

## Chapter 48

# Urban Climate Challenges in Hanoi: Urban Heat Islands and Global Warming



**Andhang Rakhmat Trihamdani, Han Soo Lee, Tetsu Kubota, Satoru Iizuka, and Tran Thi Thu Phuong**

**Abstract** Urban climate of rapidly growing cities such as Hanoi will alter not only owing to land use changes but also global warming effect. This chapter investigates the contributions of land use changes and global warming to the future increases in urban temperature in Hanoi for 2030 through a numerical simulation using the Weather Research and Forecasting (WRF). The future climate data utilized the fifth phase of the Coupled Model Intercomparison Project (CMIP5) projected by the Model for Interdisciplinary Research on Climate Version 5 (MIROC5) through a direct dynamical downscaling method. In the 2030s, the average air temperature increase in the existing urban areas was projected to be up to 2.1 °C, of which up to 1.5 and 0.6 °C are attributable to global warming and land use changes, respectively. The future increase in urban temperature will likely exceed the cooling effects of any urban heat island (UHI) mitigation measures.

**Keywords** Urban heat island · Developing cities · Master plan · Global warming · Dynamical downscaling

## 48.1 Introduction

Currently, major cities in the Southeast Asia tend to propose the large-scale urban development plans and increase their populations further. In Hanoi, Vietnam, a long-term urban development plan, namely, the Hanoi Master Plan 2030, was created and

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A. R. Trihamdani (✉)  
YKK AP R&D Center, PT. YKK AP Indonesia, Banten, Indonesia

H. S. Lee · T. Kubota  
Graduate School for International Development and Cooperation (IDEC), Hiroshima University, Hiroshima, Japan  
e-mail: [leehs@hiroshima-u.ac.jp](mailto:leehs@hiroshima-u.ac.jp); [tetsu@hiroshima-u.ac.jp](mailto:tetsu@hiroshima-u.ac.jp)

S. Iizuka  
Graduate School of Environmental Studies, Department of Environmental Engineering and Architecture, Nagoya University, Nagoya, Japan  
e-mail: [s.iizuka@nagoya-u.jp](mailto:s.iizuka@nagoya-u.jp)

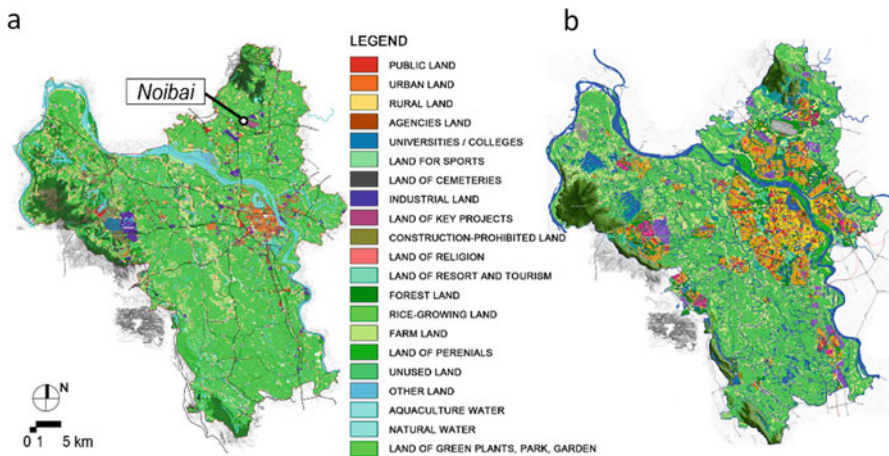
T. T. T. Phuong  
Vietnam Institute of Urban and Rural Planning, Hanoi, Vietnam

its urban population is projected to increase from 6.7 million in 2010 to 9.2 million by 2030 [1]. The expansion of the city would result in a dramatic change in land use and therefore the urban climate. Meanwhile, the effects of global warming vary according to geographical locations and are highly anticipated in urban areas even in the future as near as 2030 [2]. Thus, the urban climate of rapidly growing cities such as Hanoi is predicted to change not only owing to land use changes but also global warming.

In this chapter, we analyse the contributions of land use changes and global warming to future increases in urban temperature in Hanoi for 2030. From the current land use condition in 2010, we adopt the land use condition proposed by the Hanoi Master Plan for the year 2030. Then, numerical simulations – specifically, regional climate modelling using Weather Research and Forecasting (WRF) – were conducted for the present land use as well as the land use condition of the master plan under the same weather conditions for the detection of only the impact of land use changes. Subsequently, WRF simulations were conducted for the land use condition of the master plan under the influence of global warming in the 2030s, utilizing the climate data from the fifth phase of the Coupled Model Intercomparison Project (CMIP5) projected by the Global Climate Models (GCMs). The GCM data were incorporated into WRF as initial and boundary conditions using a dynamical down-scaling method [3].

## 48.2 Overview of Hanoi Master Plan 2030

The city of Hanoi includes 10 urban districts and 18 outskirts districts, which make up an area of approximately 3300 km<sup>2</sup>. The city centre is located at 21°11'2"N 105°48'E, in the area along the Red River delta, which is approximately 90 km inland from the coastal line (Fig. 48.1). Hanoi has a humid subtropical climate,



**Fig. 48.1** Land use and land cover for (a) current condition and (b) the Hanoi Master Plan 2030 (Source: VIAP [1])

which experiences a hot-humid season (April to October) and a cool and relatively dry season (November to March). The maximum monthly average air temperature is observed in June, which is approximately 30.3 °C, whereas the minimum average value is recorded in February (approximately 17.5 °C).

To cope with rapid urbanization, the long-term urban development plan, the Hanoi Master Plan 2030, was established in 2011 (Fig. 48.1b). In the master plan, the population of Hanoi is projected to reach 7.3–7.9 million by 2020, 9–9.2 million by 2030 and approximately 10.8 million by 2050. The major target of the master plan is to develop Hanoi as a green-cultured and civilized modern city. To achieve the above target, the master plan proposes a series of spatial development strategies for the city, including the network of green spaces consisting of the established green corridor, green belts, green buffers and other green spaces. As a result, the green coverage would account for approximately 52% of the total land of the city, while the urban green spaces will increase remarkably, from only 745 ha (0.2%) in 2009 to 15,770 ha (5%).

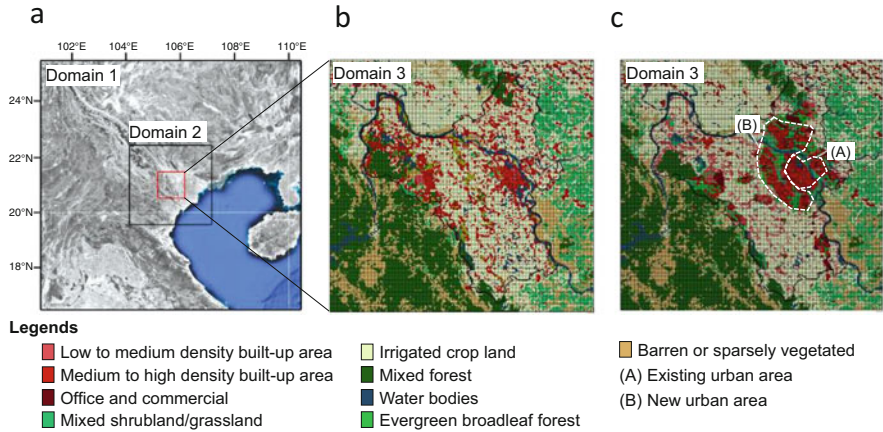
## 48.3 Methodology

### 48.3.1 WRF

Numerical simulations were performed using WRF to obtain basic weather data, such as air temperature, humidity and surface winds. The present study used WRF version 3.6 [4]. Three simulation domains were configured so that the innermost domain covers the entire Hanoi City. The horizontal grid resolution of the three domains is 4.5 km, 1.5 km and 0.5 km for domains 1, 2 and 3, respectively (Fig. 48.2). The urban canopy model (UCM) was set up with default parameters as listed in [5] for simulation of the effect of urban geometry on urban climate [6]. The physics schemes used in numerical experiments are listed in Table 48.1. The validation of this method together with sensitivity tests for selecting the model parameterization is described in [7].

### 48.3.2 Experimental Design

Most of UHI studies under future climate conditions have relied on the outputs of GCMs. However, the spatial resolution of GCMs is too coarse (approximately 50–100 km) for urban-scale climate simulation. Downscaling methods have been developed to overcome this problem and obtain local-scale weather and climatic features, particularly at the surface level, from global- and regional-scale atmospheric GCM output variables. The dynamical downscaling uses a limited-area, high-resolution regional climate model (i.e. WRF in this study) driven by initial and boundary conditions from a GCM to derive smaller-scale features of the local



**Fig. 48.2** (a) Three computational domains for WRF simulations. Domain 3 (indicated with red-line square) covers the whole Hanoi City. Land use map of domain 3 with 0.5 km horizontal grid resolution for (b) current condition and (c) master plan condition [8]

**Table 48.1** WRF physics scheme

Physics scheme	Physics options
Cumulus scheme	Kain-Fritsch scheme
Microphysics	WRF single-moment (SM) 3-class scheme
Planetary boundary layer	Yonsei University (YSU) scheme
Longwave radiation	RRTM scheme
Shortwave radiation	Dudhia scheme
Surface layer	Monin-Obukhov similarity scheme
Land surface	NOAH land surface model (NOAH LSM) with UCM

climate. Among CMIP5 datasets from various GCMs, the Model for Interdisciplinary Research on Climate Version 5 (MIROC5) was used in this study [9].

The projected climatic data by CMIP5 are based on the assumption that the concentrations of greenhouse gases such as CO<sub>2</sub> will change in the future. The IPCC refers to it as the Representative Concentration Pathways (RCPs), comprising four pathways, known as RCP8.5, RCP6.0, RCP4.5 and RCP2.6 [10]. In this study, the dynamical downscaling processes with the WRF were performed for RCP4.5 and RCP8.5 for moderate and extreme cases, respectively. Furthermore, in order to consider climate variability and uncertainty from the interannual variability in climate projection, the WRF simulation was conducted for each June between 2026 and 2035. These 10-year repetitive simulations of each June will also provide the upper and lower bounds from the dominant interannual variability and further insight for a multi-model ensemble mean and variation over the Hanoi region. The full months of June were chosen as the simulation periods so that the maximum air temperatures during the summer can be observed.

In order to understand the contributions of land use change and global warming to the future increase in urban temperature in Hanoi, this study assessed four scenarios, namely, cases 1, 2-1, 2-2 and 2-3. Case 1 represents the current land use condition (Fig. 48.2b). The simulation for case 1 was conducted in June 2013 in which the monthly average air temperature (33.6 °C) is relatively close to the average air temperature in June over the 15-year period from 2000 to 2015. Accordingly, the initial and boundary conditions for WRF simulation were imposed by the NCEP Final (NCEP-FNL) Analysis 6-hourly data from June 2013.

The land use conditions in cases 2-1, 2-2 and 2-3 represent the proposed land use plan in the Hanoi Master Plan 2030 (Fig. 48.2c). In case 2-1, the WRF simulation was conducted under the same weather conditions as those in case 1. Thus, the impact of land use change on UHI can be observed by contrasting the results between cases 1 and 2-1. On the other hand, cases 2-2 and 2-3 were examined under the two scenarios utilizing RCP4.5 and RCP8.5 datasets of MIROC5, respectively, in order to analyse the influence from global warming. The simulations for both cases were conducted in each June, from 2026 to 2035. In addition, only the days with prevailing southeasterly winds (i.e. winds coming from directions between 90° and 180°) were taken into account in the analysis. Further explanations are included in [8].

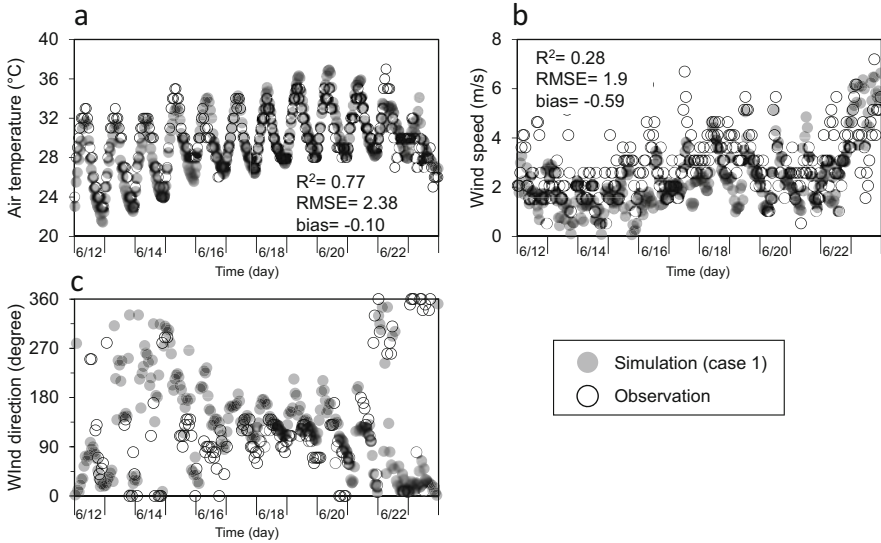
### 48.3.3 Model Validation

The WRF simulation was performed for case 1 from 00:00 UTC on 12 June 2013 to 00:00 UTC on 24 June 2013. The simulation results were compared with the observation data from the weather station located in Noibai International Airport (see the location in Fig. 48.1a). The validation results are shown in Fig. 48.3. Overall, the simulation results agree with the observed values with the coefficient of determination ( $R^2$ ) of 0.77 and 0.28 for the air temperature at 2 m and wind conditions at 10 m above the ground.

## 48.4 Results and Discussion

### 48.4.1 Impacts of Land Use Changes on Urban Climate

This section discusses the results from cases 1 and 2-1 to analyse solely the impacts of land use changes on UHIs under the same climatic conditions. Figures 48.4 and 48.5 illustrate the average air temperature distribution at 2 m above the surface and the wind directions at 10 m above the surface for all cases at 1:00 and 14:00, respectively. For a fair comparison of the results of all cases, the analysis in this section shows the temporally averaged results from the days with prevailing southeasterly winds (winds coming from directions between 90° and 180°).



**Fig. 48.3** Comparison between observed and simulated (a) air temperature, (b) wind speed and (c) wind direction at Noibai weather station, (21.22° N and 105.8072° E) [8]

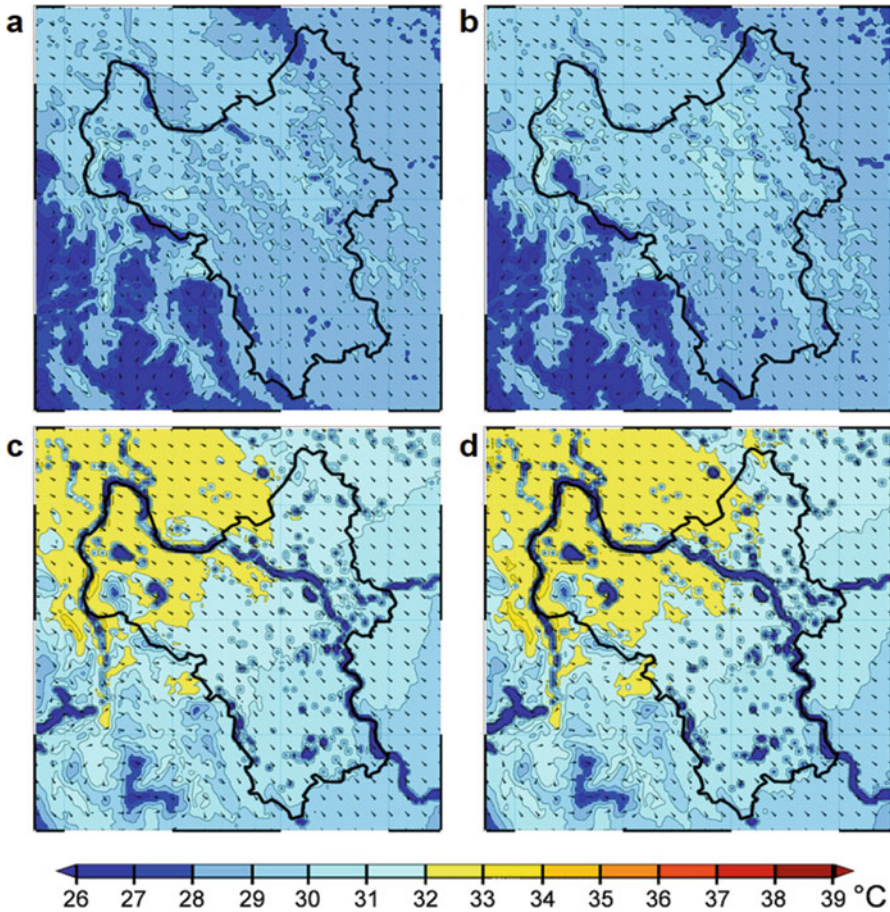
As expected, the average air temperatures in urban areas are higher than those over the agricultural fields (i.e. rural areas). In general, the air temperature difference between urban and rural areas becomes significant at night, reaching up to 2–3 °C while it is up to 1 °C during the daytime in case 2-1 (Figs. 48.4b and 48.5b).

In the current condition (case 1), the maximum nocturnal average air temperatures are approximately 30–31 °C. The peak average air temperature of 31 °C is generally observed in urban areas (Fig. 48.4a). At night, the implementation of the master plan results in the expansion of the hotspots significantly both in existing and new urban areas (Fig. 48.4b). The average air temperature in these newly emerged hotspots increases by up to 2–3 °C over that of the same areas in case 1.

During the daytime, peak average air temperatures are observed in most parts of the urban areas in both cases (Fig. 48.5a and b). Although the peak average air temperatures remain almost at the same level even after the implementation of the master plan, the new hotspots with temperatures between 37 and 38 °C expand over the newly developed urban areas in case 2-1 (Fig. 48.5b). The average air temperature in these newly emerged hotspots increases by up to 1 °C over that of the same areas in case 1.

#### 48.4.2 Impacts of Global Warming on Urban Climate

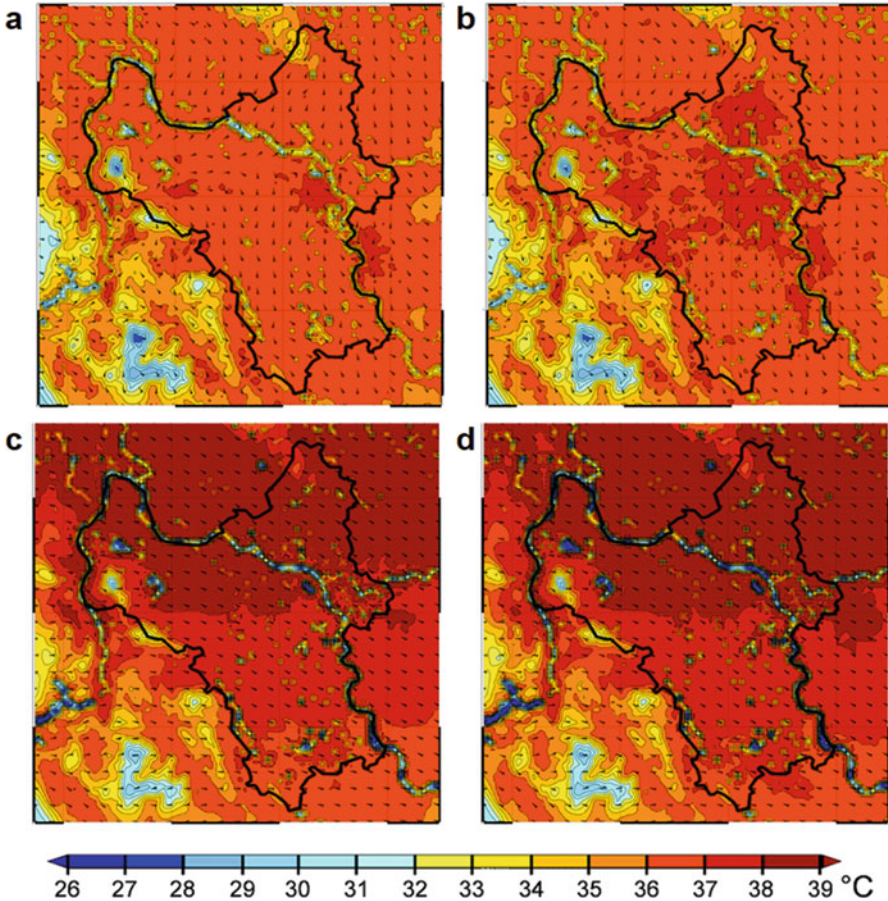
In this section, the impacts of global warming are discussed based on the comparisons among case 2-1, case 2-2 (RCP4.5) and case 2-3 (RCP8.5). The analysis in this



**Fig. 48.4** Spatial distribution of average air temperature at 2 m and wind directions at 10 m above the surface at 1:00 for (a) case 1, (b) case 2-1, (c) case 2-2 and (d) case 2-3. The analysis is based on the temporal-averaged results calculated from the days with prevailing southeasterly winds. The results of cases 1-1 and 1-2 are the mean value from the days with southeasterly winds from 10 simulated months (every June from 2026 to 2035). The black line highlights the city's boundary [8]

section is generally divided into two types of urban areas: existing and new urban areas (see Fig. 55.2c). Although there are various land use types within each urban area, the results in this section are calculated only from the values taken from the built-up lands.

Figure 48.6 shows the statistical summary of air temperature for 10 simulated months (2026–2035) in cases 2-2 (RCP4.5) and 2-3 (RCP8.5), calculated for existing and new urban areas. For comparison, the results of cases 1 and 2-1 are also included. In general, the future climate conditions show a dynamic variation over the 10-year period for different RCP scenarios. For instance, the year 2027 is

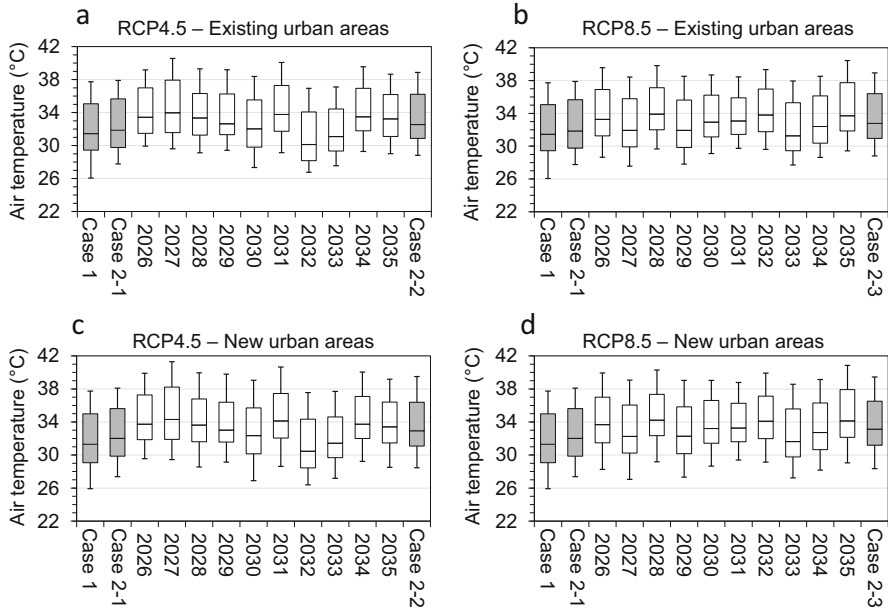


**Fig. 48.5** Same as Fig. 5 but at 14:00 [8]

the hottest year under RCP4.5, while 2035 is the hottest for RCP8.5. The future air temperature can even be cooler than present, as seen in 2032 and 2033 in case 2-2 (Fig. 48.6a and c). This may be due to interannual climate variations in existing urban and new urban areas for RCP4.5. However, the interannual variability in RCP8.5 results is not distinct, and the variations in air temperature are rather narrower than that of RCP4.5. Nevertheless, hotter years would occur more often in the near future than would cooler years.

Global warming would significantly alter the urban climate in Hanoi City. Under global warming conditions (i.e. cases 2-2 and 2-3), temperature increases are observed in the whole region (Figs. 48.4 and 48.5c, d). As shown in Fig. 48.6, the maximum average temperature in the global warming conditions is up to 1.7 °C greater than that of case 1 and 1.4 °C greater than that of case 2-1. The minimum



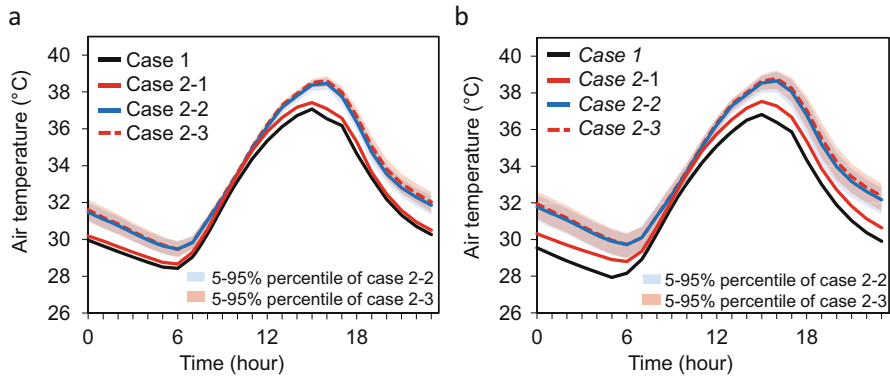


**Fig. 48.6** Statistical summary (maximum, minimum, 25th percentiles, 75th percentiles, and median) of average air temperature in the existing urban area for (a) case 2-2 (RCP4.5), (b) case 2-3 (RCP8.5) and at the new urban area for (c) case 2-2 (RCP4.5) and (d) case 2-3 (RCP8.5). In order to see the climate variations over the 2030s, the results from 10 simulated months are shown. The box-plot at the far right of each graph is the mean value from 10 simulated months [8]

average air temperature that would be experienced by the urban areas in the future scenarios would also increase by up to 2.7 °C from case 1 and by up to 1 °C from case 2-1.

### 48.4.3 Contributions of Land Use Changes and Global Warming to the Future Temperature Increase

Figure 48.7 shows the diurnal variations of spatially and temporally averaged air temperatures in existing and new urban areas for all cases. As shown in Fig. 48.7a, the implementation of the master plan slightly increases the average air temperature in existing urban areas both in the daytime (6:00–17:00) and at night (0:00–5:00, 18:00–0:00). The increases in air temperature due to the land use changes in existing areas are up to 0.5 and 0.6 °C in the daytime and at night, respectively. In the new urban areas (Fig. 48.7b), the massive land use changes brought by the master plan result in a greater increase in average air temperatures than in the existing urban areas, by 0.9 and 1 °C in the daytime and at night, respectively.



**Fig. 48.7** Diurnal variation of spatial- and temporal-average air temperature in (a) existing urban area and (b) new urban area for all cases. The results are calculated from the days with prevailing southeasterly winds, and only the values from the built-up land use types are taken into account [8]

Meanwhile, under the global warming scenarios, the average air temperatures for the whole day are generally higher than in present condition. In the 2030s, the air temperatures in the existing urban areas increase by up to 1.3 and 1.5 °C for cases 2-2 and 2-3, respectively, over those in case 2-1 (Fig. 48.7a). A similar trend is also observed in the new urban areas (Fig. 48.7b), where the average air temperatures increase by up to 1.5 and 1.7 °C in case 2-2 and 2-3, respectively, over those in case 2-1. The average air temperatures under RCP8.5 scenario (case 2-3) are slightly warmer than those under RCP4.5 (case 2-2), by up to 0.2 °C.

In total, global warming and land use changes contribute to the temperature increases of up to 2.1 and 2.7 °C on average in existing and new urban areas, respectively. In the existing urban areas, out of the average increase of 2.1 °C, up to 1.5 °C (or 71%) and 0.6 °C (or 29%) are attributable to global warming and land use changes, respectively. Meanwhile, in the new urban areas, the corresponding contributions out of the average increase of 2.7 °C, up to 1.7 °C (or 63%) and 1 °C (or 37%) are attributable to global warming and land use changes, respectively.

## 48.5 Conclusions

The impacts of land use changes and global warming on the urban climate in Hanoi in the 2030s were investigated using numerical experiments with WRF modelling. For the near future climate conditions, direct dynamical downscaling with WRF was conducted with initial and boundary conditions from the MIROC5 datasets for RCP4.5 and RCP8.5.

The main findings are summarized as follows:

- Hotspots widely expanded following the pattern of new built-up areas in the master plan scenario. The implementation of the master plan increased the

number of hotspots with peak average air temperatures in the existing urban areas, largely at night.

- The land use changes proposed in the master plan are expected to increase the average air temperature in the existing and new urban areas by up to 0.6 and 1 °C, respectively.
- The results illustrated that the urban air temperature was projected to increase along with global warming. In the 2030s, the average air temperature increase in the existing urban areas was projected to be up to 2.1 °C, of which up to 1.5 °C (or 71%) and 0.6 °C (or 29%) are attributable to global warming and land use changes, respectively.
- The increase in air temperature in the near future (2030s) will likely exceed the cooling effects from any UHI mitigation measures. Under this circumstance, adaptation measures to urban warming might be prioritized rather than the mitigation measures particularly in the growing cities of emerging economies.

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