Effects of Urban Redevelopment on Surface Urban Heat Island

Dan Li, Shaofeng Yan, and Guangzhao Chen

Abstract—**Urban expansion and urban redevelopment can affect the surface urban heat island (SUHI) phenomenon, a major topic in the study of urban climates. The effects of urban expansion on SUHI have been studied by numerous researchers, while the effects of urban redevelopment remain unclear. We aimed to understand the effects of urban redevelopment on SUHI. Using the thermal bands of Landsat-5 TM and Landsat-8 TIRS, we retrieved the land surface temperature and calculated the SUHI intensity of the redevelopment areas during 2000–2019 in Guangzhou (China). Based on the high-spatial-resolution images from Google Earth, 253 redevelopment areas were identified and classified as village low residential areas, low-industrial areas, middle residential areas, high residential areas, and commercial areas. Furthermore, the change in SUHI intensity in redevelopment areas was analyzed. Results showed that urban redevelopment, including the transitions from urban village to high-rise commercial land, from low-rise industrial land to high-rise residential land, from industrial land to parking lot, from bare land to mid-rise buildings, and from parking lot to high-rise commercial land, can considerably reduce the speed of increase of local SUHI intensity. These new findings have theoretical and practical implications for urban planning and redevelopment.**

Index Terms—**Surface urban heat island (SUHI), thermal remote sensing, urban redevelopment.**

I. Introduction

THE world is experiencing a huge urbanization process [1], [2], which includes urban expansion and redevelopment. The former is a regular urbanization process [3] that is more evident than urban redevelopment. Gong et al. [1] showed that the impervious surface area of the world in 2018 was 1.5 times higher than that in 1990. Thus, urban climate and environmental problems caused by urban expansion have attracted considerable attention [4], [5], [6], especially concerning the urban heat island (UHI) and surface urban heat island (SUHI) phenomena. Li et al. [7] studied the effects of urban expansion on SUHI, and the results showed that there is a statistically significant positive relationship between SUHI and urban area size; doubling the urban area size led to a SUHI increase by as much as 0.7 °C. The replacement of an impervious surface with a natural surface makes the surface material properties and geometric characteristics different from those of the surrounding natural surfaces, resulting in an urban surface energy exchange that differs from that of the natural surface.

Another important urbanization process is urban redevelopment or renovation. Urban renovation does not change the impervious areas of urban areas but may change the urban surface material properties and geometric characteristics. This also changes the energy exchange within the urban canopy, resulting in different urban microclimates. Renard et al. [8] studied the effects of three urban redevelopment areas on the surface temperature, and the results showed that the surface temperature decreased when industrial areas were transformed into tertiary or residential areas. Therefore, renovation of urban spaces affects SUHI because changes in urban geometry and surface properties alter the surface energy balance. Many new construction materials will be used during an urban renovation project, and the urban surface albedo and thermal properties will be modified. The albedo affects the absorption and reradiation of solar radiation. The thermal properties, in combination with the geometry of the surface, affect the surface heating and cooling rates. This directly changes the net radiation and ground heat conduction exchanges, which may result in a change in the SUHI. Additionally, the renovation will likely change building height and density, resulting in different sky view factor (SVF) patterns. The latter alters the magnitude of incoming and outgoing radiative and convective fluxes through various processes, which is the key to understanding the energy balance of urban areas and the principal driver of SUHI [9], [10]. Many authors have investigated the effects of urban canopy geometry and surface properties on urban climate using both numerical and field experiments [11], [12], [13], [14]. Changes in urban geometry also affect aerodynamic resistance. This changes the turbulent flux exchange between the urban canopy and atmospheric boundary layer, which affects the SUHI magnitude and pollutant dispersion in urban areas. Thus, the renovation of urban spaces considerably impacts the SUHI and urban local environments. Renard et al. [8] and Pan et al. [15] studied the effects of urban redevelopment on SUHI in a small district,

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and the results demonstrated that the SUHI effect had a mitigation trend because of the urban redevelopment process in the study area. However, the long-term trends of SUHI in urban redevelopment areas for different urban land-use classifications are still unclear. In addition, how urban redevelopment changes albedo and vegetation remains unclear. Albedo is the dominant factor for absorbing solar radiation, which is the main driver of the urban climate. Latent heat from vegetation helps cool the urban space. How albedo and vegetation change with urban redevelopment is important for urban climate. The development of SUHI trends in renovation areas can help urban planners and designers understand the types of urban renovation that can help urban sustainability.

Therefore, we used high-spatial-resolution images from Google Earth to determine the redevelopment areas first and then classified the land-use type of the redevelopment areas. The SUHI changes in the redevelopment areas were analyzed based on a long time series of satellite data according to different redevelopment types. Urban development mainly changes the urban surface materials and geometry. This changes albedo and vegetation cover. Thus, the changes in albedo and NDVI before and after redevelopment were obtained to analyze the effects of urban redevelopment on SUHI. This study provided guidelines for urban planning and redevelopment.

II. Research Area and Data

A. Research Area

Guangzhou, the capital of Guangdong province and one of Guangdong–Hong Kong–Macao Greater Bay Area's largest cities, is located in the middle southern part of Guangdong province, at the junction of the West River, North River, and East River (see Fig. 1). The terrain is relatively flat in the southern regions of Guangzhou, whereas areas to the north are mountainous. Guangzhou has a typical oceanic semitropical monsoon climate characterized by warm and rainy year round, long summers, and a short frost period. According to meteorological records from 2000 to 2019, the annual mean air temperature in Guangzhou is 295 K. Guangzhou is a historic city that is rapidly developing. The redevelopment areas in Guangzhou cannot be neglected; thus, it was selected as the study area.

B. Data

Because Guangzhou is always cloudy from spring to autumn, the thermal bands of Landsat-5 TM and Landsat-8 TIRS from October to December during 2000–2019 period (see Table I and Fig. 2) were used based on the Google Earth engine (GEE). High-resolution remote sensing images were collected using Google Earth. Thus, we can determine the area of urban redevelopment by comparing historical images. Based on the Google Earth, 253 redeveloped areas were identified and classified into different redeveloped types (see Table II). The selected samples are located in the core urban areas, and the areas of the selected samples range from 397.34 to 249773.07 m^2, with an average area of 5416.26 m^2. The selected samples included urban villages with low-rise and high-density residential buildings, low-rise industrial areas with metal buildings, high-rise commercial and residential areas, and bare lands (see Table II). These samples had different land-use types and geometries.

The corresponding atmospheric transmittance, upwelling atmospheric radiance, and downwelling atmospheric radiance from the Landsat C2L2 products were obtained and used to retrieve the land surface temperature (LST).

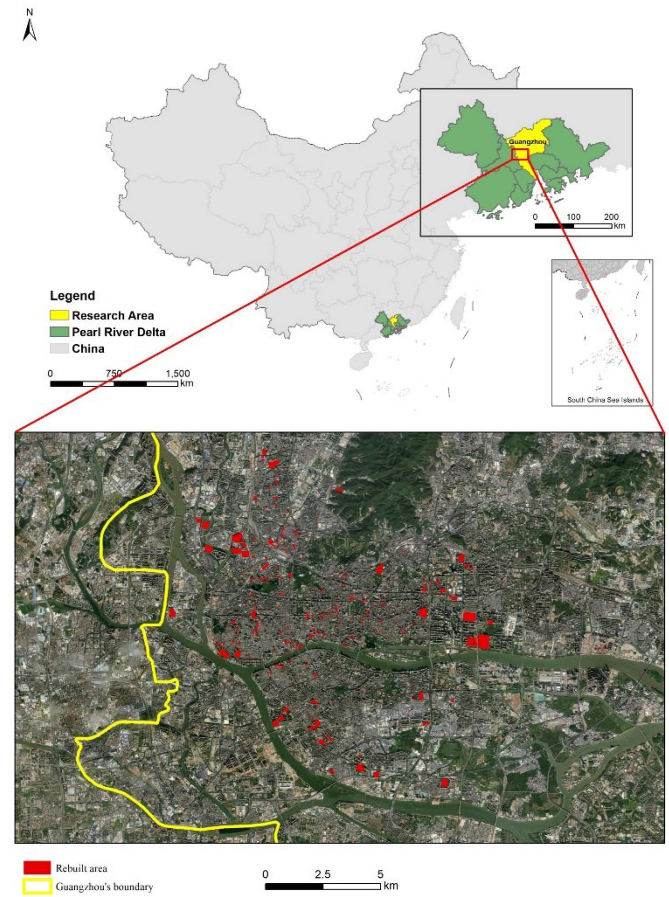
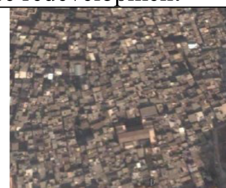
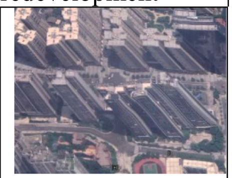
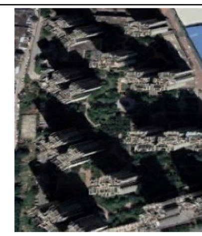
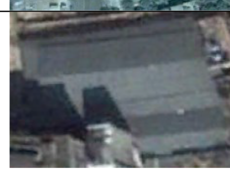
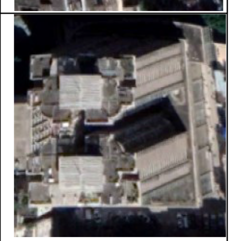
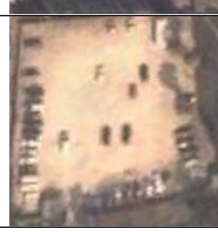
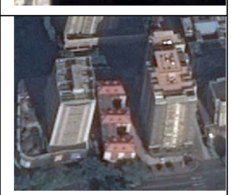


Fig. 1. Location of the research area and selected samples.

TABLE I
Research Data

Data Type	Data
Satellite data	Landsat-5 TM from 2000 to 2011 Landsat-8 TIRS from 2013 to 2019 High resolution remote sensing images from 2000 to 2019 in Google Earth
Meteorological data	Near surface temperature Atmospheric transmittance Upwelling atmospheric radiance Downwelling atmospheric radiance

TABLE II
REDEVELOPMENT TYPES IN GUANGZHOU

Before redevelopment		After redevelopment	
urban village		high-rise commercial land	
low-rise industrial land		high-rise residential land	
industrial land		parking lot	
bare land		mid-rise buildings	
parking lot		high-rise commercial land	

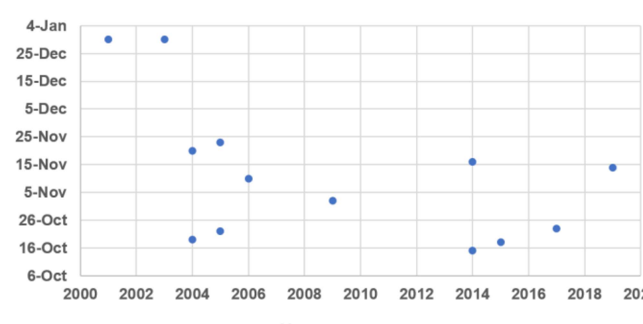


Fig. 2. Date of the sample data used in this study.

III. METHODOLOGY

A. LST Retrieval

LST was retrieved from Landsat images based on GEE. Considering the operational time of Landsat, we used Landsat-5 TM to retrieve LST data from 2000 to 2011 and Landsat-8 TIRS to retrieve LST data from 2013 to 2019. To retrieve LST from Landsat-5 TM images, we chose a monowindow algorithm [16] in which only the emissivity, transmittance, and effective mean atmospheric temperature were required. Considering the accuracy and feasibility, we chose the single-channel algorithm [17] to retrieve LST from the tenth band of the Landsat-8 TIRS data.

B. Methods for Exploring Thermal Environmental Factors

To measure the effects of urban redevelopment on SUHI, we used high-spatial-resolution images from Google Earth to determine the redevelopment areas of Guangzhou from 2000 to 2019. We derived 253 sample areas and divided them into five types: urban village to high-rise commercial land, parking lot to high-rise commercial land, low-rise industrial land to high-rise residential land, industrial land to parking lot, and bare land to mid-rise buildings.

Using the retrieved LST data, we obtained the LST values of the sample areas from 2000 to 2019. Similar to the urban

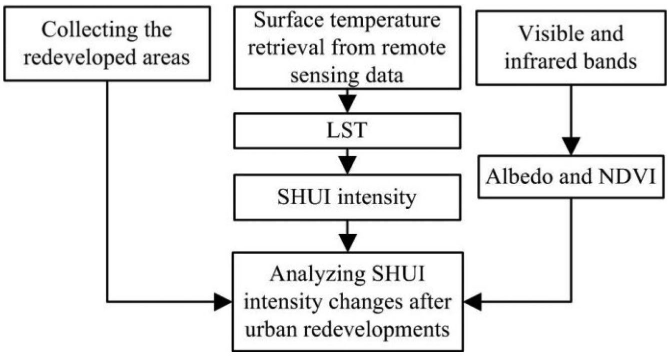


Fig. 3. Flowchart of this study.

expansion effect measurement, an unchanged rural region was chosen as the reference to calculate the SUHI intensity (1) of the redevelopment areas before and after the change

$$\Delta I_i = \mathrm{LST}_{iu} - \mathrm{LST}_{ir} \quad (1)$$

where LST_{iu} is the LST of the redevelopment areas in year i; LST_{ir} is the LST of the reference rural region in year i.

We then conducted a trend analysis of SUHI based on ΔI_i and computed the increasing rate of SUHI intensity to discuss the effects of urban redevelopment on SUHI. Urban redevelopment changes the urban materials and geometry; thus, the albedo, NDVI, and building density are extracted to analyze the effects of urban redevelopment on the SUHI. A flowchart of the study is shown in Fig. 3.

The albedo is calculated as [18], [19] follows:

$$\alpha_{L5} = ((0.356 * \mathrm{B1}) + (0.130 * \mathrm{B3}) + (0.373 * \mathrm{B4}) + (0.085 * \mathrm{B5}) + (0.072 * \mathrm{B7}) - 0.018) / 1.016 \quad (2)$$

$$\alpha_{L8} = (0.3 * \mathrm{B2}) + (0.277 * \mathrm{B3}) + (0.233 * \mathrm{B4}) + (0.143 * \mathrm{B5}) + (0.036 * \mathrm{B6}) - (0.012 * \mathrm{B7}) \quad (3)$$

where for α_{L5}, B represents the Landsat 5 bands 1, 3, 4, 5, and 7; for α_{L8}, B represents the Landsat 8 bands 2, 3, 4, 5, 6, and 7.

IV. Results

The SUHI performance before and after redevelopment was segmented for analysis according to the identified types of urban redevelopment samples and time of occurrence. Changes in land characteristics, such as land type, building density, and height, considerably influenced SUHI performance. By monitoring the SUHI change of the sample areas, we noticed that urban redevelopment might mitigate SUHI effectively, while different types of urban redevelopment show differential effects on SUHI.

A. From Urban Village to High-Rise Commercial Land

We noticed that the SUHI intensity had a rising trend in urban villages, but this trend changed when the urban village was transformed into high-rise commercial land. As shown in Fig. 4(a), after the sample area was rebuilt as high-rise commercial land, the SUHI intensity decreased gradually. As shown in Fig. 4(b), although the SUHI intensity continued to increase after renovation, the rate of increase decreased from 0.41 to 0.12. The results demonstrated that redevelopment by transforming urban villages into high-rise commercial land could mitigate the SUHI effect.

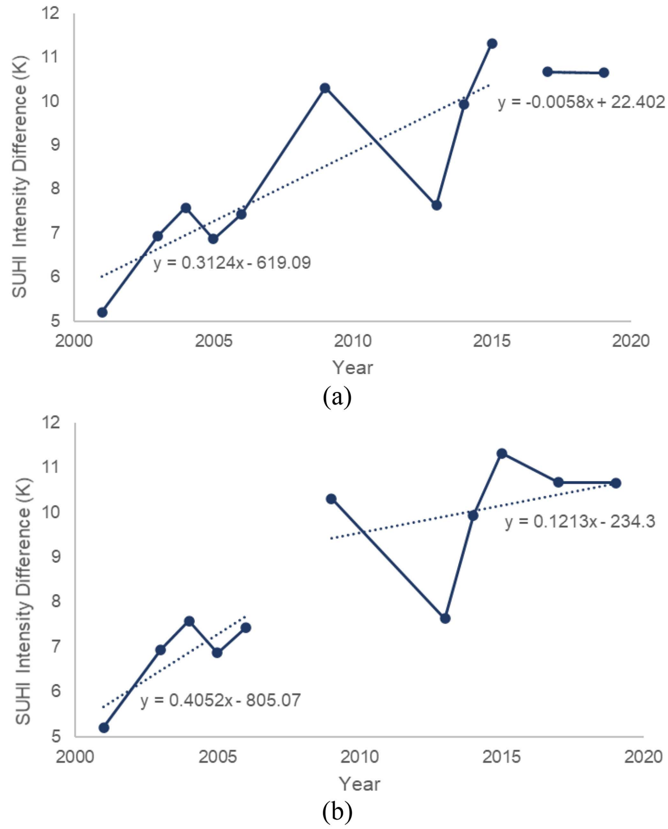


Fig. 4. Change of SUHI intensity from urban village to high-rise commercial land. (a) Change of SUHI intensity in a sample area where the urban village was demolished in 2011 and rebuilt as high-rise commercial land in 2017. (b) Change of SUHI intensity in a sample area where the urban village was demolished in 2004 and rebuilt as high-rise commercial land in 2008.

Compared with urban villages, the new high-rise commercial land was built under elaborate planning with broader building spacing and more rational building density, which leads to better ventilation, accelerating heat dissipation, and thus, transforming urban villages into high-rise commercial land with a noticeable cooling effect. In addition, high-rise commercial land has a different pattern in SVF from that of urban villages. This changes the energy exchange and surface energy balance, which affects SUHI. Fig. 5 shows the changes in albedo and NDVI of the redevelopment areas in Fig. 4(b). The results showed that NDVI continued to increase after redevelopment, while albedo tended to decrease. This means that high-rise commercial land has a higher vegetation cover than urban villages, thereby helping to reduce urban surface temperature. However, the albedo decreases after redevelopment because high-rise buildings add shadows, resulting in a lower albedo than that in urban villages. The shadow is also helpful in cooling the urban space.

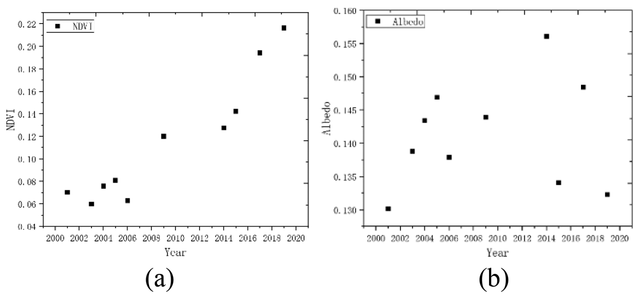


Fig. 5. Changes of albedo and NDVI difference for the redevelopment areas in Fig. 4(a). (a) NDVI. (b) Albedo.

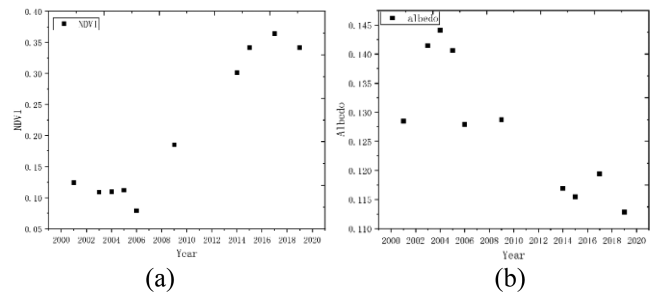


Fig. 7. Changes of albedo and NDVI difference for the redevelopment areas in Fig. 6(a). (a) NDVI. (b) Albedo.

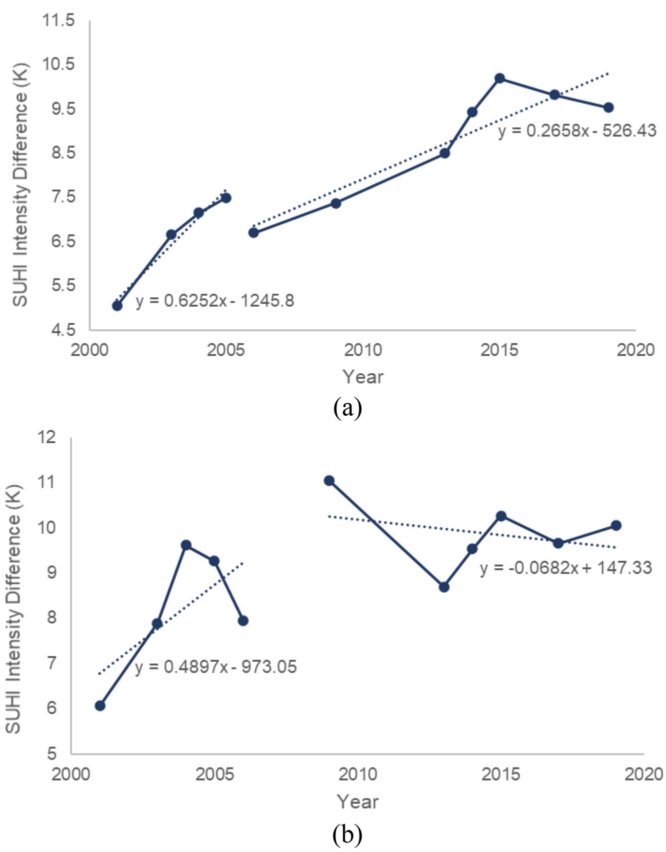


Fig. 6. Change of SUHI intensity from low-rise industrial land to high-rise residential land. (a) Change of SUHI intensity in sample area where low-rise industrial land was transformed to high-rise residential land in 2006. (b) Change of SUHI intensity in sample area where low-rise industrial land was transformed to high-rise residential land in 2009.

B. From Low-Rise Industrial Land to High-Rise Residential Land

The SUHI intensity increased annually in the low-rise industrial land (see Fig. 6). However, the SUHI effect was mitigated after the low-rise industrial land was redeveloped into high-rise residential land (see Fig. 6), which indicates that changing low-rise industrial land to high-rise residential land helps mitigate the SUHI effect.

The significant difference between low-rise industrial land and high-rise residential land is in the construction materials and layout. Construction materials used in industrial land are always heat-absorbing metal materials, which results in a severe SUHI effect. High-rise residential buildings are always built with new and clean materials because the effects of construction materials on the urban microclimate should be considered during urban redevelopment. Thus, the urban surface albedo and thermal properties were changed, affecting the SUHI effects [increased NDVI values, as shown in Fig. 7(a)]. The albedo of high-rise residential land is still lower than that of low-rise industrial areas [see Fig. 7(b)]. One reason is that the materials in residential areas have a lower albedo than metals in industrial areas. Another reason is the shadow caused by high-rise buildings. Thus, in this case, the main reasons for cooling down urban spaces were vegetation and building shadows. Owing to factory activities, industrial land is a typical heat source. According to Stewart et al. [20], the anthropogenic heat flux in industrial areas is higher than 300 W/m^2, whereas the anthropogenic heat flux in other land-use areas is less than 100 W/m^2. When the industrial area was transformed into high-rise residential land, anthropogenic heat decreased [20], and thus, the SUHI effect was mitigated.

C. From Industrial Land to Parking Lot

The effects of SUHI on industrial land showed an apparent increasing trend (see Fig. 8). When industrial land was changed to a parking lot, the SUHI intensity showed an increasing trend but a decrease in the increasing rate (see Fig. 8), which means that changing industrial land to park lots can reduce the SUHI effect as well.

As mentioned previously, industrial land is a heat-friendly area. Parking lots generate less anthropogenic heat than industrial land, thereby slowing down the increasing SUHI effect. In addition, parking lots have more open spaces than industrial land. According to Yang et al. [21], a higher SVF results in higher LST during the daytime. Industrial areas have higher anthropogenic heat and materials with higher heat absorptivity. Therefore, material and anthropogenic heat fluxes are the dominant factors affecting the thermal environment in industrial areas.

D. From Bare Land to Mid-Rise Buildings

The comparisons of the gaps between the redevelopment and invariant regions are shown in Fig. 9. The slope before urban redevelopment was 1.69 K/year, and it decreased to −0.08 K/year

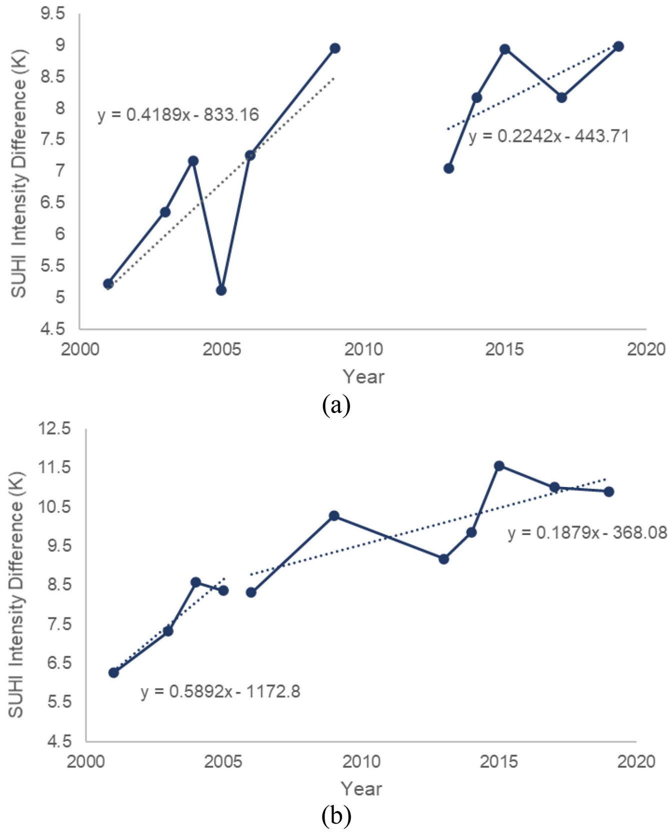


Fig. 8. Change of SUHI intensity from industrial land to parking lot. (a) Change of SUHI intensity in sample area where industrial land was knocked down in 2010 and rebuilt as parking lot in 2010. (b) Change of SUHI intensity in sample area where industrial land was knocked down in 2004 and rebuilt as parking lot in 2006.

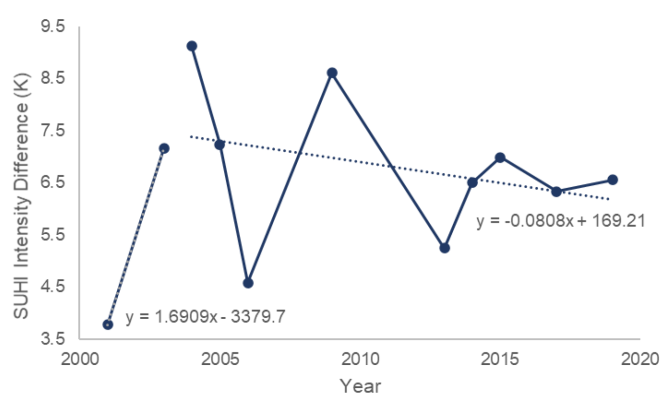


Fig. 9. Change of SUHI intensity from bare land to mid-rise buildings, which were bare land before 2004 and built as mid-rise buildings in 2007.

after redevelopment. This indicates that the SUHI effect can be weakened by bare land to mid-rise building redevelopment. This is because, compared with the mid-rise built-up surface, bare land has no vegetated surface; therefore, it is more easily affected by solar radiation. Bare land surfaces are usually open areas; thus, they can easily absorb solar radiation. Mid-rise built-up areas increase the shadow areas because of the blocking

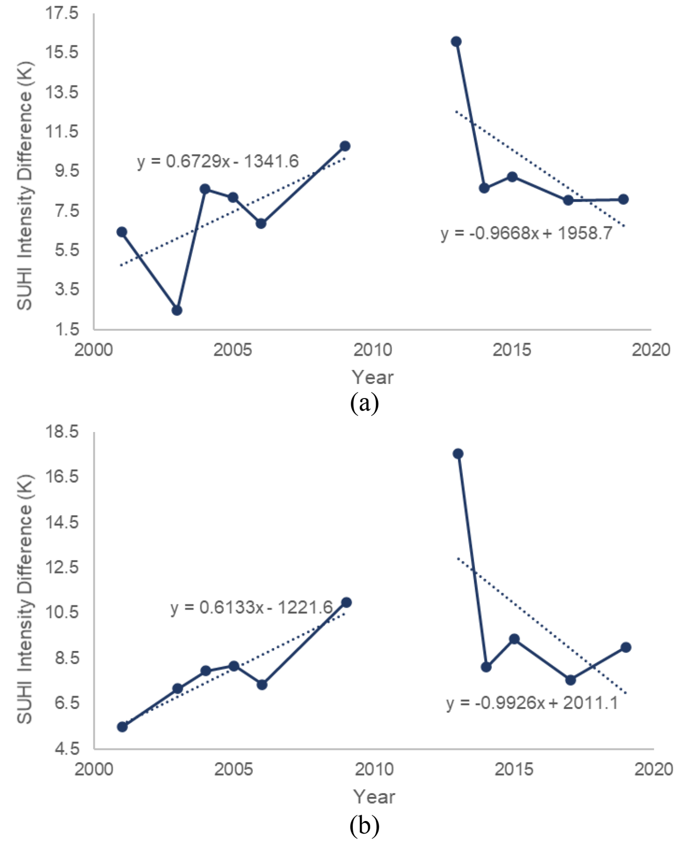


Fig. 10. Change of SUHI intensity from car park to high-rise commercial land. (a) Change of SUHI intensity in sample area, which was bare land before 2008 and built as high-rise commercial land in 2010. (b) Change of SUHI intensity in sample area, which was bare land before 2010 and built as high-rise commercial land in 2012.

of buildings and vegetation; thus, it shows a decrease in SUHI intensity.

E. From Parking Lot to High-Rise Commercial Land

A comparison of the gaps between the redevelopment and invariant regions is shown in Fig. 10. We calculated the slope of the SUHI intensity gap before and after the redevelopment. Both Fig. 8(a) and (b) are positive to negative, indicating that urban redevelopment can weaken the local SUHI. Because of the massive heat emissions of the parking lot and the received solar radiation in open areas, it is always presented as a strong SUHI region. However, high-rise commercial land forms wind porches and shadows by the buildings to promote thermal dissipation and reduce the input solar radiation. Thus, the local SUHI intensity is considerably reduced.

V. Discussion

Urban redevelopment is an important part of this research and is markedly different from other studies on the urban thermal environment. Other studies have also pointed to the mitigating effect of urban development on SUHI [15]. Lan et al. [22] studied the research from a micropoint of view; we investigated the actual land-use types through high-spatial-resolution images from Google Earth, then classified them into five types.

After performing a statistical analysis of LST in the investigated redevelopment district, we found that all the types included in the research had different degrees of mitigation of SUHI. We then speculated the function of redevelopment types separately. This study provides a reference for the construction of an ecocity. The results revealed in this research are of great practical significance in alleviating SUHI, improving the quality of the living environment for residents, and reducing the incidence of a series of SUHI-related diseases. Based on the results, when the industrial areas were transformed into parking lots, the SUHI was reduced. The SUHI was further reduced when bare land and parking lots were transformed into mid-rise and high-rise residential or commercial areas. Therefore, industrial areas, dominated by metal construction materials and anthropogenic heat emissions, make the greatest contribution to SUHI. When bare land or park lots were transformed into high-rise and mid-rise built-up areas, vegetation fraction and geometric characteristics changed. These results reduced the SUHI, indicating that higher buildings with less vegetation were helpful for reducing SUHI.

When the urban village was transformed into a high-rise commercial area, urban geometry changed significantly. The building density decreased, but the building height increased. The reduced building density helps to increase the received solar radiation during the daytime, and the increased building height helps to increase the shadow areas during the daytime. Overall, the rate of increase of the SUHI slowed after the village area was transformed into a high-rise commercial area.

When the industrial areas were transformed into high-rise residential areas, the SUHI first decreased in Fig. 5(a), then increased more slowly. The main differences between industrial and residential areas are the materials, geometry, and anthropogenic heat. The change from mid-rise to high-rise built-up areas causes the shadow and SVFs to differ. Thus, more buildings may result in more shadows and smaller SVFs. Both of two aspects help reduce the LST and may reduce the SUHI. The anthropogenic heat emissions in residential areas are smaller than those in industrial areas, and anthropogenic heat emissions in residential areas increase with the increasing living population. Thus, the SUHI in residential areas continues to increase but is much slower than in industrial areas. As shown in Fig. 5(b), SUHI continued to decrease after being transformed into residential areas. This may be because the green rate in residential areas increases with time. Thus, commission regulation and planning must consider geometry and green rate.

Overall, the LST difference between the redevelopment areas and unchanged areas in the core city became smaller than before redevelopment. This means that redevelopment in Guangzhou has a significant effect on reducing SUHI development. In this study, based on long time-series satellite data and high spatial images from Google Earth, we analyzed the effects of urban expansion and redevelopment on SUHI to provide prudent guidelines for urban planning and redevelopment.

However, this study had some limitations. First, the low spatial resolution of the LST data (120 m for the thermal band of Landsat-5 TM and 100 m for the thermal band of Landsat-8 TIRS) limited the accuracy of the results. To simplify the calculation, all the satellite data and geospatial data used in this study were resampled at 100 m resolution. In future studies, it will be necessary to use data with better resolutions. Second, only five types of redevelopment are discussed in this study. There are more than five types of urban redevelopment. Studies on other types of urban renovation are needed in the future. Third, further studies on the mechanism of how different types of redevelopment affect SUHI are essential. Finally, because the study area was covered by clouds and fog for most of the year, which affects the availability and quality of satellite data, we chose winter as the study period. However, owing to the limited available data, only one view of satellite data was used in this study for one year. Given the seasonal variation in SUHI, future studies exploring the effects of urban expansion and redevelopment on SUHI could focus on a one-year range or use multiview data per year.

VI. Conclusion

Taking Guangzhou City as an example, this study analyzed the SUHI trends in urban redevelopment areas. According to the several typical types of urban redevelopment (from urban village to high-rise commercial land, from low-rise industrial land to high-rise residential land, from industrial land to parking lot, from bare land to mid-rise buildings, and from parking lots to high-rise commercial land), it can be concluded that urban development can reduce the local SUHI or weaken its rate of increase by several degrees; however, the effects of the above five types on the thermal environment differ slightly. Therefore, the reconstruction of urban villages, the reduction of industrial land, and the utilization of idle land as well as open spaces can slow down the SUHI phenomenon. These conclusions provide more scientific support for urban reconstruction and a direction for alleviating the UHI effect.

References

[1] P. Gong et al., "Annual maps of global artificial impervious area (GAIA) between 1985 and 2018," *Remote Sens. Environ.*, vol. 236, 2020, Art. no. 111510.

[2] X. Liu et al., "High-spatiotemporal-resolution mapping of global urban change from 1985 to 2015," *Nature Sustain.*, vol. 3, pp. 564–570, 2020.

[3] J. Li et al., "Similarities and disparities in urban local heat islands responsive to regular-, stable-, and counter-urbanization: A case study of Guangzhou, China," *Building Environ.*, vol. 199, 2021, Art. no. 107935.

[4] G. Chen et al., "Global projections of future urban land expansion under shared socioeconomic pathways," *Nature Commun.*, vol. 11, 2020, Art. no. 537.

[5] G. Xu, L. Jiao, J. Liu, Z. Shi, C. Zeng, and Y. Liu, "Understanding urban expansion combining macro patterns and micro dynamics in three Southeast Asian megacities," *Sci. Total Environ.*, vol. 660, pp. 375–383, 2019.

[6] D. Zhang, Q. Huang, C. He, and J. Wu, "Impacts of urban expansion on ecosystem services in the Beijing-Tianjin-Hebei urban agglomeration, China: A scenario analysis based on the shared socioeconomic pathways," *Resour., Conserv. Recycling*, vol. 125, pp. 115–130, 2017.

[7] X. Li, Y. Zhou, G. R. Asrar, M. Imhoff, and X. Li, "The surface urban heat island response to urban expansion: A panel analysis for the conterminous United States," *Sci. Total Environ.*, vol. 605–606, pp. 426–435, 2017.

[8] F. Renard, L. Alonso, Y. Fitts, A. Hadjiosif, and J. Comby, "Evaluation of the effect of urban redevelopment on surface urban heat islands," *Remote Sens.*, vol. 11, 2019, Art. no. 299.

[9] I. N. Harman, M. J. Best, and S. E. Belcher, “Radiative exchange in an urban street canyon,” *Boundary-Layer Meteorol.*, vol. 110, no. 2, pp. 301–316, 2004.

[10] A. M. Rizwan, L. Y. C. Dennis, and C. Liu, “A review on the generation, determination and mitigation of Urban Heat Island,” *J. Environ. Sci.*, vol. 20, no. 1, pp. 120–128, 2008.

[11] E. Andreou, “The effect of urban layout, street geometry and orientation on shading conditions in urban canyons in the Mediterranean,” *Renewable Energy*, vol. 63, pp. 587–596, 2014.

[12] B. Holmer, S. Thorsson, and I. Eliasson, “Cooling rates, sky view factors and the development of intra-urban air temperature differences,” *Geografiska Annaler, A, Phys. Geogr.*, vol. 89, no. 4, pp. 237–248, 2007.

[13] E. L. Krüger, F. O. Minella, and F. Rasia, “Impact of urban geometry on outdoor thermal comfort and air quality from field measurements in Curitiba, Brazil,” *Building Environ.*, vol. 46, no. 3, pp. 621–634, 2011.

[14] H. Yan, S. Fan, C. Guo, F. Wu, N. Zhang, and L. Dong, “Assessing the effects of landscape design parameters on intra-urban air temperature variability: The case of Beijing, China,” *Building Environ.*, vol. 76, pp. 44–53, 2014.

[15] Z. Pan, G. Wang, Y. Hu, and B. Cao, “Characterizing urban redevelopment process by quantifying thermal dynamic and landscape analysis,” *Habitat Int.*, vol. 86, pp. 61–70, 2019.

[16] Z. Qin, G. Dall’Olmo, A. Karnieli, and P. Berliner, “Derivation of split window algorithm and its sensitivity analysis for retrieving land surface temperature from NOAA-advanced very high resolution radiometer data,” *J. Geophys. Res., Atmos.*, vol. 106, no. D19, pp. 22655–22670, 2001.

[17] J. C. Jimenez-Munoz, J. Cristobal, J. A. Sobrino, G. Soria, M. Ninyerola, and X. Pons, “Revision of the single-channel algorithm for land surface temperature retrieval from Landsat thermal-infrared data,” *IEEE Trans. Geosci. Remote Sens.*, vol. 47, no. 1, pp. 339–349, Jan. 2009.

[18] S. Liang, “Narrowband to broadband conversions of land surface albedo I: Algorithms,” *Remote Sens. Environ.*, vol. 76, no. 2, pp. 213–238, 2001.

[19] B. B. da Silva, A. C. Raga, C. C. Braga, L. M. M. de Oliveira, S. M. G. L. Montenegro, and B. Barbosa Junior, “Procedures for calculation of the albedo with OLI-Landsat 8 images: Application to the Brazilian semiarid,” *Revista Brasileira de Engenharia Agrícola e Ambiental*, vol. 20, no. 1, pp. 3–8, 2016.

[20] I. D. Stewart, T. R. Oke, and E. S. Krayenhoff, “Evaluation of the ‘local climate zone’ scheme using temperature observations and model simulations,” *Int. J. Climatol.*, vol. 34, no. 4, pp. 1062–1080, 2014.

[21] J. Yang et al., “Observing the impact of urban morphology and building geometry on thermal environment by high spatial resolution thermal images,” *Urban Climate*, vol. 39, 2021, Art. no. 100937.

[22] H. Lan, K. K.-L. Lau, Y. Shi, and C. Ren, “Improved urban heat island mitigation using bioclimatic redevelopment along an urban waterfront at Victoria Dockside, Hong Kong,” *Sustain. Cities Soc.*, vol. 74, 2021, Art. no. 103172.