Urbanisation and Urban Heat Island in a Mekong Delta City: From Monitoring to Dominant Factors

Chapter · September 2023

DOI: 10.1007/978-981-99-3675-5_13

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Chapter 13
Urbanisation and Urban Heat Island in a Mekong Delta City: From Monitoring to Dominant Factors

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Abstract Urbanisation is an indispensable process along with socio-economic development. However, this is also the root of various challenges in urban areas from social to environmental and microclimate changes such as urban heat islands (UHI). This book chapter showcases a case study regarding rapid urbanisation, dynamic of surface urban heat island (SUHI), and controlling factors of UHI in Can Tho city—a regional newly developing city in the Vietnamese Mekong Delta since 2005. Using an integrated methodology framework of earth observation analyses and Analytic Hierarchy Process (AHP), we assessed the urbanisation trends based on urban density and annual growth rate (AGR). The deterioration of SUHI was analysed using land surface temperature (LST) retrieved from Landsat thermal infrared band. AHP is a social approach via expert interviews to identify the key elements and their contribution weights to UHI under the local conditions. It revealed that urban areas have continuously expanded outwards since 2005 towards the Western and main roads along the Bassac river. The AGR is about 0.73%/year over the period of 2005–2019. In particular, the city center has experienced a relatively high rate of urbanisation compared to other areas (i.e., 3.98–5.04% versus 0.5%/year). LST increased significantly and the growth of SUHI was more moderate in terms of intensity and spatial patterns. SUHI is frequently observed in industrial zones and densely populated areas. Urban sprawl was found to significantly stimulate the variations of SUHI intensity. Regarding to the driving factors of UHI, five (05) main factors including nature, society, infrastructure, policy and environment are found contributing to form of UHI at this specific area. In which, the natural factors including coverage ratio of vegetation and water surface are the most contributors to UHI. The key analytical

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A. Cheshmehzangi et al. (eds.), *Climate Change and Cooling Cities*, Urban Sustainability, https://doi.org/10.1007/978-981-99-3675-5_13

factors from AHP are likely to be prioritised elements, which should be mainstreamed into urban planning to mitigate UHI towards a cooling city.

Keywords Analytic Hierarchy Process (AHP) · Can Tho city · Land surface temperature · Surface urban heat island · Urbanisation

1 Introduction

Can Tho city is an important regional and national city in Southern Vietnam as it is located in the "heart" of the Vietnamese Mekong delta—a critical economic region in the Southwest of the country. It was established in 2004 based on the division of Can Tho province into Can Tho city and Hau Giang province. With massive investments over the past decades, Can Tho city owns key elements for development and becomes a rapidly developing city compared to the other five national municipalities. It has made drastic transformations in population and urban areas. For example, it has witnessed a population growth of 564 thousand over ten years from 2005 to 2015, in which urban residents increased by 2.6% (UNs, 2015). Urban areas have also expanded speedily, especially from 2005 onwards (Diep et al., 2021; Son & Thanh, 2018). In 2009, the city was upgraded from Class-2 city to Class-1 city due to its significant growth.

Rapid urbanisation creates favourable conditions for attracting more investment capital and general development motivations. However, it also raises many issues that need to be efficiently solved such as investment policy, land budget, land use transformation and planning, environmental degradation, microclimate change, and career transition due to changes in economic structures (Can et al., 2021; Nguyen et al., 2022). Among these alterations, urban microclimate change is one of the most concern issues since it influences human health and well-being of urban residents. It is induced by rapid urbanisation since urbanisation extensively removes natural surfaces and uses more heat retention materials. Urbanisation also reduces heat evaporative and transformative rates, modifies local climate, airflow and atmosphere.

Urban heat island can be understood as a phenomenon that at the same time, the average temperature in urban development areas with many man-made structures is higher than in rural areas with natural surroundings (Oke, 1982). Urban heat islands are often characterised by built-up areas with most surface materials such as metal roofs, paved roads, concreted structures with low reflection and high absorption of solar energy (Smith et al., 2011). The changes of surface properties and anthropogenic heat sources from human activities along with the urban expansion and industrialisation are jointly contributing to form UHI (Li et al., 2021; Raj et al., 2020).

UHI is one of the main concerns in urban areas due to its negative impacts on human health, energy consumption, and environmental pollution. A number of studies revealed the increased risk of heat-related mortality and morbidity, which mostly affected due to the land surface temperature variations (Benmarhnia et al, 2016; Longden, 2019). In addition, the increase in UHI leads to an increase in energy consumption due to the high demand for cooling during the extreme heat events (Can et al., 2020). UHI also affects the air and water quality and greenhouse gases emissions (Li et al., 2018).

There are several efforts to control and mitigate UHI. It is apparent that UHI is the main consequence of urban development. Yet, UHI is actually controlled jointly by many factors. Therefore, the current strategies intervening a few elements may lead to inefficient mitigation UHI. Enhancing understanding of controlling drivers of UHI will definitely improve the efficiency of solutions for mitigation and adaptation strategy toward greener and low carbon cities in the future, as a basis for urban development planning and orientation of the region. Besides, it also provides a good example for urban planning in similar new developing cities.

2 Rapid Urbanisation in a Just-Established City of a National Municipality

2.1 Evidence of Urban Expansion Through Earth Observation Data

The observation of normalised difference built-up index (NDBI) presents the index accumulation over the past twenty years. The high values regions are the former and unchanged urban areas over time, while the regions with lower values belong to newly developing areas and non-urban areas when it approaches minimum values of NDBI. The expanded urban areas tend to sprawl from the urban core outwards to vicinities and along the transportation system with high urban areas mainly concentrated in Ninh Kieu and Thot Not districts (Fig. 1).

A change detection analysis using land use/cover (LUC) maps was adopted to explore land use/cover changes (LUCC) and urbanisation dynamics. Specifically, LUC maps were obtained from the object-based classification using Landsat spectral bands. There were drastic shifts in LUC over the past 14 years toward urbanisation (2005–2019). LUC has converted from pure agriculture to an economy that less depends on agricultural production. In 2005, about 93.91% of the city's area was covered by green spaces. The green space proportion gradually decreased to 83.31% with more than 10% shared by paddy fields and annual crops in 2019. At the same time, the built-up areas have expanded by 146.63 km^2 to gain urban proportion from 2.16 to 12.34%.

The urban areas are also distributed along the roads and rivers as tree branch form. Specifically, it has experienced dynamic urbanisation along the Bassac River in Cai Rang, Ninh Kieu, Binh Thuy, O Mon, and Thot Not districts. It also inherits the characteristics of urban expansion as in other flat plain deltas that urban areas dominate vicinities under extension form. This expansion has clearly been observed in Ninh Kieu and Thot Not districts, where are both the two urban cores and gateways

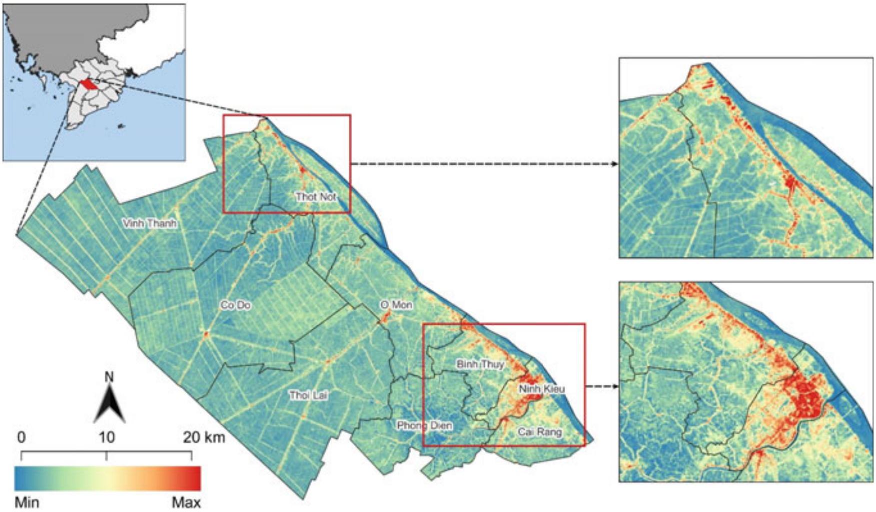

Fig. 1 Accumulative landsat-based NDBI from 2000 to 2020 in the entire Can Tho city and zoom-in areas in two primary urban cores in Ninh Kieu and Thot Not districts

connecting provinces in the Ca Mau peninsula and other parts on the West side (Fig. 2).

The urbanisation at subdistrict level was analysed by two criteria including urban density and annual growth rate (Can et al., 2021). Urban density measures the relative rate of urban area against the total area of each administrative unit. Besides, the annual growth rate (AGR) reveals the average urbanisation speed yearly. Natural break (Jenks) presents urban density and AGR at five levels corresponding to Low/Relatively low/Medium/High/Very high. It indicates that most subdistricts had low and relatively low urban density at the beginning (<8.26%). The high and very high urban density subdistricts were in the city center of Nink Kieu. At the end of the period, there were significant improvements in urban density. The high and very high urban density regions (>32.34%) expanded and occupied almost Ninh Kieu, Binh Thuy, and Cai Rang districts. The neighboring counties and the town of districts (e.g., Vinh Thanh, Co Do, Thoi Lai) had medium urban density, while rural counties in the transition zone have improved their density from low to medium–low levels (Fig. 3).

It is in line with social evidence that earth observation data also reveals the dynamic of urbanisation in terms of AGR. The subdistricts have a relatively high urbanisation speed, higher than 0.75%/year except for the slow regions in immense paddy fields in the South and Southwest of the province. An Khanh (Ninh Kieu district) is the most dynamic county within this period, with AGR = 5.04%/year. High urbanisation regions are in town of Thot Not district (3 subdistricts) and An Binh and Hung Loi (Ninh Kieu district). The contiguous areas of Ninh Kieu in An Thoi (Binh Thuy district) and Hung Thanh, Ba Lang, Phu Thu (Cai Rang district) are also relatively

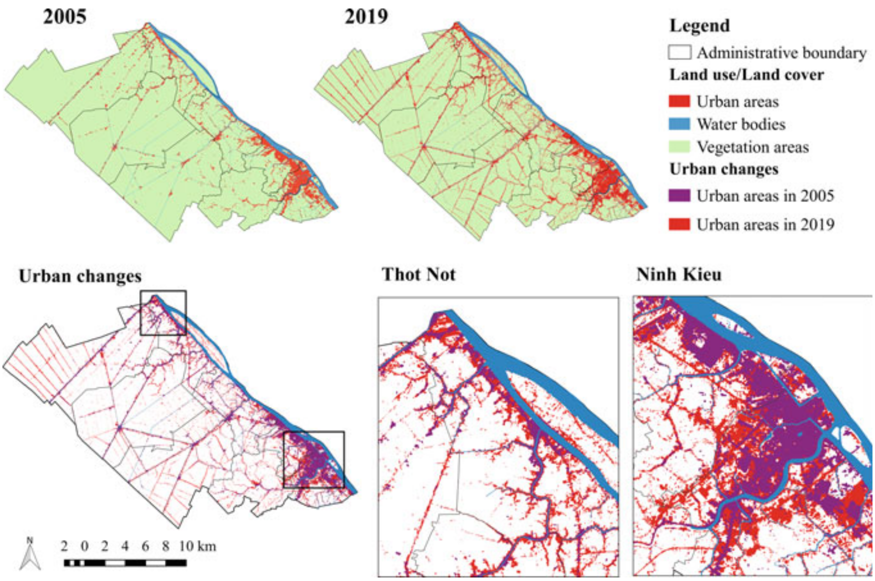

Fig. 2 Land use/cover changes from 2005 to 2019, urban changes, and fragmented maps show two primary urban cores in Ninh Kieu and Thot Not districts

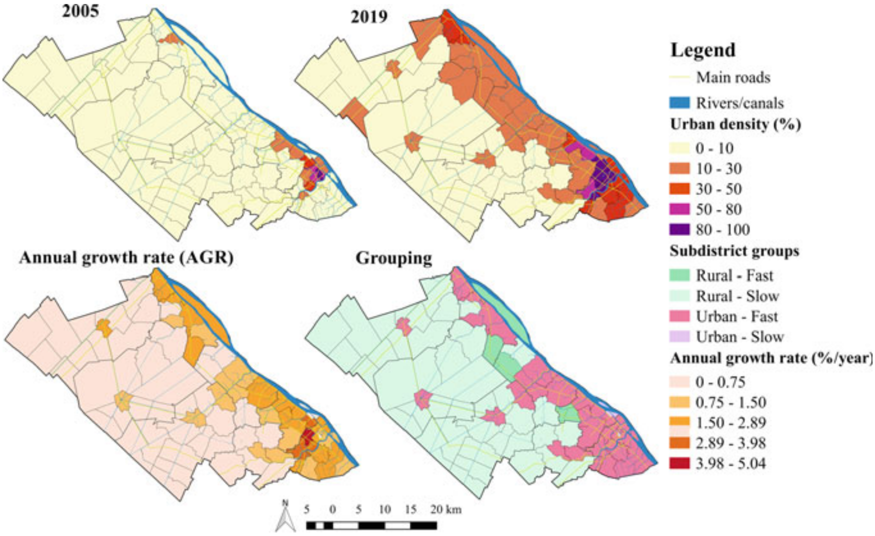

Fig. 3 Urban density over subdistricts in 2005 and 2019, annual growth rate over the period, and subdistrict groups based on urban density and AGR

dynamic (AGR = 1.5–3.98%/year). Besides, the development in peri-urban and district centers also deserves to be considered with medium and relatively low speed.

2.2 A Conventional Framework for Urbanisation Assessment

Subdistricts were considered by a conventional grouping method, which differentiates using median values of urban density and AGR as a proxy standard (Can et al., 2021). A county with an urban density higher than the median value is an urban county. A county has an AGR value higher than the median value assigned to be a fast urbanisation county and vice versa. This method generates four groups based on two-dimensional data. It reveals four unique groups with different concerns. A group of urban subdistricts with a high urbanisation rate (orange shade), where it should have efficient solutions to address common urban problems such as infrastructure overload, environmental pollution, clean water, and sanitation. Besides, rural counties with fast urbanisation have experienced the most dynamic processes when transforming from rural to urban areas. It should have a long-term vision and strategies to develop the city and ensure consistency of infrastructures. On the other hand, urban subdistricts with low urbanisation are city centers with the city seeming to be highly concentrated and saturated. Urban morphology and spatial planning should be taken into account as they will significantly contribute to stimulating urban microclimate (e.g., urban heat islands, thermal discomfort) and ultimately impact on human well-being.

3 Deterioration of Urban Thermal Environment

3.1 Spatial Distribution of Land Surface Temperatures

Landsat thermal infrared band is the main data source for retrieving land surface temperature (LST). It was obtained by converting brightness temperature and then calibrating by NDVI-based land surface emissivity (Son & Thanh, 2018; Van De Griend & Owe, 1993). LST was reclassified into seven groups from low to high based on average value and standard deviation for peer comparison (Zhang et al., 2017).

The distribution of LST shows that most of the high and very high surface temperatures were located in the central areas such as Ninh Kieu, Binh Thuy, Cai Rang districts. The surface temperature in 2019 elevated significantly compared to those in 2005, especially in sub-central districts of O Mon and Thot Not districts. In contrast, the temperature remained relatively lower than average value in the rural areas cultivating rice farming, annual crops, and agricultural crops. Notably, the dense

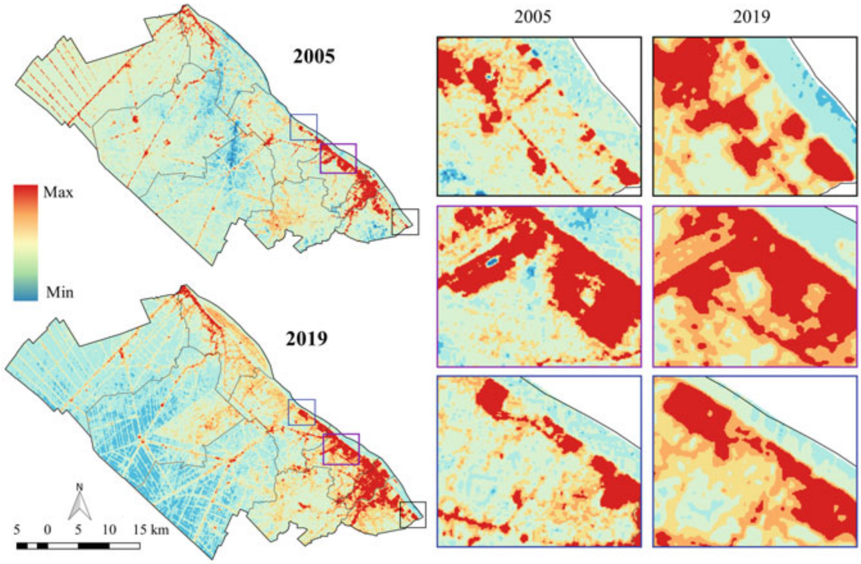

Fig. 4 Land surface temperature in 2005 and 2019 and comparison at zoom-in locations, whereas a, b, c present for first, second and third locations of LST variation between 2005 and 2019

construction and areas with high concentration of impervious surfaces, such as industrial zones of Binh Thuy and Cai Rang, thermal power plants and airport at O Mon district, where always experienced high LST of higher than 28.5 °C (Fig. 4). The areas with high-density population, built-up and less vegetation were found corresponding to higher surface temperatures over the years. The percentage of impervious surfaces and its expansion during urbanisation are closely associated with the increase in LST.

3.2 Formation of Surface Urban Heat Island Over the Past Decade

Surface urban heat island (SUHI) is determined when the surface temperature at any location greater than the average temperature of the entire considered area (Ya et al., 2010).

$$\mathrm{LST} > \mathrm{T_{mean}} + 0.5 \times \mathrm{S_d}$$

where T_{mean} is the average land surface temperature; S_d is the standard deviation.

Surface urban heat island magnitude (I_{SUHI}) is estimated based on the difference in the average surface temperature of the urban area (LST_{urban}) compared to the non-urban area ($LST_{non\text{-}urban}$), whereas the non-urban defined as the eliminating of urban areas.

$$I_{SUHI} = LST_{urban} - LST_{non\text{ - }urban}$$

Surface urban heat island tended to aggravate over time both in terms of dominated areas and heat threshold. In 2005, there was about 17.37% of Can Tho city occurred SUHI. It then expanded up to 24.18% of total areas in 2019 (Fig. 5). SUHI distributed mainly in Ninh Kieu district, residential areas along the 1A national highway in Cai Rang district, the 91 national highway connecting Ninh Kieu District, Binh Thuy and the center of O Mon, Thot Noi, Phong Dien Town, Co Do, Thoi Lai, Vinh Thanh and Thanh An Town (Fig. 5). SUHI intensity has also witnessed dramatical elevation. If the SUHI intensity of higher 6 °C is set up as an extreme proxy, SUHI severity was recognised its encroachment throughout the time. For instance, the highest SUHI in year 2005 was estimated at 6.28 °C and the areas with SUHI higher than 6 °C was only about 27 ha. These values were increased to 8.96 °C and occupied about 87 ha in the year of 2019. The areas with high SUHI intensity also distributed at industrial zones, e.g., Hung Phu 2 Industrial Park, Viet Nhat Industrial Park, and Cai Cui Port, O Mon Thermal Power Plant, Can Tho International Airport, where the temperature is always higher than the surrounding areas about 1–2 °C.

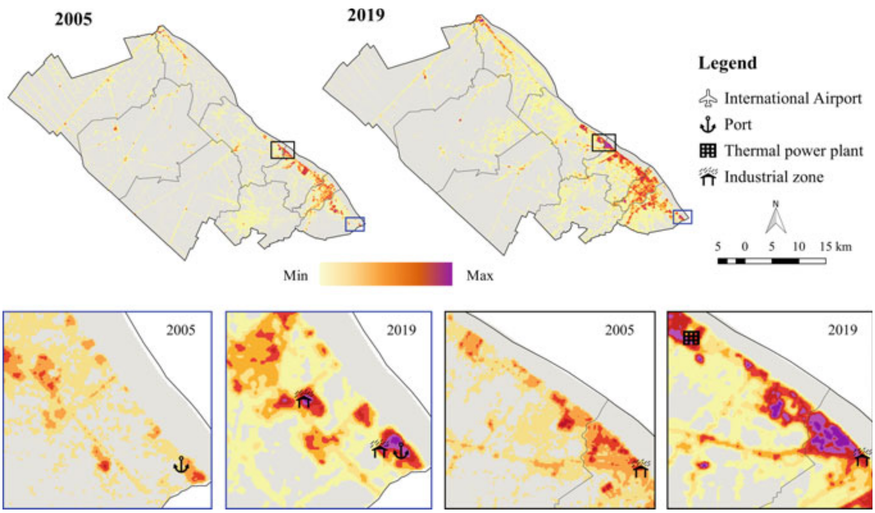

Fig. 5 Development of surface urban heat island and its spatial distribution over time at typical sites

3.3 *Significant Hotspots in Surface Urban Heat Island Formation Along with Urban Development*

The significantly meaningful hotspots have experienced changes in urban thermal environment, where urban dwellers are supposed to face thermal severity. The hotspots were detected by calculating Getis-Ord Gi* statistical value for each object in the data layer. Specifically, probability (p-value) and standard deviation (z-score) are the criterion to identify a certain region belonging to hot or cold regions of SUHI. This tool works by looking at each feature within the context of neighboring features. A feature with a high value of SUHI is interesting but may not be a statistically significant hot spot. To be a statistically significant hot spot, a feature need to have a high SUHI value and be surrounded by high SUHI values as well. The local sum for a feature and its neighbors is compared proportionally to the sum of all features; when the local sum is very different from the expected local sum, and when that difference is too large to be the result of random chance, a statistically significant z-score results.

P-values and z-scores were estimated the aggregation significance (90%, 95% and 99%) for hotspots as well as coldspots. Aggregation is considered to be statistically significant when z-scores are higher than 1.65 (confidence level of 90%), higher than 1.96 (confidence level of 95%), higher than 2.58 (confidence level of 99%) for hot spot areas, or lower than −1.65 for cold spot areas. Otherwise, the result will be responded to a random spatial distribution (Getis & Ord, 1992; Rossi & Becker, 2019). Thus, in this research, the hotspots of SUHI with a significance level of higher 90% representing a high concentration of SUHI, which distributed mainly into three isolated zones (Fig. 6). Zone I has the highest SUHI intensity in the city center of Ninh Kieu, Cai Rang, and Binh Thuy districts with the dense concentration of population and industrial zones. Zone II has the moderate SUHI intensity, distributed in the center of Thot Not district. Plus, Zone III owns a relatively low SUHI intensity in the center O Mon district.

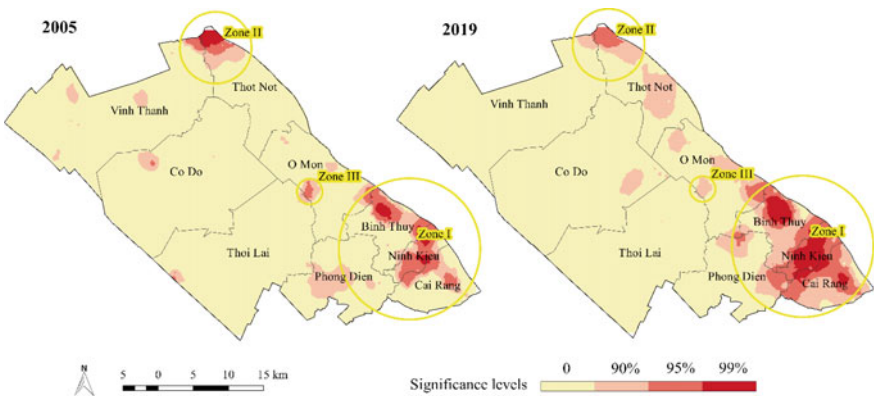

Fig. 6 Surface urban heat island clusters in 2005 and 2019 (The zone 1, 2, and 3 present the specific highlight locations of UHI clusters)

SUHI is highly correlated with the ratio of urban areas (positive) and the ratio of vegetation areas (negative) ($|r| > 0.9$). It also has a relatively high relationship with LST ($r = 0.72$). The urbanisation leads to vegetation reduction and urban expansion, which strongly contribute to exacerbate SUHI intensity. It implies a promising solution to mitigate SUHI in urban areas by enhance cool surfaces such as green spaces and water bodies within the city.

In terms of earth observation for urban theme, further studies need to be taken into consideration to overcome the uncertainty in urban extraction, the different remote sensed indices may need to apply for distinguish bare land and small parcel of impervious areas. Besides, LST analysis need to be considered by cloud issues and temporal resolution in further applications.

4 Key Controlling Factors of UHI

Analytic Hierarchy Process (AHP) was conducted through expert interviews to detect the key elements and their contribution weights to UHI under local conditions. A list of key elements (principal factors and sub-factors) was formed based on the literature review and first round interview. The elements rated by about 50% of experts as unimportant will be removed in second interview. The relative importance of the key elements was rated in nine importance scales, from absolutely less important (1/9), very less important (1/7), less important (1/5), somewhat less important (1/3), equal important (1), somewhat more important (3), much more important (5), very much more important (7), and absolutely more important (9). Nine experts were interviewed, who are considered as to have expertise in their fields related to environmental resources, economy, society, and policy to figure out different aspects of UHI. The weight of each elements was then estimated using the pairwise comparison matrix (Saaty, 1980). The Consistency Ratio (CR) is an indicator to evaluate the consistence of expert's opinions, which was obtained as follows fomular (Samo & Anka, 2009):

$$CR = CI/RI$$

where: RI is a random index; CI is a consistency index measuring the consistent deviation (Saaty, 1977, 1980). According to AHP approach, as explaintation in text, the expert's opinion with CR < 10% were selected as it is relatively consistent. In contrast, if CR > 10%, the assessment are inconsistent, there are a need to be rechecked and conduct the interview again. This study, the only CR met requirements of consistence are further processed. The bold values in Table 1 showed the highest weight in the sub-factors. Accordingly, the importance levels of five groups, principal factors, and 23 sub-factors were analysed and presented in Table 1.

Among principal factors, nature is the most important contributor to UHI ($W_N = 0.493$). It is then followed by society ($W_s = 0.211$), infrastructure ($W_I = 0.116$), environment ($W_E = 0.101$) and policy ($W_P = 0.081$). In essence, the nature of surface

Table 1 Weights of key elements obtained by AHP

Principal factor	Weight of principal factors (W_1)	Sub-factors	Weight of sub-factors (W_2)	Overall weight ($W = W_1 \times W_2$)
Nature (N)	**0.493**	**N1. Ratio of water surfaces**	**0.368**	**0.181**
		N2. Vegetation areas	0.202	0.100
		N3. Weather, climate	0.152	0.075
		N4. Solar radiation	0.113	0.056
		N5. Urban form (sky view)	0.080	0.040
		N6. Climate changes	0.052	0.026
		N7. Ratio of cool surfaces	0.032	0.016
Society (S)	0.211	**S1. Urbanisation**	**0.411**	**0.087**
		S2. Population density	0.237	0.050
		S3. Traffic at transit station and intersection	0.149	0.031
		S4. Bussiness activities	0.117	0.025
		S5. Lifestyle	0.086	0.018
Infrastructure (I)	0.116	**I1. Urban design**	**0.512**	**0.059**
		I2. Building materials	0.175	0.020
		I3. Concrete pavement	0.130	0.015
		I4. Urban structures	0.101	0.012
		I5. Direction of buildings	0.082	0.009
Policy (P)	0.081	**P1. Urban planning**	**0.640**	**0.052**
		P2. Urban design orientation	0.175	0.014
		P3. Architectural planning policy	0.107	0.008
		P4. Policy for rural construction	0.078	0.006
Environment (E)	0.101	**E1. Environmental factors, air pollution**	**0.865**	**0.087**
		E2. Solid waste disposal	0.135	0.014

characteristics mainly defines and contributes to UHI significantly compared to other factors. For example, the natural surfaces (e.g., lake, river, and dense vegetation) are always cooler than constructions at the same time.

Regarding the sub-factors of nature, the ratio of surface water and vegetation areas are the most important in comparison to others ($W_{N1} = 0.368$; $W_{N2} = 0.202$). Among sub-factors of society, urbanisation has the highest overall weight ($W_{S1} = 0.411$) following by population density (W $W_{S2} = 0.237$), traffic at intersection ($W_{S3} = 0.149$), transit stations ($W_{S3} = 0.117$) and lifestyles ($W_{S4} = 0.086$). Meanwhile, urban design is the most important element that was believed to significantly cause UHI in urban areas among the infrastructure elements ($W_{I1} = 0.512$). Urban planning is the most critical policy factor that influences UHI through stimulating or hindering urbanisation at a certain city ($W_{P1} = 0.640$). Besides, environmental variables and air pollution were supposed to be favorable conditions amplifying UHI ($W_{E1} = 0.865$).

5 Heat Mitigation Strategies

In recent, there are number of guidelines and proposed solutions to mitigate UHI from different perspectives of urban policies. However, it is obvious that UHI is regulated by a bun of different controlling factors from nature to climate, policy, and society. These factors could even interact and contribute to UHI at different extents. Therefore, the local governments often fail in UHI mitigation efforts because they only control a limited element, or they are too ambitious in trying to adjust too many elements at the same time. The AHP revealed the key controlling factors of each category, which are widely perceived by experts. Therefore, these elements should be prioritised to mainstream into urban planning to effectively mitigate UHI. Additionally, these factors are the highlights that easy to receive the consensus from the community in the development strategies toward a greener city. The following sugguestions of heat mitigation strategies could be considered in future:

- The intergated solutions need to be developed base on the interdisciplinary approaches. In fact, the UHI formed by many different factors as mention in previous sessions, so one single aspect solution could be less effectively adress the mitigation strategies.
- The increase, conservation, and optimisation, and diversification urban green and blue spaces are needed since they are considered as sink landscapes with contributing to cooling urban.
- The practical urban planning and actions based on the finding of scientific reseach intergating with the participatory of local people would be the principle framework contributing in UHI mitigation strategies.
- The pracitical urban design need to consider to construction standards, and distribution planning inside urban areas to encourage urban ventilation as well as increase landscape heterogeneity.
- The intergated implementation of environmental solutions to improve the increasingly degradation of air pollution in urban areas are need to be part of mitigation strategies.
- The raising awareness of local people specific to young people and children on UHI mitigation modelling and visualization would be long term impacts and effectively contributing on mitigation toward the greener city.

6 Conclusions

This chapter analysed the urbanisation and surface urban heat island in a typical city in the Mekong delta. An overall scene of spatial urban development, alternations in urban thermal environment, and controlling factors of UHI under indigenous conditions was depicted by different approaches to reflect the current context of the city. To conclude, Can Tho city owns the following characteristics and highlights:

- The city has rapidly developed with spatial urban expansion clearly observed during the period from 2005 to 2019. The urban density and annual growth rate have significantly increased over time, especially in the main city center, the towns at each regional districts, and the ribbon of urban areas along the Bassac River.
- SUHI has dramatically elevated with close association with urban expansion in developed centers, where have experienced rapid urban sprawl, especially in high concentration areas of constructions and industrial parks.
- The changes in urban microclimate specified as UHI in Can Tho city are relatively similar to other cities. It is dominated by a set of factors including natural and environmental characteristics, society, infrastructures, and policy. Maintaining and improving natural spaces such as water bodies and vegetation are the most promising intervention to mitigate UHI. However, integrated interventions regulating the key elements in each aspect should be a more effective solution to release UHI severity.

Beside evaluating the spatial urban expansion using remote sensed data, the highlight of this chapter is quantitatively measured the important of key elements, which support the valuable information for identifying the priorities to be implemented in urban planning. The lesson learned in Can Tho city, typical emerging city in Mekong region, will be good example for similarly cities to avoid the forming of UHI in development strategy.

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