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Salwa S. NAIF[1], Najlaa Mohamed HADI[2], Monim H. Al-JIBOOR[1]

[1]Mustansiriyah University, College of Science
[2]University of Babylon, College of Education for Pure Sciences

Study of temporal variations of nocturnal and daytime urban heat island in Baghdad

Key words: urban heat island, urban impacts, minimum and maximum temperature, temperature trend, Baghdad

Introduction

The concept of urban heat island (UHI) describes the phenomenon, which takes place in the core of cities or towns, characterized by higher air or surface temperatures, than in surrounding rural areas (Bhargava, Lakmini & Bhargava, 2017). This effect has important implications for energy consumption, environmental pollution and human health and comfort and water use. The warmer urban surface is present at all around the world and has potential impact to local warming (Kalnay & Cai, 2003). It seems with highest intensity basically at nights and inland cities when the sky is free of clouds and the winds are weak. As a result of the rising trend of the urban population, UHI effect emerges due to continued urbanization processes (Nuruzzaman, 2015) that alter the natural land cover to impervious surfaces (Rosenzweig et al., 2005), urban geometry which refers to dimension and spacing of building within a city, and anthropogenic heat activities that include heating, transportation, industry, air condition system that add a waste energy to urban canopy heating (US EPA, 2008).

Nocturnal and daytime UHI can be observed using minimum and maximum air temperature ($T_{\min}$ and $T_{\max}$) recorded at 2 m during the one day at weather stations (WMO, 2007). There is a discrepancy in difference of UHI intensity between summer and winter. Most studies reported that less UHI was in winter (Oke, 1976; Wilby, 2003; Golroudbary, Zeng, Mannaerts & Su, 2018), while others showed that most winter UHIs were more intense than summer UHIs (Souch & Grimmond, 2006; Sailor, 2006; Schatz & Kucharik, 2014). Thus, this gap in determining which season has most intense UHI requires a careful analysis that will be useful in assessing the potential implications described above. This study is the first attempt to compare climatically different areas within and outside of Baghdad dependent on real observing. Study of the temporal variations in the UHI over urban areas expresses the modifications in radiation and energy balance at the canopy air layer extending from the ground to below the tops of trees or buildings (Oke, 1976; Bhargava et al., 2017). Buildings, paved roads and other urban substructures tend to store shortwave solar energy during the daytime and then release it back to space as longwave terrestrial radiation after sunset creating increased temperature compared with suburban areas. The ongoing increase in population census in the most world cities (UN, 2018) can be considered an additional factor in intensifying UHI (Oke, 1973).

As the urban landscape transformations associated with land cover changes and increased population continue to grow, the warming effect in densely cities is enhancing the local warming climates as well. This effect has been found in the long-term trends of temperature when the temporal variations of daily, monthly, seasonal and annual mean temperature have been investigated (Huang & Lu, 2015), because of a large portion of the greenhouse gases produced in these environments. Thus, the main aim of this work is to study the nocturnal and daytime UHI in Baghdad on the basis of monthly, seasonal and annual analysis. In addition, the annual trends are also investigated to predict the behaviour of UHI intensities.

Study area and data

The city of Baghdad, capital of Iraq, is located in inner flat land of the central government which covers 894.3 km^2 and has extremely hot, dry summer and damp winter. It is located along Tigris river which divides into two sides Rasafa (east) and Karkh (west), as shown in Figure 1. The urban fabric consists of blocks of low-rise houses (1–3 floors) with 5–12 m high. Several medium-rise buildings up to 20 floors are mostly formal offices and hotels. Baghdad is the commercial, financial and cultural centre of Iraq. The average geography coordinates are of latitude 33.2°N, longitude 44.3°E and 34 m a.m.s.l. After replacing political system in 2003, random urbanization expansion and inner immigration are in particular observed in Baghdad.

The time series of the daily data for minimum (T_{min}) and maximum (T_{max}) air temperature were acquired from two automatic weather stations (see their photographs in Fig. 1) separated by 20 km distance (Sundus & Al-Jiboori, 2018). Both T_{min} and T_{max} were observed around the dawn (nighttime or nocturnal) and after the noon (daytime), respectively. First station (1) located in the centre of Baghdad on the roof of the Atmospheric Sciences Department building, the Mustansiriyah University with 14 m high above the ground level, which is considered as urban site. Another station (2) belongs to Iraqi Meteorological Organization and Seismology set up in the International Baghdad Airport with height of 2 m. This lies on the border

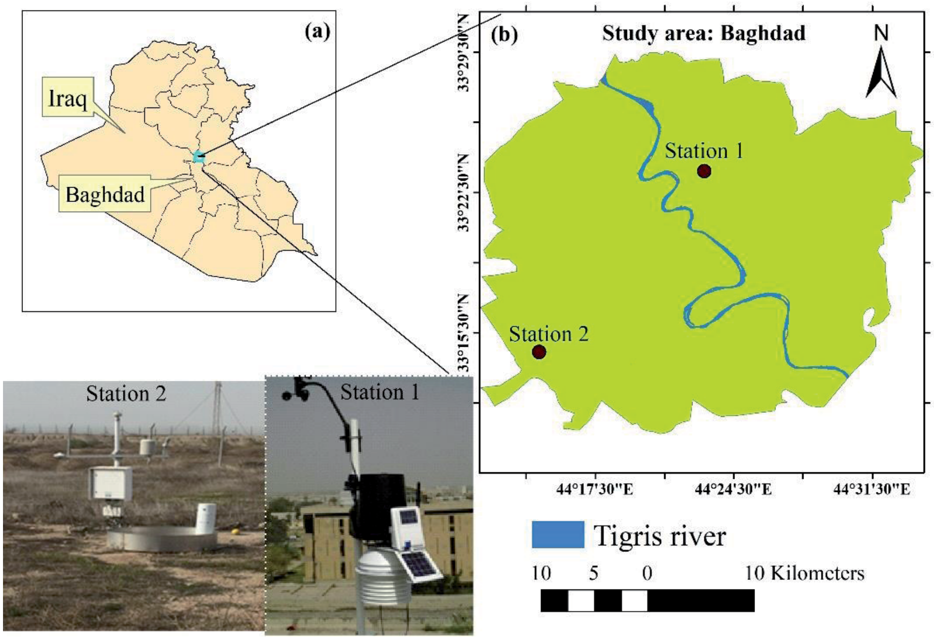

FIGURE 1. Location of Iraq (a) and Baghdad (b) with photographs of two automatic weather stations

of Baghdad with very open area, thus it is considered as rural site. Although the heights of two stations are different, air temperature measurements did not experience significantly differences. This is expected in the canopy of urban area due to theory of constant heat flux in the surface layer of lower atmosphere (Stull, 1989).

The above data collected were analysed for only three years 2008, 2013 and 2019. Fortunately, there were not any missing or gap in the time series because of continuous observation. Three five-year intervals were chosen to show real changes in landscape of Baghdad. To examine the canopy layer UHI and study the dynamic characteristics of the air mass overlying the urban area during the years, these data were chosen to represent middle months of the seasons of the year: January (winter), April (spring), July (summer) and October (autumn). The choice of only one month of each

TABLE 1. Climatic values of air temperature, rainfall and daylight hours for each season

Season	Temperature range [°C]	Average temperature [°C]	Average rainfall [mm]	Rainfall days	Average daylight [h]
Winter	4–16	12	85	18	10.5
Spring	15–29	23	67	15	12.4
Summer	22–44	35	0	0	14.2
Autumn	10–40	24	25	5	11.4

season is suitable because that the study area is generally cloud-free for most the year, as shown in Table 1 which also displays some climate features for temperature, rainfall and daylight hours at each season.

Methodology

The main root causes of modification in urban climate are the urbanization process, landscape geometry and thermal properties of building and surface materials (Nuruzzaman, 2015). To confirm the existing UHI in Baghdad, it is important to distinguish the two different areas in the surface characteristics such as urban and rural sites. The comparison of urban versus rural stations is adopted in this study.

Thus, first, daily nocturnal and daytime canopy urban heat islands are usually determined using daily T_{min} and T_{max} measurements taken from these stations, thus UHI intensities were defined as:

$$\textit{nocturnal UHI} = T_{min}(u) - T_{min}(r) = \Delta T(u\text{-}r)_{min} \quad (1)$$

$$\textit{daytime UHI} = T_{max}(u) - T_{max}(r) = \Delta T(u\text{-}r)_{max} \quad (2)$$

The symbols u and r refer to urban and rural conditions.

Second, average values of the resulting daily $\Delta T(u\text{-}r)_{min}$ and $\Delta T(u\text{-}r)_{max}$ were separately calculated for expressing seasonal averages and by the same method, annual averages were computed from seasonal averages.

Third, the three years indicated in the previous section do not experience any extreme climatic means concerning other years (i.e. from 2009–2018, except 2013), but they were in normal conditions. Thus, linear trends were fitted to the annual averages of $\Delta T(u\text{-}r)_{min}$ and $\Delta T(u\text{-}r)_{max}$ by least square method using Origin software (ver. 9.3). This is useful in determining the rate of change by year and to predict the behaviour of UHI intensities in proximity future especially in suggestion the relevant mitigation strategies for adaptation under ongoing global warming. However, the results of nocturnal and daytime UHI were separately fitted to simple linear regression given as

$$UHI(t) = \alpha + \beta \cdot t \quad (3)$$

where
t – independent variable [year],
α – intercept,
β – slope (trend).

Fourth, the significance level (t-test, $p < 0.05$) and correlation coefficient (r) were determined to explore the potential implications under local climate change.

Results and discussion

Daily variation of nocturnal and daytime UHIs

The variations in nocturnal and daytime UHIs, as derived from Equations (1) and (2) respectively, were investigated among 2008, 2013 and 2019. Figures 2 and 3 show daily variations of both nocturnal and daytime UHIs, respectively in four representative months: January, April, July and October. The intra-month variability in all UHI values is obvious due to the air layer adjacent to the sur-

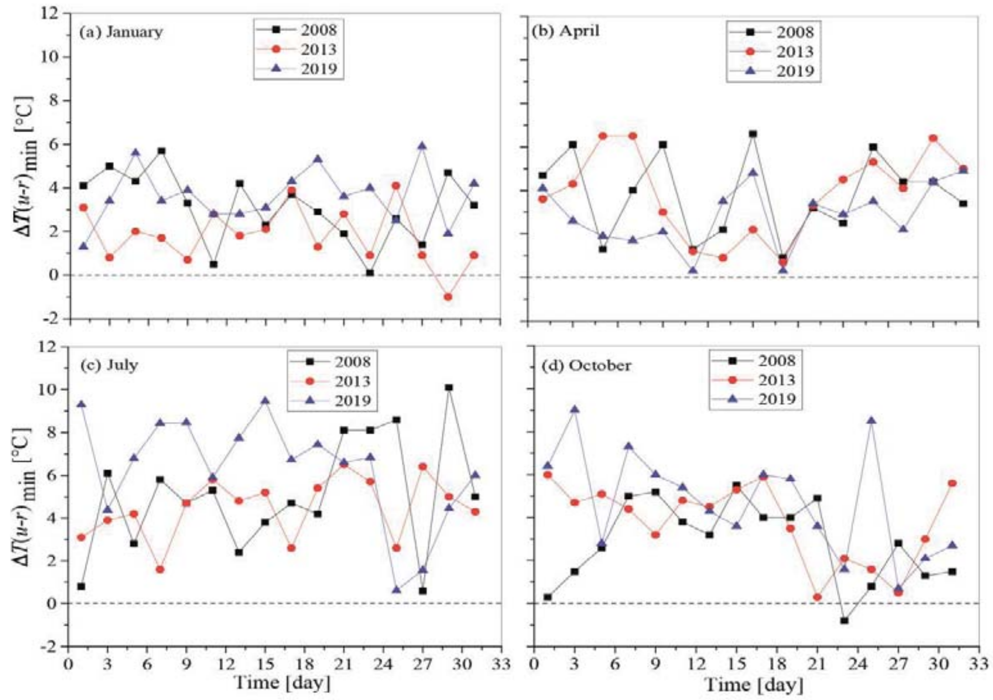

FIGURE 2. Daily variation of nocturnal UHI for three years (2008, 2013 and 2019) in months: January (a), April (b), July (c) and October (d)

face strongly affected by the physical processes as well as the external pressure systems passing the area.

Nocturnal UHI seems to have positive values along the year with its strongest value in summer exceeding 5°C at the above studied years. It can be concluded that at night minimum temperature values in urban area are always larger than those in rural areas. In summer (July) and sometimes autumn (October) months of 2019, UHI intensity reaches the largest positive values beyond 6°C (Figs. 2c and 2d). The positive moderate nocturnal UHI intensity occurred in other seasons (January, April and October) when UHI reached values of about beyond 4°C as illustrated in Figures 2a, 2b and 2d. The least positive value of about 1°C was found in January of 2013.

A different result variation is observed for the daily daytime UHI across all the months of all years. As shown in Figure 3 daily daytime UHI intensity has mostly negative values for both years 2008 and 2013, while in 2019 these values become positive, especially in April (Fig. 3b) and July (Fig. 3c) reaching more than 1°C. It is important to notice that, in Figure 3a across all years, UHI values not only show the increasing trend during the days of January, but also they are approximately close to each other. The reason is that at the last third of January in general the air temperature starts to be warm up and also continuing use with

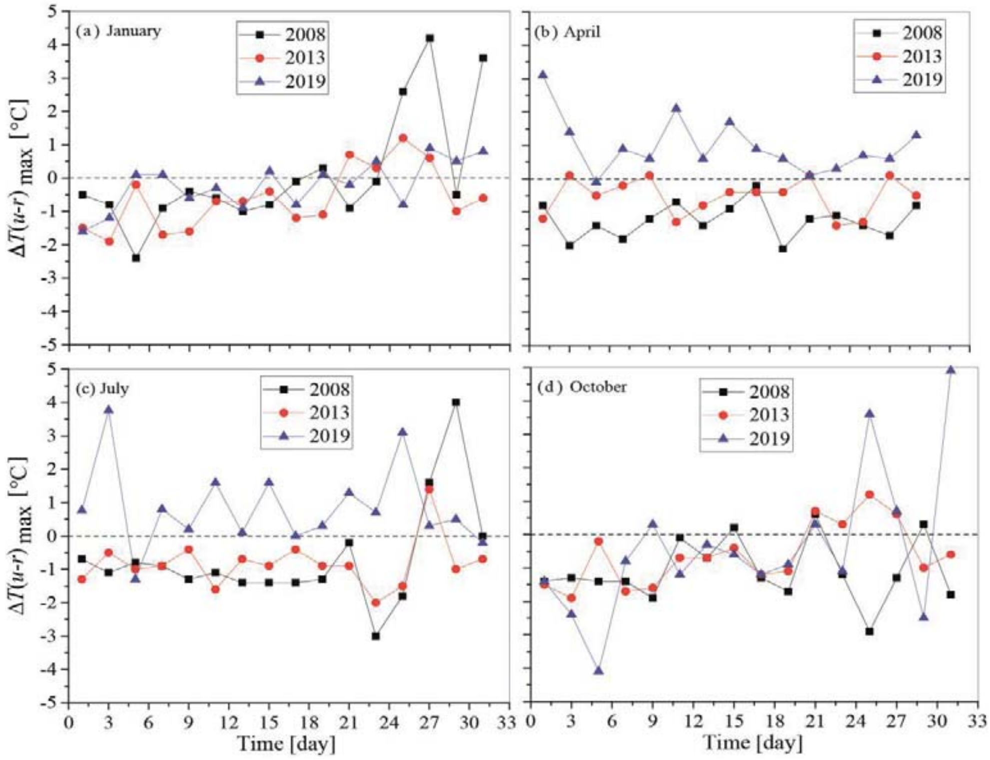

FIGURE 3. Daily variation of daytime UHI for three years (2008, 2013 and 2019) in months: January (a), April (b), July (c) and October (d)

different warming means by dwellers to facing cold winter which, of course, will raise air temperature in urban site. The similar result is nearly also found in October (Fig. 3d), but with more scatter.

Seasonal variation of nocturnal and daytime UHIs

To reduce high variability in daily nocturnal and daytime UHI, monthly means of January, April, July and October were computed which express winter, spring, summer and autumn and displayed in Figures 4 and 5, respectively. These figures show a distinct seasonal cycle of the $\Delta T(u\text{-}r)_{min}$ and $\Delta T(u\text{-}r)_{max}$. This cycle reveals the weakest and strongest UHI intensities in winter and summer, and different amplitudes in spring and autumn. Absolute positive nocturnal UHI values are found at all seasons and years with average highest during summer and weakest in winter, as shown in Figure 2, which are consistent with the result found in Arnfield (2003) and Schatz and Kucharik (2014). These values are also largest in 2019 except in spring (Fig. 4).

At semiarid environments like Baghdad the summers are characterized by strong solar energy and greater day hours (~14.2 h) with no cloud or rain (Table 1), therefore loss of energy through long wave radiation at nights is

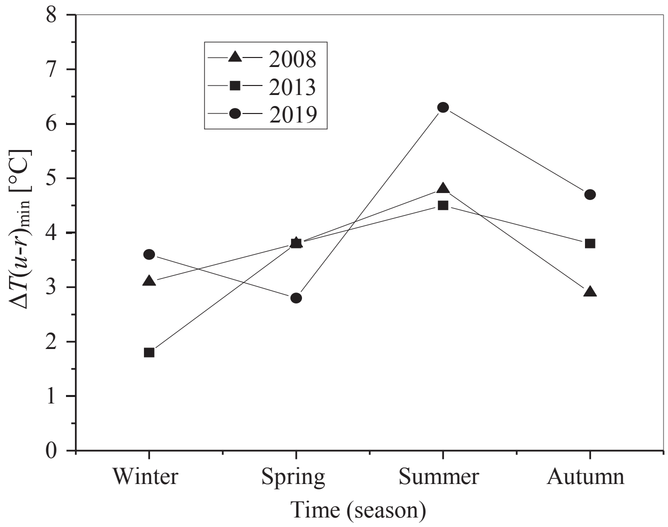

FIGURE 4. Seasonal variation of nocturnal UHI for three years: 2008, 2013 and 2019

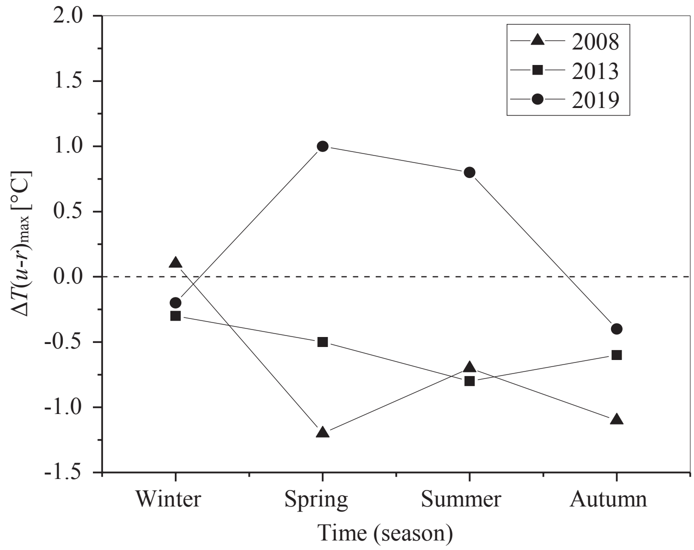

FIGURE 5. Seasonal variation of daytime UHI for three years: 2008, 2013 and 2019

little in urban cities compared to rural areas, so that the well-known effect of the UHI occurs. In general, the inversing result to nocturnal UHI is clear in seasonal variation of daytime UHI, $\Delta T(u\text{-}r)_{\text{max}}$, as shown in Figure 5, whereas the cold islands were established well especially in all seasons of two years 2008 and 2013, while in 2019 urban heat island raised in spring and summer (~0.65°C).

As mentioned in the previous discussions that there was more intense UHI in

2019. This belongs to expected several causes: (1) population growth in Baghdad is continuously increasing which reaches 7.9 million in this year (Al-Jiboori, Abu Al-Shear & Ahmed, 2020); (2) the gradual reduction in green areas and their replacement to residential, commercial and industrial are characterized in the city without official approvals (Hussain, 2018); (3) Baghdad is one of the mid-latitude cities whereas the most intensive UHIs have been observed (Wienert & Kuttler, 2005) due to regional and global climate change that might be influenced the ongoing increasing in temperature (Saaroni, Amorim, Hiemstra & Pearlmutter, 2018).

Annual variation of nocturnal and daytime UHIs

To be more clear in studying nocturnal and daytime UHI, the annual averages are computed using seasonal averages and presented in Figure 6, in which the vertical lines represent the spreading around the annual means, i.e. standard deviation (*SD*). At night time, the similar result of annual thermal differences between urban and rural sites, annual $\Delta T(u\text{-}r)_{\text{min}}$, is also confirmed with high *SD* at three values of the years 2008, 2013 and 2019. Although the values of $\Delta T(u\text{-}r)_{\text{max}}$ are little, it can also clearly see linear increase from 2008 to 2019. The same behaviour is also found in the results of daytime difference with less *SD*.

We now tried to evaluate the annual linear increases in both nocturnal and daytime UHI values during the studied period by calculating the linear trend. Their results were separately fitted using Equation (3). The constants were empirically derived from nocturnal and daytime UHI data which reported in Table 2.

The nocturnal UHI behaviour is more intense (where β = 0.09°C·year^{-1} with r = 0.09 and p < 0.001) than that of day-

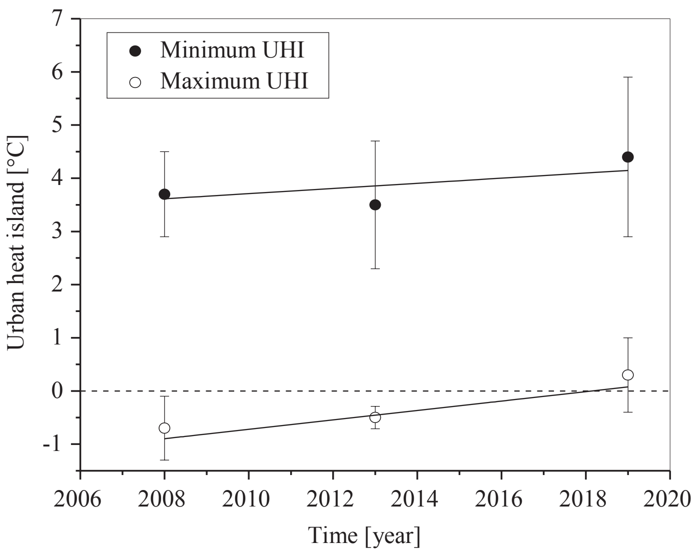

FIGURE 6. Annual variation of both nocturnal and daytime UHIs. Solid lines are for fitting data

TABLE 2. Mean intensities of nocturnal and daytime UHIs in Baghdad

UHI intensity [°C]	α	β [°C·year^{-1}]	r	p
Nocturnal	–158.3	0.09	0.79	< 0.001
Daytime	–63.4	0.05	0.63	< 0.005

time (β = 0.5°C·year^{-1} with r = 0.63 and p < 0.005). Differences between nocturnal and daytime UHI intensities are also apparent from annual trend (Fig. 6, Table 1).

Conclusions

Daily, seasonal and annual variations are fundamental to the investigation of UHI. Using minimum and maximum temperature data for three five-year period (2008, 2013 and 2019) measured by automatic weather stations located at two different sites with roughness (urban versus rural), nocturnal and daytime UHIs were calculated at four months that represent the four seasons: January (winter), April (spring), July (summer) and October (autumn). Baghdad's UHI is most intensive at the centre of city than at outlying rural site. The intensity of nocturnal UHI has positive signs at all seasons, while daytime UHI shows positive and negative signs across these seasons. In addition, nocturnal UHI intensity in summer has increased to reach maximum 6.5°C in 2019, 4.6°C in 2008 and 2013, while in summer and spring of 2019 daytime UHI reach 0.8°C. This has been attributed to rapid warming in night in the city, possible linked to land cover changes and rapid population growth. Also annual trends of nocturnal and daytime UHIs show linear increase during the studied period. This increase has adverse effects on urban climate, thus several mitigation strategies such as increase vegetated areas, planting shading trees, green roofs using high albedo building materials, etc. are suggested as powerful tools to reduce potential thermal impacts.

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Summary

Study of temporal variations of nocturnal and daytime urban heat island in Baghdad. Based on daily minimum and maximum air temperature observations for three years: 2008, 2013 and 2019, measured by automatic weather stations located at two sites of Baghdad city were used to compute nocturnal and daytime urban heat island (UHI). First station fixed in campus of the Mustansiriyah University is considered as urban area, and another station followed to Iraqi meteorological organization installed at the International Baghdad Airport was chosen as the rural site. Daily, seasonal and annual averages of nocturnal and daytime UHIs were presented to study the variability and trends.

The results show the evolution of a nocturnal UHI, whose high mean values were recorded in four seasons with largest value found in summer of 2019. Annual trend in nocturnal UHI intensities was found to be larger than that of daytime. Thus, this study propose that maintenance and increase urban parks and planting shading tall trees to mitigate UHI intensity in Baghdad city.

Authors' address:
Salwa S. Naif
(https://orcid.org/0000-0002-3793-1162)
Mustansiriyah University
College of Science
Department of Atmospheric Sciences
e-mail: naif.salwa2016@gmail.com

Najlaa Mohamed Hadi
(https://orcid.org/0000-0001-8632-8813)
University of Babylon
College of Education for Pure Sciences
Department of Physics
e-mail: awad_najlaa@yahoo.com

Monim H. Al-Jiboori
(https://orcid.org/0000-0002-0816-3918)
Mustansiriyah University
College of Science
Department of Atmospheric Sciences
e-mail: mhaljiboori@gmail.com