ISSN: 1648-6897 / eISSN: 1822-4199

VILNIUS TECH
Vilnius Gediminas Technical University

JOURNAL of ENVIRONMENTAL ENGINEERING & LANDSCAPE MANAGEMENT

2024
Volume 32
Issue 4
Pages 283–291
https://doi.org/10.3846/jeelm.2024.22353

ASSESSING OF MONTHLY SURFACE WATER CHANGES IMPACT ON THERMAL HUMAN DISCOMFORT IN BAGHDAD

Jamal S. ABD AL RUKABIE[1], Dalia A. MAHMOOD[2], Monim H. AL-JIBOORI[2]✉, Mustafa S. SRAYYIH[3]

[1]*Department of Science, College of Basic Education, University of Sumer, Thi-Qar, Iraq*
[2]*Atmospheric Sciences Department, College of Science, Mustansiriyah University, Baghdad, Iraq*
[3]*Department of Remote Sensing and GIS, College of Science, University of Baghdad, Baghdad, Iraq*

Highlights:

- digital maps of surface water were produced by Modified Normalized Difference Water Index using QGIS;
- investigate relationship between urban surface water and discomfort index;
- summer months of 2021 have the highest discomfort with severe thermal stress;
- discomfort index decreases exponentially when increasing the amount of surface water.

Article History:

- received 14 December 2023
- accepted 05 August 2024

Abstract. In urban areas, surface water bodies play an important role in mitigating thermal discomfort, which is mainly caused by increasing air temperatures. Based on daily temperature and relative humidity data recorded by the Baghdad weather station for the two years 2018 and 2021, the monthly human discomfort index was calculated and then combined with monthly surface water areas extracted by a modified normalized difference water index using Sentinel-2A satellite imagery for the same period. The results show that the winter and most spring months of these years have no discomfort, and the summer months (July and August) in 2021 have the highest discomfort with severe thermal stress due to the large deficit in rainfall events. The monthly relationship between urban water surfaces and the level of the discomfort index was also studied, which was non-linear and followed the exponential decay function. This means that as the amount of surface water increased, the levels of the discomfort index decreased exponentially until no discomfort conditions existed.

Keywords: surface water, MNDWI, Sentinel-2A satellite, discomfort index, surface water bodies, Baghdad.

✉Corresponding author. E-mail: ***mhaljiboori@gmail.com***

1. Introduction

Surface waters in urban environments are critical freshwater resources for human (Le Sève, 2023), ecological (Cheng et al., 2022) and local climate systems (Cheng et al., 2022; Zeng et al., 2017). They are of paramount importance in sustaining all living things (Karpatne et al., 2017; Genjebo et al., 2023) and suppressing rising dust emissions during dry seasons. Urban surface water bodies are considered natural resources that provide a cooling effect, where they can reduce air temperature during the day (Wong et al., 2011), but also provide humidity (Xu et al., 2010). Consequently, these meteorological factors can be formed and called heat stress, which can be originally expressed in terms of human thermal discomfort, as proposed by Thom (1959). It is a biometeorological parameter for measuring the degree of discomfort experienced under different climatic conditions, which depends on the principle of heat exchange between the human body and the near-surface atmosphere. Thermal stress has many implications for the energy (Kazmi et al., 2022) and health (Ncongwane et al., 2021) sectors and has been widely used as a criterion for microclimate assessment (Mushore et al., 2019; Nurmaya et al., 2022).

Surface water bodies have demonstrated their ability to regulate the microclimate of the surrounding regions, where they act as a natural source of cooling due to the humidity caused by evaporation during the day. These bodies can also reduce the air temperature and increase the humidity in their surroundings (Syafii et al., 2016; Hong et al., 2023). The main element, temperature, has the greatest impact on human activities. The air temperature near or over bodies of water is very different from that over land due to differences in the way water heats and cools (Febrita et al., 2021).

Ammant Baghdad is the central government of Iraq and a large and densely populated city, so it has experienced severe adverse climatic and thermal conditions under global warming, especially in summer (Wahab et al., 2022; Al-Jiboori et al., 2020). Therefore, it is important to study the impact of surface water changes on human physiological comfort and urban living. As the urbanization process continues, as in Baghdad, the higher air temperature would be a more serious problem. Water bodies such as rivers, ponds, streams and wetlands can improve outdoor comfort in the summer, which is free of clouds and rain (Zahraa et al., 2020).

Numerous previous studies have shown that human physiological changes are directly affected by most meteorological elements in nature (Al-Jiboori, 2007; Pantoja et al., 2021; Cheng et al., 2022; Dasari et al., 2021). The studies achieved to assess heat stress and discomfort in dry thermal environments such as Baghdad are by Al-Jiboori (2007), Yousif and Tahir (2013), Dasari et al. (2021) and Kishta et al. (2022). In Iraq, Al-Jiboori conducted temperature-humidity complaints in three major cities: Basra, Baghdad and Mosul, over a period of ten years (1991–2000). He found that the discomfort interval for living lasted five, four and two summer months in Basra, Baghdad and Mosul respectively. Dasari et al. (2021) also found discomfort in all summer months (June to September) over a 39-year period (1980–2018). Finally, Yousif and Tahir (2013) observed that 100% of the population in Khartoum experienced heat stress during the hot season.

With the development of remote sensing technologies, Geographic Information Sensing (GIS) was considered as a powerful tool to observe the spatial and temporal changes of surface water in a given location. Since Baghdad's land is part of the Mesopotamian alluvial plain, which is flat and roughly low-lying, GIS is a suitable method for detecting wetlands. Medium-resolution remote sensing data acquired from the Sentinel-2 satellite is most commonly used to extract and monitor surface water bodies (Huang et al., 2018). Although water bodies in urban semiarid areas such as Baghdad are often scarce, small and surrounded by complex buildings, vegetation and their shadows, medium resolution imagery acquired from this satellite could detect changes in surface water. For example, Mahdi et al. (2024) monitored land surface water areas using the Modified Normalised Difference Water Index (MNDWI) for each month of the two years 2018 and 2021. They found that the largest areas were in January, while the lowest values were in June. Using these results of their work in the presented paper, we also highlight the process of extracting water bodies. The main objectives of this study are to (1) investigate the assessment of changes in surface water within Ammant Baghdad resulting from the Tigris River and its ponds during the interannual months of both 2018 and 2021, (2) analyse the monthly means of air temperature, relative humidity and thermal discomfort, and (3) explore the relationships between surface water bodies and discomfort categories.

2. Study area and datasets

The research was carried out in Ammant Baghdad (see Figure 1b), followed by Baghdad province, which is located at 33°12'-33°29' N latitude and 44°10'-44°30' E longitude. The topography of the area is almost entirely flat, with elevations ranging from 24 m in the south to 48 m in the north above mean sea level, covering a total area of 894.3 km^2. It is a medium-sized and densely populated city among all Iraqi provinces and has 16 municipalities. The Tigris River divides Baghdad into two parts, the eastern part called Rasafa and the western part called Karkh, and joins the Diyala River 15 km south of the Ammant (Naqi et al., 2021). The land is low-lying and of alluvial origin due

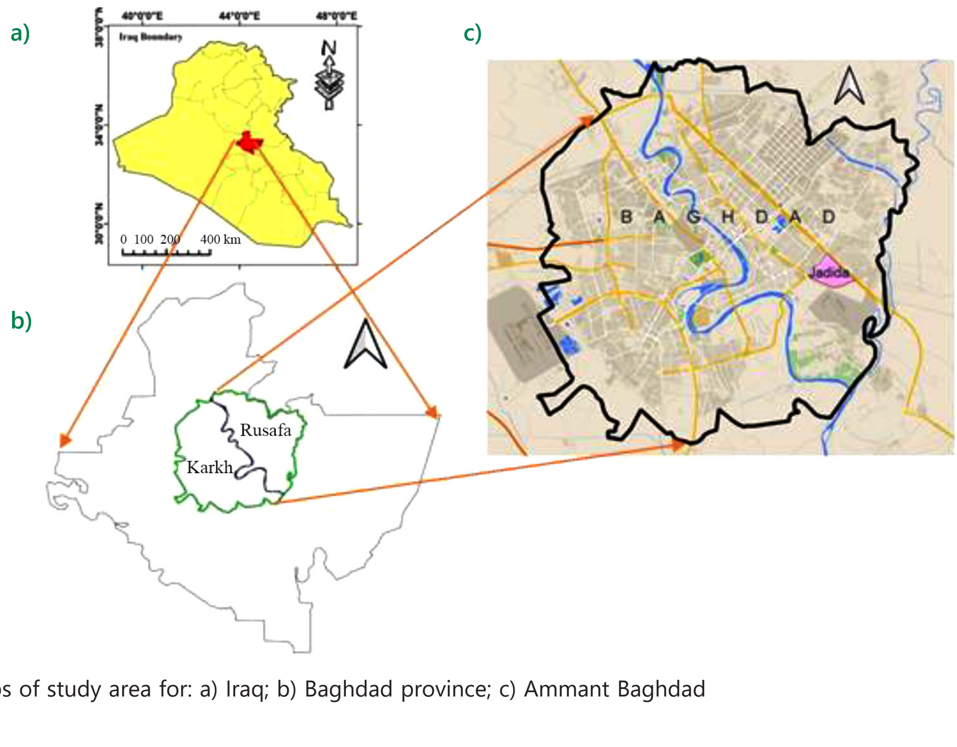

Figure 1. Maps of study area for: a) Iraq; b) Baghdad province; c) Ammant Baghdad

to the periodic large floods caused by the river. At present, these floods have been stopped by the construction of a dam on the river at Samarra to the north. Several small bodies of water, such as ponds, canals and streams, persist because they are located on semi-impermeable deposits. They received their water from the direct groundwater at a depth of (2–10) m (Al-Basrawi et al., 2015).

The climate of Baghdad is mainly semi-arid, with hot summers and cold winters, and is influenced by the Mediterranean climate. The daily mean temperature ranges between 18 °C in winter and 45 °C in summer. The annual mean rainfall is about 140 mm, which usually starts from October to May, with no rain in the remaining months (Al-Timimi & Al-Khudhairy, 2018). Due to Baghdad being far from the Arabian Gulf, the annual mean relative humidity is 52% in winter and 15% in summer; thus, the city can be described as dry, and then dust storms normally occur (Halos et al., 2017; Adeeb & Al-Timimi, 2019).

Two dataset sources were used in this paper: Monthly meteorological data of both air temperature and relative humidity obtained from the Iraqi Meteorological Organization and Seismology, and Sentinel-2A satellite images acquired from the European Space Agency Hub. The time period was 24 months, in two years 2018 and 2021. In this period, 48 satellite images were downloaded through the link (https://scihub.copernicus.eu/) that included the study region. After sub setting the images in a square area, two images were merged to cover this region, and therefore, the number of images became 24, and each one represents one month of the two years 2018 and 2021. At the same period, monthly means of surface air temperature and relative humidity were computed from hourly records that measured by weather automatic station located at 2 m above the ground level.

3. Methodology

The context of the framework, in general, is composed of three parts: detection of surface water, calculation of outdoor thermal discomfort, and statistical analysis to find out their empirical relations with each other. Figure 2 below presents the outline of the algorithm adopted in this study.

3.1. Modified Normalized Difference Water Index

To detect the change in surface water, the spectral index effectively used in urban areas is MNDWI, which is a powerful method for mapping water bodies, detection of water features from dense build-up areas, vegetation, shadows, and monitoring water content changes. It is computed as

$$\mathrm{MNDWI} = \frac{\mathrm{Green} - \mathrm{SWIR}}{\mathrm{Green} + \mathrm{SWIR}}. \tag{1}$$

From the Sentinel-2 spectral imagery, the only two bands in the above equation, Green (band 3) and SWIR (band 11), were used in this paper. They have different resolutions, with the former at 10 m and the latter at 20 m. Spatial resampling was achieved to band 11 to balance the resolution 10 m using the resampling tool in the software of Quantity GIS (QGIS). The preprocesses such as resampling band 11, merging the two images of the two bands to cover the study region, and extraction surface water bodies were implemented using QGIS, and then their digital areas (in km^2) were calculated using r.report tool in the toolbox after classifying process. MNDWI values are between –1 and +1. In this paper, only two classifications are considered: water and non-water bodies, according to the positive and negative values of MNDWI (Huang et al., 2018). For more details, output processing, image projection, and atmospheric correction, and post-processing are reported in the reference (Mahdi et al., 2023).

The urban surface water bodies were extracted by MNDWI (Eq. (1)) from the Sentinel-2 satellite using QGIS software, version 3.4, for all months of the two years 2018 and 2021. Using unsupervised classification, all images have been classified into seven classes: build-up, water, rangeland, flooded vegetation, dense vegetation, crops, and bare land. Figure 3 shows the characteristics of the urban surface of Baghdad as a sampling selected case in which the build-up area is the largest class, especially in the center of the city.

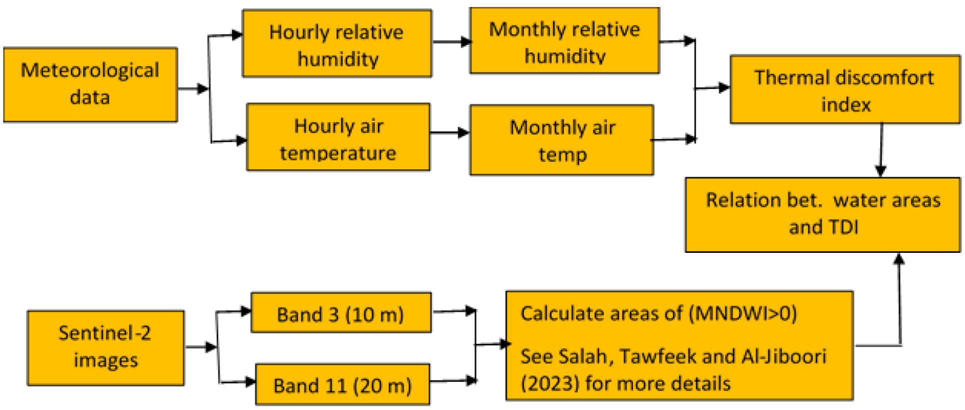

Figure 2. Flowchart of the methodology

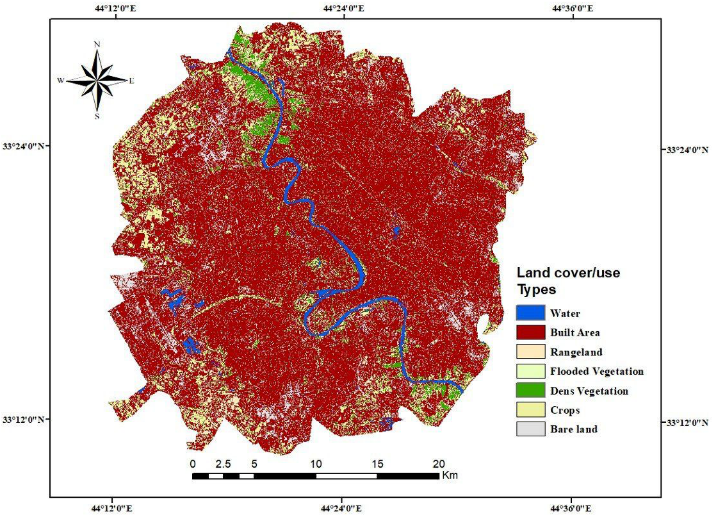

Figure 3. Classification of land cover/land use in Baghdad's surface

Table 1. Thermal discomfort index categories (source: Siami & Ramadhani, 2019)

Category	I	II	III	IV	V	VI
TDI (C)	TDI < 21	2 ≤ TDI < 24	24 ≤ TDI < 27	27 ≤ TDI < 29	29 ≤ TDI < 32	TDI ≥ 32
Discomfort level	No discomfort	Less than 50% of the population feels discomfort	More than 50% of the population feels discomfort	Most of population suffers discomfort	Everyone feels severe stress	State of medical emergency

3.2. Thermal discomfort index

There are many various approaches to expressing the relationship between the outdoor environment and human well-being, for example, the wet-bulb globe temperature index, discomfort index, temperature-humidity index, comfort index, and universal thermal climate index, among which is outdoor comfort. In the presented paper, the monthly thermal discomfort index (TDI) was applied to evaluate the impact of heat stress on the individual, taking into account the combined effect of air temperature and stress, which can be determined using the following equation (Pantoja et al., 2021; Dasari et al., 2021):

$$\mathrm{TDI} = T - \left[0.55 \times \left(1 - 0.01 \times RH\right) \times \left(T - 14.5\right)\right], \tag{2}$$

where T is the monthly mean air temperature in °C and RH is the monthly mean relative humidity in %. The selection of this index over other indices includes its simple calculation and their results are sensitive to heat levels during different seasons and climate conditions. Also, existing ambient relative humidity in Eq. (2) is necessary to evaluate the effects of evaporation on sweat, which naturally keeps human comfort levels. So this equation could be applicable for the entire globe such as in humid (Nurmaya et al., 2022), arid and semiarid (Dasari et al., 2021), and cold regions (Stathopoulou et al., 2005). However, in general, most arid regions (e.g. Baghdad) are not need to use a radiant temperature in case of existing the clouds which influence longwave radiation scattering, in which clear sky conditions with dry climate are often prevailed throughout the year, except in dawn winter (December and November) (Al-Timime et al., 2024). Hence, Eq. (2) could be valid for computing thermal discomfort in this study. In addition, TDI is used in urban and densely populated areas because of its relatively simple identification of the category of climate comfort based on essential meteorological variables such as temperature and relative humidity. At present, these elements are measured by new instruments, e.g., an automatic weather station that has a high temporal resolution at frequencies accustomed to measurement demands. The classification of TDI is reported in Table 1.

3.3. Relation between surface water area and thermal discomfort index

The method used to describe the relationship between the monthly dependent variable (i.e., surface water area) and independent variable (TDI) is a scatter plot, which implies the strength of the relationship between the variables at a glance. To comprehensively evaluate, some statistical parameters were performed in this paper through Origin software, issue 2016. (1) the standard deviation (SD), defined as a measure of the dispersion of data relative to its mean, is calculated through computing monthly means from daily meteorological data for both air temperature and relative humidity as well as testing the relationship above. (2) Pearson correlation coefficient (R) is a measure the strength of relationship with its type (i.e. positive or negative) that returns a value of between –1 and +1. This further used in testing this relationship through calculating t-value by formula given as

$$t = R \times \left(\frac{1-R^2}{n-2}\right)^{-1/2}, \quad (3)$$

where n is the sample size. (3) After specifying the relation's strength and testing, the goodness-of-fit (R^2) that ranges from 0 to 1 will be computed when passing the best line through data points in scatter plot.

4. Results and discussion

4.1. Surface water body area

To extract only water bodies, spectral MNDWI values were classified into only two groups: positive values include water bodies, and negative values show other land covers. For executing the goals of this paper, surface water bodies areas at all months of the two years 2018 and 2021 are presented and displayed in Figure 4. All spatial figures that display spectral values for MNDWI, water, and non-water bodies are found in (Mahdi et al., 2023).

The permanent surface water during the summer months is approximately constant for the two years, with an average value of 19.5 km^2, which could be considered a baseline for existing water in the Tigris River and other ponds. In other months, there were significant variations in the amounts of urban surface water, especially in 2018, which was characterized by large falling rains (total annual 284.2 mm) and was distributed uniformly in these months. Meanwhile, in 2021, less surface water areas are clear, with the exception of January with a value of 77.2 km^2, where in this year annual amounts of rain were the lowest (25 mm) over the period of 40 years (1980–2021), so it was characterized by dryness, higher temperatures, and increased frequencies of dust and sand storms. In spite of less rain in January 2021, the urban surface water area appears high which may attribute to the use of MNDWI for detecting some shadows and moist land features caused by high rates of relative humidity (perhaps fog or mist) in this month as shown in next subsection (Yang et al., 2018).

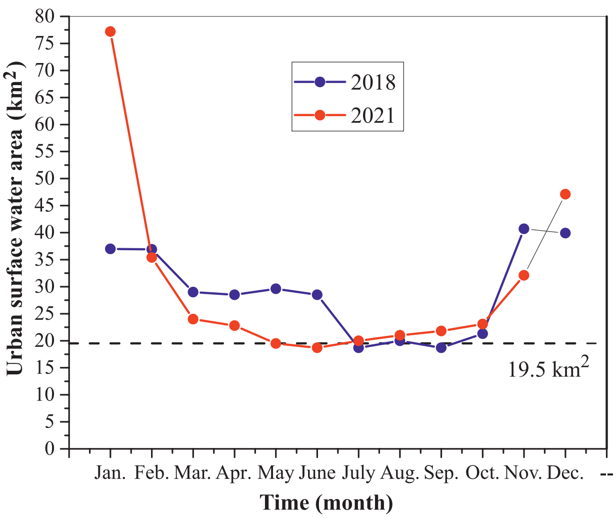

Figure 4. Monthly variation of surface water areas in 2018 and 2021. Dashed line represents water area without adding rainfall

The interesting result can be induced by annual accumulative amounts of surface water, which reach 348.8 and 362.7 km^2 in 2018 and 2021, respectively. The baseline surface water area in Baghdad without any rainfall, as shown in the summer months (June, July, and August) of the studied years, is about 19.5 km^2 (see horizontal line in Figure 4). The rationale behind taking this value is for supporting water management as an exceeded water area during rainy months. If this value is subtracted from water areas in rainy months (September–May), the result will be 114.8 and 128.7 km^2 for both years 2018 and 2021, respectively. These excess surface waters can be invested for dry summer seasons instead of being partly used for agriculture, descending to the bottom of the earth through filtration processes, or rising into the atmosphere by evaporation and evapotranspiration processes. Water management, thus, in Iraq, is one of the effective strategies to overcome the crises resulting from water scarcity and mitigate the severity of climate change.

4.2. Monthly variation of thermal discomfort index

According to Eq. (2), the thermal discomfort index depended on temperature and relative humidity, so their monthly means were first analyzed. They and their SD are presented separately in Figures 5a and 5b for both the years 2018 and 2019, respectively. The monthly variation in temperature in these years has the same behavior but slightly different values. The opposite behavior between temperature and relative humidity is clear in two years: when temperature increased, relative humidity dramatically decreased, and vice versa. Across all months of 2021, SD values around the monthly means for temperature are larger than those in 2018 (see Figure 5a) due to a sharp lack of rainfall in 2021. The monthly highest air temperature in Baghdad occurred in July, and the lowest temperature was in January. Also during the summer months, monthly mean temperatures in 2021 showed a slightly higher value compared to those observed in 2018. In the same way, the lowest values of monthly relative humidity (RH < 20%) were obvious at four months (May–August) of 2021, while they were at three months of summer (2018). At the end of 2018 (i.e., November and December), monthly RH recorded the highest values (78% and 83%), even though they were larger than those recorded in 2021.

Monthly outdoor thermal discomfort indexes were obtained from monthly data on air temperature (°C) and relative humidity (%) for both the years 2018 and 2021, as displayed in Figure 6. According to Eq. (3), TDI is directly proportional to the temperature. If temperatures increase, TDI will increase too. Therefore, in Baghdad during the summer months (June–September) of 2018, the monthly TDI was that most people felt discomfort, while in 2021 its peak TDI was severe heat stress (category V: TDI > 29) and unsuitable for performing all human activities. Also in June and September, most people suffer discomfort where the monthly TDI lies between 27 and 29 °C. In winter, some

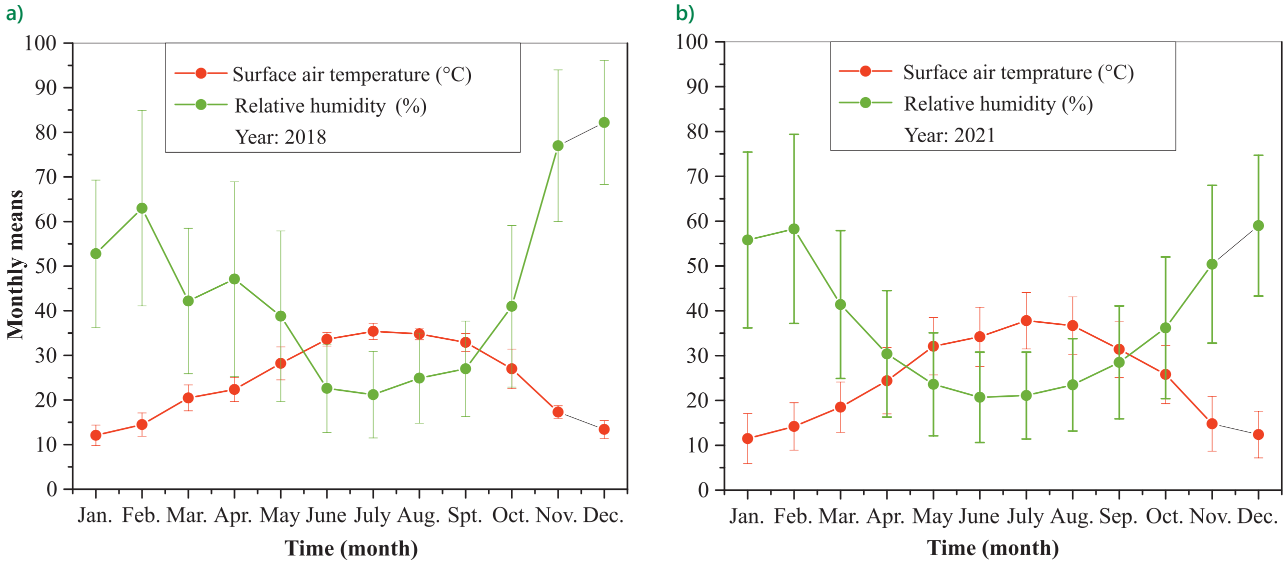

Figure 5. Monthly variations of air temperature and relative humidity for: a) 2018; b) 2021

spring months (March–April), and November of two years, the population was absolutely comfortable living and performing all activities in Baghdad's outdoor atmosphere. The reason is that climate conditions are usually fine and characterized by dropping temperatures, good humidity, and rainfall events, as mentioned in the study area. Finally, although two years had a bit of a difference in climate conditions, such as falling rain amounts, the two curves of monthly TDI coincided at one point (April), which is usually no discomfort for the population.

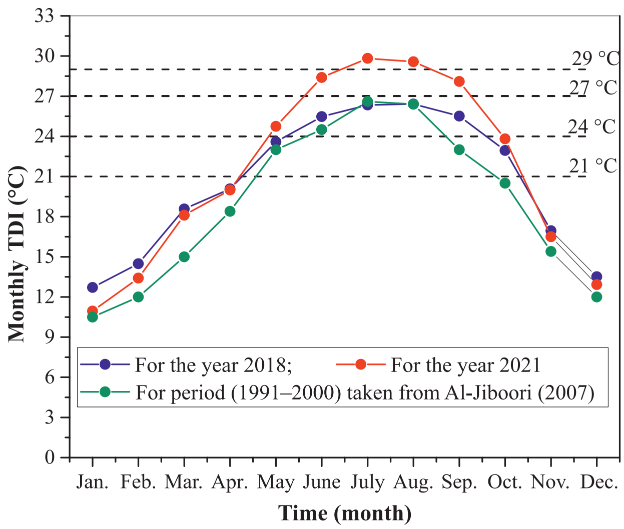

Figure 6. Monthly variation of thermal discomfort index (TDI) in Baghdad in 2018 and 2021

It is more interesting to compare the new results of TDI with those reported in Al-Jiboori (2007) for the same city (Baghdad) and data source, but during the period 1991–2000. Monthly means of TDI for this period were added to Figure 6, which have lower values throughout all months of the year, except for two summer months (July and August) of 2018. The time difference between the two studies is about 20 years, and the human discomfort has intensified across all months, especially in 2021. This is, of course, because of the ongoing increase in population and urbanization processes, especially in Baghdad (Tawfeek et al., 2020), which is also affected by global warming.

Figure 7 shows the frequency distribution of monthly mean TDI values in each year. The frequencies of no discomfort conditions reach 50% for both years, which are concerned with the months from November to April. The second category, with less than 50% of the population feeling discomfort, was found in two months (May and October) of 2018, while only one month (October) of 2021 has this category. The third category, with the same conditions as above but more than 50%, was found in four hot months (June–September) of 2018 and in only one month (October) in 2021. Two months of 2021 (June and September) display the conditions of category, and two last summer months (July and August) were severe heat stress, and nobody felt discomfort.

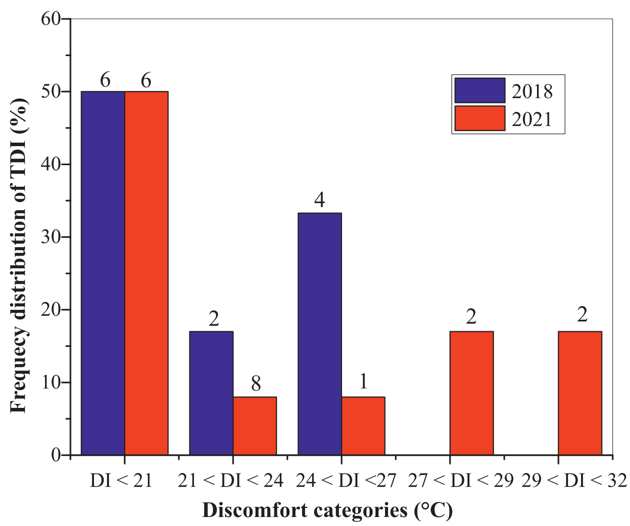

Figure 7. Histogram of frequency distribution of discomfort index in 2018 and 2021. The numbers above bars represent number of months

4.3. Relation between surface water areas and thermal discomfort index

Water bodies are regarded as an effective tool to improve urban thermal environments, so they were extracted by remote sensing techniques using satellite Sentinel-2A images within the Baghdad region. They appear to be positive in mitigating increasing outdoor thermal discomfort during hot summer months by cooling down through the evaporation process. To evaluate this influence, a scatter graph method between surface water bodies' areas on the X-axis and thermal discomfort index values on the Y-axis was used to find out the type of relationship between these variables. Figure 8 displays this graph between the results of these variables described in the above subsections for all months of the two years 2018 and 2021. There is a clear decreasing relation between these variables with less scatter whereas when increasing surface water areas, TDI values gradually drop to their lowest values.

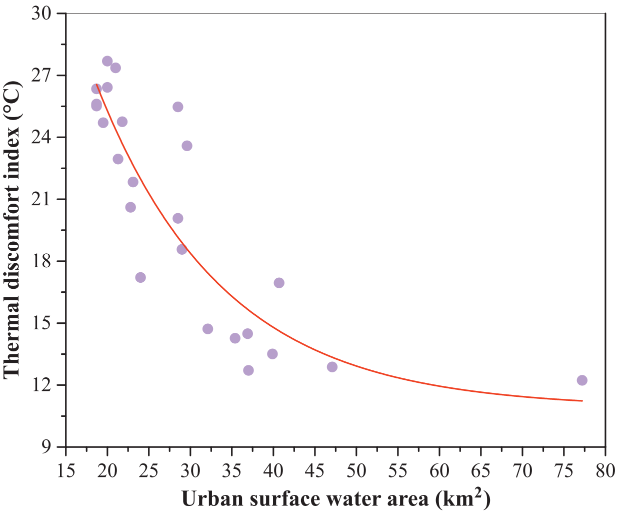

Figure 8. Relation between values of surface water area and TDI in Baghdad

To comprehensively understand, this quantitative relationship was further discussed in terms of R analysis. Before calculating this statistical parameter, means with their SD of surface water areas and thermal discomfort index were separately calculated during 12 months of each year. The results of *R* statistics with *p*-value were summarized in Table 2.

Table 2. Statistical results of monthly surface water area and TDI for 24 months of two years 2018 and 2021

Variable	Monthly mean	SD	*R*	Direction	*p*-value
Surf. water area (km^2)	29.6	±13.1	−0.77	Negative	1.3×10^{-5}
TDI (°C)	20.4	±5.4			

The negative correlation between monthly means of surface water and TDI shows that the changes in urban water area correspond TDI changes in the opposite direction. The strength of the correlation was 0.77, which represents a strong correlation (Deng et al., 2023). This was because surface water can largely contribute to mitigate higher TDI levels to lower values as shown in Figure 8 whereas, for example, when increasing 5-km^2 area of water over the 20-km^2, it was sharply dropped by 4 °C of TDI at dry conditions.

Now, we were examined several nonlinear functions using the OriginLab program and found an exponential decay function below could provide the best-fitting line passing through these data points.

$$\mathrm{TDI} = A \times e^{-\left(\text{water area}/T\right)} + B, \tag{4}$$

where *A* is amplitude, *B* is offset, and *T* is a time constant. They are empirical constants based on the results of TDI and water areas as input variables. The results of these constants are derived as follows, respectively: $A = 53.1$, $B = 10.9$, and $T = 15.3$. Also, the strong relation between scatter data points and its fitted values (R^2) was found to be 0.78. We further used to *t*-test analysis from knowing *R* value above and sample size ($n = 24$) to infer whether the relationship between water area and TDI is significant. From Eq. (3), the absolute *t*-test value was found to be (5.64) with a *p*-value (= 1.1×10^{-5}), which higher than the critical value (2.07) for significance level (0.05) and two-tailed. This means that this relationship is statistically significant. However, in areas with less water, which are permanent bodies existing in hot summer months, human discomfort indices were highest, followed by comfort when increasing surface water during rainy seasons.

5. Conclusions

This study combined two monthly data sources: meteorological variables (air temperature and relative hum'idity) and multispectral Sentinel-2A imagery, for all months of the years 2018 and 2021. Spectral values of MNDWI calculated in Mahdi et al. (2023) were used to evaluate the influence of surface water areas on the thermal discomfort index in the semi-arid urban environment of Baghdad. Several conclusions can be drawn from the research results:

1. Since the urban surface water areas (114.8 and 128.7 km^2) are available during each rainy season of the two years, water resource stakeholders and policy makers should develop strategic plans to conserve this water for agricultural purposes and face future challenges caused by climate change.

2. Due to the severe lack of rainfall events in 2021, the scatter of temperature values around their monthly means (i.e. standard deviation) was larger than in 2018. In addition, the monthly means for relative humidity were more variable in 2021.

3. For more than half of the year, from October to May, the outdoor thermal comfort index had lower values (24 °C), which represent relevant months for all human activities.

4. The highest TDI values (>27 °C) occurred in the summer months (July and August) of 2021, with severe heat stress affecting human performance and efficiency in the Baghdad ambient atmosphere.

5. The relationship between urban surface water areas and TDI levels was non-linear and well described by the exponential decay function. This shows that bodies of water can reduce levels of discomfort that are too high.

6. This study demonstrates the value of considering the impact of thermal discomfort when designing smart and sustainable cities, workplaces and learning facilities, and when determining the location and timing of outdoor activities.

Acknowledgements

The authors are grateful to Mustansiriyah University for acceptance this work. Finally, the authors thank anonymous reviewers especially Editor-in-Chief for constructive comments for improvement of the paper.

Authors contributions

MH contributed to the conception and design of the research. JS and DA performed the investigation and data analysis. MH and MS wrote the manuscript and and revised the manuscript. All authors contributed to the article and approved the submitted version.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

References

Adeeb, H. Q., & Al-Timimi, Y. K. (2019). GIS techniques for mapping of wind speed over Iraq. *Iraqi Journal of Agricultural Sciences, 50*(6), 1621–1629. https://doi.org/10.36103/ijas.v50i6.852

Al-Basrawi, N. H., Awad, J. H., & Hussain, T. A. (2015). Evaluation of the ground water in Baghdad governorate / Iraq. *Iraqi Journal of Science, 56*(2C), 1708–1718.

Al-Jiboori, M. H. (2007). Evaluation physiological human comfort in Iraq. *Al-Mustansiriyah Journal of Science, 18*(1), 63–75.

Al-Jiboori, M. H., Abu Al-Shear, M. J., & Ahmed, M. M. (2020). Impact of land surface changes on air temperatures in Baghdad. *Kuwait Journal of Science, 47*(4), 118–126.

Al-Timime, N. S., Al-Salihi, A. M., & Hameed, A. A. (2024). Investigating the optimal duration of the sun exposure for adequate cutaneous synthesis of vitamin D3 in Baghdad City: Depending on Fitzpatrick skin classification for different skin types. *Iraqi Journal of Science, 65*(1), 546–554. https://doi.org/10.24996/ijs.2024.65.1.42

Al-Timimi, Y. K., & Al-Khudhairy, A. A. (2018). Spatial and temporal temperature trends on Iraq during 1980-2015. *Journal of Physics: Conference Series, 1003*, Article 012091. https://doi.org/10.1088/1742-6596/1003/1/012091

Cheng, C., Zhang, F., Shi, J., & Kung, H. (2022). What is the relationship between land use and surface water quality? A review and prospects from remote sensing perspective. *Environmental Science and Pollution Research, 29*, 56887–56907. https://doi.org/10.1007/s11356-022-21348-x

Cheng, Y. Y., Liu, X., Zeng, Z., Liu, S. S., Wang, Z., Tang, X., & He, B. J. (2022). Impacts of water bodies on microclimates and outdoor thermal comfort: Implications for sustainable rural revitalization. *Frontiers in Environmental Science, 10*, Article 940482. https://doi.org/10.3389/fenvs.2022.940482

Dasari, H. P., Desamsetti, S., Langodan, S., Viswanadhapalli, Y., & Hoteit, I. (2021). Analysis of outdoor thermal discomfort over the Kingdom of Saudi Arabia. *GeoHealth, 5*(6), Article e2020GH000370. https://doi.org/10.1029/2020GH000370

Deng, X., Cao, Q., Wang, L., Wang, W., Wang, S., Wang, S., & Wang, L. (2023). Characterizing urban densification and quantifying its effects on urban thermal environments and human thermal comfort. *Landscape and Urban Planning, 237*, Article 104803. https://doi.org/10.1016/j.landurbplan.2023.104803

Febrita, Y., Ekasiwi, S. N. N., & Antaryama, I. G. N. (2021). Urban river landscape factors impact on urban microclimate in tropical region. *IOP Conference Series: Earth and Enviromental Science*, *764,* Article 012032. https://doi.org/10.1088/1755-1315/764/1/012032

Genjebo, M. G., Kemal, A., & Nannawo, A. S. (2023). Assessment of surface water resource and allocation optimization for diverse demands in Ethiopia's upper Bilate Watershed. *Heliyon, 9*(10), Article e20298. https://doi.org/10.1016/j.heliyon.2023.e20298

Halos, S. H., Al-Taai, O. T., & Al-Jiboori, M. H. (2017). Impact of dust events on aerosol optical properties over Iraq. *Arabian Journal of Geoscience, 10*, Article 263. https://doi.org/10.1007/s12517-017-3020-2

Hong, C., Qu, Z. K., Xu, W., & Gu, Z. L. (2023). Study on water cooling island effects under different climatic conditions. *City and Built Environment, 1*, Article 4. https://doi.org/10.1007/s44213-022-00004-7

Huang, C., Chen, Y., Zhang, S., & Wu, J. P. (2018). Detecting, extracting, and monitoring surface water from space using optical sensors: A review. *Reviews of Geophysics, 56*, 333–360. https://doi.org/10.1029/2018RG000598

Karpatne, A., Atluri, G., Faghmous, J. H., Steinbach, M., Banerjee, A., Ganguly, A., Shekhar, S., Samatova, N., & Kumar, V. (2017). Theory-guided data science: A new paradigm for scientific discovery from data. *IEEE Transactions on Knowledge and Data Engineering, 29*(10), 2318–2331. https://doi.org/10.1109/TKDE.2017.2720168

Kazmi, H., Keijsers, M., Mehmood, F., & Miller, C. (2022). Energy balances, thermal performance, and heat stress: Disentangling occupant behaviour and weather influences in a Dutch net-zero energy neighborhood. *Energy and Buildings, 263,* Article 112020. https://doi.org/10.1016/j.enbuild.2022.112020

Kishta, M., Robaa, S. M., Abdel Wahab, M. M., & Al Abadla, Z. (2022). Spatial distribution of outdoor thermal human comfort in the UAE. *World Journal of Advanced Research and Reviews, 13*(2), 43–49. https://doi.org/10.30574/wjarr.2022.13.2.0104

Le Sève, M. D. (2023). *Riding the wave: How the private sector is seizing opportunities to accelerate progress on water security.* Disclosure Insight Action. https://cdn.cdp.net/cdp-production/cms/reports/documents/000/006/925/original/CDP_Water_Global_Report_2022_Web.pdf

Mahdi, Z. S., Tawfeek, Y. Q., & Al-Jiboori, M. H. (2024). Relationship between monthly surface water derived from Sentinel-2 imagery and meteorological data (precipitation and evaporation) at Baghdad, Iraq. *Water Practice & Technology*, *19*(5), 1794–1809. https://doi.org/10.2166/wpt.2024.098

Mushore, T. D., Chimuti, B., Gwenzi, J., Mutasa, C., Mashonjowa, E., Mhizha, T., Muroyiwa, G., & Rousta, I. (2019). Localised human thermal discomfort assessment using high temporal resolution meteorological data: A case of University of Zimbabwe. *Physics and Chemistry of the Earth, 110*, 138–148. https://doi.org/10.1016/j.pce.2019.01.010

Naqi, N. M., Al-Jiboori, M. H., & Al-Madhhach, A. T. (2021). Statistical analysis of extreme weather events in the Diyala River basin, Iraq. *Journal of Water and Climate Change, 12*(8), 3770–3785. https://doi.org/10.2166/wcc.2021.217

Ncongwane, K. P., Botai, J. O., Sivakumar, V., & Botai, C. M. (2021). A literature review of the impacts of heat stress on human health across Africa. *Sustainability, 13*(9), Article 5312. https://doi.org/10.3390/su13095312

Nurmaya, E. M., Abidin, A. U., Hasanah, N. A. I., & Asmara, A. A. (2022). Heat stress analysis using the discomfort index method: Impact on macro environmental in Yogyakarta. *Journal of Ecological Engineering, 23*(1), 286–295. https://doi.org/10.12911/22998993/144092

Pantoja, W., Rodrigues, C. C., Chase, O. A., Almeida, F. S., Beirão, A. T., & Silva, K. (2021). Usage of arduino-based datalogger for thermal comfort variables monitoring. *International Journal for Innovation Education and Research, 7*, 214–223. https://doi.org/10.31686/ijier.vol9.iss7.3237

Siami, L., & Ramadhani, A. (2019). Climatology of discomfort index for decade in Bandar Lampung, Indonesia. *KnE Social Sciences*, *3*(21), 460–469. https://doi.org/10.18502/kss.v3i21.4987

Stathopoulou, M. I., Cartalis, C., Keramitsoglou, I., & Santamouris, M. (2005). Thermal remote sensing of Thom's Discomfort Index (DI): Comparison with in-situ measurements. In *Remote sensing for environmental monitoring, GIS applications, and geology* (Vol. 5983). SPIE. https://doi.org/10.1117/12.627541

Syafii, N. I., Ichinose, M., Wong, N. H., Kumakura, E., Jusuf, S. K., & Chigusa, K. (2016). Experimantal study on the influence of urban watre body on thermal environment at outdoor scale model. *Procedia Engineering, 169*, 191–198. https://doi.org/10.1016/j.proeng.2016.10.023

Tawfeek, Y. Q., Jasim, F. H., & Al-Jiboori, M. H. (2020). A study canopy urban heat island of Baghdad, Iraq. *Asian Journal of Atmospheric Environment, 14*(3), 280–288. https://doi.org/10.5572/ajae.2020.14.3.280

Thom, E. C. (1959). The discomfort index. *Weatherwise, 12*, 57–61. https://doi.org/10.1080/00431672.1959.9926960

Wahab, B. I., Naif, S. S., & Al-Jiboori, M. H. (2022). Development of anuual urban heat island in Baghdad under climate change. *Journal of Environmental Engineering and Landscape Management, 30*(1), 179–187. https://doi.org/10.3846/jeelm.2022.16374

Wong, N. H., Tan, C. L., Shinta, A. D., Jusuf, S. K., & Tan, E. (2011). Influence of water bodies on outdoor air temperature in hot and humid climate. In *ICSDC* (pp. 81–89), Kansas City, Missouri. American Society of Civil Engineers. https://doi.org/10.1061/41204(426)11

Xu, J. C., Wei, Q. L., Huang, X. F., Zhu, X. Z., & Li, G. M. (2010). Evaluation of human thermal comfort near urban waterbody during summer. *Building and Environment, 45*(4), 1072–1080. https://doi.org/10.1016/j.buildenv.2009.10.025

Yang, X., Qin, Q., Grussenmeyer, P., & Koehl, M. (2018). Urban surface water body detection with suppressed built-up noise based on water indices from Sentinel-2 MSI imagery. *Remote Sensing of Environment, 219*, 259–270. https://doi.org/10.1016/j.rse.2018.09.016

Yousif, T. A., & Tahir, H. M. M. (2013). Application of Thom's thermal discomfort index in Khartoum State, Sudan. *Journal of Forest Products* & *Industtries, 2*(5), 36–38.

Zahraa, M. H., Al-Jiboori, M. H., & Al-Abassi, H. M. (2020). The effect of the extremes heat waves on mortality rates in Baghdad during the period (2004-2018). *Al-Mustansiriya Journal of Science, 31*, 15–23. http://doi.org/10.23851/mjs.v31i2.753

Zeng, Z. W., Zhou, X. Q., & Li, L. (2017). The impact of water on microclimate in Lingnan area. *Procedia Engineering*, *205*, 2034–2040. https://doi.org/10.1016/j.proeng.2017.10.082