

Assessing Two Decades of Temperature Dynamics Across Local Climate Zones in Hanoi, Vietnam

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Abstract: *This study examines the diurnal temperature variation in relation to Local Climate Zones (LCZs) in Hanoi, Vietnam, using a 20-year time series (2004–2024) of MODIS Land Surface Temperature (LST) data. The use of MODIS imagery provides a consistent and reliable dataset for analyzing long-term urban thermal dynamics. LCZ classifications were derived from globally available datasets integrated within the Google Earth Engine (GEE) platform. Results reveal a significant warming trend during the daytime across all LCZs. Notably, LCZs 1 to 8, representing highly urbanized areas, exhibit the most pronounced temperature increases, ranging from 2.3°C to 3.0°C over the study period. In contrast, nighttime temperatures show only a modest increase of approximately 0.18°C across all LCZ types, with limited variability between them. These findings underscore a growing daytime urban heat island (UHI) effect, particularly in densely built environments such as compact mid-rise zones. Areas with dense vegetation exhibit the least temperature rise, highlighting the moderating influence of green cover. Overall, the study emphasizes the critical role of urban form and land cover in shaping spatial patterns of surface temperature variation, offering important insights for climate-responsive urban planning in rapidly developing cities like Hanoi.*

Keywords: LCZ; LST; MODIS; Hanoi

1. Introduction

In recent years, there has been growing evidence of the abnormal warming of the Earth's surface, as well as record-breaking high temperatures observed globally. The year 2023 was previously recorded as the hottest year, with an increase of approximately +1.48 °C compared to the pre-industrial period (1850–1900), according to Copernicus and NOAA/NASA data (Karen Fox, 2023). This unusual warming trend appears to be continuing (Tollefson, 2023), highlighting the importance of continuously monitoring temperature maps on regional, continental, and global scales over time. This is critical for interpreting extreme climate phenomena and understanding the responses and dynamics of organisms, ecosystems, and human societies (Pu & Bonafoni, 2023).

Through thermal infrared sensors mounted on satellites, thermal remote sensing products enable spatial-temporal monitoring at high frequency, thereby facilitating the modeling of the Earth's climate cycle and supporting accurate future climate predictions. Recently, remote sensing technology has made it possible to observe two key temperature parameters: land surface temperature (LST) and air temperature (also known as near-surface temperature). LST products are more widely used due to their availability from satellite observations and their critical role in assessing the impact of different surface cover types (Li et al., 2013), (Neinavaz, Schlerf, Darvishzadeh, Gerhards, & Skidmore, 2021). Moreover, LST is recognized as one of the 55 Essential Climate Variables (ECVs) defined by the Global Climate Observing System (GCOS) under the World Meteorological Organization (WMO).

Among the popular satellite data sources today, MODIS provides daily monitoring capabilities but is limited by its moderate spatial resolution (1 km). In contrast, thermal infrared remote sensing data with lower observation frequency can offer higher spatial resolutions, such as Landsat (100 m) and ASTER (90 m). Newer satellites such as Sentinel-3A (2016) and 3B (2018) carry the Sea and Land Surface Temperature Radiometer (SLSTR) with a native spatial resolution of 1 km. Additionally, while daytime temperature

products receive more attention, nighttime temperature data are relatively under-researched. This is mainly due to two reasons: (1) daytime products are more relevant for studying and interpreting solar radiation, land cover, and topography; (2) there are significantly fewer sensors dedicated to nighttime LST monitoring compared to daytime sensors (Qi et al., 2020). However, several studies have shown that nighttime cooling and diurnal temperature variations are closely linked to phenomena such as urban heat islands (UHIs), heatwaves, and localized climate impacts.

In 2012, the Local Climate Zone (LCZ) classification system was introduced globally to address the shortcomings of conventional climate classification systems at the continental or global scale, which often lack sufficient detail for small areas (Stewart & Oke, 2012). LCZs are categorized based on similarities in land cover, population density, building architecture, and construction materials. The ultimate goal of this system is to provide a standardized framework for measuring urban heat island effects, a topic that is gaining increasing attention amid global warming. This includes quantifying UHI intensity and evaluating cooling strategies (Huang et al., 2023). With the adoption of LCZs, research on temperature dynamics and UHIs in relation to specific urban structural patterns has informed various urban planning and construction policy decisions. LCZ-based UHI assessments have been conducted in over 50 cities worldwide (Bechtel et al., 2019).

In Vietnam, scientific understanding of LCZs remains relatively new and underexplored. However, several studies have used thermal remote sensing to assess temperature trends, analyze interactions with land cover, and identify UHI patterns (Le et al., 2020) (Nguyen et al., 2025). Thermal remote sensing began to be studied and tested in Vietnam in the 1990s, but significant development only occurred from the early 2000s, when satellite-based LST data (e.g., Landsat TM/ETM+/TIRS, MODIS) became more accessible through platforms such as USGS EarthExplorer, NASA Earthdata, and various international collaborations. Early studies focused on estimating LST using constant emissivity values across remote sensing scenes (Le Van Trung, 2006), (Thi Van & Duong Xuan Bao, 2010), or using emissivity data from previous research (Dinh, Trung, & Van, 2007), (Hung & Yasuoka, 2002). More recently, (Le et al., 2021) used Sentinel-3 SLSTR imagery to calculate both daytime and nighttime LST, revealing the relationship between UHI effects and population density.

Building upon these perspectives, this study aims to identify surface temperature trends in Hanoi, the capital of Vietnam, during the historically hottest period on record from 2004 to 2024. The study incorporates Local Climate Zones (LCZs) to quantify the degree of interaction and variability in both daytime and nighttime surface temperatures, estimated from MODIS remote sensing imagery. By observing the spatial and temporal variations of monthly average surface temperatures (day and night), the hottest and coolest periods, the extreme minimum and maximum surface temperatures, and the data series for each LCZ type, this research expands the discussion on the applicability of satellite-based surface temperature monitoring in tropical monsoon climates, with a detailed focus on LCZs. These findings contribute to clarifying the relationship between surface temperature and specific urban architectural types, thereby enhancing our understanding of urban climate dynamics in the current context of global warming.

2. Study area and data

2.1. Study area

The study area is Hanoi city, the capital of Vietnam. Covering an area of over 3,300 km², Hanoi is home to more than 8 million people (as of 2024), ranking second in population after Ho Chi Minh City. Geographically, it is located between 20°53' to 21°23' N latitude and 105°44' to 106°02' E longitude, situated in the heart of the Red River Delta one of the most fertile and densely populated deltas in Southeast Asia. The city experiences a humid subtropical climate with four distinct seasons, characterized by hot, humid summers and cool, dry winters.

Since the administrative boundary expansion in 2008, Hanoi has encompassed both the urban core and outlying rural districts, creating a vast and diverse area in terms of topography and land use. The city has undergone rapid urbanization over the past two decades, marked by the development of new urban zones, transportation networks, technical infrastructure, and increased population density. The uncontrolled increase in impervious surfaces and high-density construction has significantly contributed to the Urban Heat Island (UHI) phenomenon one of the most prominent environmental concerns in Hanoi.

In terms of topography, Hanoi is primarily situated on flat, low-lying plains with an average elevation ranging from 5 to 20 meters above sea level. However, the terrain is relatively diverse and can be broadly categorized into three regions. The lowland delta region, which comprises most of the city's area including

the urban center and southern and eastern districts, is interlaced with major rivers such as the Red River, Duong River, and Nhue River. The hilly and semi-mountainous region lies to the west and southwest, encompassing districts such as Quoc Oai, Thach That, and Chuong My, with elevations ranging from 20 to 50 meters. This transitional zone between the plains and mountains is currently being developed into satellite urban areas and high-tech zones, notably including Hoa Lac. Further to the northwest, the low mountain region is located in Ba Vi District, where Ba Vi Mountain reaches an elevation of approximately 1,296 meters. This area contains rich protected forest ecosystems and plays a crucial role in regulating the local microclimate. This topographical diversity offers favorable conditions for studying surface temperature variations influenced by land cover and Local Climate Zones (LCZs). At the same time, it poses significant challenges for climate monitoring and urban adaptation in a fast-growing metropolitan area like Hanoi. Fig. 1 below is the research area on the map of Vietnam.

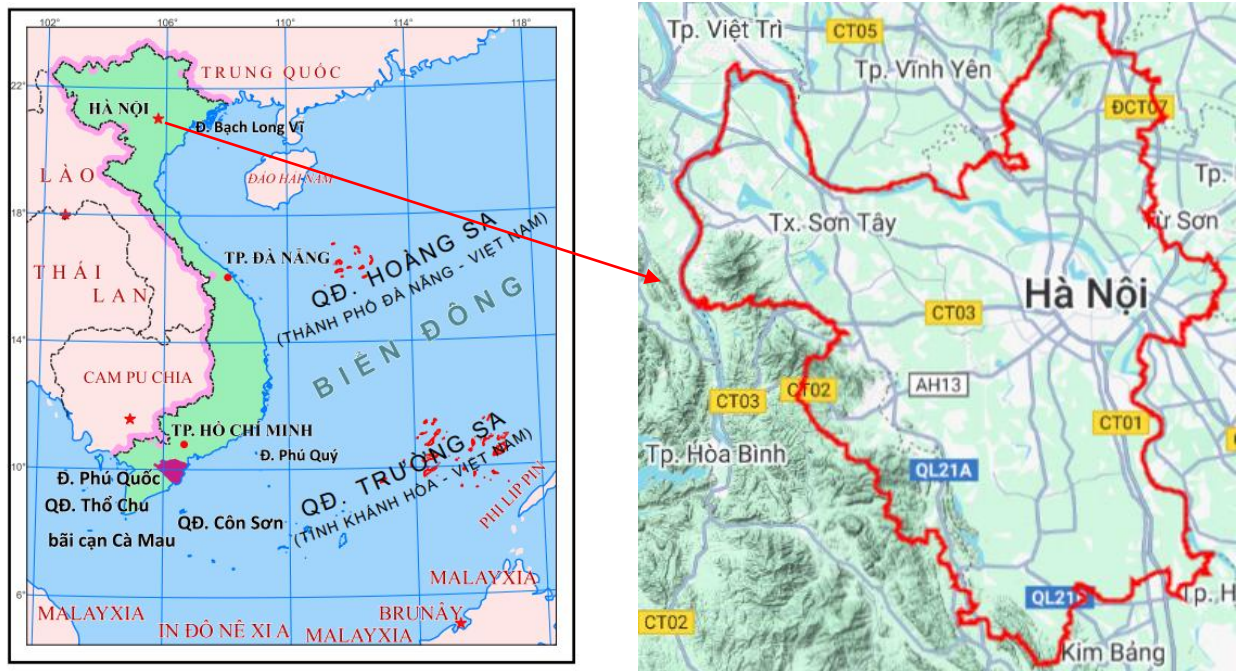


Fig. 1. Study area in Vietnam map

2.2. Data

In this study, we utilized MODIS satellite imagery (MOD11A2 V6.1 product) with a spatial resolution of 1000 meters, comprising a total of 966 images acquired between 2004 and 2024 over the Hanoi region. These MODIS images were captured by the Terra and Aqua satellites and provide 8-day average land surface temperature (LST) data. Each pixel value represents the simple average of all corresponding pixels from images acquired within the 8-day period. The LST data used in this study include both daytime and nighttime temperatures, which are separated to allow for a clearer comparison of diurnal temperature variations across different land use types.

Local Climate Zone (LCZ) data are obtained from the RUBCLIM - WUDAPT (World Urban Database and Accessibility Portal Tool) dataset. The LCZ map, representative of the nominal year 2018, was generated using multiple Earth observation datasets and expert-labeled LCZ classes through machine learning techniques applied to satellite imagery and urban geospatial data within the LCZ classification system (Demuzere et al., 2022). The map classifies urban and non-urban areas into 17 standard LCZ types, including built-up areas of varying heights and densities, as well as natural land cover types such as forests, grasslands, and water bodies. With a spatial resolution of 100 meters, the LCZ dataset is well suited for detailed spatial analysis, including urban heat island (UHI) assessment, surface temperature mapping, and integration of remote sensing data to study the relationship between land cover and urban climate change. As analyzed above, the terrain of Hanoi is the Red River Delta, with low elevation, the mountains are mostly dirt mountains, so when classifying LCZ for the Hanoi area, some types such as LCZ 15 (Bare rock or paved), LCZ 13 (Bush, Scrub) and LCZ 7 (lightweight low-rise) will be missing. Details of the LCZ types of the Hanoi area are listed in Tab. 1. Fig. 2 presents the LCZ map of the Hanoi area, which includes 14 LCZ types.

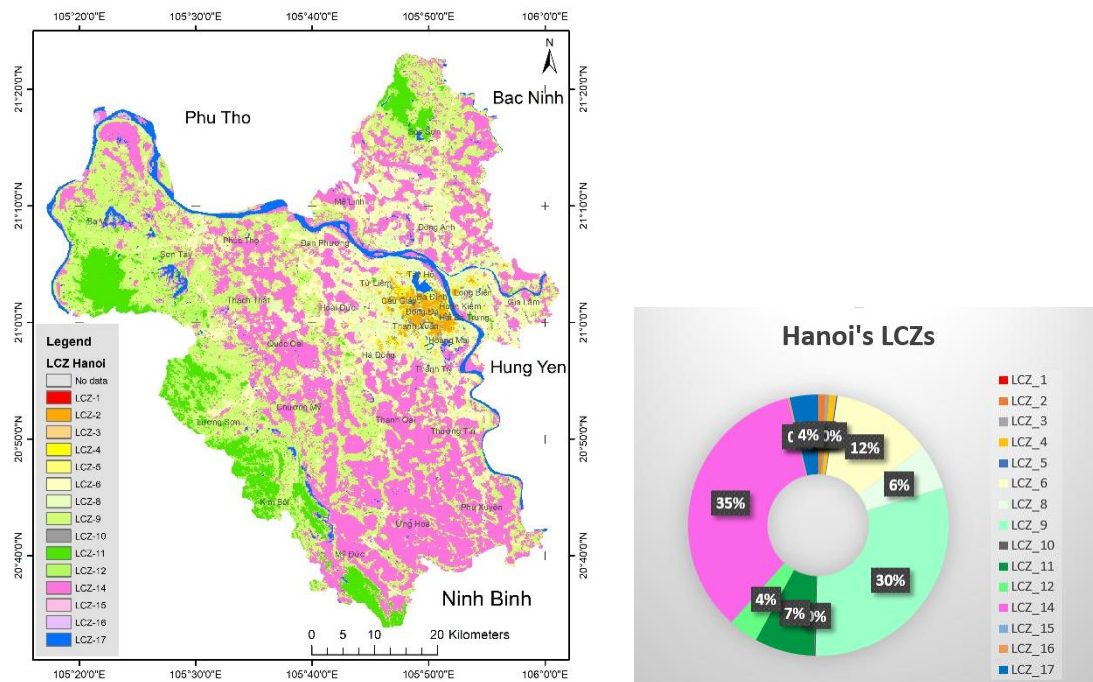


Fig. 2. LCZ map and percentage of each LCZ types

Tab. 1. 14 types of Hanoi LCZ

LCZ type codes	LCZ names
1	Compact highrise
2	Compact midrise
3	Compact lowrise
4	Open highrise
5	Open midrise
6	Open lowrise
7	Large lowrise
8	Sparsely built
9	Heavy industry
10	Dense Trees
11	Scattered Trees
12	Low plants
13	Bare soil or sand
14	Water
15	Compact highrise
16	Compact midrise
17	Compact lowrise

3. Methodology

3.1. Data Processing Workflow

In this study, the Google Earth Engine (GEE) cloud computing platform was used. GEE allows users to quickly retrieve, preprocess images and calculate through the Internet connection. We use the JavaScript programming language on GEE to collect and process remote sensing products for research according to the flowchart in Fig. 3.

As illustrated in the flowchart, the Local Climate Zone (LCZ) data used in this study were obtained from the global WUDAPT project dataset, with a spatial resolution of 100 meters, and clipped to match the administrative boundary of Hanoi City. Land Surface Temperature (LST) data were derived from the MOD11A2 Version 6.1 dataset on Google Earth Engine, which provides two variables: LST_Day_1km and LST_Night_1km. These represent 8-day average surface temperatures at approximately 1 km spatial resolution. Temperature values were converted from Kelvin to degrees Celsius using a linear transformation, as shown in Equation (1) below:

$$LST (^{\circ}C) = DN \times 0.02 - 273.15 \quad (1)$$

where: LST ($^{\circ}C$) - Land surface temperature in degrees Celsius; DN - Digital number (pixel value); 0.02: Scale factor.

The dataset was filtered for the period from 2004 to 2024 and seasonally averaged, with summer defined as June–August and winter as December–February. Images were grouped by year and season, and the corresponding temperature values were averaged for each combination. LCZ classes from 1 to 17 were used as spatial masks to extract and analyze the average temperature for each land use type. The temporal evolution of both daytime and nighttime temperatures was visualized using line graphs for each LCZ class.

Additionally, an interactive mapping tool was developed to allow users to click on any location within the study area and view seasonal temperature trends from 2004 to 2024 at that specific point. This functionality supports the spatial and temporal visualization of temperature variations in relation to urbanization dynamics.

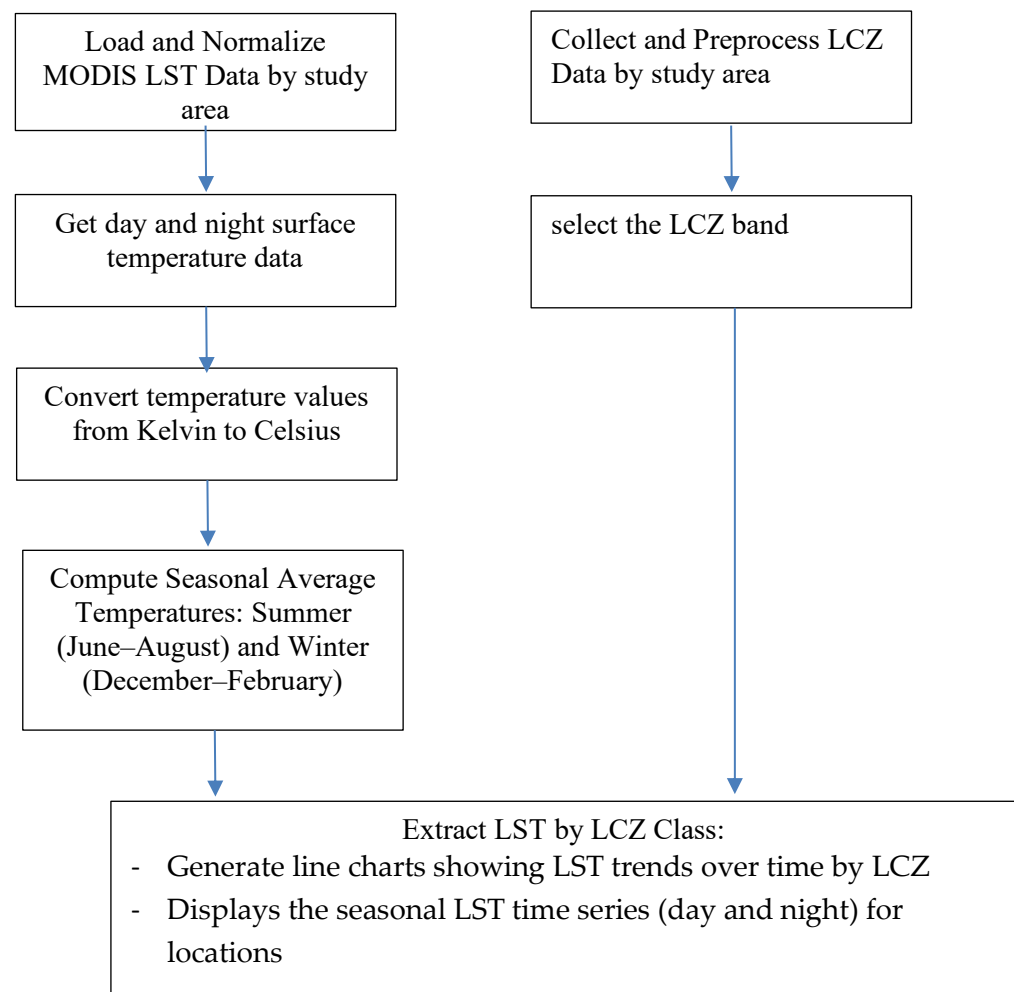


Fig. 3. Data processing flowchart on Google Earth Engine (GEE)

3.2. Analysis of temperature trends over 20 years by LCZ types

The trend of land surface temperature (LST) variation over a 20-year period (2004–2024) in the Hanoi area was analyzed for each Local Climate Zone (LCZ) type using a linear trend model. Temperature data were extracted as a time series with an 8-day interval from MODIS satellite imagery, allowing for continuous monitoring of temporal changes. By applying linear regression to each LCZ type, the trend equations were determined in the form of Equation (2).

$$y_t = \beta_0 + \beta_1 t + \varepsilon_t \quad (2)$$

where: y_t - is the observed land surface temperature at time t ; t - denotes time, represented as a sequence of integers corresponding to 8-day intervals; β_0 - is the intercept, indicating the estimated baseline temperature at the beginning of the time series; β_1 - is the trend slope, representing the rate of temperature change over time. A positive value of β_1 indicates a warming trend, while a negative value implies a cooling trend; ε_t -

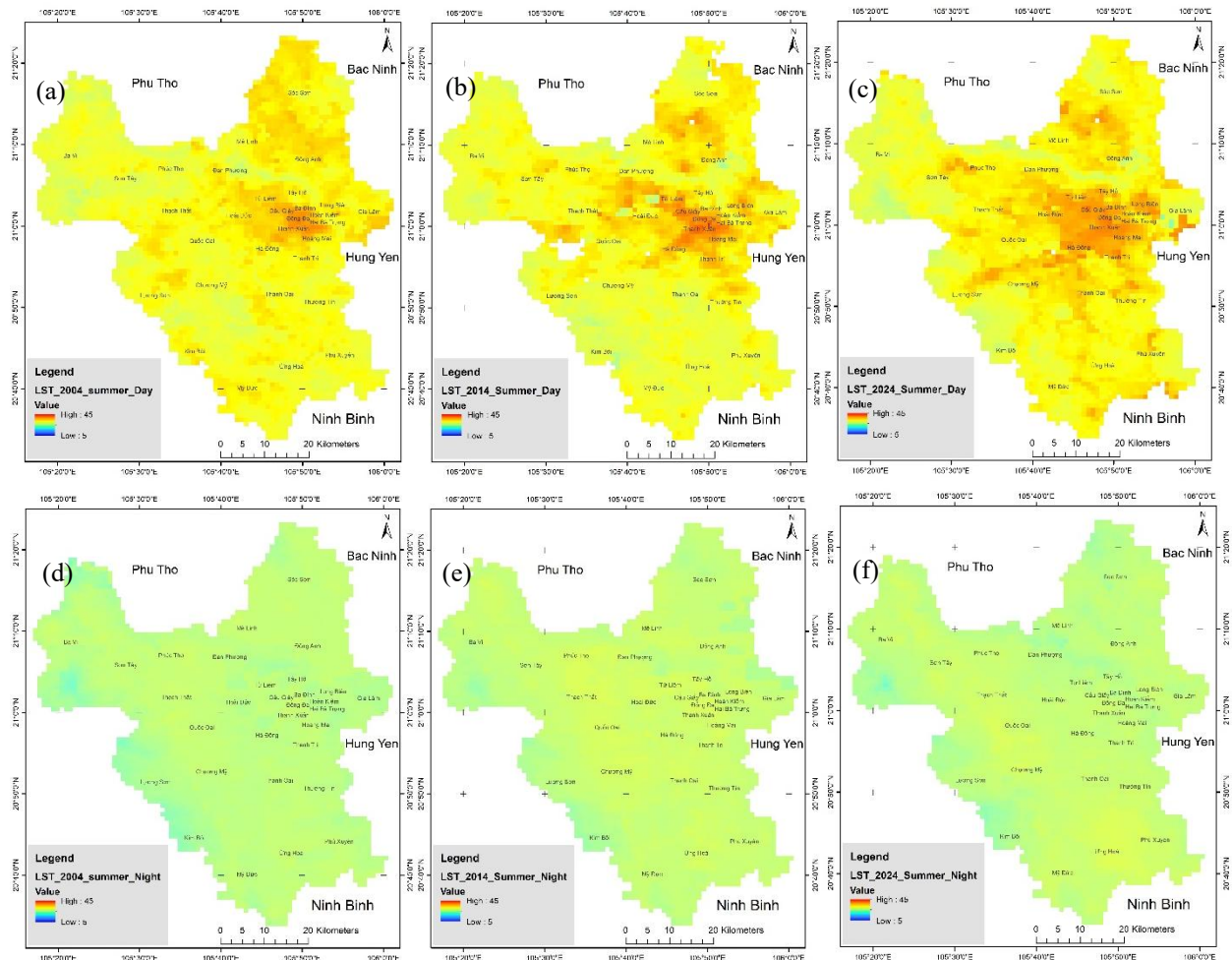
is the residual term, accounting for the difference between the observed and predicted values, which may result from random variability or external factors not included in the model.

This model allows the estimation of long-term LST trends across different LCZ types by quantifying the direction and magnitude of temperature change over the 20-year period (2004–2024). The slope coefficient β_1 serves as a key indicator of urban warming, particularly in built-up zones, and enables comparison of thermal behavior among LCZ classes.

4. Results and discussions

4.1. Results

Based on the data processing flowchart, daytime and nighttime land surface temperatures in the Hanoi study area over the past 20 years were extracted separately. To highlight seasonal differences, average temperatures for summer (June–August) and winter (December–February) were calculated for each year, for both daytime and nighttime periods. To illustrate the long-term changes more clearly, we present heat maps for three representative years, spaced 10 years apart (Fig. 4).



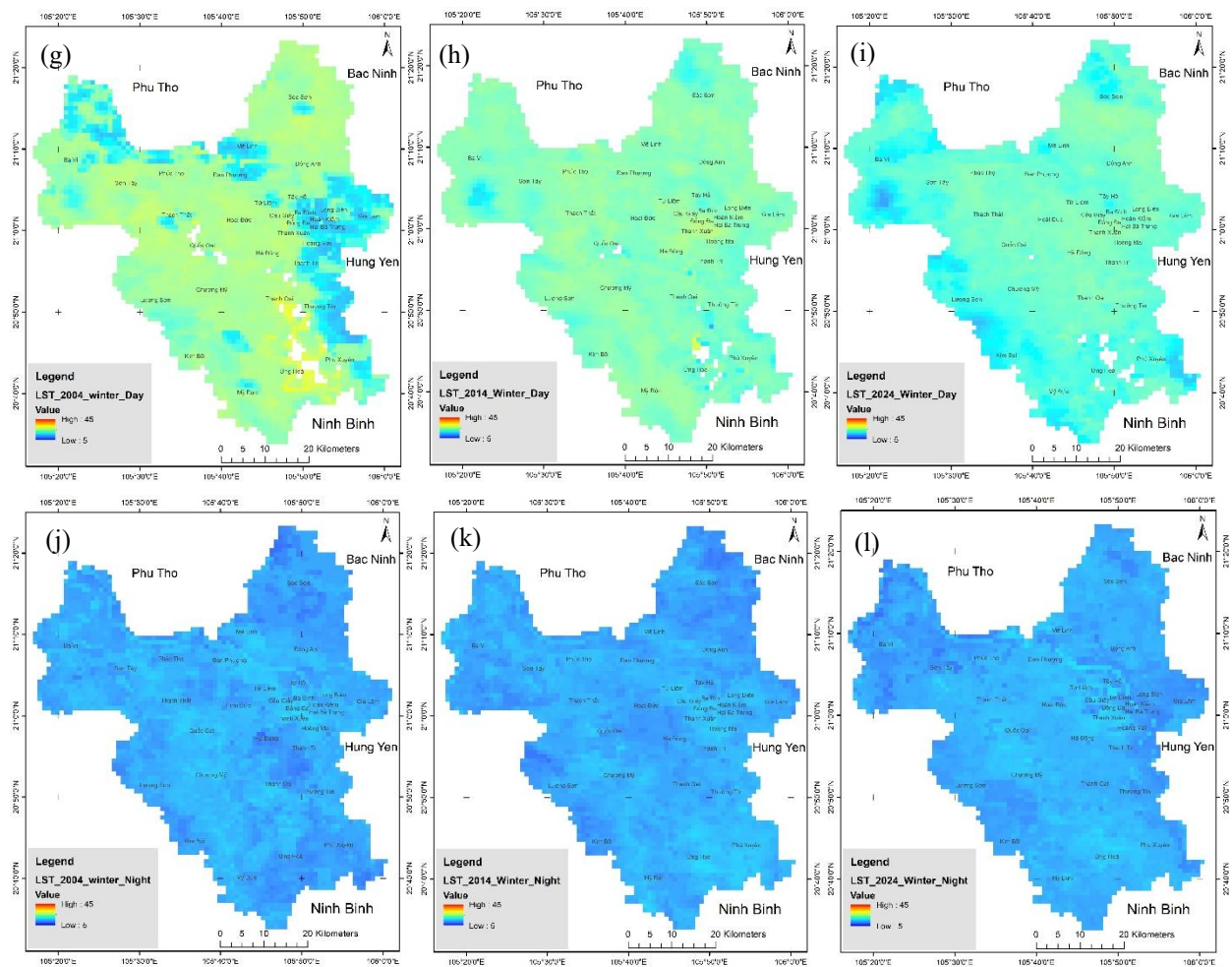


Fig. 4. Land surface temperature maps of the Hanoi area: (a) Daytime, summer 2004; (b) Daytime, summer 2014; (c) Daytime, summer 2024; (d) Nighttime, summer 2004; (e) Nighttime, summer 2014; (f) Nighttime, summer 2024, (g) Daytime, winter 2004; (h) Daytime, winter 2014; (i) Daytime, winter 2024; (j) Nighttime, winter 2004; (k) Nighttime, winter 2014; (l) Nighttime, winter 2024.

4.2. MODIS LST Validation

To assess the reliability of MODIS temperature data, we used Landsat 8 imagery. Because Landsat data are often limited for long-term time-series analysis primarily due to frequent cloud cover causing significant data gaps, it was not feasible to compare the two datasets over the entire study period. Therefore, we selected 2014–2015 as a representative mid-period for the evaluation, with the reliability assessment conducted separately for summer and winter. A total of 140 sampling points were distributed across 14 main LCZ types within the Hanoi study area to perform this comparison. Here is the figure showing the distribution of temperature sampling points and the temperature correlation charts for the Hanoi study area in both summer and winter.

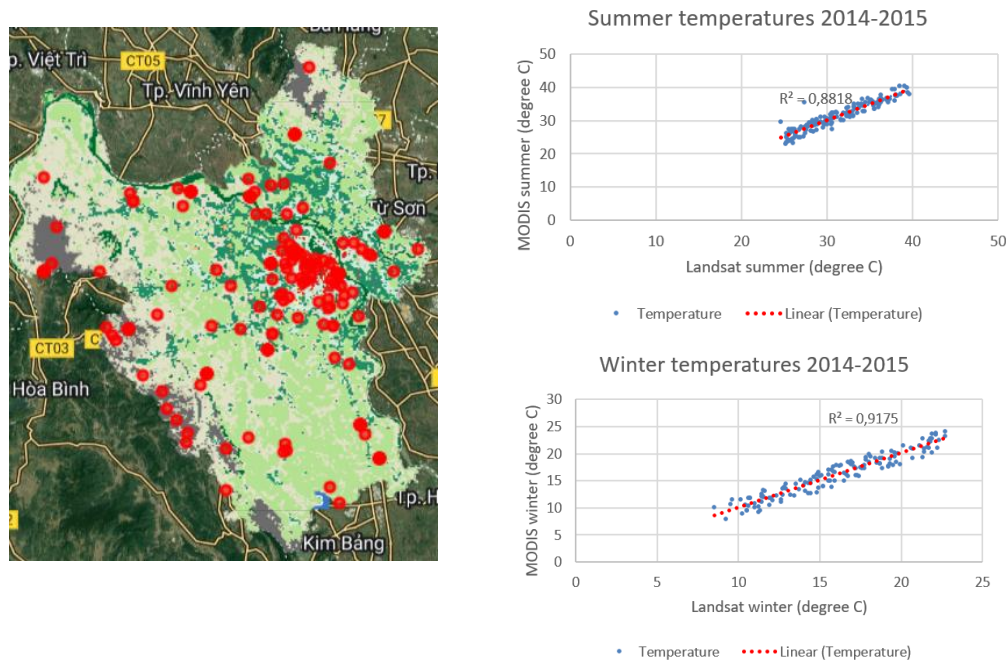


Fig. 5. Temperature correlation between MODIS and Landsat 8 data and the location map of the sampling points

The correlation analysis in the Fig.5 indicates that MODIS data provide a reliable representation of surface temperature patterns in Hanoi. For the winter season, the relationship between MODIS and Landsat temperatures shows a very strong coefficient of determination ($R^2 = 0.9175$). In summer, the correlation remains strong ($R^2 = 0.8818$), slightly lower than in winter but still demonstrating high consistency between the two datasets. These results suggest that, despite the coarser spatial resolution of MODIS, its temperature estimates are sufficiently accurate to support long-term time-series analyses of surface temperature in the Hanoi area, particularly when continuous data coverage is required to overcome the limitations of cloud contamination in Landsat imagery.

4.3. Discussion

Based on the land surface temperature maps of the Hanoi area for the years 2004, 2014, and 2024, a clear upward trend in temperature over the past 20 years is evident. In summer, the daytime temperature in 2004 (Fig. 4a) was predominantly below 40°C. However, by 2014 (Fig. 4b), and more notably in 2024 (Fig. 4c), the central urban areas and surrounding districts such as Bac Tu Liem, Ha Dong, and Hoang Mai experienced a significant increase in areas exceeding 42°C. A similar trend is observed in nighttime summer temperatures (Fig. d, e, f), which show a gradual rise, clearly indicated by the expansion of light blue and yellow zones representing higher temperatures. This suggests that the urban heat island (UHI) effect is more pronounced at night.

In winter, although the temperature increase is less intense compared to summer, an overall warming trend is still noticeable. The winter daytime temperature maps (Fig. 4g, h, i) reveal a modest rise in average temperature, with warmer colors (light blue and green) expanding over time. Notably, in winter nighttime maps (Fig. 4 j, k, l), many areas recorded temperatures below 12°C (dark blue) in 2004, whereas by 2024, most regions remained above this threshold. These patterns clearly reflect the impact of global warming on Hanoi across both summer and winter seasons, during both day and night.

To better quantify this trend, we extracted temperature data across different Local Climate Zones (LCZs) over time and plotted temperature time-series charts. From these, we calculated linear trend lines to more clearly observe temporal changes in temperature. Fig. 6 presents the temperature trends for each LCZ.

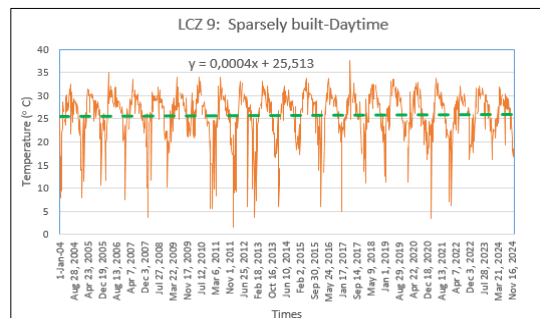
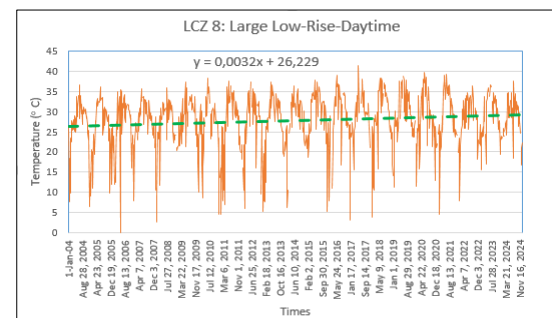
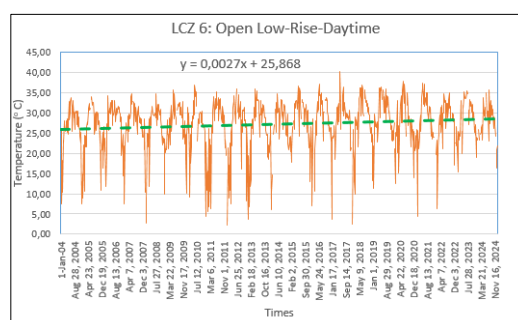
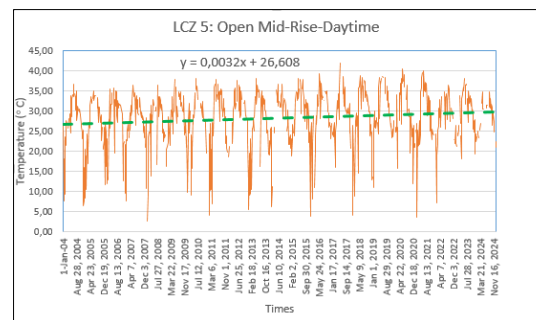
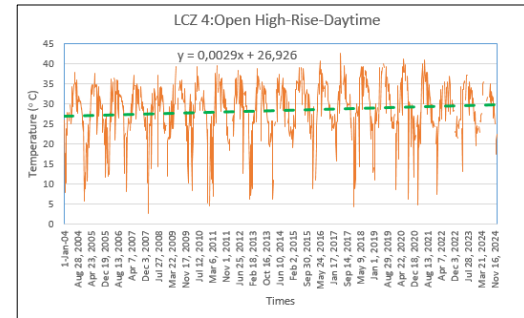
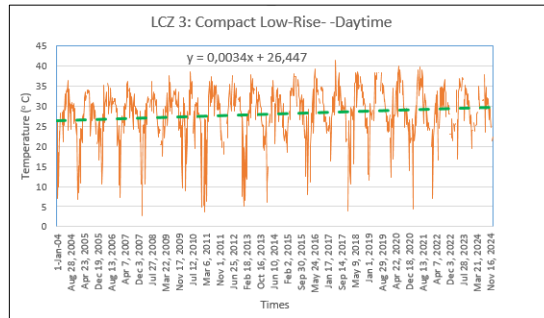
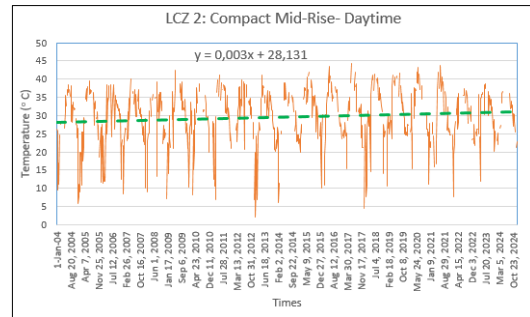
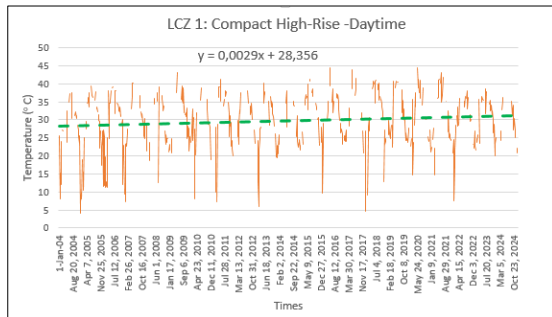




Fig. 6. Daytime temperatures at different LCZs

According to the daytime temperature charts of the LCZs over the past two decades, highly urbanized zones, particularly LCZ 1 (Compact High-Rise), LCZ 2 (Compact Mid-Rise), and especially LCZ 3 (Compact Low-Rise), consistently exhibit significantly higher temperatures compared to other LCZ types. The trend analysis shows that LCZ 3 has the most pronounced temperature increase, with a regression coefficient of 0.0034, followed by LCZ 1 and LCZ 2 with coefficients of 0.0030 and 0.0029, respectively. This indicates that dense horizontal urban structures (low-rise compact) tend to retain heat more effectively than vertically developed structures (high-rise), due to greater surface area exposed to solar radiation, less shading, and poorer ventilation. Over the 20-year period from 2004 to 2024, daytime temperatures in these zones increased by approximately 2.3°C to 3.0°C.

In the group of "open" LCZ types (LCZ 4–6), daytime temperatures are generally slightly lower than in compact zones, though still relatively high. These areas feature more open space, higher green cover interspersed with built-up areas, and better ventilation, all contributing to more efficient heat dissipation. While a warming trend is still observed, the rate of increase is lower and less variable. Among the open types, LCZ 5 records a slightly higher regression coefficient (0.0032) compared to the others. Temperature differences among open LCZs result from a balance between the volume of heat-absorbing materials, ventilation potential (influenced by urban geometry and density), and the extent of vegetation cover. Open Low-Rise zones are generally the coolest due to the lowest material density and highest ventilation capacity. Open High-Rise zones, if truly "open," can benefit from building shade and improved nighttime heat dissipation (due to higher Sky View Factor, SVF). Open Mid-Rise zones may accumulate heat more due to having enough built mass to store heat, but insufficient height to generate effective shading, and possibly limited airflow, leading to higher temperatures under certain conditions.

Notably, areas dominated by natural features, such as LCZ 11 (Dense Trees) and LCZ 12 (Scattered Trees), record the lowest daytime temperatures across all LCZ types. Temperatures in these zones have changed very little over the past two decades (approximately 0.6°C), highlighting the strong climate-regulating role of dense vegetation. Trees not only reduce solar radiation absorption but also contribute to evapotranspiration, which facilitates natural cooling.

Other zones, such as LCZ 8 (Large Low-Rise), LCZ 9 (Sparsely Built), and LCZ 10 (Heavy Industry), also show relatively high daytime temperatures and notable warming trends. These are areas characterized by minimal shade, large impervious surfaces, and often industrial activities, all contributing to a low capacity for heat dissipation. The average temperature increase in these zones over 20 years is approximately 2.3°C .

Finally, LCZ 14 (Low Plants) and LCZ 16 (Bare Soil or Sand) exhibit moderate temperature increases, with an average rise of 1.2°C over the 20-year period. However, these zones show significant diurnal temperature fluctuations, reflecting the characteristics of surfaces with low or no vegetation cover, namely rapid heat absorption during the day and rapid heat loss at night.

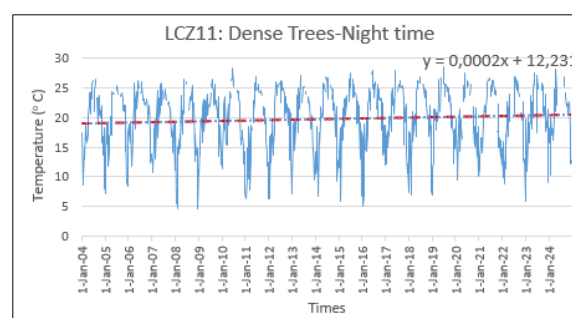
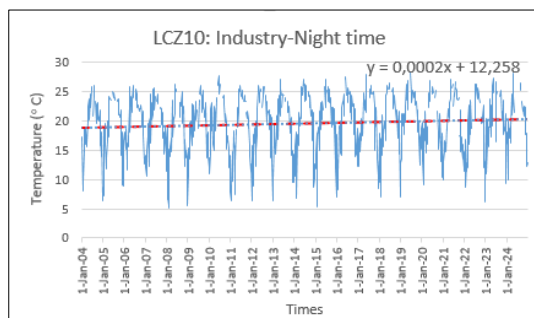
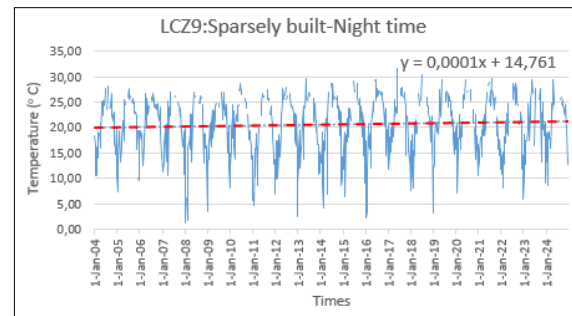
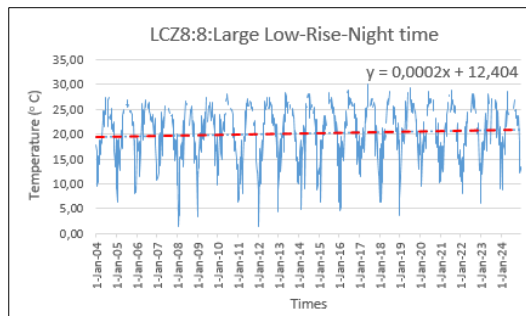
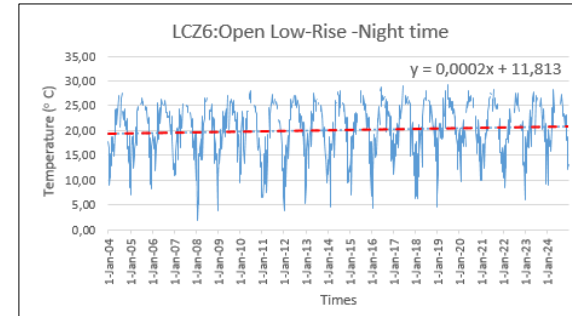
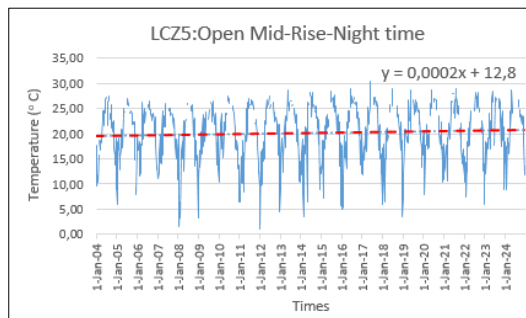
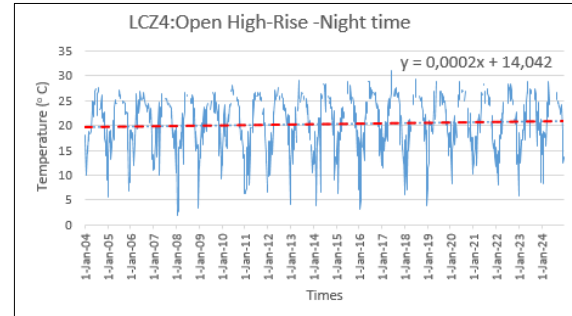
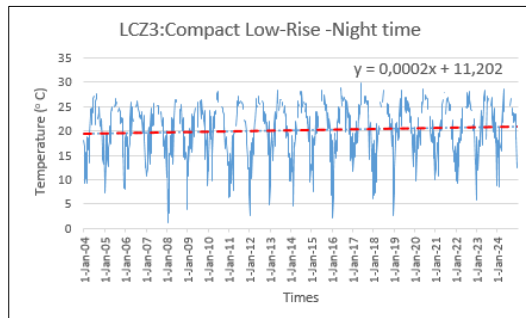
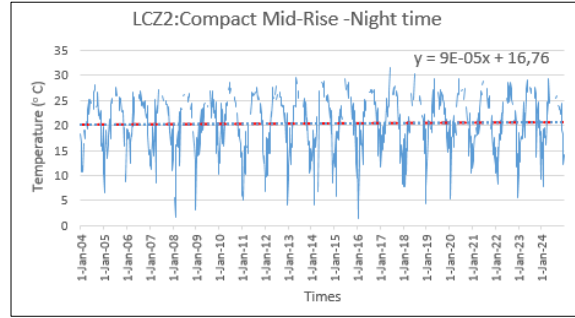
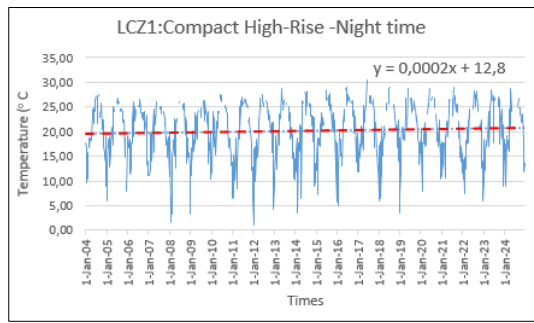
Compared to daytime, nighttime temperatures across the LCZs in the study area tend to be more stable and show less fluctuation. Fig. 6 presents the nighttime temperature trends of the LCZs in the Hanoi area. From this figure, a slight upward trend in temperature can still be observed in most zones, particularly in urban LCZs. Zones such as LCZ 1, 3, 8, and 10 maintain relatively higher nighttime temperatures and continue to increase slightly, with a regression coefficient of approximately 0.0002, indicating a temperature rise of about 0.18°C over the past 20 years. This suggests that artificial urban surfaces have a high capacity for heat retention at night, contributing to the phenomenon of elevated urban baseline temperatures.

In contrast, LCZs characterized by vegetation cover or bare soil (LCZ 11–14, LCZ 16) maintain lower nighttime temperatures, and the rate of temperature increase in these areas is nearly negligible. The temperature difference between day and night is also larger in these zones, reflecting a greater capacity for nighttime heat dissipation due to the physical properties of natural surfaces.

Through the analysis of both daytime and nighttime temperature charts, it is evident that urban structure is a key determinant of the long-term temperature increase. The results highlight a strong correlation between LCZ types and temperature trends over the past 20 years. Highly urbanized zones particularly LCZ 1 to LCZ 8 (Compact High-Rise, Compact Mid-Rise, Compact Low-Rise, Open High-Rise, Open Mid-Rise, Open Low-Rise), as well as LCZ 10 (Heavy Industry) are significantly affected by the urban heat island (UHI) phenomenon, experiencing notable increases in daytime temperatures.

In contrast, areas characterized by dense vegetation or natural land cover tend to maintain more stable and lower temperatures, thereby contributing to urban microclimate regulation. These clear distinctions between LCZ types underscore the critical importance of incorporating green spaces into urban planning. Furthermore, unsustainable urban expansion such as the unchecked growth of industrial zones and the reduction of green areas can exacerbate warming trends, making them more pronounced and harder to manage.

Building on these LCZ-specific patterns, it is important to consider how Hanoi's rapid urban expansion over the past two decades has further intensified these warming trends. Over the past two decades, Hanoi has experienced rapid and spatially uneven urban expansion, with built-up areas steadily encroaching on surrounding agricultural lands and peri-urban green spaces. This transformation has increased impervious surface coverage and reduced vegetation, leading to greater heat storage and reduced evaporative cooling. Such land-cover changes amplify the intensity of the urban heat island effect and contribute to the upward temperature trends observed in highly urbanized LCZs. The continued conversion of natural or semi-natural areas into dense residential, commercial, and industrial developments underscores the need for urban planning strategies that balance growth with the preservation of cooling green infrastructure.



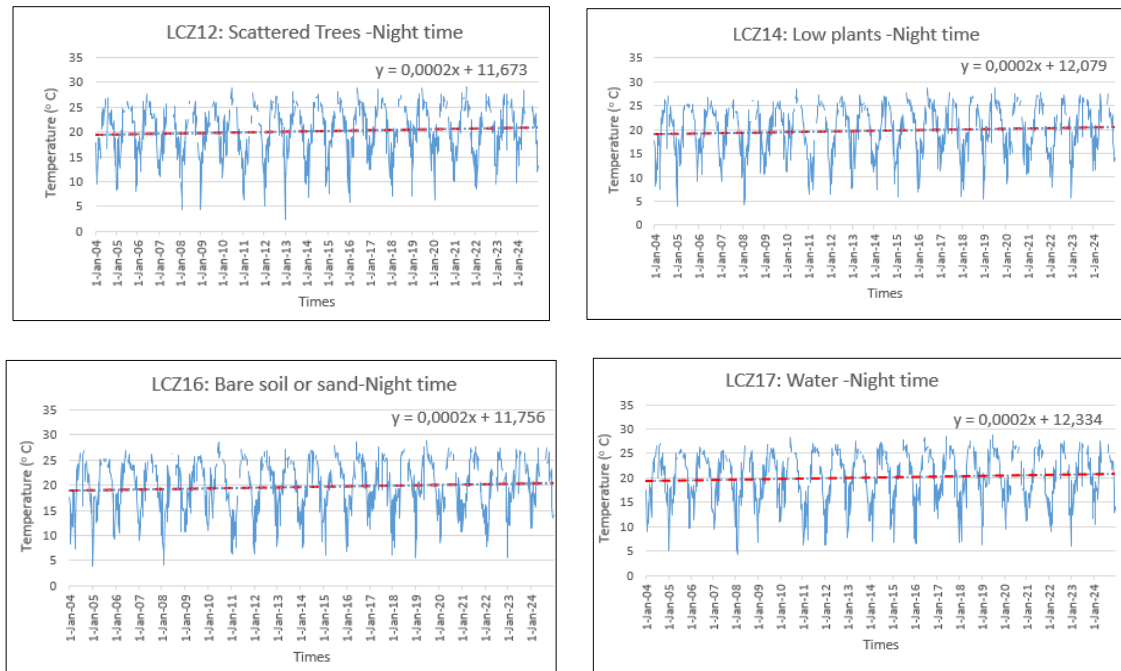


Fig. 7. Nigh-time temperatures at different LCZs

5. Conclusions

The integration of 20 years of MODIS land surface temperature data with Local Climate Zone (LCZ) classification has proven to be an effective approach for analyzing long-term urban thermal dynamics. The results show that LCZ types 1 to 8, representing highly urbanized and built-up areas, exhibit a pronounced daytime temperature increase of approximately 2.3–3.0 °C between 2004 and 2024. In contrast, LCZ 11 and LCZ 12, corresponding to low-density or sparsely built zones, experienced a much smaller temperature rise of around 0.6 °C over the same period. LCZ 14 (Low Plants) and LCZ 16 (Bare Soil or Sand) show a moderate warming trend, with mean daytime temperatures increasing by about 1.2 °C, accompanied by greater interannual variability.

For nighttime temperatures, all LCZ types exhibit a slight but consistent warming of approximately 0.18 °C over the 20-year period. This pattern indicates that daytime heating in urbanized LCZs is far more pronounced than nighttime warming, highlighting the strong influence of surface cover and built density on thermal response.

These findings emphasize that urbanization, particularly the expansion and densification of LCZ types 1 to 8 that has significantly contributed to the intensification of daytime heat, especially during the summer months. This reinforces the role of urban morphology in amplifying local heat conditions and underscores the importance of climate-sensitive urban planning to mitigate future warming in rapidly developing cities.

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References

- Bechtel, B., Demuzere, M., Mills, G., Zhan, W., Sismanidis, P., Small, C., & Voogt, J. (2019). SUHI analysis using Local Climate Zones - A comparison of 50 cities. *Urban Climate*, 28, 100451.
- Demuzere, M., Kittner, J., Martilli, A., Mills, G., Moede, C., Stewart, I. D., . . . Bechtel, B. (2022). A global map of Local Climate Zones to support earth system modelling and urban scale environmental science. *Earth System Science Data Discussions*, 2022, 1-57.

- Dinh, H. T. M., Trung, L., & Van, T. (2007). Surface emissivity in determining land surface temperature. Paper presented at the The International Symposium on Geoinformatics for Spatial-Infrastructure Development in Earth and Applied Sciences (GIS-IDEAS).
- Huang, F., Jiang, S., Zhan, W., Bechtel, B., Liu, Z., Demuzere, M., . . . Xia, W. (2023). Mapping local climate zones for cities: A large review. *Remote Sensing of Environment*, 292, 113573.
- Hung, T., & Yasuoka, Y. (2002). Remote Sensing to analyze the changes of surface biophysical parameters in Vietnam's urbanized area. Paper presented at the The 23rd Asian Conference on Remote Sensing, Kathmandu, Nepal.
- Karen Fox, A. K., & Jacob Richmond (Producer). (2023). NASA Announces Summer 2023 Hottest on Record.
- Le, H. T. T., Doan, N. D., Huynh, L. T., Nguyen, T. T. T., Nguyen, H. N. T., Luu, T. T. T., . . . Le, N. T. (2020). The Influences of Landcover structure on surface urban heat islands: A case study of Ho Chi Minh, Vietnam. *Journal of Mining and Earth Sciences Vol*, 61(2), 76-85.
- Le, H. T. T., Van Nguyen, T., Nguyen, K. N., Nguyen, P. D., Vo, T. T., Nguyen, T. G., . . . Van Le, D. (2021). Relationship between urban heat island and population density of districts in Ho Chi Minh City derived from Sentinel-3 SLSTR data. *Journal of Mining and Earth Sciences Vol*, 62(5), 67-75.
- Le Van Trung, N. T. M. (2006). Mapping land surface temperature (LST) from Satellite Imageries. Case study in Hochiminh City. Paper presented at the Proceedings of the International Symposium GIS-IDEAS.
- Li, Z.-L., Tang, B.-H., Wu, H., Ren, H., Yan, G., Wan, Z., . . . Sobrino, J. A. (2013). Satellite-derived land surface temperature: Current status and perspectives. *Remote Sensing of Environment*, 131, 14-37.
- Neinavaz, E., Schlerf, M., Darvishzadeh, R., Gerhards, M., & Skidmore, A. K. (2021). Thermal infrared remote sensing of vegetation: Current status and perspectives. *International Journal of Applied Earth Observation and Geoinformation*, 102, 102415.
- Nguyen, H. C., Nguyen, B. A., Le, H. T. T., Ho, M. N., Nguyen, T. P. T., & Nguyen, A. N. (2025). Quantifying the influence of local climate zones on diurnal and nocturnal land surface temperature variations: a case study in Ho Chi Minh City. *Journal of Mining and Earth Sciences Vol*, 66(3), 1-13.
- Pu, R., & Bonafoni, S. (2023). Thermal infrared remote sensing data downscaling investigations: An overview on current status and perspectives. *Remote sensing applications: Society and environment*, 29, 100921.
- Qi, P., Cui, Y., Zhang, H., Hu, S., Yao, L., & Li, L. B. (2020). Evaluating multivariable statistical methods for downscaling nighttime land surface temperature in urban areas. *IEEE Access*, 8, 162085-162098.
- Stewart, I. D., & Oke, T. R. (2012). Local climate zones for urban temperature studies. *Bulletin of the American Meteorological Society*, 93(12), 1879-1900.
- Thi Van, T., & Duong Xuan Bao, H. (2010). Study of the impact of urban development on surface temperature using remote sensing in Ho Chi Minh City, Southern Vietnam. *Geographical Research*, 48(1), 86-96.
- Tollefson, J. (2023). Earth's hottest month: these charts show what happened in July and what comes next. *nature*.