



Did the Covid-19 restrictions influence land surface temperatures in Southeast Asia? A study from Ho Chi Minh City, Vietnam

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Abstract

There have been a prolonged lockdown period and reduction in human activities in most of the major cities in the world during the Covid-19 pandemic period between the early 2020 and the late 2021. Such a reduction in human activities was believed to have influenced pollution levels and land surface temperatures (LST) in urban areas. This paper describes the variations in LSTs before, during and after the Covid-19 lockdown in Ho Chi Minh City in southern Vietnam, which is the economic hub of the country. For this purpose, Landsat-8 OLI and TIRS images acquired between 2015 and 2022 were used. It is observed that there was a significant reduction of 1 to 1.8 °C in LST in open areas, excepting impervious surfaces and built-up areas, during the strict lockdown period in Ho Chi Minh City, and an increase in LST since then. The observed reduction in LST during the lockdown period in Ho Chi Minh City is in agreement with the reduction in greenhouse gases during the same period in recent studies. Human mobility and industrial activities have been restored in November 2021 in the study area which would explain the regain in LST in the post-lockdown period.

Keywords Land surface temperatures (LST) · Urban heat island (UHI) · Urban remote sensing; Urban sprawl

Introduction

More than half of the global population is inhabiting in cities (Cohen 2003). Compared to developed countries in North America and Europe, the number of people living in urban settlements is smaller in Asia (UN 2014, 2016). However, UN (2014) also reported that there will be a 64% increase in urban population in Asia by 2025 due to the rapid growth of urban areas. Urban sprawl, which is the rapid expansion

of the extend of cities and towns, has a number of negative impacts, such as deforestation, habitat loss, pollution (air, water, land), greenhouse gas emission and the formation of urban heat islands (UHI), biodiversity degradation and alterations in nutrient and mineral cycles, on the environment (Estoque and Murayama 2014; Son and Thanh 2018; Veetil and Grondona 2018). These negative impacts can be particularly high when the urban areas are expanded without proper planning (Ranagalage et al. 2014).

Among the above-mentioned environmental issues associated with rapid urbanization and urban sprawl, the formation of UHIs attracted the scientific community to a great extent in recent years, particularly in the context of global warming and extreme weather events. Grondona et al. (2013) mentioned that global mean temperature has increased since the nineteenth century as a consequence of industrialization and rapid urbanization. Voogt and Oke (2003) defined UHI as the existence of higher atmospheric and land surface temperatures (LST) in the urbanized areas compared to the nearby non-urban areas. The spatiotemporal measurements of LST, particularly using satellite data, have been used by a number of researchers as a reliable method to understand the development of UHI (e.g. Son and Thanh 2018; Veetil and Grondona 2018). Another

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method to understand UHI dynamics is by in situ measurements of air temperatures (Nichol et al. 2009). However, spatiotemporal, in situ measurement of air temperatures is often time consuming and expensive, and the information gap due to less spatiotemporal coverage is also one of the drawbacks of air temperature measurements. The UHI phenomena cause cities several degrees warmer than countryside (Van and Bao 2020). Not only the expansion of impervious surfaces due to urbanization but also an increase in the amount of greenhouse gases often causes an amplified LST in urban areas. The measurement of LST as well as the development of UHI is necessary for the sustainable development of urban areas.

Remote sensing applications have been used as an effective tool for understanding spatiotemporal patterns of UHI formation in a number of studies (Grondona et al. 2013; Son et al. 2017; Veetttil and Grondona 2018). As a result of the availability of Landsat image series and ASTER imagery with thermal data since the 1980s, it is possible to understand the complex patterns and development of UHIs in urban areas ranging from small cities to megacities (Son and Thanh 2018; Veetttil and Grondona 2018). Moreover, despite the limitations in spatial resolution, remote sensing methods are still effective and faster in monitoring UHI phenomena compared to time-consuming and expensive in situ data collection and analysis methods, particularly when the study period is long.

At the end of 2019, Covid-19 (SARS-CoV-1) virus has emerged in Wuhan in China and later spread to the rest of the world as a pandemic. During the pre-pandemic conditions, UHI phenomena in major cities in the world have been observed to be increasing annually, particularly in the winter (Manoli et al. 2019). The Covid-19 pandemic period, when majority of the cities were under strict lockdown and/or extremely reduced human activities, was a unique condition to investigate the influence of anthropogenic activities on LST (and hence UHI phenomenon) (Wai et al. 2022). A number of studies reported a reduction in LST (and hence UHI effect) during the pandemic period (e.g. El Kenawy et al. 2021; Jallu et al. 2022; Liu et al. 2022; Saputra et al. 2022; Wai et al. 2022). The key reason for variations in UHI during the lockdown period was reported as the reduction in greenhouse gas emissions (El Kenawy et al. 2021).

In Vietnam, the government authorities have implemented a strict lockdown to control the Covid-19 pandemic, particularly in its urban areas, in 2021. The present study investigated the spatiotemporal variations in LSTs in a megacity in southern Vietnam during the period between 2015 and 2022 and impacts of recent lockdown during the Covid-19 pandemic on LST using satellite imagery.

Study area

In Vietnam, the post-Vietnam war period witnessed an unprecedented economic reform, known as *Doimoi* in Vietnamese, in the country due to urbanization, economic development and socio-environmental changes (Fan et al. 2019). Vietnam underwent a rapid urban expansion, and the urban population in the country grew at a faster annual rate since 1986 (Fan et al. 2019). This has resulted in a significant increase in built-up areas and conversion of farmlands and wetlands into urban areas, particularly in the capital city of Hanoi and Ho Chi Minh City which is the southern economic hub of the country (Schaefer and Thinh 2019). In parallel with this expansion of urban areas, environmental conditions in large cities throughout Vietnam have been deteriorated (e.g. Fan et al. 2019). For example, Fan et al. (2019) reported a significant increase in PM_{2.5} and NO₂ between 1990 and 2010 in Vietnamese cities. Nevertheless, a few recent studies reported that there has been a significant alleviation in poverty in the country during the same period (Arouri et al. 2017; Fan et al. 2019). In addition to air pollution, rapid urbanization has resulted in reduced water quality in cities, such as Ho Chi Minh City, in Vietnam due to the huge volume of domestic and industrial wastes (Vo 2007).

In the present study, the spatiotemporal changes in the patterns in LST in a highly populated and urbanized city—Ho Chi Minh City (10°10′–10°38′N; 106°2′–106°54′E)—in Southern Vietnam during the period between 2015 and 2022 were investigated. Ho Chi Minh City (Fig. 1) is the largest city in Vietnam, which has been urbanized at an unprecedented rate since the economic reformation in the late 1980s (Son et al. 2017). The expansion of urbanized areas in Ho Chi Minh City, which is estimated as from 142 km² in 1997 to 494 km² in 2008, was mainly by the transformation of agricultural land to settlement areas (Storch and Downes 2011). The population in this metropolitan city exceeds 8.1 million (Fan et al. 2019). Urban spaces with a large area of impervious surfaces are mainly concentrated in the center of the city (Van and Bao 2020), and, therefore, the districts in the periphery (Can Gio and Cu Chi) were not considered for mapping UHI in this study.

In parallel with the urbanization process and related environmental degradation throughout Vietnamese cities, rapid expansion of urban areas in Ho Chi Minh City has resulted in lower environmental quality, particularly the air quality, over the last few decades (Ho et al. 2020). In addition, a number of recent studies have reported urban heat island effects in this megacity in southern Vietnam (e.g. Son et al. 2017; Van and Bao 2020). For example, Son et al. (2017) estimated that majority of the land surface temperatures in the central districts of Ho Chi Minh city

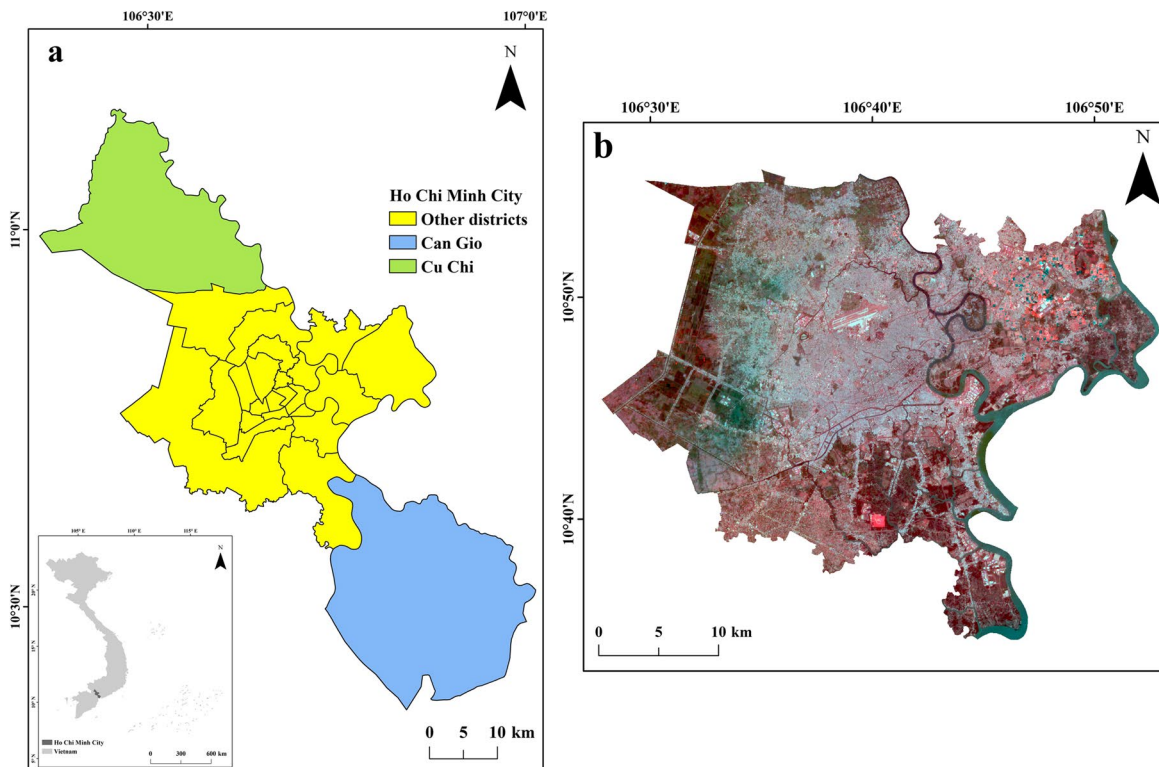


Fig. 1 Geographical location of Ho Chi Minh City and the study area

in the 1990s were below 31 °C, whereas majority of LSTs in the 2000s were above 31 °C, and above 32 °C in 2016. Van and Bao (2020) estimated LSTs above 45 °C in a few industrial areas in Ho Chi Minh City, whereas between 36 and 40 °C in urban areas. It is worth noting that the monthly average temperature in Ho Chi Minh City vary between 25 and 30 °C.

During the Covid-19 pandemic period, Vietnam imposed strict restrictions to human activities and lockdown in its urban areas, including the capital city of Hanoi in the north, Ho Chi Minh City in the south and Danang City in the central region. As a result of the strict lockdown in Ho Chi Minh City in 2021 (particularly between May and December), a number of anthropogenic activities, including construction works, public transport and industries, have been stopped or worked under restrictions. As a number of anthropogenic activities stopped or underwent at a minimum rate, such conditions allow us to investigate how such conditions influence the environment in urban areas. For example, Nguyen et al. (2022) studied the impact of Covid-19 partial lockdown on PM_{2.5}, SO₂, NO₂, O₃ and trace elements in PM_{2.5} in Hanoi in northern Vietnam. Dang and Trinh (2022) also came up with similar results for the entire Vietnam. Due to the influence of greenhouse gases on LST, it is expected that urban areas would experience impacts of lockdown period on LST to some extent. However, LST of impervious surfaces is not

expected to vary significantly. The present study investigated the influence of the Covid-19 lockdown on LST in Ho Chi Minh City with the aid of satellite imagery.

Data and methodology

The notion of using of remotely sensed data acquired by satellites for identifying the UHI phenomena dates back to the early 1970s (Rao 1972). The emergence of Landsat image series (TM, ETM+, OLI) with thermal data has revolutionized the study of UHI using remote sensing (Chen et al. 2006; Zhou et al. 2019). Satellite imagery having thermal information, such as Landsat series (e.g. Son et al. 2017) and ASTER (e.g. Van and Bao 2020), have been used in previous studies for understanding the spatiotemporal distribution of LST in Ho Chi Minh city. The present study used Landsat-8 Operational Land Imager and Thermal Infrared Sensor (OLI and TIRS) images acquired between 2015 and 2022. Landsat-8 imagery have a spatial resolution of 30 m in its optical channels, 15 m in panchromatic band and 100 m in its two thermal channels. Landsat images are available at no cost from the United States Geological Survey (USGS: <https://earthexplorer.usgs.gov/>). Only Level-2 products were used in this study, and, therefore, no additional atmospheric correction was applied to the imagery. Only those images without or minimum cloud cover

were used in this study. Details of Landsat-8 OLI data used in the present study are given in Table 1.

LST in Ho Chi Minh City during the study period has been estimated using the thermal channel (Band 10) and the normalized difference vegetation index (NDVI) estimated from the red (Band 4) and near infrared (Band 5) channels (Avdan and Jovanovska 2016). The first step to estimate LST is the conversion of Band 10 DN values to the top of the atmosphere spectral radiance (L) using the following equation:

$$L = M_L * Q_{cal} + A_L - O_i \tag{1}$$

where, M_L represents the band-specific multiplicative rescaling factor, Q_{cal} is the Band 10 image, A_L is the band-specific additive rescaling factor and O_i is the correction for Band 10. The next step is to convert the top of the atmosphere spectral radiance to the brightness temperature (BT) using the following equation:

$$BT = K_2 / \ln[(L_1/L) + 1] - 273.15 \tag{2}$$

where, $K1$ and $K2$ are the band-specific thermal conversion constants from the metadata; for Landsat-8, $K1$ and $K2$ are 774.8853 and 1321.0789, respectively, from the metadata. The subtraction by 273.15 is used for obtaining the results in degree Celsius. In the third step, NDVI is calculated from the red and near infrared bands as given below:

$$NDVI = (Band\ 5 - Band\ 4) / (Band\ 5 + Band\ 4) \tag{3}$$

From the NDVI image, the proportion of vegetation (P_v) can be estimated as follows:

$$P_v = [(NDVI - NDVI_{min}) / (NDVI_{max} - NDVI_{min})]^2 \tag{4}$$

where, $NDVI_{min}$ and $NDVI_{max}$ denote the minimum and maximum value of NDVI in a particular image. In the next

step, emissivity (ϵ) from Landsat-8 data has been estimated from P_v using the following equation:

$$\epsilon = 0.004 + P_v * 0.986 \tag{5}$$

Once emissivity is estimated, land surface temperature (LST) in °C has been estimated as

$$LST = (BT + (1 + 0.00115 * BT / 1.1388) * \ln(\epsilon)) \tag{6}$$

A flowchart for the LST retrieval algorithm from Landsat-8 data is given in Fig. 2.

Results and discussion

A spatiotemporal analysis of LST in Ho Chi Minh City during the period between 2015 and 2022 has shown some interesting results, particularly when compared the LST values during the pre-pandemic, pandemic and post-pandemic periods. The present study can be considered a continuation of Son et al. (2017) which investigated the LST changes in the same study area between 1996 and 2016 (pre-pandemic period), considering the influence of recent halt in anthropogenic activities due to the Covid-19 pandemic.

Estimated changes in land surface temperatures showed that there was an overall increasing trend in LST during the pre-pandemic period, a lower LST values during the strict lockdown period and an increase in LST during the post-lockdown period. It has been observed that the maximum LST was above 40 °C and the minimum LST below 20 °C between 2017 and 2019 (Fig. 3). This result is comparable with the results obtained by Son et al. (2017) for Ho Chi Minh City between 1996 and 2016. In fact, it can be affirmed that the estimated increase in LST is due to the expansion of urban areas, particularly the increase in impervious surfaces, in Ho Chi Minh City since the early 1990s.

Table 1 Details of Landsat-8 OLI and TIRS data used for estimating UHI spatiotemporal patterns in Ho Chi Minh City

| Date of acquisition | Path/row | Scene/product ID |
|---------------------|----------|--|
| 24 January 2015 | 125/52 | LC08_L1TP_125052_20150124_20200910_02_T1 |
| 28 February 2016 | 125/52 | LC08_L1TP_125052_20160228_20200907_02_T1 |
| 14 February 2017 | 125/52 | LC08_L1TP_125052_20170214_20200905_02_T1 |
| 31 October 2018 | 125/52 | LC08_L1TP_125052_20181031_20200830_02_T1 |
| 19 January 2019 | 125/52 | LC08_L1TP_125052_20190119_20200829_02_T1 |
| 06 January 2020 | 125/52 | LC08_L1TP_125052_20200106_20200823_02_T1 |
| 07 February 2020 | 125/52 | LC08_L1TP_125052_20200207_20200823_02_T1 |
| 23 February 2020 | 125/52 | LC08_L1TP_125052_20200223_20200822_02_T1 |
| 08 January 2021 | 125/52 | LC08_L1TP_125052_20210108_20210307_02_T1 |
| 13 March 2021 | 125/52 | LC08_L1TP_125052_20210313_20210318_02_T1 |
| 10 December 2021 | 125/52 | LC08_L1TP_125052_20211210_20211215_02_T1 |
| 28 February 2022 | 125/52 | LC08_L1TP_125052_20220228_20220309_02_T1 |
| 22 July 2022 | 125/52 | LC08_L1TP_125052_20220722_20220802_02_T1 |

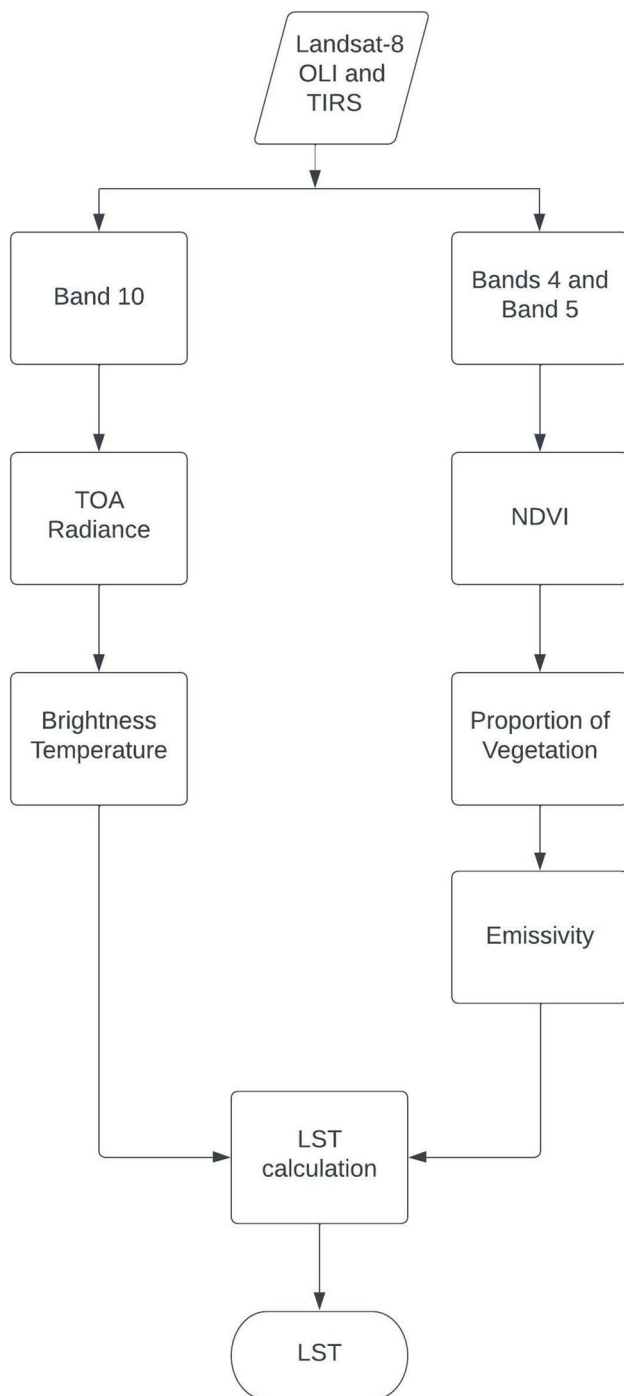


Fig. 2 Flowchart for LST retrieval algorithm using thermal data and NDVI derived from Landsat-8 imagery

During the pandemic period, Vietnam has commenced its restrictions from March 2020. It is observed that the maximum LST was lower (compared to 2017–2019) during pandemic period (in January 2020, before restrictions have been implemented) (Fig. 4). It has to be noted that the maximum LST on impervious surfaces and built-up areas may remain

similar independent of restrictions, and only non-impervious surfaces showed a reduction in LST (between 1 and 1.8 °C). For example, LST estimated in the vicinity of the airport and industrial parks remained the same throughout the study period. The unusual drop in estimated LST in January 2021 (Fig. 4d) is, possibly, due to image quality issues, such as the presence of slight cloud cover.

The estimated LST during the post-restriction period from end of 2021 to 2022 showed higher values (Fig. 5) compared to the lockdown period, particularly in those non-impervious areas that showed a lower LST during the restrictions. The highest maximum LST (44.6 °C) was estimated during the post-lockdown period. This observation is obvious as the social isolation in Ho Chi Minh City was eased at the end of 2021 and the population mobility and industrial activities has become normal again in the study area. Figure 6 shows the differences in average LST between pre-pandemic and pandemic lockdown period (Fig. 6a), and between the post-pandemic lockdown period and pandemic lockdown period (Fig. 6b), respectively.

A number of recent studies observed a drop in urban LST during the pandemic period in major cities around the world. For example, El Kenawy et al. (2021) observed a significant drop in LST in major cities, such as Dubai and Doha, in the Middle East. This reduction in LST was observed to be associated with reduced concentrations of air pollutants, such as CO, NO₂ and SO₃ (El Kenawy et al. 2021). Similar observations were reported from Chinese cities by Liu et al. (2022), where the surface UHI intensity was reduced by 0.25 K in the daytime and by 0.23 K at night during lockdown periods. A variation in LST during the pandemic period in the largest city in southeast Asia (Jakarta, Indonesia) was already reported in a recent study (Saputra et al. 2022). Ho Chi Minh City is the second largest city in this region, and the results of the present study indicated a slight decrease in LST values during the lockdown period in the study area.

There has been a decrease in human activities, such as automobiles, restaurants and industries, in Ho Chi Minh City in the second half of 2021. It is worth noting that the mobility of work force in Ho Chi Minh City before and after the pandemic period is highly based on motorbikes (e.g. Truitt 2008), and, therefore, a large amount of greenhouse gases is expected in the atmosphere during this time. During the pandemic lockdown period, there was a sharp decline in the mobility of people in the study area (Nguyen 2020). Moreover, there were reports mentioning a reduction in the air pollution (and greenhouse emissions) in the entire Vietnam due to the reduction in human activities related to the Covid-19 social isolation in the country (e.g. Ngo et al. 2021). For example, there was a strong decrease of NO₂ density (11.77% less) during the lockdown period in the urbanized areas of Ho Chi Minh City, where the population mobility and industrial activities are usually high during

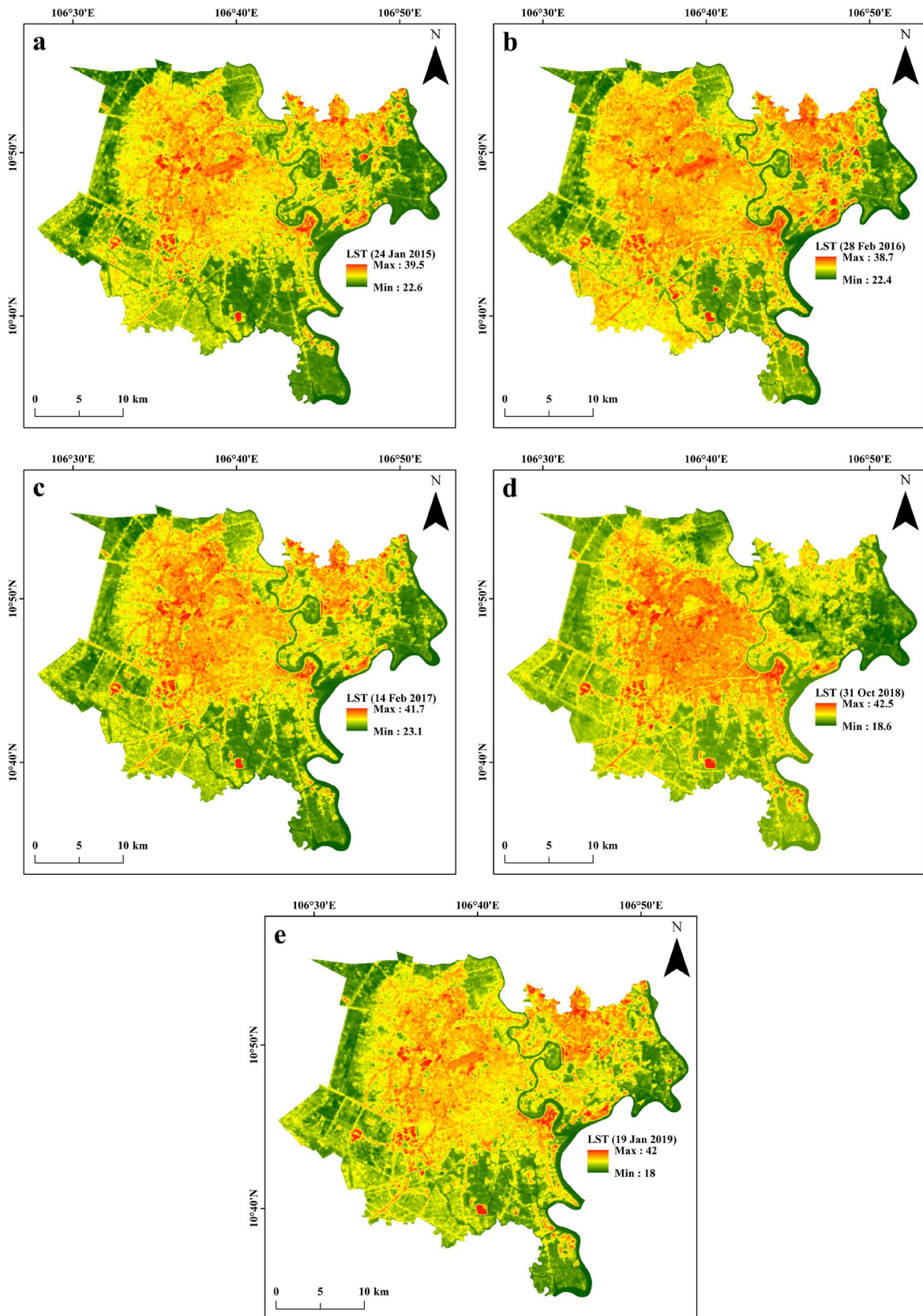


Fig. 3 LST estimated during the pre-pandemic period

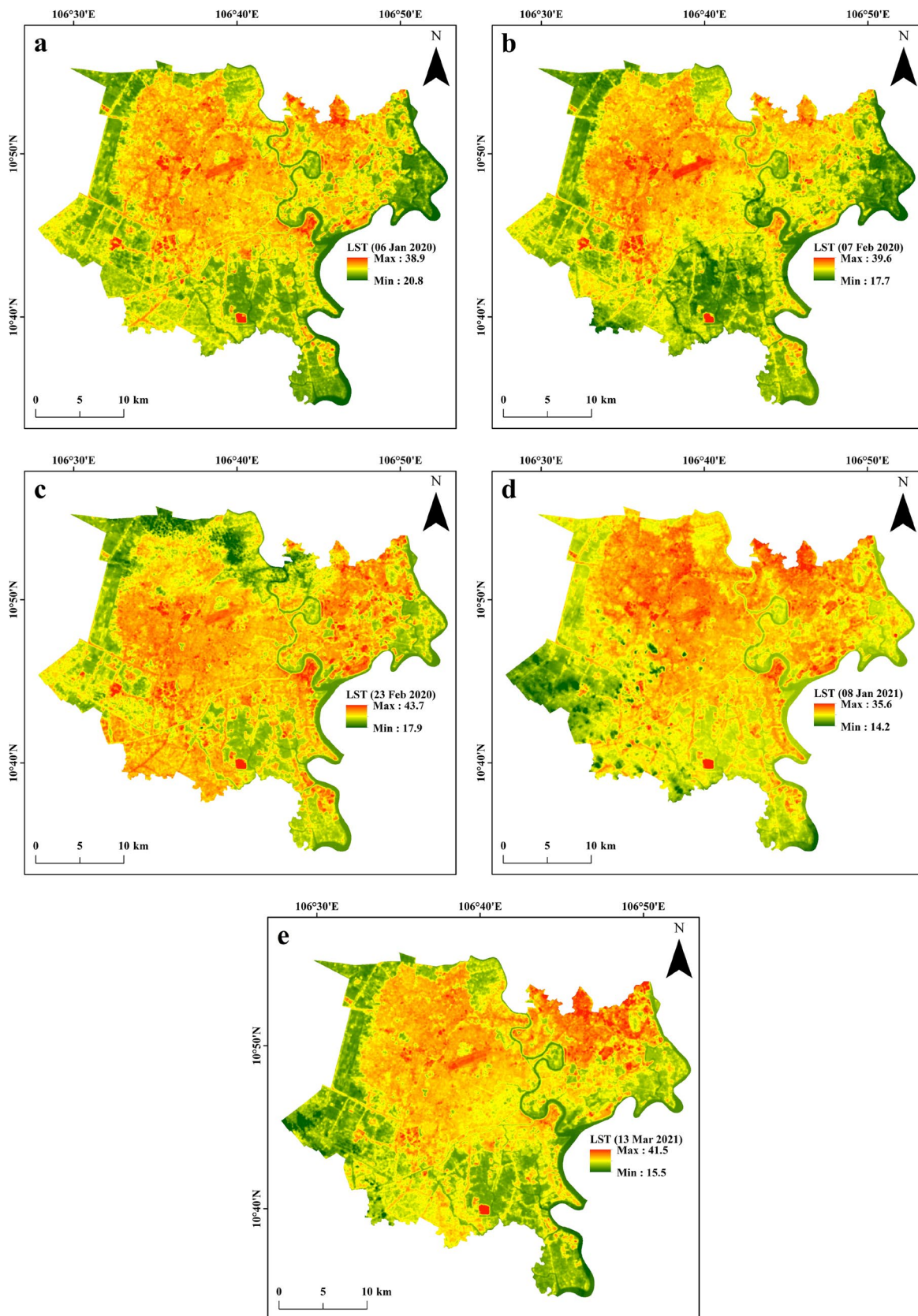


Fig. 4 LST estimated during the pandemic period

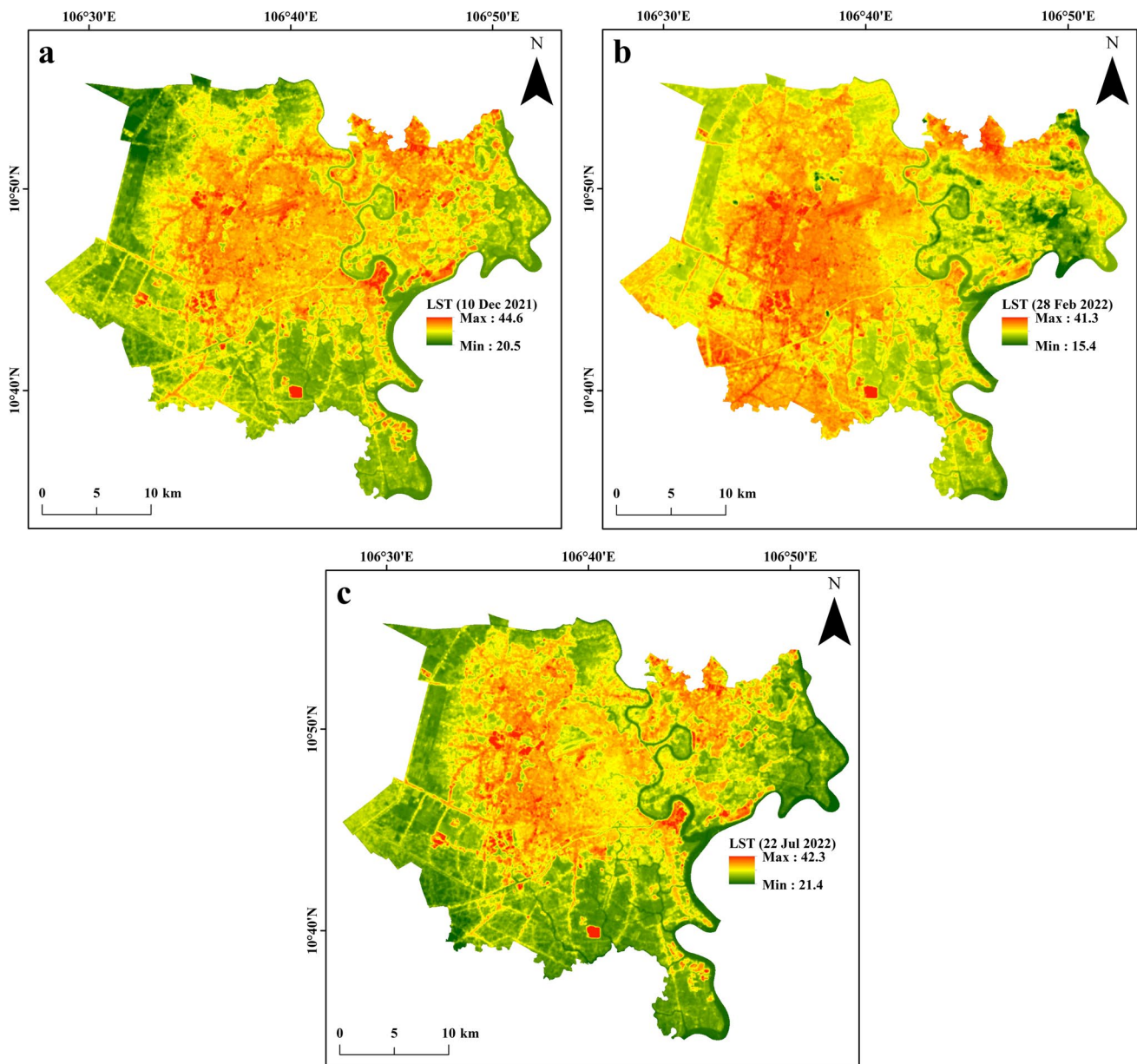


Fig. 5 LST estimated during the post-restriction period

non-pandemic period (Ngo et al. 2021). This observation is highly relevant in the present study as the relationship between atmospheric NO_2 concentration and UHI phenomena is well established in the past (Gotoh 1993).

Conclusions and future perspectives

This study estimated the changes in land surface temperatures between 2015 and 2022 and the impact of Covid-19 lockdown in the highly populated Ho Chi Minh city in southern Vietnam. There was a gradual rise in the LST in

Ho Chi Minh City from 2015 until the pre-pandemic period in 2019–2020. This observation is in agreement with recently published studies on LST changes in the study area in the same period (2015–2019). However, there was a small reduction in LST during the pre-lockdown period with stringent restrictions, including reduced public transport in the early 2021. There was a significant reduction in minimum LST, varying between 1 and 1.8 °C, during the complete lockdown period in 2021 in Ho Chi Minh City. However, this reduction in LST was mainly observed in the open spaces without impervious surfaces. The considerable decrease in greenhouse gases, particularly NO_2 , reported in

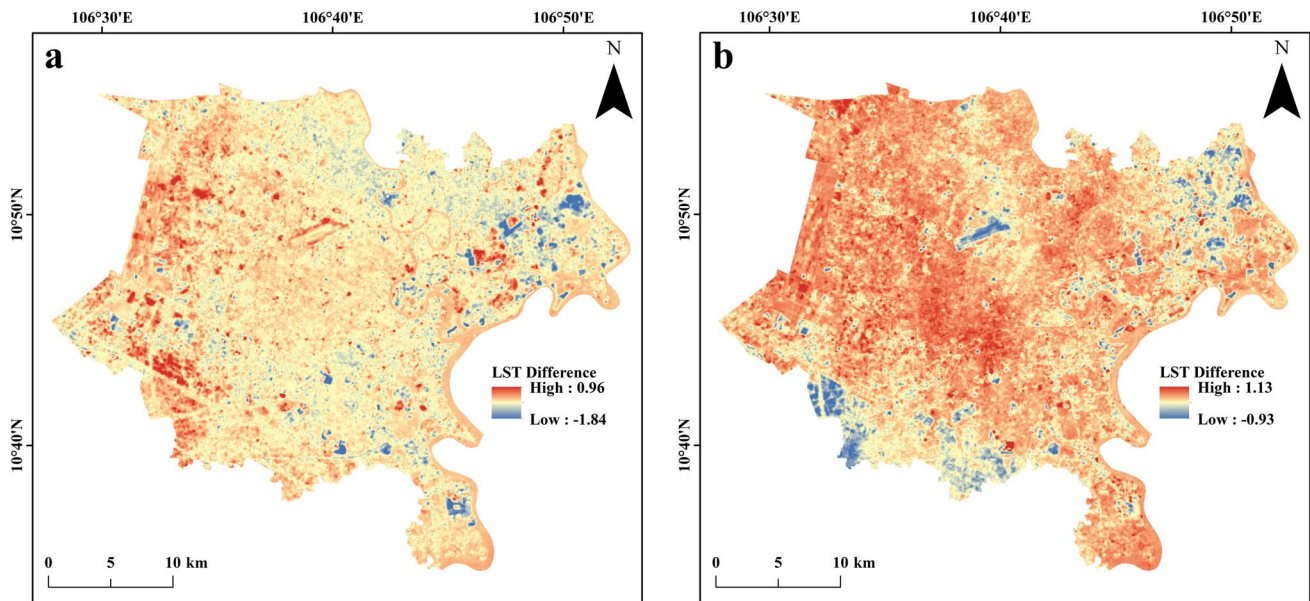


Fig. 6 Difference in average LST (a) between the pre-pandemic and pandemic lockdown period; (b) between the post-pandemic lockdown period and pandemic lockdown period

recent studies can provide an explanation of this reduction in LST during the lockdown period. LST on the impervious surfaces, such as built-up areas and roads, remained nearly unchanged throughout the study period. During the post-lockdown period since the early 2022, LST has been reaching the same level as during the pre-pandemic period due to the restoration of mobility and industrial activities in the area. The results indicated that LST changes during the Covid-19 pandemic period in Ho Chi Minh City were comparable to the observed reductions in LSTs in other major cities in the world. It would be interesting to understand the variations occurred in the concentrations of air pollutants at the study area; a detailed study is needed in this direction.

Author contribution BKV designed the study. BKV and DDV contributed equally to the manuscript.

Data availability All data used in this study are available from public domain resources.

Declarations

Ethical approval Hereby, we consciously assure that for the manuscript/insert title/the following is fulfilled: (1) This material is the authors' own original work, which has not been previously published elsewhere. (2) The paper is not currently being considered for publication elsewhere. (3) The paper reflects the authors' own research and analysis in a truthful and complete manner. (4) The paper properly credits the meaningful contributions of co-authors and co-researchers. (5) The results are appropriately placed in the context of prior and existing research. (6) All sources used are properly disclosed (correct citation). Literally copying of text must be indicated as such by

using quotation marks and giving proper reference. (7) All authors have been personally and actively involved in substantial work leading to the paper and will take public responsibility for its content.

Consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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