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Ahmed J. Obaid
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Advanced Studies on Environmental Sustainability

Proceeding of International Conference on Environment and Sustainability 2023

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Preface

This volume presents proceedings of the International Conference on Environment and Sustainability (ICES 2023). The International Conference on Environment and Sustainability (ICES 2023) was held at the College of Science and College of Applied Sciences—Heet, University of Anbar, Iraq, in collaboration with Al-Maarif University College, Anbar, Iraq, from November 29 to 30, 2023. The Conference aimed to provide a platform for researchers, academicians, scientists, students, and practitioners to share their research findings, developments, and applications related to various aspects of environment and sustainability. The conference proceedings, which will be published, will include selected papers that have undergone rigorous review by a panel of reviewers to meet international publication standards. The Conference brought together experts and scholars from different backgrounds to discuss topics such as energy research, environmental technology, chemical engineering, power engineering, and sustainable development. This proceedings volume presents the most recent studies and research in environmental sciences and sustainability, which contribute to resolving environmental issues (air, water, soil, noise, thermal, radioactive, light, and global warming). Discharging environmental pollutants from industrial, commercial, residential, and sensible locations must be handled carefully since it may harm the air, water, and land if not adequately treated. As a result of the enormous volume of wastewater and environmental pollution generated daily, most designs and developments of wastewater technologies and environmental treatment were unable to handle the load. This threat to sustainable growth must be resolved in a precise, dependable, urgent, and timely manner. Sustainable creative and technical transfer approaches that can support, operationalize, and provide sustainable wastewater and environmental treatment solutions are of interest to us. The authors hope the book will cover the possible spectrum of wastewater technologies and environmental treatment up to a high level of environmental protection, clean and green management lessons, identifying the barriers to transformational change, and then informing the agenda and initiatives for sustainable development. ICES 2023 is devoted to wastewater technology and environmental treatment, emphasizing environmental protection at the highest level. ICES 2023 aims to disseminate current knowledge and sustainable development, share experiences and lessons gained, and generate conversation and reflection to promote a sustainable paradigm shift. With the distribution of sustainable wastewater technology and environmental treatment, the ultimate goal is to bring revolutionary change to sustainable development. The Conference's success relied on the efforts and contributions of the organizing committee, keynote speakers, and participants.

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Acknowledgments

The success of the International Conference on Environment and Sustainability (ICES 2023) owes much to numerous individuals and institutions' collective efforts and support. As we reflect on the moments shared and knowledge disseminated during this conference, we extend our sincere gratitude to those who played pivotal roles in making ICES 2023 a memorable and impactful event. First and foremost, we thank the College of Science and Applied Sciences at the University of Anbar, Iraq, for graciously hosting ICES 2023. The commitment of these institutions to fostering academic exchange and promoting sustainable practices has been fundamental to the conference's success. A special acknowledgment is reserved for our esteemed partner, Al-Maarif University College, Anbar, Iraq, for their invaluable cooperation. The collaborative spirit demonstrated by Al-Maarif University College significantly enriched the diversity of perspectives and expertise represented at the conference. We extend heartfelt thanks to the Scientific and Organizing Committee members whose tireless dedication ensured the seamless planning and execution of ICES 2023. Their commitment to excellence and attention to detail contributed immeasurably to the conference's overall success. Our gratitude also goes out to the presenters, speakers, and participants who shared their research, insights, and experiences, enriching the intellectual discourse and contributing to advancing knowledge in environmental and sustainability. Last but not least, we acknowledge the sponsors whose generous support made ICES 2023 possible. Your commitment to the ideals of environmental stewardship and sustainability has helped create a lasting impact on the academic community.

Together, we have laid the foundation for a more sustainable and environmentally conscious future. Thank you to everyone who played a part in making ICES 2023 a resounding success.

Najaf, Iraq

Ahmed J. Obaid
Conference Lead Editor

About the Conference

The topics of the Conference cover the latest studies and research in environmental sciences and environmental sustainability, which help in finding solutions to environmental problems (air pollution, water pollution, soil pollution, noise pollution, thermal pollution, radioactive pollution, light pollution, and global warming). The Conference will also cover the environmental technology section, which is essential in achieving sustainable development goals and promoting renewable energy sources.

Aims of the Conference

ICES2023 brings together scientists, academics, researchers, and students to enhance communication and dialogue among them and exchange their experiences, ideas, and knowledge related to environmental sciences and sustainable development. Visions will be drawn, and cooperation between various organizations and institutions in the world will be encouraged in opening scientific channels to address various contemporary issues and challenges in the environmental field. The scientific concepts supporting modern biotechnologies, exploiting innovations, and trends towards biofuels and waste conversion technologies will be discussed. The main goals of this Conference are to bring together researchers, academicians, environmentalists, scientists, research scholars, and students to foster communication and dialogue regarding the sharing and exchanging their experiences, ideas, and knowledge concerning Agriculture, Environment, and Sustainable Development. Establish an interdisciplinary forum for critical discussion in key areas related to various topics, such as green growth and sustainable development, climate change and environmental pollution, environmental technology and sustainable management, ecosystem and biodiversity conservation, and environmental education and legislation. Provide an excellent platform for publishing research articles on closely related environmental and sustainable development issues. Offer a scientific gateway into the most up-to-date technologies and methods for various environmental and sustainable development research through workshops and seminars. This Conference will assist in contributing to and proposing solutions for existing concerns and difficulties. Conclude and stimulate collaboration between various international institutional bodies to develop scientific channels to address these concerns and challenges.

- Ahmed J. Obaid, Iraq
- Emad Abdulrahman Al-Heety, Iraq
- Zdzislaw Polkowski, Poland
- Neyara Radwan, Saudi Arabia.

Modeling and Analysis of Land Surface Temperature Variations in Basrah Governorate, Iraq, Using Remote Sensing Data and Geomatics Techniques

Forqan Kh. Al-Daraji, Dakhil R. Ndewi, and Hussein M. Al-Shammari

Abstract This study was conducted within the administrative boundaries of Basrah Governorate, Iraq, covering a total area of approximately 354.450 km^2 from the southern borders of Al-Haritha District to the northern borders of Al-Qurnah District along the Shatt al-Arab River and its surrounding areas. The field data on daily temperature values were collected from the Al-Qurnah meteorological station. Surface temperature values in the study area were calculated and modeled by deriving thermal energy values from the 10th spectral band (Band 10) of Landsat-8 satellite imagery using the thermal energy balance algorithm. The study's results showed a strong correlation between the temperature values obtained from the meteorological station and the values calculated from remote sensing data using the thermal energy balance algorithm, with the correlation coefficients ranging from 0.950 to 0.982. Furthermore, there was a noticeable temporal variation in surface temperature values in the months of January and July for the years 2018–2022. Generally, the highest temperature values were recorded in July, while the lowest values were recorded in January for all the study years. The results also demonstrated a clear spatial variation in temperature values according to the location of each category. The values generally decreased in areas close to the Shatt al-Arab River and in regions with higher soil moisture content and good vegetation cover. In contrast, they increased in arid and urban areas.

Part of Ph.D. dissertation of the first author.

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Keywords Land surface temperature · Shatt al-Arab Basin · Vegetation cover · Landsat 8 imagery

1 Introduction

The unsustainable use of water resources, e.g., decreasing river discharges, excessive groundwater pumping, wetland drainage, seawater intrusion, and soil salinization, together with climate change issues, pose a significant challenge to the future of water resources across the world, particularly those in arid and semi-arid regions [1]. Thus, it is imperative to explore innovative approaches in hydrological sciences that enable the analysis of water usage and consequently aid the development of sustainable strategies for water resource management [2]. Measurements derived from remote sensing data and geographic information systems (GIS) that use satellite imagery are among the most important tools for monitoring and measuring terrestrial and hydrological variables in remote and temporally constrained areas. Remote sensing instruments capture electromagnetic radiation (EMR) reflected from land surface features represented by solar radiation within the thermal infrared and microwave regions of the electromagnetic spectrum. In contrast, radar sensors can receive reflected active microwaves [3]. The reflected solar energy and microwave frequencies are utilized to create thermal infrared radiation emission maps for the purpose of calculating surface temperature energy flux and microwave properties [4]. In this regard, the remote sensing and GIS technologies play a crucial role in collecting data on terrestrial targets without physical contact, thus enabling their remote study. They achieve the same by capturing EMR reflected from their target using sensors and converting it into the required information. The electromagnetic radiation spectrum consists of specific wavelengths and frequencies that can be stored, managed, analyzed, and displayed as data [5]. These technologies are essential and beneficial in advancing various environmental models that contribute to the generation of spatial and temporal information crucial for hydrological studies [6].

1.1 Climate in the Shatt Al-Arab Basin

The Shatt al-Arab Basin is characterized by a hot and dry climate in the summer, with southeast winds prevailing over the basin at this time. During the winter, northwest winds dominate, bringing moderate temperatures and increased chances of rainfall. Spring and autumn are short seasons and represent the transitional phases between summers and winters [7]. Overall, the climate in southern Iraq is characterized by high temperatures and aridity. The monthly average temperature varies from 9 to 41 °C in January and July, respectively. Rainfall occurs here with an annual average of approximately 100 mm in October and May [8]. Abbas [9] specifically pointed out that the Shatt al-Arab Basin has a hyperthermic thermal system and a torric (aridic) moisture system owing to high temperatures exceeding 22 °C, dry soil, and a desert climate that prevails throughout the year according to the Köppen classification. The winter season in the basin is characterized by moderate temperatures of around 20 °C and reduced solar radiation, accompanied by decreasing temperatures. Moreover, low-pressure systems are frequently observed throughout the year in the basin. As for its relative humidity, it averages about 38.8%, increasing to 64% in January and decreasing to around 55% in February, with an annual average humidity of 61%. Notably, humidity continues to decline progressively throughout the summer, reaching its lowest levels in June at around 19%.

1.2 Modeling Surface Temperature

The surface temperature of an area affects the rates of evaporation from the soil. Dry soils tend to heat up and cool down more rapidly compared to moist soils. This phenomenon is attributed to the higher heat capacity of water, which allows it to absorb and release heat multiple times more effectively than dry soil. Additionally, temperature influences water properties such as viscosity, density, surface tension, and angle of contact. Therefore, the heat capacity of soil depends on its water content and the moisture characteristic curve that affects its temperature [10]. Advancements in remote sensing technologies, with their high-resolution imaging and multiple spectral bands observed over specific time intervals using various viewing angles, have made remote sensing data valuable sources of comprehensive information about the geometric structure water conditions and the surface temperature of a land area as compared to other methods. In fact, remote sensing techniques demonstrate a clear advantage in estimating optimal and latent heat flux on the surface, a crucial component in the study of energy and mass exchange between the hydrosphere atmosphere and biosphere that is difficult to calculate accurately using traditional meteorological and climatological methods [11]. Pivato et al. [12] used remote sensing to estimate the dynamics of water temperature in tide environments by comparing water temperature data derived from high-resolution satellite imagery with data recorded by a limited coverage network of ground-based measurement stations. In their study, the Landsat ETM + satellite demonstrated its high capability to monitor thermal infrared data, showing its efficiency in modeling and evaluating the spatial distribution of water temperatures in coastal environments affected by tidal phenomena. This further assisted the creation of accurate maps of some hard-to-reach areas, especially those involving shallow water bodies. Moreover, Marcq et al. [13] highlighted the common use of the thermal infrared (TIR) spectral region, with wavelengths ranging from 8 to 14 μm, in calculating and estimating surface temperatures via various remote sensing methods. Notably, the maximum radiative emissions for typical surface temperatures are around 300 K within the TIR window.

Therefore, the present study aimed to monitor and model the spatiotemporal variations in surface temperatures within the Shatt al-Arab River Basin, located to the north of Basra Governorate, using geomatics techniques and the thermal balance algorithm. We achieved the same within individual pixels each covering an area not exceeding 900 km^2. The primary purpose of this study was to reduce the effort and time required for data collection and avoid the measurement errors associated with ground-based climate stations that cover limited areas.

2 Materials and Techniques

2.1 Location and Area

The study area was undertaken within the administrative boundaries of Basrah Governorate (see Fig. 4) and extended from the southern borders of Al-Haritha district (at coordinates 47° 46′ 54″ E–30° 34′ 57″ N and 47° 45′ 33″ E–30° 33′ 38″ N) to the northern borders of Al-Qurna district (at 47° 27′ 16″ E–31° 1′ 59″ N and 47° 22′ 46″ E–30° 59′ 54″ N) along the Shatt al-Arab River and its adjacent areas. In total, the study region covered approximately 354,450 km^2 (Fig. 1).

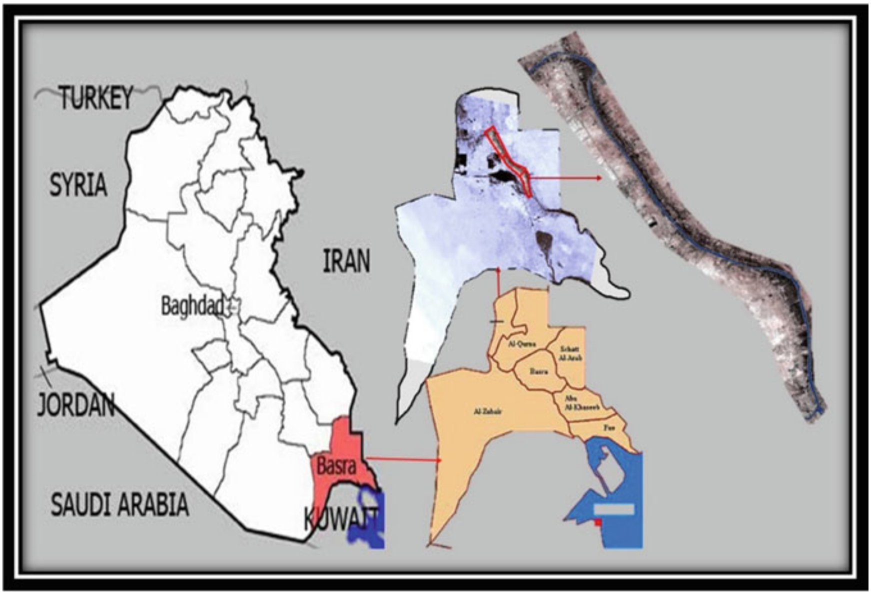

Fig. 1 Study area location and administrative boundaries (*Source* The drawing was drawn by the researcher using Arc Gis v 10.8)

2.2 Remote Sensing Data Sources and Information

In this study, satellite imagery, particularly multispectral imagery, played a crucial role as a primary data source. The multispectral imagery encompassed 11 spectral bands with a spatial resolution of 30–15 m, making it one of the most significant sources of information. The satellite imagery was obtained and processed, and data for the study area were derived from it in the year 2022; the data spanned four time periods and a three-month interval. These data were acquired from sensors on the American satellite Landsat 8 including Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS). Additionally, recent images for the year 2021–2022 were downloaded from the websites of the United States Geological Survey (USGS), the University of Maryland, and the University of Maryland Institute of Advanced Computer Studies. These data were instrumental in determining the topographical factors, deriving essential spatial information, delineating study area boundaries, and obtaining spectral signatures for monitoring the studied variables. They also facilitated temporal and spatial analysis, contributing to the database construction analysis and interpretation processes.

2.3 Field Data for Surface Temperature

Field data for daily surface temperature values were collected from the Al-Qurna Climatic Station in Basra Governorate, located at longitude 47.45° E and latitude 30.94° N. This station is affiliated with the Agricultural Meteorology Center of the Iraqi Ministry of Agriculture. It provided data for a period of five years, from 2018 to 2022.

2.4 Modeling Land Surface Temperatures Using Remote Sensing

In the study area, the land surface temperatures (LST) were calculated and modeled by deriving thermal energy values from the 10th spectral band (Band 10) and the Normalized Difference Vegetation Index (NDVI) based on the following equations [14].

1. Calculation of spectral radiance from satellite imagery using Eq. (1):

$$L\lambda = M_L * Q_{cal} + A_L - Oi \tag{1}$$

- L(λ): Spectral radiance at the top of the atmosphere (TOA).

- ML and AL: Constants for the tenth spectral band obtained from the attached satellite imagery files (MULT_BAND ADD_BAND).
- B and 10: The 10th thermal spectral band.
- Oi: Spectral correction factor for the tenth spectral band (0.29).
- Conversion of spectral radiance to temperature in degrees Celsius using Eq. (2):

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

- BT: Brightness temperature at the top of the atmosphere in Celsius.
- $K2$ and $K1$: Constants for the tenth spectral band obtained from the attached satellite imagery files.
- 273.15: Constant for converting temperature from Kelvin to Celsius.

2. Calculation of Normalized Difference Vegetation Index (NDVI) using Eq. (3):

$$NDVI = \frac{B5 - B4}{B5 + B4} \quad (3)$$

- $NDVI$: NDVI value ranging from –1 to 1.
- $B4$: Fourth spectral band for red light.
- $B5$: Fifth spectral band for near-infrared light.

3. Calculation of Portion of Vegetation (Pv) using Eq. (4):

$$Pv = \left(\frac{NDVI - NDVImin}{NDVImax - NDVImin} \right)^2. \quad (4)$$

- Pv: Portion of Vegetation.
- $NDVI\_min$ and $NDVI\_max$: Minimum and maximum values of NDVI from the imagery.

4. Calculation of Land Surface Emissivity (E) using Eq. (5):

$$E = 0.004 * Pv + 0.98 \quad (5)$$

- Pv: Portion of Vegetation (from Eq. 4).

5. Calculation of Land Surface Temperature (LST) using Eq. (6):

$$LST = \frac{BT}{1 + \left(W \times \frac{BT}{C2}\right) \times \ln(E)} \quad (6)$$

- *LST*: Land Surface Temperature in Celsius.
- *BT*: Brightness temperature at the top of the atmosphere (from Eq. (2)).
- *E*: Land surface emissivity (from Eq. (5)).
- *W*: Wavelength of the tenth spectral band (10.8).
- *C2*: A value calculated by Eq. (7).

$$p = h \times \frac{C}{S} = 1.4388 * 10^{-2}\text{mk} = 14388\ \mu\text{mk} \tag{7}$$

- *h*: Black's constant ($6.626 * 10^{-34}$ joules)
- *S*: Boltzmann constant ($1.38 * 10^{-34}$ joules)
- *C*: Speed of light ($2.998 * 10^{8}$ m s^{-1})

The correlation and determination coefficients between the values derived from satellite imagery and the field values obtained from the climatic station were computed using correlation analysis in SPSS. A software model was built within the ArcGIS software environment, as illustrated in the Fig. 2.

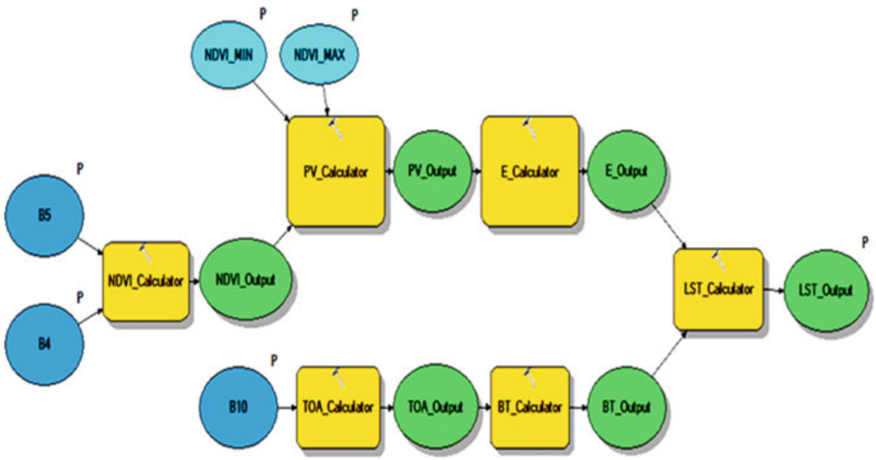

Fig. 2 A diagram depicting the sequence of actions involved in operating the thermal balance tool in the ArcMap software framework

3 Results and Discussion

3.1 Temporal Modeling of Land Surface Temperatures

The results presented in Table 1 demonstrate a strong correlation between the temperature values obtained from the meteorological station and those calculated from remote sensing data using the thermal balance algorithm. The correlation coefficients varied, with the highest value recorded at 0.982, between the maximum temperatures from the meteorological station (A) and the values calculated using remote sensing data for the same station location (RA). In contrast, the lowest correlation coefficient was 0.950 between the maximum temperatures (A) and the values calculated for the average temperatures in the study area (RD). Notably, the correlation coefficients ranged between the highest and lowest values, with values of 0.976, 0.975, 0.972, and 0.951 for C&RA, RD&A, RD&A, and B&RA, respectively. The variations in temperature values between the meteorological station and the calculated values could be attributed to differences in the acquisition time of the Landsat-8 satellite imagery for the study area during varying sun angles and intensities throughout a day. These could differ from the values recorded at the ground-based meteorological stations (reliant on organized time sequences). The difference between maximum and minimum temperature values reflected the diurnal temperature variation, with maximum temperatures representing the expected daytime peak temperature and minimum temperatures representing the expected nighttime or early-morning temperature lows [12].

The results presented in Table 2 show a variation in surface temperatures between the months of January and July for the years 2018–2022. Generally, the highest temperatures were recorded in July, while the lowest temperatures were observed in January for all the study years. For the study area (see Fig. 3), the highest recorded temperature was 49.162 °C in July 2019 and the lowest temperature was 43.628 °C in 2022. In 2021, an intermediate value of 46.802 °C was recorded. For the same month, the overall average temperature variation across the study area maintained the order 39.345 °C > 38.414 °C > 37.901 °C for the years 2022, 2019, and 2021, respectively. These results indicate significant temperature variations in January in the study area (see Fig. 4): 27.267, 17.719, and 16.784 °C for 2018, 2020, and 2022, respectively. Moreover, the overall average temperature ranking for January was 19.571 °C > 14.354 °C > 13.217 °C for 2018, 2020, and 2022, respectively. This variation was linked to reduced human activities including decreased traffic and industrial operations during the COVID-19-induced economic lockdowns. This reduction positively impacted the environment by lowering the emissions of greenhouse gases (CO_2, NO_2, and CH_4) known for heat-trapping properties and contributing to the greenhouse effect. Indeed, CO_2, with a high atmospheric concentration, is a major global warming contributor. Despite having a lower concentration, methane surpasses CO_2 in terms of heat-trapping potential. The combined effect of these gases along with the impact of nitrogen oxide (NO_x) compounds and chlorofluorocarbons (CFCs) leads to the depletion of the ozone layer and subsequently results in higher surface temperatures [15].

Table 1 Temperature values obtained from meteorological station and calculated using remote sensing data

No.	Date of satellite image	Temperatures (C°)						
		Climatological station values			Temperature assessments using remote sensing			
		Maximum values (A)	Minimum values (B)	Average e (C)	Climatological station location values (RA)	Highest values in the study area (RB)	Lowest values in the study area (RC)	Average in the study area (RD)
1	**2018M01D15**	21.880	5.050	13.465	20.703	27.267	11.874	19.571
2	**2019M07D13**	46.260	31.910	39.085	47.750	49.162	27.666	38.414
3	**2020M01D18**	20.950	11.900	16.425	15.318	17.719	10.988	14.354
4	**2021M07D17**	46.680	30.550	38.615	43.956	46.802	29.000	37.901
5	**2022M01D10**	16.650	4.540	10.595	12.799	16.784	9.650	13.217
6	**2022M04D16**	30.400	20.570	25.485	30.524	37.002	23.742	30.372
7	**2022M07D05**	47.410	31.060	39.235	41.935	43.628	35.063	39.346
8	**2022M10D14**	34.363	15.858	25.110	31.035	37.786	17.170	27.478
Correlation coefficient		**A&RA**	**B&RA**	**C&RA**	**RD&A**	**RD&A**	**RD&A**	
		0.982	0.951	0.976	0.975	0.950	0.972	

Table 2 Statistical distribution of land surface temperature in the study area

No.	Period no.	Temperatures (Celsius)				Area (km^2)	Percentage of area (%)
		Lowest value	Highest value	Average	Range		
2018M01D15	1	11.874	18.117	16.339	6.243	170.749	48.172
	2	18.118	18.685	18.412	0.567	35.022	9.880
	3	18.686	27.267	19.844	8.581	148.568	41.914
	4	–	–	–	–	0.117	0.033
2019M07D13	1	27.666	38.330	33.439	10.664	60.803	17.154
	2	38.331	45.339	42.845	7.008	157.554	44.450
	3	45.340	49.162	46.651	3.822	135.851	38.327
	4	–	–	–	–	0.248	0.070
2020M01D18	1	10.988	14.045	13.299	3.057	139.267	39.290
	2	14.046	14.770	14.393	0.724	100.052	28.227
	3	14.771	17.719	15.337	2.948	114.932	32.425
	4	–	–	–	–	0.204	0.058
2021M07D17	1	29.000	38.556	35.144	9.556	86.502	24.404
	2	38.557	40.821	39.838	2.264	70.488	19.886
	3	40.823	46.802	42.997	5.979	197.422	55.697
	4	–	–	–	–	0.039	0.011
2022M01D10	1	9.650	10.510	10.275	0.860	9.849	2.779
	2	10.511	12.442	11.645	1.932	178.045	50.231
	3	12.443	16.784	13.116	4.341	167.018	47.120
	4	–	–	–	–	–	–
2022M04D16	1	23.742	29.409	28.102	5.667	62.030	17.500
	2	29.410	31.335	30.426	1.925	122.554	34.575
	3	31.336	37.002	32.842	5.666	170.329	48.054
	4	–	–	–	–	–	–
2022M07D05	1	35.063	40.999	39.497	5.936	157.927	44.555
	2	41.000	41.450	41.229	0.450	55.944	15.783
	3	41.451	43.628	41.822	2.177	140.983	39.775
	4	–	–	–	–	0.059	0.017
2022M10D14	1	17.170	29.264	26.179	12.094	150.555	42.475
	2	29.265	32.910	30.994	3.645	142.518	40.208
	3	32.911	38.786	34.904	5.875	61.278	17.288
	4	–	–	–	–	0.104	0.029

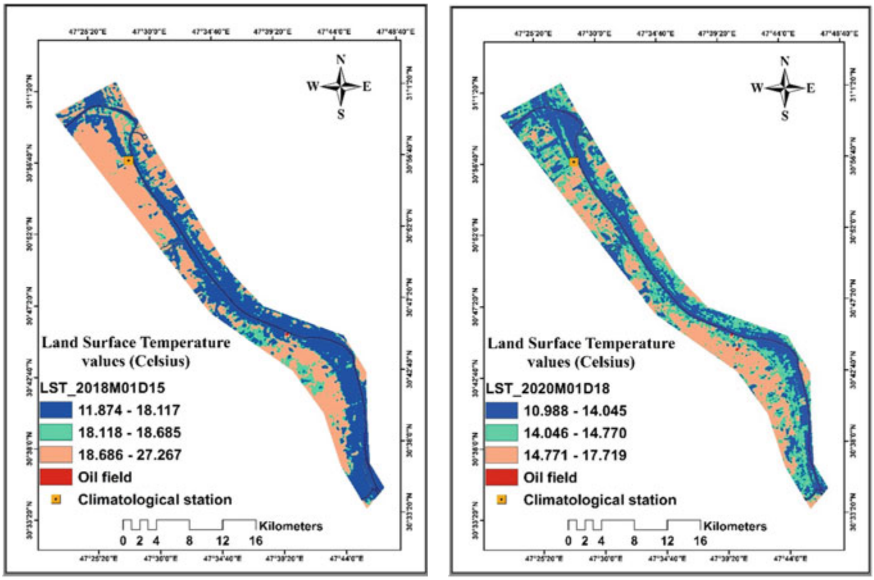

Fig. 3 A map showing the distribution of land surface temperatures in study area in January 2018 and January 2020

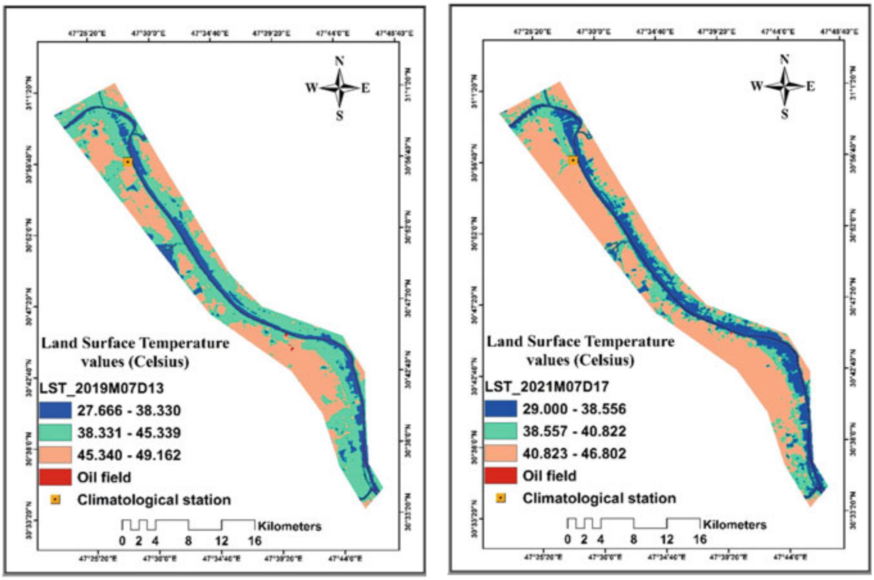

Fig. 4 A map showing distribution of land surface temperatures in study area in July 2018 and July 2020

As for the temperature variation between the four seasons, the results shown in Table 2 for the year 2022 indicate a noticeable difference between January, April, July, and October, with a three-month interval between each month of data collection. The highest temperatures were recorded in July (reaching 43.628 °C) while the lowest temperatures were observed in January, with a temperature of 16.784 °C. For April and October, relatively similar values of approximately 37.00 and 37.785 °C, respectively, were recorded. The overall average temperature ranking in the study area (see Figs. 4 and 5) maintained the order 39.346 °C > 30.372 °C > 27.478 °C > 13.217 °C for the months of July, April, October, and January, respectively. This temperature variation could be attributed to the natural fluctuations in temperature across the seasons, which are directly influenced by weather and climate conditions. Indeed, in the study region, solar radiation intensity increases during the summer, especially in July, when the angle of solar rays becomes nearly perpendicular to the land surface. Additionally, the proximity of the sun to the land during this season contributes to higher temperatures. These conditions are reversed during the winter season, when the sun's angle becomes more oblique and results in lower temperatures. Furthermore, the climate of southern Iraq is characterized by hyperthermic thermal conditions and aridic moisture conditions, with temperatures often exceeding 22 °C [14]. According to the Köppen climate classification, the region experiences a desert climate throughout the year. Here, the winter season is characterized by moderate temperatures (around 20 °C) and reduced solar radiation accompanied by the occurrence of frequent weather depressions throughout the year. The region's relative humidity averages around 38.8%, with increases in January (reaching up to 64%) and decreases in February (to 55%) and with an annual average of 61%. In fact, humidity in this region continues to decline over the summer, reaching its lowest levels in June at approximately 19% [9]. This natural temperature variability is a result of the complex interplay of climatic factors and seasonal changes in solar radiation and solar angle, all of which contribute to the observed temperature fluctuations in the study area.

3.2 Spatial Temperature Variation in the Study Area

The results in Table 2 and Figs. 3, 4, 5 and 6 reveal distinct spatial temperature variations across months and years for different categories within the study area. The study area was broadly categorized into three main types, with a fourth category representing a small area containing the flares of the oilfield within the study boundaries. Figure 3 illustrates the surface temperature variation and spatial distribution for January in 2018 and 2020. In this study, the third category displayed the highest values with an overall spatial average temperature of 19.844 and 15.337 °C covering 41.914 and 32.425% of the study area, respectively. The first category recorded the lowest average temperature, with values of 16.339 and 13.299 °C covering 48.172 and 39.290% of the area, respectively. The second category showed an intermediate spatial average temperature of 18.412 and 14.393 °C covering 9.880 and 28.227%

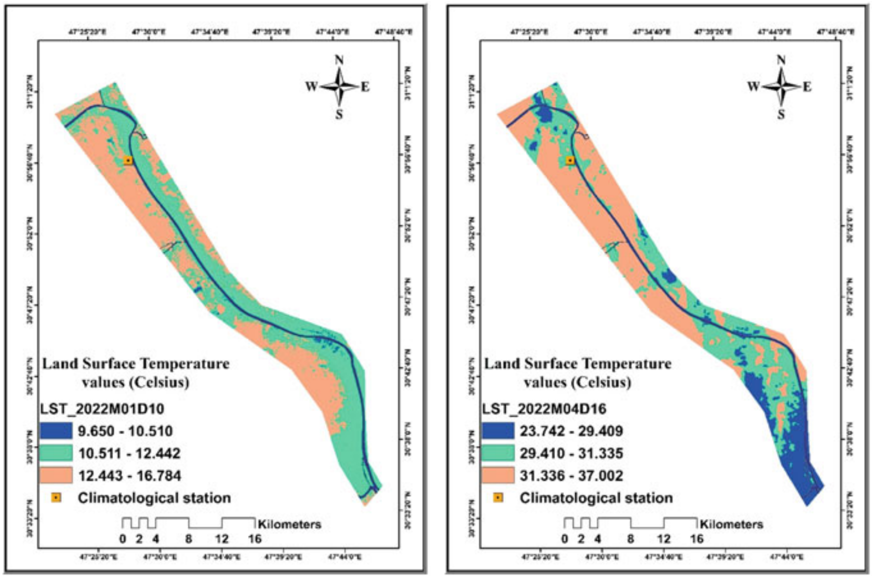

Fig. 5 A map showing the distribution of land surface temperatures in study area in January and April 2022

for the years 2018 and 2020, respectively. Similarly, the results in Table 2 and Fig. 4 show temperature variations and spatial distribution for the month of July for the years 2019 and 2021 in the study area. Notably, the third category recorded the highest values with overall spatial average temperatures of 46.651 and 42.997 °C covering 38.327 and 55.697% of the study area, respectively. The first category recorded the lowest average temperatures, with values of 33.439 and 35.144 °C covering 17.154 and 24.404% of the study area, respectively. The second category exhibited intermediate spatial average temperatures of 42.845 and 39.838 °C covering 44.450 and 19.886% of the study area for the years 2019 and 2021, respectively.

The spatial temperature variation in the study area could be attributed to significant variations in climatic and environmental characteristics, natural and human activities, land use patterns, vegetation cover, and soil moisture content. Indeed, these factors play a crucial role in energy and mass exchange between the hydrosphere atmosphere and biosphere [11]. It is noteworthy that the first category, representing most agricultural lands with vegetation cover and proximate to the Tigris River, experienced lower average temperatures compared to the second and third categories. This could be attributed to the vegetation cover's capacity to absorb some of the heat and the coverage area it represents on the land surface that contributes to improved air quality and reduced greenhouse gas emissions. Furthermore, soil moisture content plays a crucial role in the land energy balance, thanks to water's high heat capacity facilitating the dispersal of thermal energy [14]. Hence, the spatial temperature variations observed in the study area resulted from the intricate interaction of diverse environmental and human factors. This underscores the significance of comprehending these dynamics for local climate studies and land use planning in the study area.

Regarding the spatial temperature variation in the study area for the year 2022, for the four study phases in the months of January, April, July, and October (see Table 2 and Figs. 5 and 6), the results demonstrated a noticeable gradient in the spatial variation of temperature values according to the location of each category. Overall, it was observed that temperature values decreased in regions near the Shatt al-Arab River areas with high moisture content and good vegetation cover. In contrast, temperatures tended to rise in the arid and urban areas. For January and April (see Fig. 4), the third category exhibited the highest temperature values with average spatial temperatures of 13.116 and 32.842 °C covering 47.120 and 48.054% of the study area, respectively. In contrast, the first category recorded the lowest temperature values with average temperatures of 10.275 and 28.102 °C covering 2.779 and 17.500% of the study area, respectively. The second category fell between the first and third categories, with average spatial temperatures of 11.645 and 30.426 °C covering 50.231 and 34.575% of the study area, respectively.

However, for July and October (see Fig. 5) the results did not significantly differ from the overall spatial temperature gradient. The third category continued to show the highest temperature values (41.822 and 34.904 °C) while the first category had the lowest temperatures (39.497 and 26.179 °C). The distribution percentages varied spatially over the study area for all three categories, with the first category expanding in the vicinity of the Shatt al-Arab River and in areas with good vegetation cover

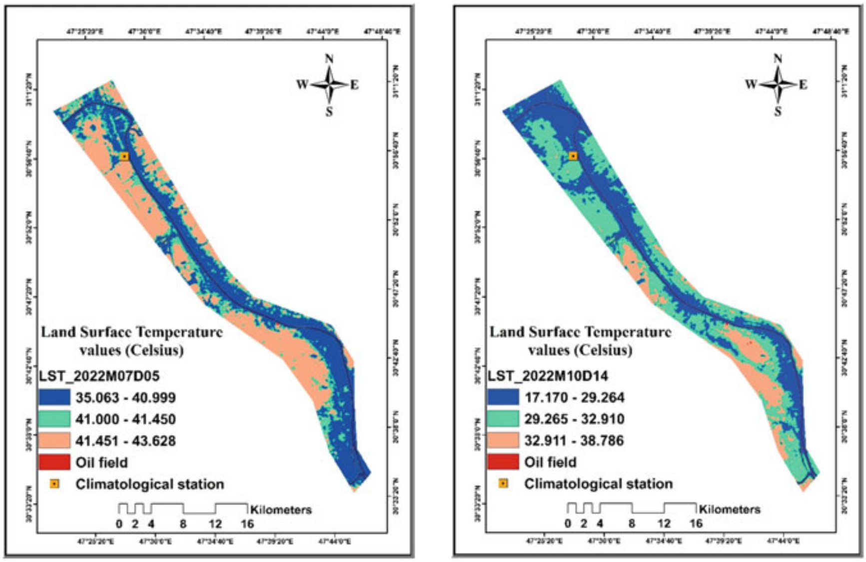

Fig. 6 A map showing distribution of land surface temperatures in study area in July and October 2022

during January and April; on the other hand, there was a reduction in spatial extent for the second and third categories, representing urban and arid regions. The spatial temperature variations among these three categories could be attributed to significant disparities in climatic and environmental characteristics as well as both natural and human activities, along with factors such as vegetation cover, soil moisture content, and urbanization, which play pivotal roles in modulating temperature variations. Moreover, seasonal temperature differences in the study area were influenced by the gradual decrease in temperature during the summer months, heightened air humidity, and increased vegetation activity especially with respect to winter crops. All these factors contributed to lower temperature values. Conversely, urban areas and arid land showed a contrasting effect with wider spatial extents for their categories in the study area. This could be attributed to the thermal properties of building surfaces, paved roads, and arid soil, which tend to release heat into the atmosphere. Moreover, increased traffic emissions from vehicles and industrial activity possibly led to elevated surface temperatures particularly in July and April [16].

4 Conclusions

- The results of this study demonstrated a strong correlation between temperature values obtained from the climatic weather station and the values calculated from remote sensing data using the thermal balance algorithm. The correlation coefficients ranged from the highest value of 0.982 for maximum temperatures from the climatic weather station to the values calculated using remote sensing data for the same location, while the lowest correlation coefficients were recorded at 0.950 between maximum temperatures and the values calculated for the average temperature in the study area. The correlation coefficients exhibited a range of values that lay between the abovementioned highest and lowest values.
- The results showed temperature variations and spatial distribution for the month of July in the years 2019 and 2021. In this regard, the third category recorded the highest values, with overall spatial average temperatures of 46.651 and 42.997 °C covering 38.327 and 55.697% of the study area, respectively. The first category recorded the lowest average temperature with values of 33.439 and 35.144 °C covering 17.154 and 24.404% of the study area, respectively. The second category exhibited intermediate spatial average temperatures of 42.845 and 39.838 °C covering 44.450 and 19.886% of the study area for the years 2019 and 2021, respectively.
- Regarding the spatial variability of surface temperatures, the results showed a clear gradient in the spatial distribution of temperature values based on the location of each category. Generally, temperatures were lower in areas near the Shatt al-Arab River Basin that have higher moisture content and better vegetation cover, while they were higher in the arid and urban areas. This pattern was attributed to the gradual decrease in temperature values during the winter season and the increase

in relative humidity in the air in this basin. These factors led to increased soil moisture retention, playing a significant role in lowering surface temperatures.

5 Future Work and Limitations

This study can be used to monitor climate change and the greenhouse effect resulting from various gases, such as CO_2. Additionally, future studies examining non-soil moisture and evaporation can be enhanced by this study's contributions. However, one of the challenges faced by this study is the difficulty of obtaining sufficient field data for calibration owing to the unavailability of precisely distributed devices within the study area.

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