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Studying the Spatial and Temporal Changes of the Surface Urban Heat Island Using Geographic Information Systems (GIS) and Remote Sensing (Mosul City as a Model)

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ABSTRACT

Surface heat islands are formed due to the increase in surface temperatures of the earth alongside air temperature within urban areas compared to the surrounding suburban and rural areas. This increase is primarily attributed to the concentration of various human activities and prevalent land uses. This study aims to analyze the spatial and temporal variation of surface temperature across different seasons and the reasons for their concentration in specific locations within the study area. In this study, satellite imagery from Landsat-8 was used. The researcher examined all images from the year 2023 for all seasons to select a set of images that align with the nature of the study to determine the surface temperature of the Earth, providing a true representation of the surface heat island in the city of Mosul using Geographic Information Systems (GIS) and remote sensing. Thermal map results showed that surface heat islands. vary from season to season, with the highest values recorded in the fall, ranging between (42-48.6°C). In contrast, the lowest surface temperatures were recorded in the winter, reaching (13.6-17.1°C). The study also indicated that areas with high population density and desert lands are among the regions that fall within the highest temperature ranges compared to others. Furthermore, it was observed that areas adjacent to the Tigris River and forest areas with dense vegetation cover are less hot, indicating a negative relationship where the surface temperature decreases with an increase in vegetation cover.

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دراسة التغيرات المكانية والزمانية لجزيرة الحرارة الحضرية السطحية باستخدام نظم المعلومات الجغرافية (GIS) والاستشعار عن بُعد (مدينة الموصل أنموذجًا)

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الملخص

تتشكل الجزر الحرارية السطحية نتيجة لارتفاع درجات حرارة سطح الأرض بالتزامن مع درجات حرارة الهواء داخل المناطق الحضرية، وذلك مقارنةً بالمناطق شبه الحضرية (الضواحي) والريفية المحيطة بها. ويُعزى هذا الارتفاع بشكل أساسي إلى تركز الأنشطة البشرية المختلفة واستعمالات الأرض السائدة. تهدف هذه الدراسة إلى تحليل التباين المكاني والزماني لدرجة حرارة السطح عبر الفصول المختلفة، والكشف عن أسباب تركزها في مواقع محددة داخل منطقة الدراسة. وقد استُخدمت في هذه الدراسة مرئيات فضائية من القمر الصناعي (Landsat-8)، حيث قام الباحث بفحص جميع مرئيات عام 2023 ولكافة الفصول لاختيار مجموعة منها تتوافق مع طبيعة الدراسة؛ بغية تحديد درجة حرارة سطح الأرض بما يوفر تمثيلاً حقيقياً للجزر الحرارية السطحية في مدينة الموصل باستخدام نظم المعلومات الجغرافية (GIS) وتقنيات الاستشعار عن بعد. وقد أظهرت نتائج الخرائط الحرارية أن الجزر الحرارية السطحية تبايناً فصلياً للجزر الحرارية السطحية؛ إذ سُجِّلت أعلى القيم خلال فصل الخريف، حيث تراوحت بين (42–48.6) درجة مئوية. وفي المقابل، سُجِّلت أدنى درجات حرارة للسطح خلال فصل الشتاء، حيث بلغت (13.6–17.1) درجة مئوية. كما أشارت الدراسة إلى أن المناطق ذات الكثافة السكانية المرتفعة والأراضي الصحراوية (الجرداء) تقع ضمن النطاقات الحرارية الأعلى مقارنةً بغيرها. علاوةً على ذلك، لوحظ أن المناطق المحاذية لنهر دجلة ومناطق الغابات ذات الغطاء النباتي الكثيف تكون أقل حرارة، مما يؤشر إلى وجود علاقة ارتباطية عكسية؛ حيث تنخفض درجة حرارة السطح بزيادة كثافة الغطاء النباتي.

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Introduction

Urban planning significantly impacts daily temperatures, whereas temperatures within cities differ from those in open rural areas due to various factors such as weather conditions, wind speed, sunlight intensity, humidity, and the structural layout of the city, this includes building density, the ratio between building heights and the spaces between them, different construction materials and their colors, street width, and pollution influenced by urban planning and the urban fabric. These factors contribute to increased temperatures. The surface temperature of the earth in the study differs greatly from the temperatures commonly reported in weather forecasts, which refer to the free air surface temperature measured at heights ranging from 1.25 to 2m above the ground (Ismail, 2023), and accordingly the land surface temperature (LST) is an important parameter for studying surface energy balance, climate change, and various physical and chemical processes on Earth (Ullah et al., 2023). (LST), It is a phenomenon in which urban areas experience higher temperatures than surrounding rural areas (Richard and Abah, 2019). The Earth's surface absorbs shortwave solar radiation and then emits longwave radiation toward the atmosphere, which retains most of it, allowing only a small portion to escape into space. Although atmospheric components absorb only a very small percentage of the shortwave solar radiation passing through it, the atmosphere is capable of retaining a very large percentage of the longwave terrestrial radiation reflected from the Earth's surface. Water vapor and carbon dioxide are primarily responsible for this latter function. Therefore, studying the Earth's thermal changes is one of the most important climatological studies due to its direct impact on various living organisms and urban planning (Ahmad, 2018).

Materials and Methods

Study area

The city of Mosul serves as the administrative center of Nineveh Governorate, located in the northwestern part of Iraq, within the middle basin of the Tigris River (northern Iraq). The Tigris River divides the city into two unequal parts in terms of shape, area, and population (Al-Janabi, 1996). Geographically, the city is bordered by agricultural lands and villages extending to the Tal Kaif district and the Hamidat sub-district to the north and northwest, the Bartella and Bashiqa sub-districts to the east and northeast, the Tal Afar district to the west, and the Hamam al-Alil sub-district to the south (Adnan, 2022). The study area is situated between the latitudes of (36°, 24′,10″ - 36°, 14′, 40″) north and two longitudes (43°, 18′, 10″- 43°,05′,30″) east. The total area of the study area is 4409 km2 (Ismail, 2023), out of the total area of Nineveh Governorate, which is 36767.97 km2. Geospatial location of the city of Mosul (Fig. 1).

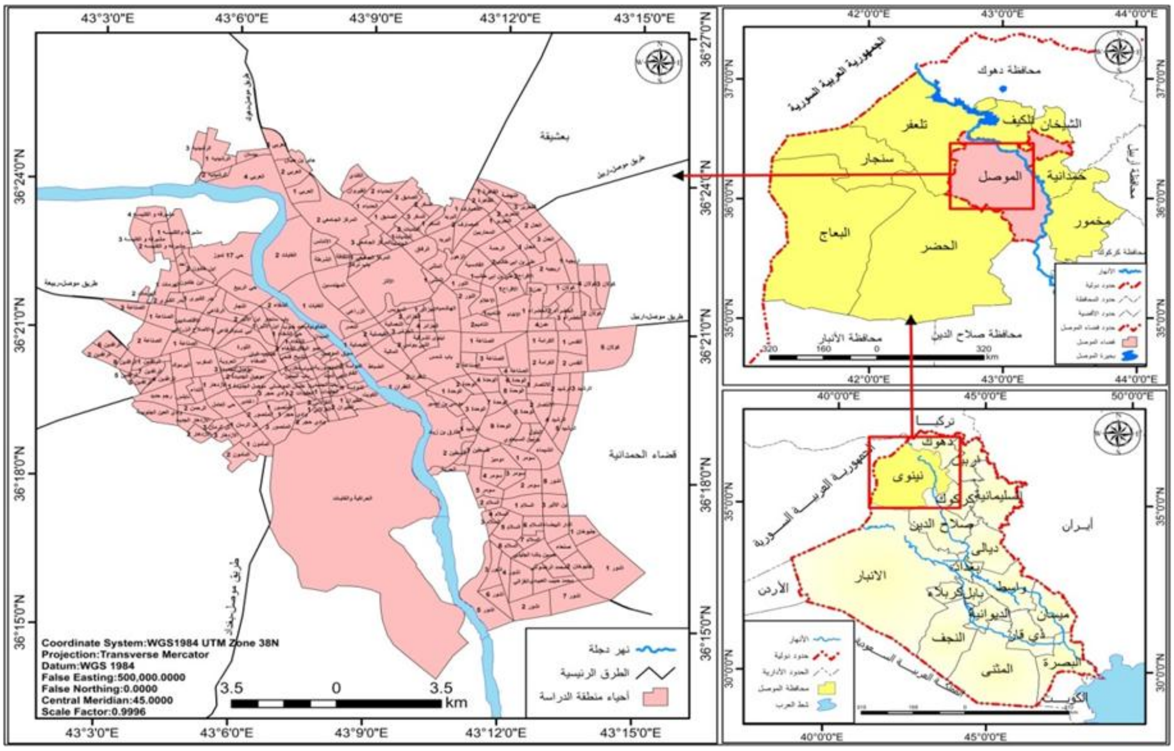

Fig. 1. The geographical and astronomical location of the city of Mosul

Source: Work of the researcher based on Nineveh Governorate, Nineveh Municipalities Directorate, Planning Department, unpublished data, 2022, and ARC MAP program.

2.2 Data sets and methods

The image satellites were downloaded from the US Geological Survey (https://www.usgs.gov/). The researcher examined all the satellite imagery dates according to the specified time period for the study area, which is the year 2023, to select the set of images that best fit the nature of the study. Accordingly, satellite images from Landsat-8 were used for different seasons of the year to determine the surface temperature, which will provide an accurate depiction of the surface urban heat island in the study area, as illustrated in Table 1 and Fig. 2.

Table 1: Characteristics of the visuals used in the study (Source: https://www.usgs.gov)

Sequence	Satellite name	Date the photo was taken	The chapter that the image represents
1	LANDSAT 8	25/1/2023	winter season
2	LANDSAT 8	30/3/2023	spring season
3	LANDSAT 8	28/7/2023	summer season
4	LANDSAT 8	22/9/2023	Autumn season

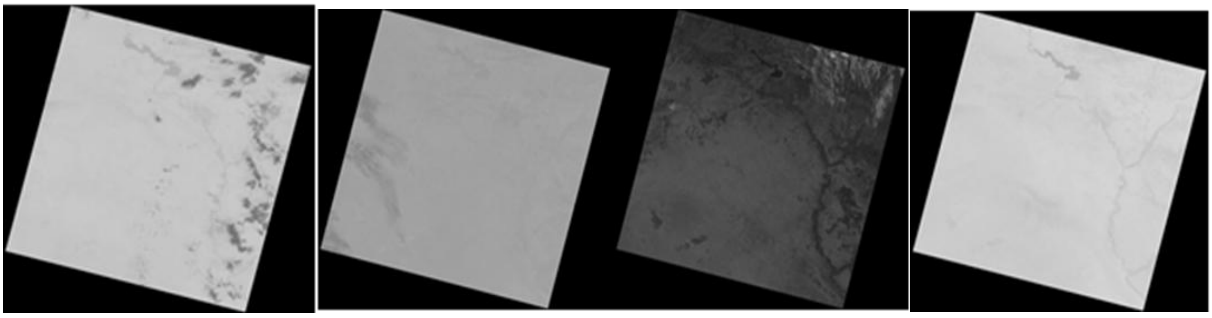

Fig. 2. The image satellite adopted in the study (Source: https://www.usgs.gov)

After acquiring the satellite imagery for the study area, the bands used in the study are identified as follows:

The Band (10) file, which reflects thermal infrared radiation (TIRS1), is included in the Landsat (8) satellite imagery and is used to extract the Earth's surface temperature.

The thermal spectral radiance in LANDSAT-8 is calculated using several equations, as follows:

First step: create a file that reflects the radiation value at the top of the atmosphere (Top of Atmosphere) (TOA), spectral radiance. Through this step, the (raw spectral) value in the band (10) is converted to the radiation value at the top of the atmosphere through the following equation:

$$L\lambda = ML * QCAL + Al \quad \text{...} \quad (1)$$

Whereas ML = the value of the multiplier scale factor, which is obtained from the metadata file (MTL), QCAL = calorific value of the tenth band, Al = the value of the additional scaling factor, which is obtained from the metadata file (TML), QI = 10th band correction factor, fixed value (0.29).

-The second step: Create a file representing the brightness temperature value: (Brightness temperature) (BT) according to the following equation:

$$T_{(K)} = \frac{K2}{\ln\left(\frac{K1}{L\lambda} + 1\right)} - 273.15 \quad \text{..} \quad (2)$$

Since ln = logarithm, k1, k2 = fixed values for the thermal transfer obtained from the metadata file (MTL). They are fixed values and vary depending on the satellite, and their value for the Landsat 8 satellite is shown in Table 2.

Table 2: Constants used for Landsat satellite (8)

Sequence	Heat packs	Value	Constants
1	10	799.0284	K1
2	10	1329.2405	K2
3	10	3.3420E-04	ML
4	10	0.10000	AL

From the researcher's work using visual data

TOA = Lλ, the value 273.15 is a constant value for converting from Kelvin temperature to Celsius temperature.

The third step: Create a Normalized Difference vegetation Index (NDVI) file:

To determine the amount of vegetation cover by measuring the difference between the near infrared light reflected by the vegetation cover and the red light absorbed by the vegetation cover, through the equation:

$$NDNI = \frac{NIR(BAND5) - RED(BAND4)}{NIR(BAND5) + RED\ (BAND4)} \quad \text{.........................(3)}$$

Fourth step: Create a file calculating the percentage of vegetation cover (PORPORTION OF VEGETATION) (PV) according to the equation:

$$\mathbf{Pv} = \left(\frac{\text{NDVI}-\text{NDVImin}}{\text{NDVImax}-\text{NDVImin}}\right) \text{..(4)}$$

Step five: Create a file to calculate emissions values from the Earth's surface: Land surface Emissivity (LSE) or (ε) according to the equation:

(ε = 0.004* pv + 0.986)..(5)

Step Six: Create a file that reflects the Earth's surface temperature in the city of Mosul according to previous time periods, through the equation:

$$\text{LST} = \frac{BT}{\{1+[(\lambda BT/P)Ln\varepsilon_\lambda]\}} \quad \text{...(6)}$$

Whereas Lst = Land surface temperature, BT = Land surface emissivity value, and where ph = 14388 and h = (Planck's constant), and C = (Boltzmann constant) is one of the physical constants to obtain the relationship between the energy of the atom or molecule in the gaseous state and the temperature. The symbol ***σ*** represents the speed of light (Muhammad, 2023).

Results and Discussion

Land surface temperature during the winter

It is observed from Fig. 3, cold colors, specifically dark and light green, which indicate lower surface temperatures, have shown a notable increase in area coverage during the winter season compared to previous periods. In the first instance, they covered an area of 53,819 m^2 within the study area, with temperatures ranging between 6.9°C and 9.2°C, encompassing many neighborhoods, including Mushayrifa, Al-Kaneesa 1, Al-Najjar, Al-Rifa'i, Al-Muthanna, Nabi Yunus 2, Al-Shurta, Al-Andalus, and Al-Arabi 2. Meanwhile, the light green color covered the largest area, reaching 59,030 m^2, with temperatures ranging between 9.3°C and 10.4°C. This mostly covered the neighborhoods on the left side of the city compared to the right side. The observed increase is attributed to natural factors related to weather and climate elements previously mentioned, as well as a noticeable expansion of vegetative cover recently, driven by the increased attention from government and civil bodies. In contrast, warm colors (dark red, orange, and yellow) covered substantial areas. Dark red occupied 13,924 m^2, with temperatures ranging from 13.6°C to 17.1°C, mostly covering the southern, southeastern, and southwestern parts of the study area. Orange covered an area of 33,905 m^2, with temperatures varying between 11.9°C and 13.5°C, including southeastern and southwest-southern parts of the city and several neighborhoods. Yellow occupied 33,905 m^2, with temperatures ranging from 10.5°C to 11.8°C, covering various neighborhoods on both sides of the city, such as Wadi Hajar, Al-Ta'mim Industry 3, Industry 1, Salam 8, and Tal Al-Rumman 2. Regarding the Tigris River, cold colors (dark and light green) dominated the largest areas. Dark green covered 4,227 m^2, with temperatures ranging from 8.4°C to 9.7°C, mostly in the northern and central parts of the river. Light green covered 3,566 m^2, with temperatures between 9.8°C and 10.6°C, distributed along the river's course, particularly in its lower sections. On the other hand, warm colors (dark red, orange, yellow) occupied limited areas, with yellow covering 2,095 m^2, with temperatures ranging from 10.7°C to 11.9°C, mostly in the southern sections and some small patches in the northern parts of the river. Orange ranked second, occupying 0.956 m^2, with temperatures between 12°C and 13.6°C, mostly in the lower sections of the river, while dark red occupied 0.450 m^2, with temperatures ranging from 13.7°C to 16.1°C, confined to the southern sections of the river's course. Table 3 illustrates the colors included in the classification of Earth's surface temperature, along with the area represented by each color and the corresponding temperature, as well as the number of regions covered by each classification.

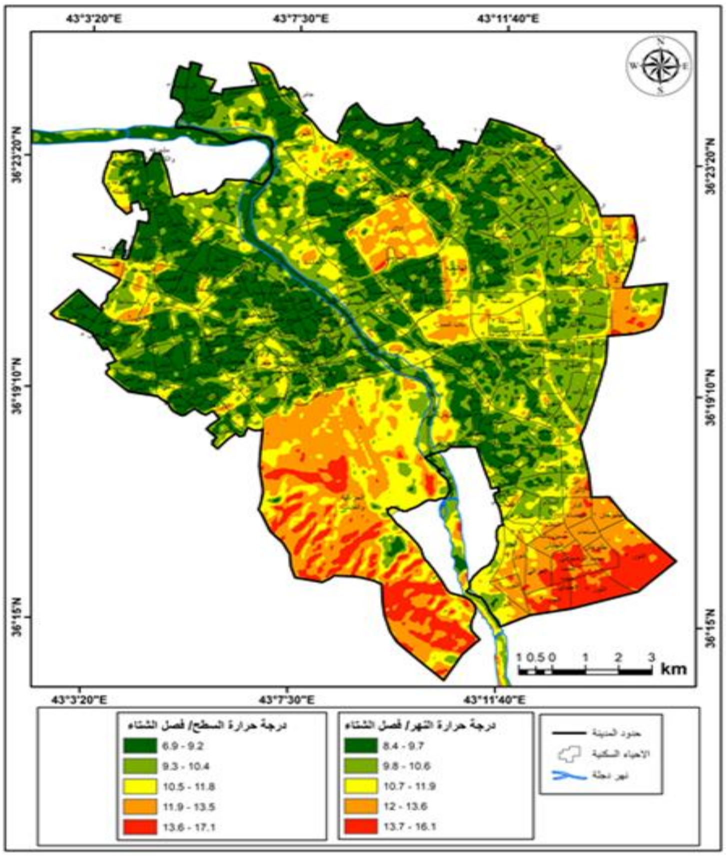

Fig. 3. Surface temperature during the winter Land

Source: Based on Landsat-8 satellite imagery (2023) of the city of Mosul

Table 3: Illustrates the colors, areas, temperatures, and number of regions included in the classification of Earth's surface temperature during the winter

sequence	Color	area	temperature	Covered areas
1	Dark green	53,819m^2	(6.9°C to 9.2°C)	(Meshirfa and Al-Kanisa 1, Al-Najjar, Al-Rifai, Al-Muthanna, Nabi Yunus 2, Al-Shurta, Al-Andalus, Al-Arabi 2),
2	Light green	59 ,030m^2	(9.3°C to 10.4°C)	(Jerusalem 1, Al-Karamah, Al-Afrah 2, Al-Sinaa 2, Arbajiyeh, Al-Salam 6)
3	Dark red	13,924m^2	(13.6°C to 17.1°C)	(mostly covering the southern, southeastern, and southwestern parts of the study area)
4	color orange	33,905m^2	(11.9° to 13.5°C)	(Ashur 4, Jalikhan 1, Bab Shams, Antiquities, Al-Arabi 2, Ibn Al-Athir 3)
5	Yellow color	33.905 m^2	(10.5°C to 11.8°C)	(Wadi Hajar, Al-Ta’mim Industry 3, Industry 1, Salam 8, and Tal Al-Rumman 2)

Source: Based on Landsat-8 satellite imagery (2023) of the city of Mosul

Land surface temperature during the spring

In spring, as observed in Fig. 4, the proportions of cool color areas (dark green and light green) have decreased after being high during the winter season. The first color occupied an area of 3.047 m^2 with temperatures ranging from 10.5 to 16.3°C, covering parts of the green spaces adjacent to the Tigris River and portions in the southeastern parts of the study area.

Meanwhile, the second color (light green) covered an area of 16.018 m², with temperatures ranging between 16.4 and 18.2°C, including the southeastern, southern, and southwestern parts of the city, along with limited areas as shown on the thermal map. In contrast, the spatial coverage of warm colors (dark red, orange, yellow) increased, with the first color occupying an area of 40.476m² and temperatures varying between 20.2 and 25°C, mainly in the southern, southwestern, and eastern parts, while the remaining areas covered various city neighborhoods, such as Sin'a 2, Al-'Urubah, Nabi Shayt, Sin'a al-Ta'mim 3, Al-Jami'ah, and Al-Faisaliyah. The second color (orange) occupied a larger area, 88,703 m², with temperatures ranging from 19.3 to 20.1°C, covering a substantial number of neighborhoods, including Al-Islah al-Zira'i, Al-Rifai 1, Al-Rafidayn, Al-Wahda 1, Al-Quds, Al-Tahrir, Al-Adl, and Al-Masaref 2. The third color (yellow) occupied an area of 53.981 m², with temperatures varying between 18.3 and 19.2°C, covering the southern, southeastern, northern, and northwestern parts of the study area, in addition to scattered spots across neighborhoods such as Al-Hashimiyah, Al-Zuhur, Al-Muhandisin, Al-Tayran, Rajm Hadid, and Al-Harmat 1. Along the river, the cool colors (dark green and light green) covered extensive areas, with the first color covering 2,819 m² and temperatures ranging from 13.1 to 14.8°C, distributed along the watercourse, particularly in its northern and central parts. The second color (light green) occupied 2,085 m² with temperatures ranging between 14.9 and 16°C, primarily covering the southern, central, and northern parts of the upper river course, along with some limited areas in the river's northern sections. In contrast, the warm colors (dark red, orange, yellow) covered significant areas. The first color registered 662 m², with temperatures ranging from 18.9 to 21.3°C, mainly covering the lower parts of the river. The second color (orange) occupied an area of 2.644 m², with temperatures varying from 17.4 to 18.8°C, including the northern and southern sections of the river. Lastly, the third color (yellow) covered a wide portion of the area, amounting to (3.085 m²) with temperatures ranging from 16.1 to 17.3°C, covering the three main parts of the river (upper, middle, and lower) within the administrative boundaries of the study area, Table (4) illustrates the colors included in the classification of Earth's surface temperature, along with the area represented by each color and the corresponding temperature, as well as the number of regions covered by each classification.

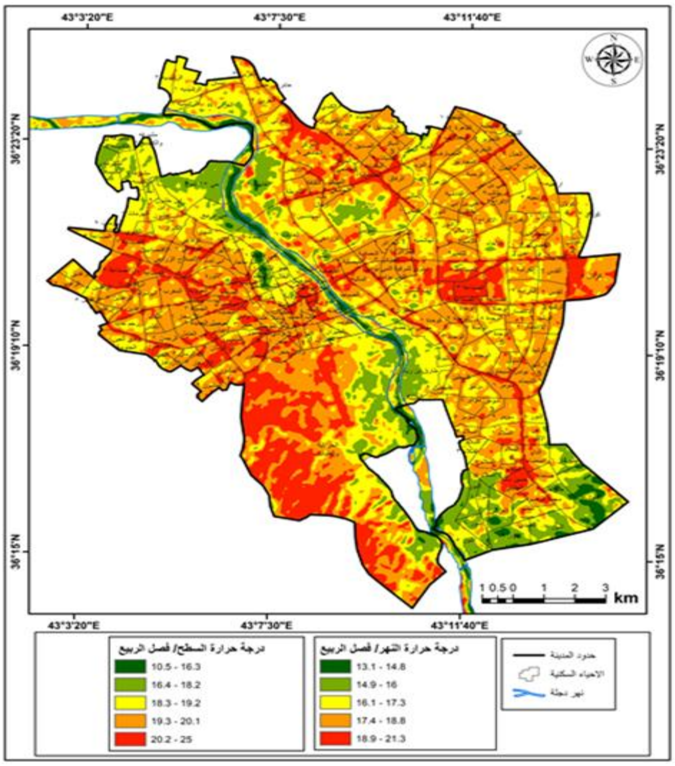

Fig. 4. Land surface temperature during the spring
Source: Based on Landsat-8 satellite imagery (2023) of the city of Mosul

Table 4: Illustrates the colors, areas, temperatures, and number of regions included in the classification of Earth's surface temperature during the spring

Sequence	Color	Area	Temperature	Covered areas
1	Dark green	3.047 m^2	10.5-16.3°C	covering parts of the green spaces adjacent to the Tigris River and portions in the southeastern parts of the study area
2	Light green	16.018m^2	16.4-18.2°C	including the southeastern, southern, and southwestern parts of the city
3	Dark red	40.476m^2	20.2-25°C	Sin'a, Al-'Urubah, Nabi Shayt, Sin'a al-Ta'mim, Al-Jami'ah, and Al-Faisaliyah
4	color orange	88.703m^2	19.3-20.1°C	Al-Islah al-Zira'i, Al-Rifai, Al-Rafidayn, Al-Wahda, Al-Quds, Al-Tahrir, Al-Adl, and Al-Masaref
5	Yellow color	53.981m^2	18.3-19.2°C	Al-Hashimiyah, Al-Zuhur, Al-Muhandisin, Al-Tayran, Rajm Hadid, and Al-Harmat

Source: Based on Landsat-8 satellite imagery (2023) of the city of Mosul

Land surface temperature during the summer season

In the summer, as observed in Fig. 5, the observed area occupied by warm colors (dark red, orange, yellow) is increasing. The first of these, dark red, covers an area of 49.222 m^2, with temperatures varying between 36.4°C and 42°C. This color is concentrated in the southern, southwestern, and southeastern parts of the city and includes several neighborhoods such as Sanaye2, Al-Athar, Bab Shams, and Al-Arabi1. The second color, orange, occupies an area of 55.476 m^2, with temperatures ranging from 31.4° to 36.3°C, covering a wide range of neighborhoods across both sides of the city, such as New Mosul3, Qadib Al-Ban, Al-Sanaye, Arabiya2, University Center3, Kulan5, and Nabi Yunus1. This area is characterized by a diverse, highly active environment, encompassing both industrial and commercial activities with constant vehicular movement throughout the day, contributing to higher temperatures and the phenomenon under study. It is worth noting that these neighborhoods will also be examined in the following section, which addresses air pollutant measurements for the specified elements. These areas recorded the highest levels in previous classifications and now exhibit the highest temperatures. The third color, yellow, has temperatures ranging between 27.6° and 31.3°C and spans an area of 88.713 m^2, covering much of the study area. Most of this area is concentrated on the left side of the city. As for the cool colors (light and dark green), their area has increased compared to the previous section. Light green occupies an area of 5.946 m^2, with temperatures ranging from 24° to 27.5°C, predominantly in the lands adjacent to the lower parts of the river, along with some patches noticeable on the thermal map, representing green spaces within the study area. Dark green, on the other hand, covers an area of 2.895 m^2, with temperatures ranging between 20.1° and 23.9°C, restricted to small patches in the study area. From another perspective, the cool colors (light and dark green) registered the highest values along the river, with the former covering an area of 3.3399 m^2 and temperatures between 20.1° and 26.9°C, mainly concentrated in the northern and central parts of the river.

The latter (light green) spans an area of 2.3589 m^2, with temperatures between 27° and 32.4°C. Its distribution pattern is similar to that of dark green, extending along most of the river course. On the other hand, the warm colors (dark red, orange, yellow) cover substantial areas, with dark red occupying 1.2051 m^2 and temperatures ranging between 39° and 44°C, primarily concentrated in the southern parts of the river, as well as small patches observed in the northern sections of the river course. Orange covers an area of 1.7199 m^2, with temperatures between 36° and 38.9°C, distributed between the upper and lower sections of the river course. Finally, yellow occupies an area of 2.7108 m^2, with temperatures ranging from 32.5° to 35.9°C, extending across vast parts of the river course, particularly in the upper sections. Table 5 illustrates the colors included in the classification of Earth's surface temperature, along with the area represented by each color and the corresponding temperature, as well as the number of regions covered by each classification.

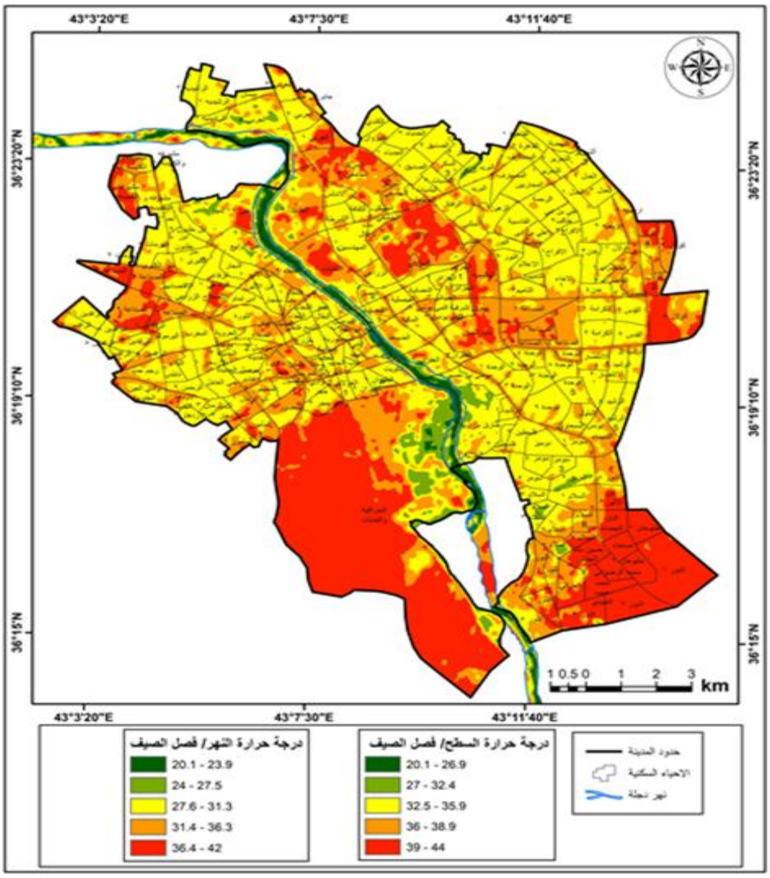

Fig. 5. Land surface temperature during the summer season

Source: Based on Landsat-8 satellite imagery (2023) of the city of Mosul

Table 5: illustrates the colors, areas, temperatures, and number of regions included in the classification of Earth's surface temperature during the summer

sequence	Color	area	temperature	covered areas
1	Dark green	(2.895) m^2	20.1° to 23.9°C	(restricted to small patches in the study area)
2	Light green	(5.946) m^2	24° to 27.5°C	(Limited predominantly in the lands adjacent to the lower parts of the river, along with some patches noticeable on the thermal map, representing green spaces within the study area. Dark green)
3	Dark red	(49.222) m^2	36.4° to 42°C	(Sanaye2, Al-Athar, Bab Shams, Al-Arabi1)
4	color orange	(55.476) m^2	31.4° to 36.3°C	(New Mosul3, Qadib Al-Ban, Al-Sanaye, Arabiya2, University Center3, Kulan5, Nabi Yunus1)
5	Yellow color	(88.713) m^2	27.6° to 31.3°C	(Al-Qadisiyah, Al-Zuhur, Al-Intisar, Al-Wahda 1, Al-Rifai, Al-Najjar, Nablus, Mosul Jadida 1)

Source: Based on Landsat-8 satellite imagery (2023) of the city of Mosul

Land surface temperature during the autumn

In the autumn season, as shown in Fig. 6, through satellite imagery analysis, the most severe heat zones were observed in the southern, southwestern, and eastern parts of the study area, where dark red areas cover a surface area of 39,929 m² with temperatures ranging between 42 °C and 48.6°C. These high-heat zones extend across several neighborhoods on both sides of the city, represented by red spots on the thermal map. The color orange ranks second in terms of high surface temperature coverage, occupying an area of 37,808 m² with temperatures between 38.9°C and 41.9°C, and it spans relatively large sections within city neighborhoods. Following this, yellow areas cover (53,880) m² with temperatures ranging between 36.4° and 38.8°C, as shown on the map, and extend over a significant portion of the study area, including neighborhoods such as Al-Shifa 2, Al-Safa, Al-Faisaliah, Al-Sina'a 4, and the University Center 2. On the other hand, the cooler colors, dark green and light green, occupy relatively large areas. The dark green covers 3,318 m² with temperatures between 22° and 30.9°C, mainly along parts of the riverbank. Light green spans 67,311 m² with temperatures between 31° and 36.3°C, predominantly on the city's left side compared to the right. Along the Tigris River, the hot colors (dark red, orange, yellow) cover considerable areas. Dark red accounts for 0.972234 m² with temperatures between 38.8° and 44.9°C, limited to the lower river sections. The orange covers 1,964 m² with temperatures between (33.4° and 38.7°C), distributed across the upper and lower parts of the river. Yellow occupies (2,768) m² with temperatures between 29.7 °C and 33.3°C, representing the northern and southern sections of the river. The cooler colors, light green and dark green, cover larger river areas, with light green occupying 2,191 m² and temperatures between 26.1° and 29.6°C, while dark green extends over 3,411 m² with temperatures from 22° to 26°C, distributed across the middle, upper, and lower river sections, Table 6 illustrates the colors included in the classification of Earth's surface temperature, along with the area represented by each color and the corresponding temperature, as well as the number of regions covered by each classification.

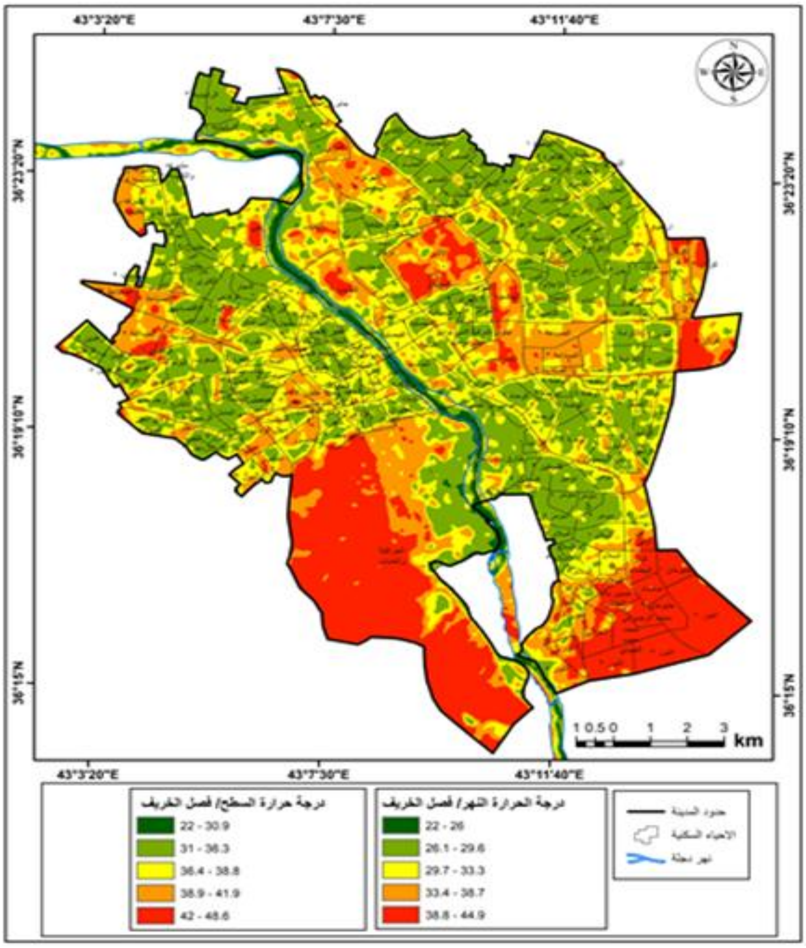

Fig. 6. Land surface temperature during the Autumn

Source: Based on Landsat-8 satellite imagery (2023) of the city of Mosul

Table 6: Illustrates the colors, areas, temperatures, and number of regions included in the classification of Earth's surface temperature during the Autumn

sequence	Color	area	temperature	covered areas
1	Dark green	3.318 m^2	22° to 30.9°C	(Limited parts of the lands adjacent to the river)
2	Light green	67.311 m^2	31° to 36.3°C	(Al-Najjar, Al-Rafai, New Mosul, Al-Muthanna, Al-Zahour, Al-Hadba 1, Unit 7)
3	Dark red	39.929 m^2	42° to 48.6°C	(Al-Rafidain 1, Al-Rifai, Al-Sinaa 3, Bab Shams, Al-Athar, Kulan 3, Al-Ghabat 1, Al-Arabi 1)
4	color orange	37.808 m^2	38.9° to 41.9°C	(Industry 3, Industry 2, Tel Al-Rumman 1, Mushairfa and the Church, Al-Shimaa, Al-Ezdehar)
5	Yellow color	53.88 m^2	36.4° to 38.8°C	(Ibn Al-Atheer, Al-Faisaliah 1, Ashur 8, Al-Salam District 8, Al-Salam District 6, New Mosul 2)

Source: Based on Landsat-8 satellite imagery (2023) of the city of Mosul

Conclusions

The surface temperature of the Earth is distributed heterogeneously in the city of Mosul due to the topography of the area, so the surface temperatures of the earth rise in the southern, southeastern and western parts of the city of Mosul in particular, these areas are areas almost completely devoid of vegetation and facing the sun as well as the main roads passing through them, while the surface temperature of the Earth decreases in areas adjacent to the Tigris River as a result of being affected by the influences coming from it, and the relationship between the surface temperature of the Earth and the vegetation index Normalized Difference Vegetation Index (NDVI) is an inverse relationship, as areas with dense vegetation cover can reduce the thermal difference. The thermal difference of surface temperatures between desert and barren areas and vegetation cover areas ranges between 10-18 °C in the city of Mosul during the summer. Moreover, due to the diversity of land cover in the study area, the single pattern of heat islands does not appear consistently across large areas, but rather intermittently with other patterns of heat islands, resulting from varying environmental activities, as well as population and urban variations.

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