials and Methods

Study Area and Scope. The study area covers Padang City, located on the west coast of Sumatra Island, Indonesia, which serves as the main administrative and economic center of West Sumatra Province. Spatially, this area is located within the Universal Transverse Mercator (UTM) coordinate system, Zone 47S, and directly borders the Indian Ocean to the west, while its eastern part is mostly occupied by protected forest areas (Fig. 1).

Padang City exhibits highly heterogeneous topographic characteristics, with relatively flat coastal lowlands in the western sector and steep mountainous terrain in the eastern region. Elevations across the study area range from 0 to 1,853 m above sea level, with most urban activities concentrated in the coastal lowlands. According to the Köppen-Geiger climate classification, this area is categorized as having a tropical rainforest climate (Af) [26].

This study applies spatial restrictions based on the Padang City Spatial Plan 2010-2030 [27], limiting the analysis to lowland areas designated as cultivation zones and built-up areas. Upland areas, including protected forests,

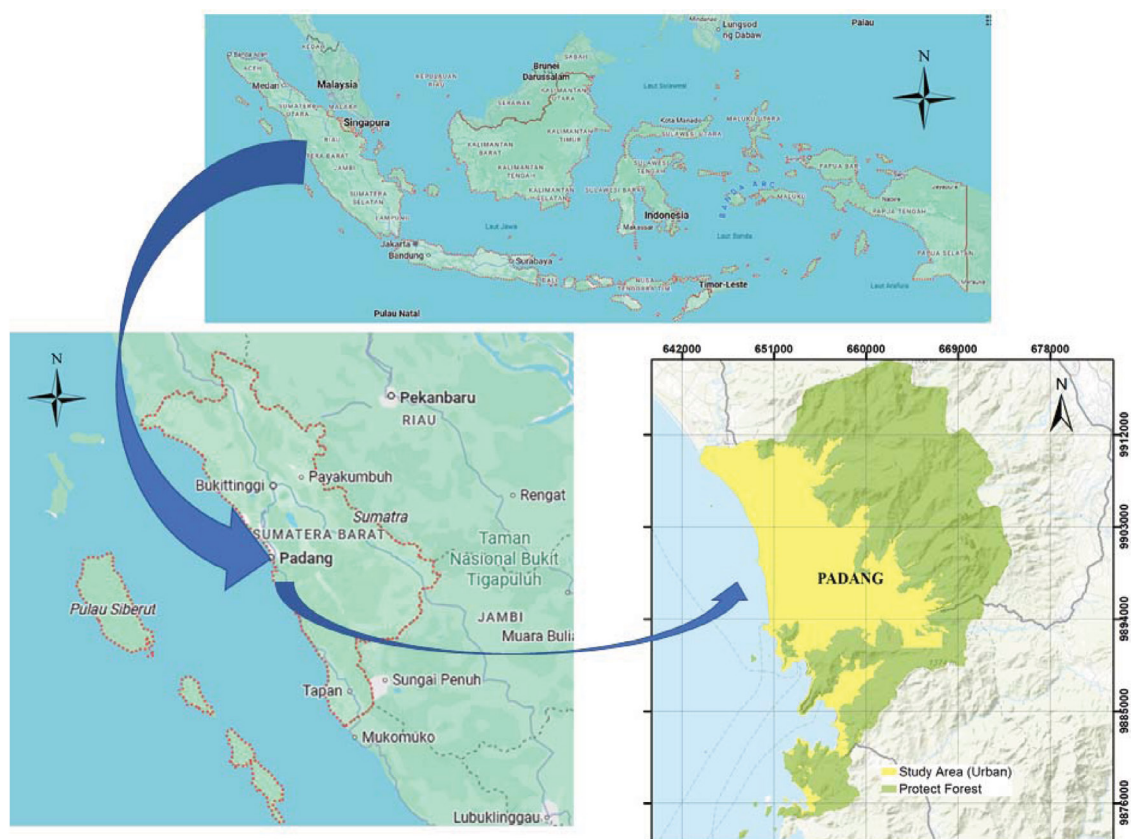


Fig. 1. Study Area

were systematically excluded from all stages of the analysis, including NDVI calculation, LST extraction, and Urban UTFVI modeling; in other words, these areas were categorized as areas without urbanization activity. This was also done to reduce high spatial heterogeneity due to the influence of changes in surface topography factors [28]. By normalizing the data distribution based on urban lowland zones, the UTFVI analysis becomes statistically more robust and more relevant for identifying heat vulnerability patterns in residential areas and economic activity centers. This approach allows for the evaluation of thermal interactions between impermeable surfaces and urban vegetation in a comparable spatial context in Padang City.

NDVI and LST Computation. This study employed Landsat 8 Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS) satellite imagery processed using Precision and Terrain Correction (L1TP). Multispectral band 4 (red) and band 5 (near-infrared) were utilized to derive surface reflectance and calculate the NDVI, while thermal band 10 was used for LST estimation. Although the original spatial resolution of the Thermal Infrared Sensor (TIRS) band is 100 m, the data have been resampled to 30 m by the United States Geological Survey (USGS) in the distributed products, ensuring consistency with the Operational Land Imager

(OLI) bands and enabling integrated spatial analysis. All satellite images used in this study were geometrically corrected spatial datasets and were freely downloaded from the USGS portal(<https://earthexplorer.usgs.gov/>).

Spatial delimitation was applied by restricting the analysis to lowland areas designated as built-up and cultivation zones in accordance with Padang City Regulation No. 3. 2019. Protected areas including protected forests, conservation zones, and designated greenbelt areas, were systematically excluded from the analysis to prevent thermal bias and to maintain analytical consistency. Detailed specifications of the Landsat 8 OLI/TIRS data utilized in this study are provided in Table 1.

Spatial delimitation was implemented by restricting the analysis to lowland areas designated as built-up and cultivation zones. Protected forests (such conservation areas, and greenbelt zones) were excluded using shapefile boundaries as spatial masks to prevent thermal bias and to ensure analytical consistency.

Landsat 8 OLI/TIRS imagery was used to extract surface temperature for the period 2015-2024. The temperature retrieval procedure followed the methodology outlined in the Landsat 8 User Handbook [29] and consisted of several sequential steps. First, the digital number (DN) values of TIRS band 10 were converted into top-

Table 1

Specification of Landsat 8 OLI/TIRS

Path/Row	Sensor	Date	Spatial Resolution
127/ 061	Landsat 8 OLI/TIRS	01/07/2015	30 meter
		22/07/2017	
		25/05/2019	
		11/05/2020	
		04/07/2022	
		25/07/2024	

of-atmosphere (TOA) spectral radiance, using the following equation (2.1).

$$Reflektan = \rho\lambda' = M\rho * Qcal + Ap \quad (2.1)$$

where $\rho\lambda'$ represents the top-of-atmosphere (TOA) reflectance uncorrected for the solar elevation angle, $M\rho$ is a specific band multiplicative rescaling factor), Ap is a specific band additive rescaling factor dan $Qcal$ denotes the pixel value expressed as digital numbers (DN).

Furthermore, the satellite brightness temperature is derived from the spectral irradiance values [29], using the following equation (2.2):

$$T = \frac{K2}{\ln(\frac{K1}{L\lambda} + 1)} - 273.15 \quad (2.2)$$

where T represents temperature (in Kelvin, subsequently converted to degrees Celsius), $L\lambda$ denotes the spectral radiance value of the thermal band (band 10), $K1$ dan $K2$ are the calibration constants obtained from the Landsat 8 metadata.

To obtain the final LST from Landsat 8 imagery, surface emissivity (ϵ) must be calculated [30], which can be derived using the following equation (2.3):

$$(\epsilon) = 0,004 \times pv(NDVI) + 0.986 \quad (2.3)$$

where ϵ denotes land surface emissivity and, pv represents the proportion of vegetation.

NDVI values were used to determine land surface emissivity (ϵ) following by [30]. Subsequently, NDVI was further employed to calculate the proportion of vegetation (Pv) [31]. The NDVI calculation applied in this study is expressed by the following equation (2.4 and 2.5) [32].

$$NDVI = \frac{\text{band 5} - \text{band 4}}{\text{band 5} + \text{band 4}} \quad (2.4)$$

$$Pv = \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \quad (2.5)$$

The final LST was calculated using the following equation (2.6):

$$LST = \frac{BT}{\{1 + [(\lambda BT / \rho) \ln \epsilon / \lambda]\}} \quad (2.6)$$

where BT denotes brightness temperature, λ represents the wavelength of the emitted radiation for each band, ρ is the Boltzmann constant (1.38×10^{-23} J/K), and ϵ refers to land surface emissivity [33].

NDVI was utilized as a key parameter in estimating land surface emissivity, which subsequently constitutes an essential component in the calculation of final LST. The role of NDVI is critical because this index is directly associated with the estimation of vegetation proportion (Pv) and land surface emissivity (ϵ), two fundamental factors that determine the accuracy of land surface temperature measurements. In addition to its function in LST computation, NDVI was also employed in this study to evaluate the spatial relationship between vegetation cover and variations in land surface temperature. Theoretically, NDVI values range from -1 to 1, where values approaching 1 represent dense vegetation cover, while values close to zero or negative indicate sparsely vegetated areas or non-vegetated surfaces.

Urban Thermal Field Variance Index (UTFVI). To evaluate the spatial intensity of urban thermal stress and ecological quality, this study employed the UTFVI. UTFVI is designed to quantify the deviation of local land surface temperature from the mean temperature of the study area, thereby enabling the identification of zones experiencing relatively high thermal stress [34, 35]. UTFVI was calculated using the following equation (2.7):

$$UTFVI = \frac{LST_i - LST_{mean}}{LST_{mean}} \quad (2.7)$$

where LST_i represents the land surface temperature of the i -th pixel, LST_{mean} denotes the average land surface temperature of the entire study area.

Higher UTFVI values indicate the presence of the Strongest UHI class and correspond to the worst ecological quality, whereas lower UTFVI values represent more stable thermal conditions and Excellent ecological status. To facilitate interpretation and spatial analysis, UTFVI values

were classified into six UHI presence classes and Ecological Evaluation Index (EEI) categories (35, 36], as presented in Table 2.

Table 2

Classification of Urban ecological condition

UHI Presence	UTFVI	EEI
None	<0	Excellent
Weak	0-0.005	Good
Middle	0.005-0.010	Normal
Strong	0.010-0.015	Bad
Stronger	0.015-0.020	Worse
Strongest	>0.020	Worst

This classification enables the identification of zones experiencing extreme thermal stress and facilitates the evaluation of temporal changes in the spatial distribution of heat stress. The UTFVI approach was selected because it effectively captures urban thermal heterogeneity that cannot be identified through analyses based solely on average LST values. By integrating UTFVI results with NDVI and LST dynamics, this study provides a comprehensive analytical framework for assessing the relationships among ecological degradation, urban surface structure, and the intensity of thermal stress in Padang City.

3. Results and Discussion

Analysis of NDVI-LST dynamics in the lowlands of Padang City, 2015-2024). The analysis results indicate that the relationship between NDVI-LST in the lowland areas of Padang City consistently exhibits a negative correlation throughout the observation period from 2015 to 2024 (Fig 2.A and 2.B). This pattern underscores the role of vegetation as a key regulator of surface temperature, particularly through evapotranspiration and shading mechanisms, which are highly relevant in the context of a tropical humid coastal city.

Statistically, this negative relationship is confirmed by spatial linear regression analysis conducted for each year of observation (Fig 2.C). In 2015, the NDVI and LST relationship exhibited the strongest explanatory power, with a coefficient of determination ($R^2=0.554$), indicating that increases in NDVI were significantly associated with reductions in surface temperature (slope = -8.04). This condition reflects a lowland landscape that remained relatively responsive to vegetation influences, characterized by an average surface temperature of 28.61 °C and a mean NDVI value of 0.51 (Table 3).

In 2017 and 2019, the direction of the relationship remained negative, but its strength declined (R^2 values of 0.3803 and 0.3528,

respectively), even though the mean surface temperature reached relatively high levels (up to 29.95 °C in 2017). This indicates that the aggregate increase in vegetation density (mean NDVI of 0.56-0.58) was not sufficient to fully offset the intensification of urban activities and the expansion of impervious surfaces in the lowland areas. In other words, thermal control began to shift from vegetation dominance toward a combination of urban morphological factors and anthropogenic activities.

Interestingly, during the 2020 period-coinciding with the COVID-19 pandemic and the implementation of Large-Scale Social Restrictions [37] in Padang City average surface temperature declined to 28.18 °C, even though the strength of the NDVI-LST relationship further weakened ($R^2=0.3207$). This finding aligns with previous studies showing reductions in land surface temperature intensity during COVID-19-related activity restrictions, primarily due to decreased anthropogenic heat emissions, and indicating that reduced human mobility can weaken the NDVI-LST relationship despite relatively stable vegetation cover [38-40].

Table 3

Mean LST and NDVI in the lowlands of Padang City, 2015–2024

Years	Mean LST (°C)	Mean NDVI
2015	28.61	0.51
2017	29.95	0.58
2019	28.94	0.56
2020	28.18	0.54
2022	27.41	0.56
2024	29.84	0.50

In 2022, the mean surface temperature reached its lowest value during the study period (27.41 °C), followed by a slight strengthening of the NDVI-LST relationship ($R^2=0.378$). This condition suggests that urban vegetation including intra-urban green open spaces still possesses significant thermal mitigation capacity when anthropogenic pressures are relatively reduced. Conversely, in 2024, a renewed increase in mean surface temperature (29.84 °C) was accompanied by a decline in average NDVI (0.50) and a further weakening of the NDVI and LST relationship ($R^2=0.33$), indicating heightened thermal stress associated with the expansion of built-up areas and the intensification of anthropogenic activities in the post COVID-19 period.

Overall, these results indicate that the NDVI-LST relationship remains directionally stable but progressively weakens in strength over time as the complexity of the urban surface increases. This trend reflects a fragmentation

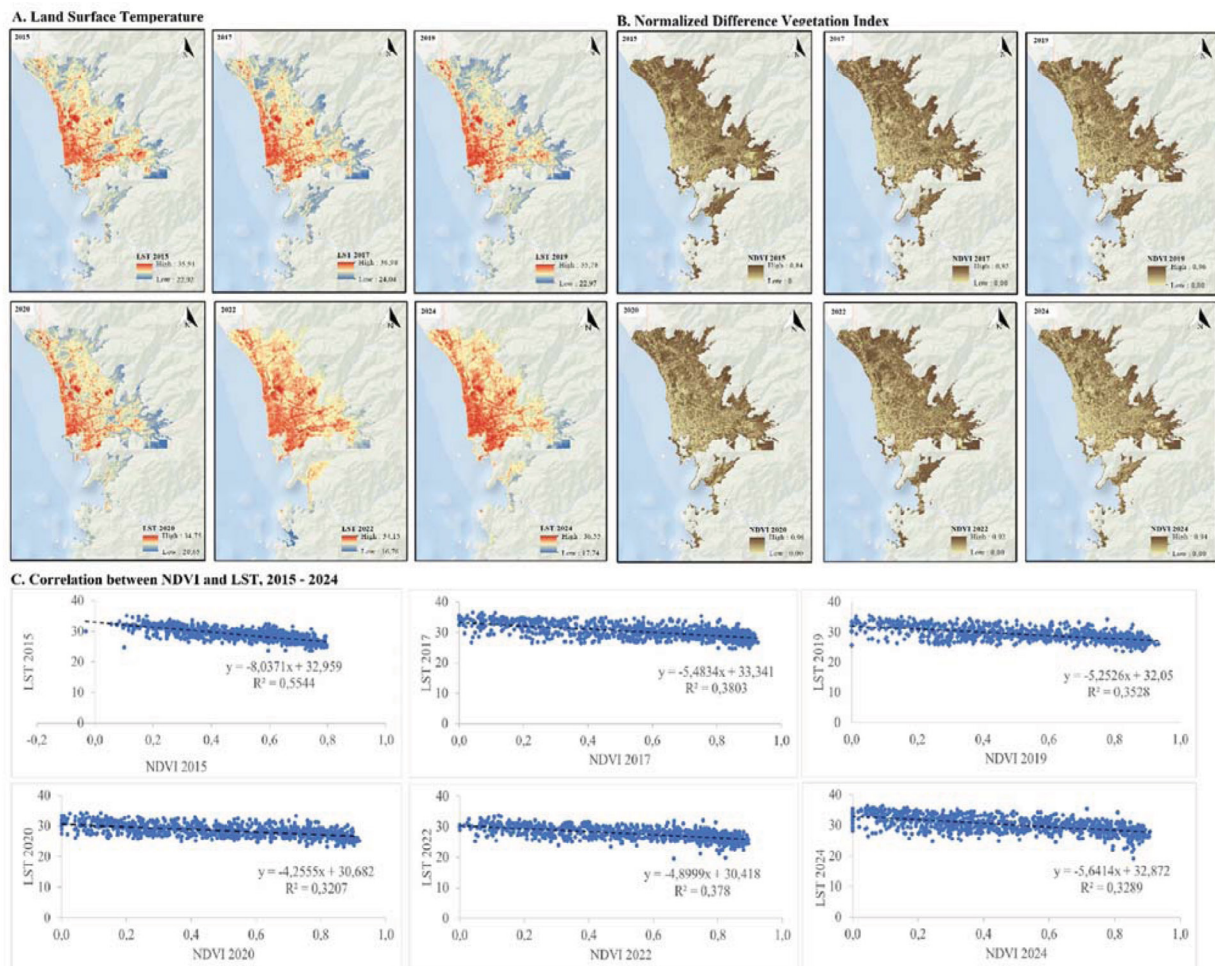


Fig. 2. A) LST dynamics, 2015-2024, B) NDVI dynamics, 2015-2024, C) Correlation between NDVI and LST, 2015-2024.

of the role of vegetation in regulating surface temperature, alongside the growing structural complexity of the city and the dominance of impervious materials. By restricting the analysis to lowland areas and excluding highland forest zones, this study captures thermal variability that is more representative of actual urban conditions. The spatial patterns of LST generated in this subsection subsequently provide a quantitative basis for evaluating thermal stress levels and heat vulnerability using the UTFVI approach.

Urban Ecological Quality of The Lowland Areas of Padang City. The UTFVI analysis provides a comprehensive perspective on urban ecological quality by integrating presence of UHI classifications with the EEI. Unlike mean surface temperature analysis, UTFVI emphasizes relative thermal variance, enabling the precise identification of heat concentrations within a microclimatic context. Annual pixel data from 2015 to 2024 indicates that the thermal structure of Padang city lowland areas is consistently dominated by two contrasting extreme classes: 'None-Excellent' and 'Strongest-Worst', which cumulatively account for over 65-70% of the total observation area (table 4 and table 5).

During the initial phase (2015-2019), the 'None-Excellent' class exhibited a moderate expansion trend, with area increases of 0.34% (2015-2017) and peaking at 1.95% in 2019 (187,159 pixels). The spatial distribution in Fig.3.(a, b, c) shows that this zone is concentrated in the urban periphery with continuous vegetation, indicating that natural cooling mechanisms remained effective. This finding is supported by a strong negative correlation between NDVI and LST during this period (2015 = 0.5544), confirming the crucial role of green cover in mitigating surface heat. However, the 'Strongest-Worst' class continued to dominate the urban core, reflecting densely built-up zones that are structurally susceptible to heat entrapment.

A significant disruption occurred in 2020, marked by a -1.97% contraction in the 'None-Excellent' class and a 1.00% increase in the 'Strongest-Worst' class. This anomaly coincided with the implementation of Large-Scale Social Restriction policies. Despite the macro-level decline in human activity, UTFVI results reveal that areas dominated by impermeable materials maintained their heat stress intensity. This phenomenon reinforces the argument regarding the high thermal

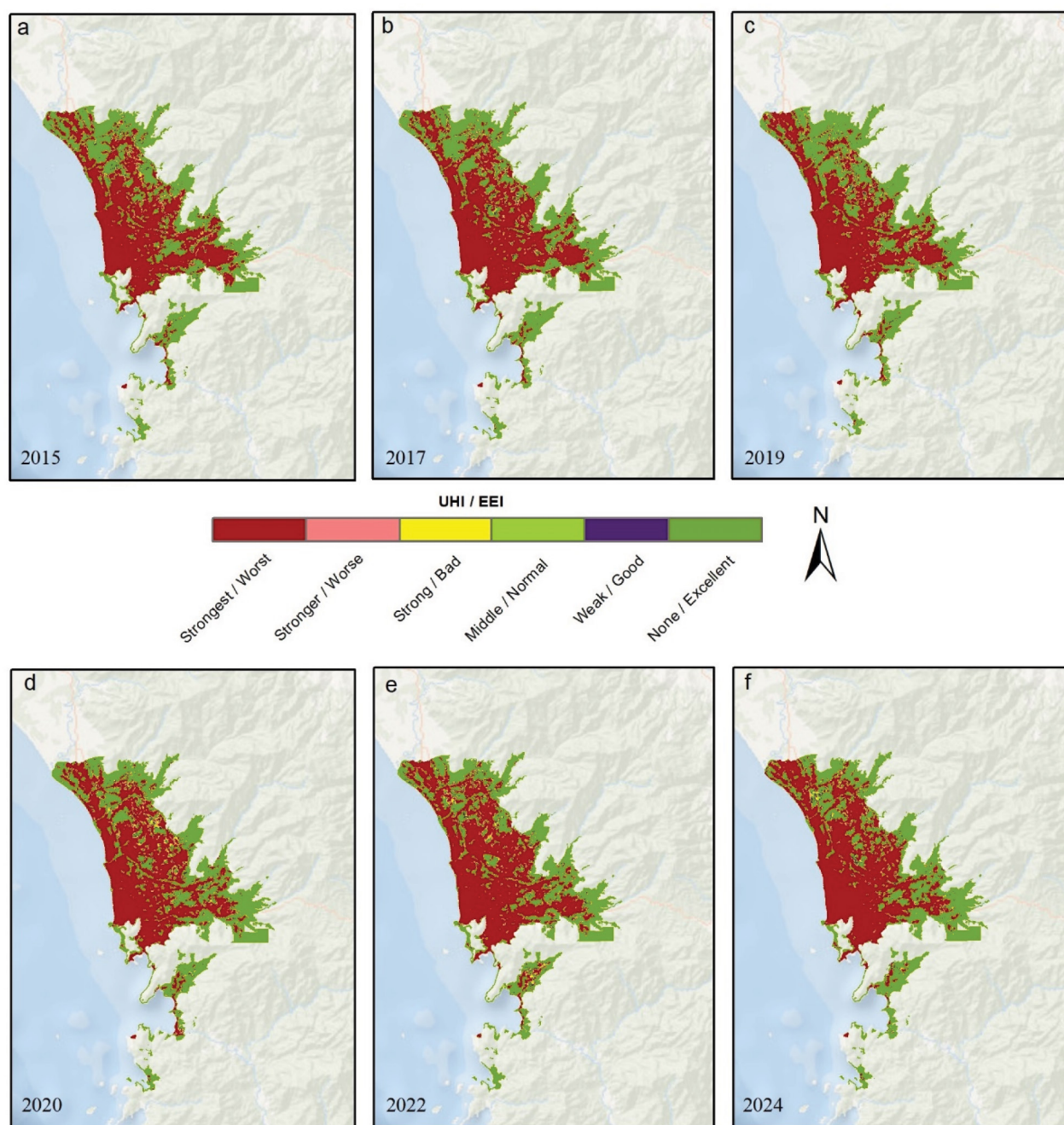


Fig. 3. Spatial distribution of UTFVI in the lowlands of Padang City, 2015-2024

inertia of concrete and asphalt materials, which retain heat longer, aligning with findings by [41, 42] that physical material characteristics are more determinant of surface heat retention than short-term fluctuations in anthropogenic emissions. This condition is exacerbated by the morphology of high-density built-up areas-such as residential and commercial areas-which significantly contribute to increasing surface temperatures through the concentration of heat-absorbing materials [43].

In the post-pandemic period (2020-2024), thermal ecological quality showed a more aggressive degradation. The 'Strongest-Worst' class surged by 3.20% between 2020 and 2022, reaching its peak at 135,739 pixels in 2024, while the 'None-

Excellent' class experienced a significant decline. Spatially (Fig.3: d. e. f), the massive expansion of the 'Strongest-Worst' zone (red) indicates 'heat leakage' and ecological fragmentation, where green space connectivity is increasingly severed by built-up expansion. This is further evidenced by the decline in the coefficient of determination in the NDVI-LST correlation (2024 = 0.3289), suggesting that sporadic vegetation additions are no longer sufficient to reduce heat in areas dominated by impermeable surfaces.

Overall, the degradation of the thermal environmental quality in Padang City is structural. The consistent growth of the 'Worst' zone indicates a weakening capacity of the urban ecological

Table 4

UTFVI distribution in the lowlands of Padang City, 2015–2024

		Years (in pixel 30x30 meter)					
UHI Presence	EEI	2015	2017	2019	2020	2022	2024
None	Excellent	179,47	180,6	187,16	180,53	170,3	174,273
Weak	Good	7,575	7,269	7,526	7,681	7,77	6,837
Middle	Normal	7,647	6,994	7,018	7,873	7,628	6,848
Strong	Bad	7,063	6,595	6,707	7,768	7,567	6,305
Stronger	Worse	7,303	6,454	6,423	7,619	7,411	6,224
Strongest	Worst	127,168	128,31	121,39	124,76	135,5	135,739

Table 5

Percentage change of UTFVI in the lowlands of Padang City, 2015–2024

		Percentage Pixel Change (%) in UTFVI, 2015-2024				
UHI Presence	EEI	2015-2017	2017-2019	2019-2020	2020-2022	2022-2024
None	Excellent	0.34	1.95	-1.97	-3.03	1.17
Weak	Good	-0.09	0.08	0.05	0.03	-0.28
Middle	Normal	-0.19	0.01	0.25	-0.07	-0.23
Strong	Bad	-0.14	0.03	0.32	-0.06	-0.38
Stronger	Worse	-0.25	-0.01	0.36	-0.06	-0.35
Strongest	Worst	0.34	-2.06	1	3.2	0.07

system to neutralize heat stress. Future mitigation strategies can no longer rely solely on preserving existing vegetation; instead, they must include radical spatial interventions such as surface material albedo control and the optimization of urban morphological design to enhance the thermal resilience of tropical coastal cities.

4. Conclusion

This study demonstrates that the thermal ecological environmental quality in the lowlands of Padang City is undergoing increasingly structural degradation. Although the negative correlation between vegetation density and surface temperature remains consistent, its strength continues to weaken annually, indicating the limitations of urban vegetation in neutralizing accumulated heat amidst massive built-up land expansion. The binary dominance between high

ecological quality areas in the peripheries and extreme heat stress in the city center reflects a sharp and persistent thermal polarization across the city's lowland landscape.

Anomalies identified in 2020 reveal that the reduction in anthropogenic activities during the pandemic was insufficient to improve structural thermal conditions due to high thermal inertia in impermeable materials and non-vegetated areas. Post-pandemic (2022-2024), the escalation of heat stress has shown a more aggressive pattern, with heat penetration beginning to encroach into buffer zones through ecological fragmentation mechanisms. These findings emphasize that UHI mitigation can no longer rely solely on vegetation conservation; rather, it necessitates integrated spatial interventions encompassing surface material control, urban morphological design, and the strengthening of blue-green infrastructure to enhance the thermal resilience of tropical coastal cities.

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Конфлікт інтересів: автори повідомляють про відсутність конфлікту інтересів

Декларація про використання генеративного штучного інтелекту: Автори використовували інструменти генеративного штучного інтелекту (GenAI) для допоміжної роботи: моделі ChatGPT-5.5 (OpenAI, 2026) виключно для мовного редагування, структурного впорядкування тексту; Grammarly – для перевірки правильності перекладу тексту, а також для виправлення граматичних та стилістичних помилок. Усі результати роботи з цими інструментами були ретельно контрольовані, перевірені та, за необхідності, відредаговані авторами. Весь науковий контент, матеріали та висновки були створені авторами. Автори несуть повну відповідальність за зміст та цілісність публікації.

Authors Contribution: All authors have contributed equally to this work

Conflict of Interest: The authors declare no conflict of interest

Declaration of use of generative artificial intelligence: The authors utilized generative artificial intelligence (GenAI) tools in a supportive capacity: the ChatGPT-5.5 model (OpenAI, 2026) exclusively for language editing and structural text organization; Grammarly – to verify the correctness of the text translation, as well as to correct grammatical and stylistic errors. All outputs from these tools were carefully supervised, reviewed, and, where necessary, edited by the authors. All scientific content, materials, and conclusions were created by the authors. The authors retain full responsibility for the content and integrity of the publication.

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Міська динаміка термічного стресу в тропічному прибережному місті: аналіз дистанційного зондування в місті Паданг, Індонезія

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АНОТАЦІЯ

Феномен міського теплового острова (МТО) є однією з ключових екологічних проблем сучасних міст, що негативно впливає на тепловий комфорт населення, збільшує витрати енергії на охолодження та підвищує ризики для здоров'я. У тропічних регіонах ці наслідки посилюються високими температурами, інтенсивною сонячною радіацією, швидкою урбанізацією та деградацією природних буферних зон. Особливо це характерно для тропічних прибережних міст, де зміни землекористу-

вання суттєво порушують мікрокліматичний баланс. Дослідження присвячене місту Паданг (Індонезія), яке протягом останнього десятиліття зазнало значної урбанізації, що супроводжувалася перетворенням природних і сільськогосподарських територій на житлову та комерційну забудову й формуванням локальних теплових аномалій. Для аналізу просторово-часової динаміки використано багаточасові супутникові знімки Landsat 8 OLI/TIRS за 2015–2024 рр. Дослідження охоплювало прибережні низовини, виключаючи гірські ліси для мінімізації топографічного впливу. Щільність рослинності оцінювали за індексом NDVI, температуру поверхні землі (LST) визначали за тепловими інфрачервоними каналами після калібрування даних і розрахунку випромінювальної здатності поверхні. Для оцінки теплового стресу застосовано індекс варіації міського теплового поля (UTFVI), який класифікує екологічний стан території за шістьма категоріями. Результати показали стійку негативну кореляцію між NDVI та LST, що підтверджує важливу роль рослинності у зниженні температури поверхні. Водночас сила цього зв'язку поступово зменшувалася, що свідчить про ослаблення охолоджувального ефекту зелених насаджень через розширення непроникних поверхонь. Під час пандемії COVID-19 у 2020 році середня температура поверхні тимчасово знизилася до 28,18 °C внаслідок скорочення антропогенних теплових викидів. Проте аналіз UTFVI засвідчив подальше розширення зон із найвищим рівнем теплового стресу, особливо в центральній частині міста, а після пандемії (2022–2024) їх площа досягла максимуму. Отримані результати свідчать про структурне погіршення теплоекоекологічного стану Паданга та підкреслюють необхідність інтеграції синьо-зеленої інфраструктури, використання матеріалів із вищим альбедо й оптимізації міського планування для підвищення теплової стійкості в умовах зміни клімату та подальшої урбанізації.

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UHI, UTFVI, EEI, LST, екологічна якість, NDVI, дистанційне зондування, тропічне місто, прибережне місто, місто Паданг.