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EFFECT OF MEASURING TIMES ON THE MAGNITUDE OF HEAT ISLAND (UHI) THROUGH URBAN AND SUB-URBAN QUARTERS IN KARBALA CITY

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Abstract

During recent decades, a clear difference in temperature between city centres and suburban and rural areas can be attributed to the phenomenon called the Urban Heat Island (UHI). The objective of this study is to analyse the variation of this phenomenon during daytime and night-time in urban and sub-urban quarters of the Karbala City. These two times were selected to cover the whole change of temperature fluctuations that participate in the consistency of UHI, considering both processes of warming during daytime and cooling during night-time. This inclusive vision permits a preferable grasp of UHI effects and submits strategic solutions to mitigate the rising heat problems in urban areas. To show the influence of measuring times on UHI in Karbala City, two areas in Karbala City were selected, the first one is named the Saif Saad district which was selected because it has a small size compared to the Karbala population density ratio. Also, a suburban area in this City named Karbala-Najaf Road was chosen. This examination concentrated on three measurement points in each of the urban and suburban areas to clarify the impact of two measuring times which are around 12 pm during the daytime, and approximately after sunset during the night. A regression model was built to simulate the correlation between daytime and night-time temperatures in urban and suburban areas. The findings revealed that at a height of 1.5 meters over the ground, there is a fluctuation in air temperature during daytime, while a symmetric temperature recording was noticed during night-time. According to this model, a powerful linear correlation was found between temperatures in urban and suburban areas for both conditions of daytime and night-time. It was observed high magnitudes of UHI values during daytime and night-time in each of the urban and suburban regions. The magnitude of UHI in these regions fluctuates between a 1.67 °C minimum average in the third week of March and a 4.37 °C maximum average in the first week of February. In addition, the values of temperature recorded in the urban area were constantly observed higher by 2.38 °C than that in the suburban area. The main conclusion of the present study is that during the winter period, the air temperatures in a small urban area were constantly higher than those in a suburban area. So, this can be attributed to the presence of the UHI impact on the small urban area regardless of its population. Furthermore, the study results confirm that measuring air temperatures during daytime and night-time gives a more accurate assessment of the UHI influence. According to these findings, it can be recommended to the significance of carrying out more research on UHI impacts and develop various strategies for mitigation.

Keywords: Air temperature, Karbala city, Suburban area, Urban area, Urban heat island.

1. Introduction

The sharp fluctuations in temperatures that the world is witnessing are considered a main factor contributing to climate change. There are usually differences in temperature values between urban and suburban or rural areas, with temperatures being highest in rural areas [1]. This difference in air or surface temperature is attributed to the phenomenon called the urban heat island (UHI) [2]. Figure 1 exhibits a profile of this phenomenon. Urban cities with a high population are prominently under the impact of UHI [3], where the urbanization level affects this impact [4]. Although UHI effects are widespread worldwide, these effects vary with locations and times.

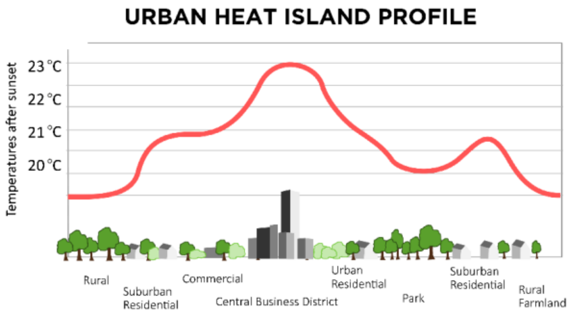

Fig. 1. Definition of urban heat island (UHI) phenomenon [5].

Many researchers pursue to clarify the detrimental effects of the UHI, particularly its attribution with increasing death rates [6], passive impacts on the economy [7], and negative effects on urban planning [8]. A study by Liou et al. [9] concluded that the high-temperature index is a serious threat to people's lives, leading to high death rates, in areas with a high population density, regardless of the construction ratio. Furthermore, elevated air temperature levels have detrimentally affected the quality of life in cities, especially in coastal areas [10]. UHI also affects the hydrological cycle parameters, especially on evapotranspiration [11, 12] as well as on the storage of groundwater [13]. Thus, the present study intends to handle the scarcity of research by investigating the UHI phenomenon in locations of small size through various measuring times.

It is clear in recent research that major contributors to urban temperature variations are spatial and temporal characteristics. UHI size is considerably affected by the conspicuous locative parameters [14]. In many studies, air temperature was a key factor in evaluating the size of urban heat islands [15, 16]. Similarly, comparing UHI values between cities is commonly implemented using direct measurements [17]. Yet, cities are usually characterized by different urban patterns, constructions, and various densities of population. Therefore, several studies have focused on the significance of studying the UHI changing UHI in urban areas. For instance, the UHI severity for numerous sites in Gothenburg was examined by Svensson and Eliasson [18]. They found that the UHI values varied from high to low according to the densities of urban areas including green areas and outdoor building areas.

Salman and Saleem [19] studied the influence of UHI attenuation strategies on human beings' outer heat comfort in three familiar urban regions in Baghdad, the capital of Iraq with the highest population density. The aim of their study was to find the impact of UHI alleviation strategies on the thermal relief of citizens in the outer areas of domestic quarters in Baghdad. Their results can give evolved criteria for planning and designing urban areas, especially to amend the thermal state in arid and hot urban regions.

Temporal change is considered an essential factor that directly affects the UHI value. Accordingly, the change in UHI values during the day and through various days in the week and in each season has been investigated by several studies. These investigations for UHI were conducted in the study of Wilby in 2008, which found that the UHI value at night was greater than that during the day by 1.5 °C [20]. Moreover, slight variations in the intensity of UHI were recorded for all times of measurement during the week.

In 2005, Kim and Baik used numerous stations of weather in Seoul to examine the dissimilarity in the intensity of UHI during night and day [21]. The measurements were recorded at various eight times for intervals of three hours along the year. They found that the value of UHI at each of 3:00 am and 6:00 am was 3.0 °C, which was greater than the UHI value of 2.0 °C at both 6:00 pm and 12:00 am. Furthermore, this higher value of UHI exceeded the UHI value of 1.0 °C recorded at the measuring times of 9:00 am, 12:00 pm, and 3:00 pm.

In their study, Svensson and Eliasson found that temperature magnitudes at nighttime were higher than that at daytime by 8.0 °C [18]. The study by Li et al. similarly for seven years in Berlin showed that there is a negative relation between the UHI intensity close to the surface of the earth and the intensity of UHI in the Atmosphere, particularly at nighttime [22]. Many studies recommended that the best time for measuring UHI is after sundown, specifically at night in winter [23, 24].

Therefore, two particular times of measurement are selected in this study, one was in the daytime and the other was at nighttime to precisely evaluate the UHI value. This study concentrates on determining variations between UHI magnitudes recorded at daytime and nighttime to clarify the influence of some parameters like a sunbeam and the selected region on the get-up in air temperature.

The impacts of UHI have been examined by many studies in different regions of the world. The findings of these studies revealed that the UHI values for large cities like Paris, Adelaide, Orlando, Erbil, Melbourne, Moscow, and North Carolina are about 4.9 °C [25], 4.8 °C [26], 4.16 °C [27], 4.0 °C [28], 3.9 °C [29], 3.0 °C [30], and 2.24 °C [24], respectively. Conversely, smaller cities with populations below a million inhabitants also experience UHI effects. For instance, Praga, Poznan, Bydgoszcz, and Glucholazy cities in Poland exhibit average UHI magnitudes of 1.1 °C, 2.2 °C, 1.0 °C, and 0.8 °C, respectively [31]. Consequently, this study focuses on a specific small district (Saif Saad quarter in Karbala) relative to its size to calculate UHI magnitude. This approach is chosen due to the scarcity of studies examining the impact of the UHI phenomenon on small cities, similar to quarters or sector areas.

The rationale behind assessing the impact of various measurement times on temperature in the city of Karbala is rooted in the pursuit of scientific advancement for calculating the Urban Heat Island (UHI) magnitude in Karbala City, Iraq. Moreover, there is a limited body of research specifically addressing UHI magnitudes between urban and suburban areas, especially within Iraqi cities in the Middle East. Hence, this field study represents the initial exploration aimed at estimating UHI magnitude in the Middle Euphrates area of Iraq, employing a particular methodology. However, this study uniquely concentrates on a small urban area compared to a suburban area, utilizing multiple points during diverse measurement times throughout both day and night hours.

The choice of Karbala City is based on its significance, attracting thousands of tourists annually. Hence, it is imperative to study this city due to temperature increases observed in certain districts. What sets this study apart from others is the distinct methodology employed, particularly in terms of measuring points and distances.

2. Study Area

Karbala City faces various challenges, including climate change concerns [32], and a rising population that exerts significant pressure on various aspects such as wastewater treatment [33] and urbanization issues, notably the emergence of Urban Heat Islands in smaller locales. In this current study, two small areas in Karbala City were selected, each with three measuring points, to assess air temperature at a height of 1.5 meters above the ground. The first area is an urban location known as Saif Saad district, while the second is a suburban area named Karbala-Najaf Road, with a distance exceeding 3000 meters between them. Saif Saad district has a population ranging from 30,000 to 40,000 inhabitants [34]. Figure 2 illustrates the selected case study along with population details.

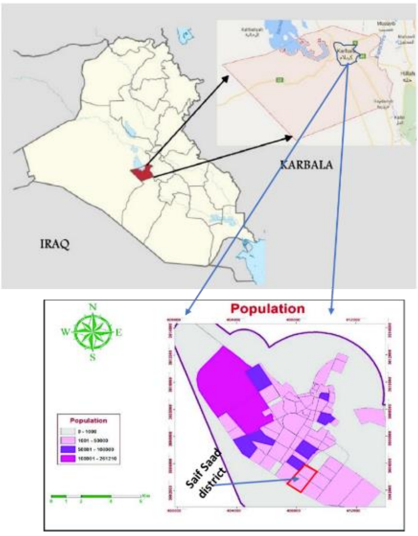

Fig. 2. Study area (Saif Saad district) in Karbala city - Iraq [34].

3.Methodology and Data Sets

This study focused on urban (Saif Saad district) and suburban (Karbala-Najaf Road) areas within Karbala City, shown in Fig. 3. Saif Saad district is a residential zone with diverse structures serving various purposes, including houses, markets, service offices, commercial shops, and streets (Fig. A-1, *Appendix A*). In contrast, the chosen suburban area comprises a limited number of scattered buildings surrounded by green spaces and the (Karbala - Najaf) road, which constitutes a significant portion of this area. (Fig. A-2, *Appendix A*). As a result, the distance between the urban area, designated by the letter (U), and the suburban area, denoted by the letter (S), is 3120 meters as shown in Fig. 4.

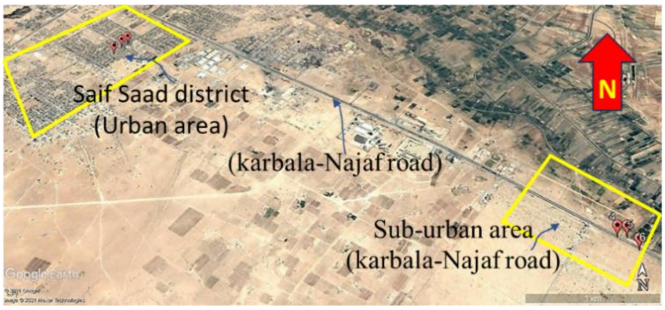

Fig. 3. Aerial map of the selected areas, urban (Saif Saad district) and sub-urban (Karbala-Najaf Road). (Image source: Google maps).

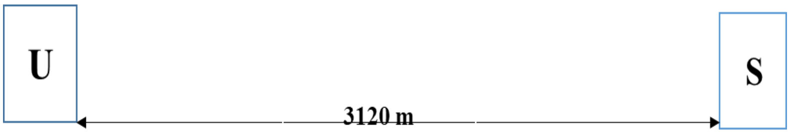

Fig. 4. Distance between urban area (U) and suburban area (S).

Three measuring points at varying distances were chosen for both urban and suburban areas as shown in Fig. 5. In the urban region (Saif Saad district), the selection of these points was based on the distinctive features surrounding each one. The three measuring points (U1, U2, and U3) were specifically located near a three-story building under construction, a commercial building, and a four-star restaurant, respectively (Fig. A-3. A, *Appendix A*). These areas are constantly surrounded by people and vehicular traffic, engaging in various urban activities.

Fig. 5. (A)The three measuring points at both urban area and (B)suburban area. (Image source: Google Maps).

Hence, the distances between the three designated points (U1, U2, and U3) within the urban area vary Fig. A-3. B, *Appendix A*), and their coordinates are presented in Table 1. Similarly, in the suburban area, the selection of these points was based on the density of vegetation surrounding each one. The three measuring points (S1, S2, and S3) were chosen close to bushes and trees (Fig. A-4. A, *Appendix A*). Consequently, the distances between the points (S1, S2, and S3) are not uniform in magnitude (Fig. A-4. B, *Appendix A*), and their coordinates are detailed in Table 1. The rationale behind selecting these distances is to mitigate the impact of weather changes on temperature variations, ensuring the accuracy of temperature values attributed to the Urban Heat Island (UHI) phenomenon.

Table 1. Coordinates of the measuring points.

U1	**U2**	**U3**
32.579776, 44.028175	32.580446, 44.028792	32.580955, 44.029246
S1	**S2**	**S2**
32.572405, 44.046953	32.572086, 44.047511	32.571653, 44.048242

A Kestrel 5200 series handheld weather and environmental meter device was utilized for measuring air temperature at a height of 1.5 meters above the ground as shown in Fig. 6. The device offers a temperature accuracy of +/- 0.5 °C. To ensure precision, air temperature measurements were averaged over 3-5 minutes, confirming that the temperature had stabilized before recording the values. In the present study, two particular times of measuring, one in the daytime and the other at nighttime. These times were chosen to comprise day and night hours to record the best time for a maximum temperature in the daytime and the perfect time at nighttime to determine the largest value of UHI during the winter [35].

Fig. 6. An environmental meter device is called a Kestrel 5200 series hand-held device.

Several studies found that the UHI intensity was resorted to be low during the afternoons in summer and high during the night in winter for different regions in the world [36]. As a result, the specific period for this study was selected to be during the winter of comparatively appropriate climate situations in Iraq. Precisely, there is a contrast between the characteristics of winter weather and those of other seasons. Precisely, there is a contrast between the characteristics of winter weather and those of other seasons. This contrast is represented in varying wind velocity, changing sky characteristics by covering moderate to big clouds, decreasing the humidity, and oscillating rainfall rates from agile to dense with probable flooding for specific hours [24]. Monitoring peak UHI values at conclusive times about sunup or after sundown may depend on the choice of test hours [24, 37].

All measurements were conducted at both urban and suburban measuring points on a single day, and this process was repeated on the same day of each week in February, as well as on the same day of the first four weeks in March. In total, the measurements were recorded eight times during the same day. Consequently, the study period covers eight weeks spanning the months of February and March within the winter season. The study period was confined to February and March, chosen due to the notable temperature fluctuations observed throughout the day and month in Iraq during these specific months. In contrast, other months exhibit less variability in temperature records.

The methodology employed in this study centred around a unique case and avoided the use of modelling. This decision was influenced by the limited data available in this particular area and the relatively short duration of the study period. Mathematical models typically require substantial data to yield a scientifically meaningful response for a selected study case.

4. Results

The findings can be presented as follows:

4.1. Air temperature at 1.5 m above the ground

Air temperature measurements were taken during both day and night periods. In the daytime, specifically between 12:42 pm and 1:00 pm, the results were derived by averaging the air temperature readings from three measuring points at a height of 1.5 meters above the ground as shown in Fig. 7.

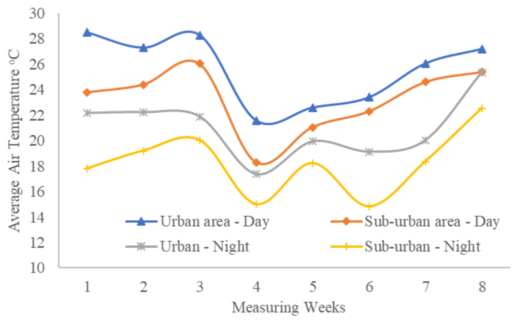

Fig.7. Average air temperature in urban and suburban areas during day and night times.

Consequently, the urban area consistently exhibited higher daytime temperatures on average than the suburban area throughout the study period. Notably, the urban area registered maximum and minimum air temperature magnitudes of 28.3 °C and 21.6 °C, respectively (Saif Saad quarter), while the suburban area (Karbala-Najaf Road) recorded maximum and minimum air temperature values of 26.03 °C and 18.3 °C. These extremes were observed in the third and fourth weeks of February, respectively.

The temperature variation could be attributed to several urban factors, including heightened heat absorption and retention, diminished green spaces, and increased anthropogenic heat sources such as buildings and vehicles.

Regarding the nighttime air temperature results shown in Fig. 7, the measurements were conducted between 07:00 pm and 07:15 pm, and the average air temperature magnitudes were determined at the same specified measuring points. Consequently, the average air temperature in the urban area exceeded that in the suburban area throughout the study period. The maximum and minimum air temperature values for both urban and suburban areas occurred in the eighth and fourth weeks, respectively. These nighttime findings differ from the daytime results, where the highest air temperature was observed in the last week of March, and the lowest air temperature was recorded in the last week of February.

4.2. Urban heat island (UHI) magnitudes

The minimum average Urban Heat Island (UHI) magnitude is 1.1 °C in the second week of March, while the maximum average UHI magnitude is 4.7 °C in the first week of February as shown in Table 2. In general, the urban area exhibits higher temperatures than the suburban area, with a temperature difference of 2.38 °C as shown in Fig. 8.

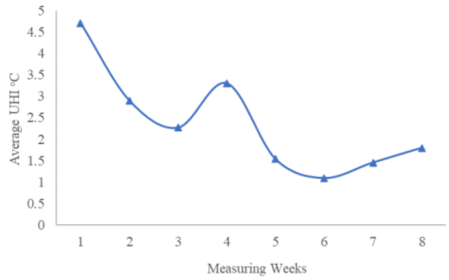

Fig. 8. Average urban heat island (UHI) magnitude during daytime.

Concerning Urban Heat Island (UHI) during nighttime as shown in Fig. 9, the UHI magnitude between the urban and suburban areas varies, ranging from a minimum average of 1.67 °C in the third week of March to a maximum average of 4.37 °C in the first week of February as shown in Table 3. Generally, urban areas experience higher temperatures than the suburban area by an average of 2.76 °C, considering all UHI records during February and March. Figures 10 and 11 illustrate that average UHI values during nighttime exhibit more variability compared to those during daytime. This discrepancy is attributed to the impact of sunlight on temperature variations during the daytime hours.

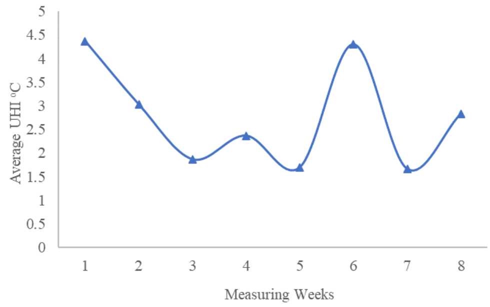

Fig. 9. Average Urban Heat Island (UHI) magnitude during nighttime.

Moreover, Tables 2 and 3 offer statistical assessments of temperature data in urban and suburban areas for both daytime and night-time, respectively, demonstrating statistical parameters including maximum, minimum, average, and standard deviation.

Table 2. Statistical parameters of the recorded daytime temperatures for urban and suburban areas.

Statistical Parameter	Temperature, °C		
	Urban	Suburban	Difference
Minimum value	21.6	18.3	1.1
Maximum value	28.5	26.03	4.7
Average	25.62	23.24	2.38
Standard deviation	2.7	2.56	1.2

Table 3. Statistical parameters of the recorded night-time temperatures for urban and suburban areas.

Statistical Parameter	Temperature, °C		
	Urban	Suburban	Difference
Minimum value	17.37	14.83	1.67
Maximum value	25.36	22.53	4.37
Average	21.02	18.25	2.77
Standard deviation	2.43	2.53	1.09

Using SPSS software, a simulated regression model was developed to explore the relationship between temperatures in urban and suburban areas throughout the daytime and nighttime. Eighty percent of the temperature datasets from both daytime and night-time were utilized to calibrate the model, with the remaining 20% reserved for validation. Figure 10 provides a graphical representation of this relationship, characterized by a linear regression model exhibiting a coefficient of determination (R2) of 0.86 for model calibration, where equation (1) represents this regression model.

$$ts = 0.8518\ tu + 0.8914 \qquad (1)$$

where (ts) is temperatures of daytime and night-time for the suburban area, °C. (tu) is temperatures of daytime and night-time for the urban area, °C.

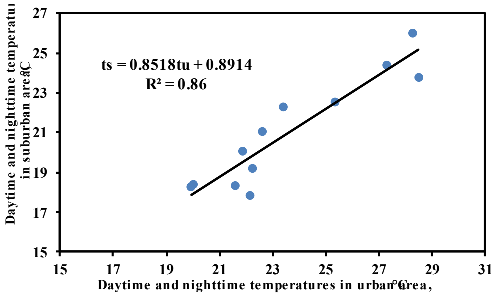

Fig. 10. The established relationship through the calibration process between temperatures in urban and suburban areas during both daytime and night-time.

Figure 11 illustrates the model verification process, aligning the relationship between recorded daytime and nighttime temperatures in suburban areas with those derived from Equation 1. The coefficient of determination (R2) for this relationship equals 0.97.

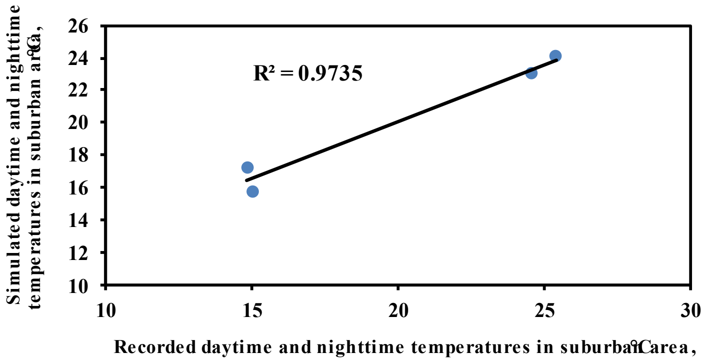

Fig. 11. The correlation between recorded and simulated daytime and night-time temperatures in suburban areas.

5. Discussion

Concerning the measurement of air temperature during daytime hours (Fig. 9), the results indicate variability in magnitude, possibly attributed to the fluctuating weather conditions in Iraq during the same winter season, akin to the weather in Baghdad city [38]. Both Karbala and Baghdad share similar weather characteristics, particularly dry and cold parameters, in winter [39]. Conversely, air temperature magnitudes at night (Fig. 9) exhibit greater stability compared to daytime measurements, with a decrease in value by 4.79 °C, possibly influenced by adverse weather conditions in the city.

Similarly, Daham et al. observed an increase in air temperature during the same period but in different governorates in Iraq, employing a different data acquisition method [40]. Their findings contradicted those of which suggested an increase in temperature at night throughout the entire year. The disparity may stem from variations in the hypotheses adopted between this study and theirs, as they utilized data collected from decades ago without accounting for the rapid climate changes, especially the lack of rain and unexpected flooding periods.

Urban Heat Island magnitudes during both day and night times (Figures 8 and 9) exhibit a general decreasing trend from the first week to the final week. This study employs a small-scale approach to determine UHI magnitude, representing a unique methodology not extensively covered in recent research. Notably, the average UHI value during nighttime was found to be greater than during daytime.

These findings align with numerous contemporary studies conducted in various cities, such as Manchester in the United Kingdom [41], and Barcelona [42], albeit those studies utilized remote sensing techniques for nighttime data acquisition. Conversely, UHI magnitudes during daytime show a significant impact, closely resembling nighttime values in Birmingham [43]. Discrepancies between this study and contemporary research may arise from differences in population demographics, data collection methods involving satellite sensors, and variations in the study periods across different cities.

The statistical analysis of the data from Tables 2 and 3 reveals that maximum, minimum, and average temperatures in urban areas exceeded those in suburban areas both during the day and at night. This discrepancy is attributed to urban areas lacking sufficient vegetation cover compared to their suburban counterparts. Furthermore, throughout both daytime and nighttime, the standard deviation of temperatures in urban and suburban areas, as well as the standard deviation of temperature disparities between them, exceeds 1.

These underscore significant fluctuations in temperature values compared to their typical averages, likely due to the Urban Heat Island effect, recognized as a primary contributor to these fluctuations.

Equation 1 demonstrated a strong linear correlation between temperatures in urban and suburban areas during both daytime and nighttime (Fig. 10), indicating excellent validation (Fig. 11). This indicates a regular linear style exists in variation of temperature between urban and suburban areas for daytime and nighttime intervals.

It was found that the air temperature values of a small urban area were constantly greater than those recorded in the suburban areas during the winter season. This can be considered as the most important result of the present study which confirms the existence of the UHI influence due to this contrast in air temperatures. Human activity, surface properties, and infrastructure cause significant temperature differences between urban, suburban, and rural areas, an indicator of the urban heat island effect.

Higher urban temperatures are contributed to by other influencing factors, such as increased heat sources through heat emissions from vehicle and industrial activity, as well as decreased vegetation cover. This study found that the UHI effect particularly affected small urban areas with comparatively lower inhabitance density.

Accordingly, it can be argued that the urban extending process can contribute to temperature increases even in areas with low density of population. Further research and probable alleviation strategies are needed to decrease the negative impact of the urban heat island on the temperature of the small urban areas.

The present study generally confirms the significance of comprehension and remediation of the urban heat island impact, specifically in small urban quarters to alleviate the negative effects on residents and develop strategies of urban planning and design.

6. Conclusions

The conclusions can be summarized in the following points:

- The recorded air temperatures at daytime and nighttime during winter in small urban areas were greater than those in suburban areas.
- While the magnitudes of air temperature decrease in the winter season, the daytime values fluctuated weekly, with an overall increase in the last four weeks. In contrast, nocturnal air temperature exhibited minimal fluctuation in magnitude.
- The Urban Heat Island phenomenon was evident in Karbala City, as indicated by the temperature difference between urban and suburban areas observed during both daytime and nighttime measurements.
- In general, the average Urban Heat Island (UHI) values were higher during the nighttime compared to the daytime throughout the study period. Consequently, temperature readings around midday and near sunset exhibited consistent UHI magnitudes.

- Based on the simulated regression model, it was determined that a robust linear relationship exists between temperatures in urban and suburban areas throughout both daytime and night-time.
- Unexpectedly, modest zones like neighbourhoods exert a noteworthy influence on temperature variations with neighbouring areas. Additionally, each week during the research period witnessed extreme temperature readings for both daytime and nighttime measurements, with an average Urban Heat Island (UHI) of 2.5 °C. Consequently, the Urban Heat Island effect escalated swiftly even in residential quarters with a population of 30,000 to 40,000 inhabitants in suburban areas.

Nomenclatures

S	Suburban area
S1	Measuring point number 1 at suburban area
S2	Measuring point number 2 at suburban area
S3	Measuring point number 3 at suburban area
U	Urban area
U1	Measuring point number 1 at urban area
U2	Measuring point number 2 at urban area
U3	Measuring point number 3 at urban area

Abbreviations

UHI	Urban Heat Island

References

1. Neave, M.; Rayburg, S.; and AL-Obaidi, I.H. (2016). Winter urban heat island magnitudes of major Australian cities. *International Journal of GEOMATE*, 11(24), 2322-2327.
2. Algretawee, H.; Rayburg, S.; and Neave, M. (2019). Estimating the effect of park proximity to the central of Melbourne city on urban heat island (UHI) relative to land surface temperature (LST). *Ecological Engineering*, 138, 374-390.
3. Algretawee, H.; Rayburg, S.; and Neave, M. (2016). The cooling effect of a medium sized park on an urban environment. *International Journal of GEOMATE*, 11(26), 2541-2546.
4. Stone Jr, B.; and Rodgers, M.O. (2001). Urban form and thermal efficiency: How the design of cities influences the urban heat island effect. *American Planning Association. Journal of the American Planning Association*, 67(2), 186-198.
5. Royal Meteorological Society (2021). Urban heat island information. Retrieved September 23, 2023, from https://www.metlink.org/fieldwork-resource/urban-heat-island-introduction/
6. Susca, T.; and Pomponi, F. (2020). Heat island effects in urban life cycle assessment: Novel insights to include the effects of the urban heat island and UHI-mitigation measures in LCA for effective policy making. *Journal of Industrial Ecology*, 24(2), 410-423.

7. Hong, J.W.; Hong, J.; Kwon E.E.; and Yoon, D.K. (2019). Temporal dynamics of urban heat island correlated with the socio-economic development over the past half-century in Seoul, Korea. *Environmental Pollution*, 254, 112934.
8. Acosta, M.P. et al. (2021). How to bring UHI to the urban planning table? A data-driven modeling approach. *Sustainable Cities and Society*, 71, 102948.
9. Liou, Y.A.; Nguyen, K.A.; and Ho, L.T. (2021). Altering urban greenspace patterns and heat stress risk in Hanoi city during Master Plan 2030 implementation. *Land Use Policy*, 105, 105405.
10. Martinelli, A.; Kolokotsa, D.D.; and Fiorito, F. (2020). Urban heat island in Mediterranean coastal cities: The case of Bari (Italy). *Climate*, 8(6), 79.
11. Algretawee, H.; and Alshama, G. (2021). Modeling of evapotranspiration (ETo) in a medium urban park within a megacity by using artificial neural network (ANN) model. *Periodica Polytechnica Civil Engineering*, 65(4), 1260-1268.
12. Algretawee, H. et al. (2022). Determination of difference amount in reference evapotranspiration between urban and suburban quarters in Karbala city. *Journal of Ecological Engineering*, 23(7), 180-191.
13. Alshammari, M.; Al Juboury, M.F.; and Algretawee, H. (2020). A comparison of two methods of the environmental treatment for water wells: case study in Kufa City-Iraq. *Proceedings of the IOP Conference Series: Materials Science and Engineering, the First International Conference of Pure and Engineering Sciences* (*ICPES*2020), Karbala, Iraq, 871, 012008.
14. Kim, S.W.; and Brown, R.D. (2021). Urban heat island (UHI) intensity and magnitude estimations: A systematic literature review. *Science of the Total Environment*, 779, 146389.
15. He, X. et al. (2020). Observational and modeling study of interactions between urban heat island and heatwave in Beijing. *Journal of Cleaner Production*, 247, 119169.
16. Montaner-Fernández, D. et al. (2020). Spatio-temporal variation of the urban heat island in Santiago, Chile during summers 2005-2017. *Remote Sensing*, 12(20), 3345.
17. Thomas, G.; Sherin, A.P.; Ansar, S.; and Zachariah, E.J. (2014). Analysis of urban heat island in Kochi, India, using a modified local climate zone classification. *Procedia Environmental Sciences*, 21, 3-13.
18. Svensson, M.K.; and Eliasson, I. (2002). Diurnal air temperatures in built-up areas in relation to urban planning. *Landscape and Urban Planning*, 61(1), 37-54.
19. Salman, A.M.; and Saleem Y.M. (2021). The effect of Urban Heat Island mitigation strategies on outdoor human thermal comfort in the city of Baghdad. *Frontiers of Architectural Research*, 10(4), 838-856.
20. Wilby, R.L. (2008). Constructing climate change scenarios of urban heat island intensity and air quality. *Environment and planning. B: Planning and Design*, 35(5), 902-919.
21. Kim, Y.H.; and Baik, J.J. (2005). Spatial and temporal structure of the urban heat island in Seoul. *Journal of Applied Meteorology and Climatology*, 44(5), 591-605.
22. Li, H. et al. (2018). Interaction between urban heat island and urban pollution island during summer in Berlin. *Science of the Total Environment*, 636, 818-828.

23. Oke, T.R. (1982). The energetic basis of the urban heat island. *Quarterly Journal of the Royal Meteorological Society*, 108(445), 1-24.
24. Eastin, M.D. et al. (2018). Temporal variability of the charlotte (sub) urban heat island. *Journal of Applied Meteorology and Climatology*, 57(1), 81-102.
25. Pal, S. et al. (2012). Spatiotemporal variability of the atmospheric boundary layer depth over the Paris agglomeration: An assessment of the impact of the urban heat island intensity. *Atmospheric Environment*, 63, 261-275.
26. Erell, E.; and Williamson, T. (2007). Intra-urban differences in canopy layer air temperature at a mid-latitude city. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, 27(9), 1243-1255.
27. Yow, D.M.; and Carbone, G.J. (2006). The Urban Heat Island and local temperature variations in Orlando, Florida. *Southeastern Geographer*, 46(2), 297-322.
28. Rasul, A.; Balzter, H.; and Smith, C. (2015). Spatial variation of the daytime Surface Urban Cool Island during the dry season in Erbil, Iraqi Kurdistan, from Landsat 8. *Urban Climate*, 14, 176-186.
29. Al-Obaidi, I.; Rayburg, S.; Półrolniczak, M.; and Neave, M. (2021). Assessing the impact of wind conditions on urban heat islands in large Australian cities. *Journal of Ecological Engineering*, 22(11), 1-15.
30. Shahgedanova, M.; Burt, T.P.; and Davies, T.D. (1997). Some aspects of the three‐dimensional heat island in Moscow. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, 17(13), 1451-1465.
31. Blazejczyk, K.; Bakowska, M.; and Wieclaw, M. (2006). Urban heat island in large and small cities. *Proceedings of the 6th International Conference on Urban Climate*, Göteborg, Sweden, 794-797.
32. Hassan, W.H.; Hussein, H.H.; and Nile, B.K. (2022). The effect of climate change on groundwater recharge in unconfined aquifers in the western desert of Iraq. *Groundwater for Sustainable Development*, 16, 100700.
33. Abdulameer, L.S. (2022). Comparison between Hazen-Williams and Darcy-Weisbach equations to calculate head loss through conveyancing treated wastewater in Kerbala city, Iraq. *Eastern-European Journal of Enterprise Technologies*, 1(1 (115)), 36-43.
34. Al-yasery, H.; Almuhanna, R.; and Al-jawahery, Z. (2018). Metro stations site selection in Karbala city using (GIS). *Proceedings of the IOP Conference Series: Materials Science and Engineering*, 433(1), 012036, Kerbala, Iraq.
35. Varentsov, M. et al. (2018). Anthropogenic and natural drivers of a strong winter urban heat island in a typical Arctic city. *Atmospheric Chemistry and Physics*, 18(23), 17573-17587.
36. Jabbar, H.K.; Hamoodi, M.N.; and Al-Hameedawi, A.N. (2023). Urban heat islands: a review of contributing factors, effects and data. *Proceedings of the IOP Conference Series: Earth and Environmental Science,* 1129(1), 012038.
37. Grimmond, S.U.E. (2007). Urbanization and global environmental change: local effects of urban warming. *The Geographical Journal*, 173(1), 83-88.
38. Alobaydi, D.; Bakarman, M.A.; and Obeidat, B. (2016). The impact of urban form configuration on the urban heat island: The case study of Baghdad, Iraq. *Procedia Engineering*, 145, 820-827.

39. Nassif, W.G.; Jasim, F.H.; and Al-Taai, O.T. (2021). Analysis of air temperature, relative humidity and evaporation over Iraq using ECMWF reanalysis. *Indian Journal of Ecology*, 48(2), 446-452.

40. Daham, A.; Han, D.; Rico-Ramirez, M. and Marsh, A. (2018). Analysis of NVDI variability in response to precipitation and air temperature in different regions of Iraq, using MODIS vegetation indices. *Environmental Earth Sciences*, 77, 1-24.

41. Skelhorn, C.P.; Levermore, G.; and Lindley, S.J. (2016). Impacts on cooling energy consumption due to the UHI and vegetation changes in Manchester, UK. *Energy and Buildings*, 122, 150-159.

42. Arellano, B.; and Roca, J. (2019). Combining different sensors for the detailed analysis of the daytime and nighttime UHI. *Proceedings of the SPIE 11157, Remote Sensing Technologies and Applications in Urban Environments IV*. Strasbourg, France. 1115703.

43. Azevedo, J.A.; Chapman, L.; and Muller, C.L. (2016). Quantifying the daytime and night-time urban heat island in Birmingham, UK: A comparison of satellite derived land surface temperature and high-resolution air temperature observations. *Remote Sensing*, 8(2), 153.

Appendix A

Fig. A-1. Some urban area (Saif Saad district) features, such as a restaurant (A), and a multi-story building (B).

Fig. A-2. Suburban area (Karbala-Najaf Road) features, such as scattered houses at both roadsides (A), and scattered vegetations (B).

Fig. A-3. A. Features around the selected three measuring points at urban area (U1, U2 and U3).

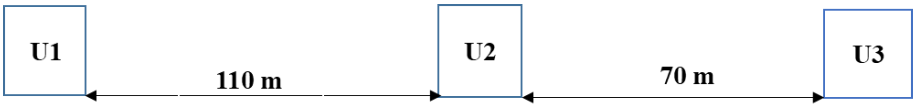

Fig. A-3. B. Distances between the measuring points at urban area (U1, U2 and U3).

Fig. A-4. A. Features around the selected three measuring points at suburban area (S1, S2 and S3).

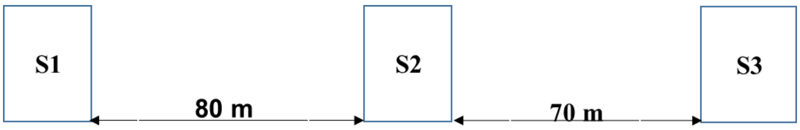

Fig. A-4. B. Distances between the measuring points at suburban area (S1, S2 and S3).