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Research paper

Assessment of land surface temperature and urban heat island using remote sensing in the Kurdistan region, Iraq

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ABSTRACT

Urban heat island (UHI) is a prevalent environmental hazard in modern cities, with higher surface and air temperatures than adjacent rural regions. The current study assessed the spatiotemporal distribution of land surface temperature (LST) in Iraq's Kurdistan region and the existence of urban heat islands during the daytime and at nighttime. The land surface temperature (LST) was composited from 2001 to 2024 using the historical Moderate-Resolution Imaging Spectroradiometer (MODIS) Terra satellite 8. The average LSTs of the rural and arid regions were contrasted with the average LSTs of the urban and suburban areas in three governorates of the study area, namely Erbil, Sulimaniyah, and Duhoke. Daytime and nighttime LST were also compared. The results revealed that the highest values of LST occurred in the urban region of the southern parts of the study area, where the mean value was 32.2 ^{0}C during the daytime. During the summer, Erbil had a higher temperature of 49.5 ^{0}C, while Sulimaniyah had the lowest (0.98 ^{0}C). According to annual data, almost 80% of the study region had an NLST score of 0.6 or 0.7. The biggest difference in LST mean value between urban and suburban regions was recorded in the summer daytime in Erbil city, with a value of 5.1 ^{0}C, while the smallest variances were reported in the fall season for all governorates in the study area, reaching 0.01 ^{0}C at night in Sulimaniyah city.

Keywords**:** Land surface temperature (LST), Urban heat island, Google Earth Engine, MODIS, Kurdistan of Iraq, Remote sensing

The combined impacts of urbanization and climate change are raising temperatures in metropolitan areas. These rising temperatures are a serious problem for the ecology and socioeconomic structures (Eshetie, 2024). Urbanization results in the "Urban Heat Island" phenomenon, marked by increased surface temperatures in urban regions relative to rural areas, which has substantial climatic consequences (Huang *et al.,* 2024). Urban heat island effects, exacerbated by global climate change, significantly impact urban life by increasing temperatures, energy demands, and air quality, causing resource strain and reduced comfort (Jalilov *et al.,* 2021; Huang *et al.,* 2024). The reduction of vegetation cover plays an important role in increasing impervious surfaces. The building materials and anthropogenic heat also contribute to the temperature increase in the urban area (Ren *et al.,* 2022; Siddique *et al.,* 2021). Future projection studies indicate that the UHI intensity effect will continue to increase over the years, so there is an urgent need to manage it in densely urbanized areas, as well as to develop effective strategies for sustainable initiatives and policies that target the reduction of excessive warming to prevent heat-related emergencies (Piracha & Chaudhary, 2022; De Almeida *et al.,* 2021). Remote sensing technique have been widely used in studies related land use and land cover analysis based on land surface temperatures and vegetation characteristics (Gasparrini *et al.,* 2015; Tawfik & Al-Lami, 2025) and also identifying urban heat island (Wang *et al.,* 2016).

Iraq faces significant challenges due to climate variability, particularly in water availability. The Kurdistan region has experienced severe temperature swings, drought, and precipitation changes, leading to a significant decline in water supply (Hamoodi, 2018). Like all developing countries, particularly those in the Middle East and Arab regions, the Kurdistan region is undergoing rapid urbanization and construction. Building practices in the studied region are quite common in other developing countries, where rapid urban development is associated with an increase in surface temperature due to the prevalence of dense asphalt,

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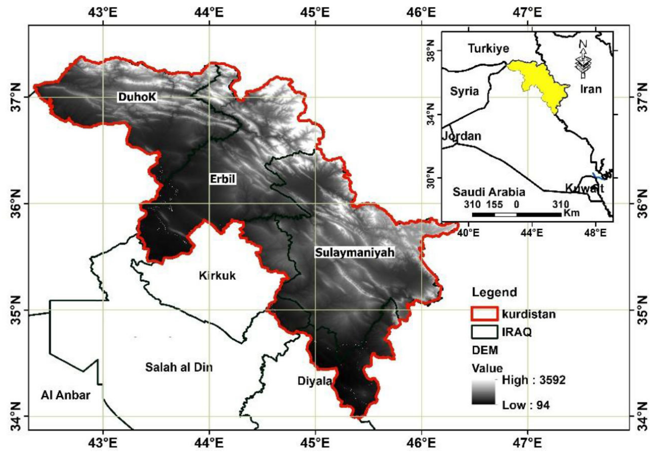

Fig. 1: Location of aera study, Kurdistan Region/Iraq

concrete, and building roofs (Zhao *et al.,* 2021; Parker, 2020; Morabito *et al.,* 2020). Kurdish meteorological data confirm the increase in temperature, as the first year of the 21st century marked the highest record of air temperature in the peninsular region of Iraq and Kurdistan of Iraq (Eklund *et al.,* 2021; Nasir *et al.,* 2022). Comprehensive studies on urban heat in the Kurdistan region of Iraq have not received sufficient attention. This study analyzed the regional distribution of land surface temperatures and the impact of urban heat effects in Kurdistan region of Iraq.

MATERIALS AND METHODS

Study area and data source

The Kurdistan region (Area: 40,643 km^2) is an autonomous region in Federal Iraq. It comprises the three governorates of Erbil (the capital), Sulaymaniyah, and Duhok. It borders Syria to the west, Iran to the east, and Turkey to the north, where fertile plains meet the Zagros Mountains Fig. 1. The Kurdistan region's climate is semi-arid continental, with hot and dry summers and cold and rainy winters. The area is colder than the central and southern areas of Iraq (Chomani, 2023). The climate in the mountains is wetter but just slightly colder than that of the steppe. Rainfall in the mountains varies by location and ranges from 400 mm to over 1,000 mm, primarily occurring between November and March (Al-Lami *et al.,* 2024). Summers are hot, with average temperatures ranging from 35 °C in the northernmost sections to 40 ^{0}C in the southwest. Lows range from 21 to 24 ^{0}C. Winter in Iraq is significantly colder than the rest of the country, with highs around 9 ^{0}C to 11 °C and lows around 3 ^{0}C in some parts and freezing in others, sinking to -2 ^{0}C and 0 ^{0}C on average. The rise was found to be significantly greater in Iraq's northern and eastern regions (Al-Lami *et al.,* 2024). For this study, we used NASA's Moderate-Resolution Imaging Spectroradiometer (MODIS) data collected by the Terra spacecraft. MODIS/Terra's MOD11A2 product includes terrestrial surface temperature and emissivity averaged over eight days with a one-kilometer resolution. Using Google Earth Engine (https://earthengine.google.com), we were able to extract daytime and nighttime LST data for Kurdistan of Iraq, from 2001 to 2024. Every eight days, there is a new measurement added to the data set. In order to make things meaningful, we changed the temperature unit from Kelvin to Celsius. To get the units back to Kelvin, we multiplied by a scaling factor of 0.02, which was provided in the user handbook (Al-Salihi *et al.,* 2013). To get the Celsius equivalent of Kelvin, we then subtract 273.15.

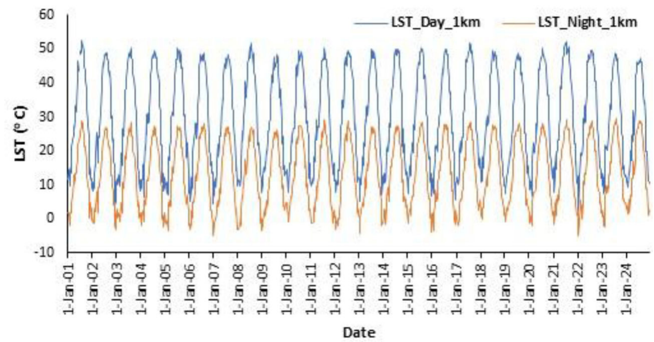

Fig. 2: Time series of day and night LST from 2001 to 2024

Methodology

The Google Earth Engine (GEE) platform was used to prepare the land surface temperature (LST) data between 2000 and 2024. Also, ArcGIS (Arc Map 10.7) was used for analyses and to produce maps of Normalized Land Surface Temperature (NLST). Throughout the whole study period, land surface temperature (LST) was characterized by its mean. The descriptive analyses were conducted for daylight and nighttime land surface temperature (LST). Prior to visualizing the raster data, we generated a normalized land surface temperature (NLST) by scaling the land surface temperature (LST) values for each pixel between the minimum (LST_{min}) and highest (LST_{max}) values in each image.

The NLST varies from 0 to 1. For a certain season or picture, an NLST value of 1 indicates the highest temperature, and a value of 0 indicates the lowest temperature. Images showing the geographic distribution of NLST in the winter, spring, summer, and autumn were compared. Surface urban heat islands were identified by computing the average land surface temperature (LST) of urban/suburban (Tu/s) governorate pixels, subtracting the average LST of rural and barren (Tr) pixels. A negative difference (Tu/s < Tr) signifies an urban cooling impact, whereas a positive difference (Tu/s > Tr) denotes an urban heat effect (Alahmad *et al.,* 2020).

RESULTS AND DISCUSSIONS

Fig. 2 presents the results of the temporal analysis of LST from January 2001 to December 2024. The finding revealed that clear seasonal variability of LST in the study area. Daytime land surface temperatures obtained through remote sensing were elevated compared to nighttime temperatures; however, both exhibited analogous temporal patterns

Fig. 3 and 4 demonstrate that the spatial distribution of normalized land surface temperature (NLST) in Kurdistan followed similar trends throughout the year, with less intensity in the fall and winter. This was true for both the daytime and nighttime variations. Over the summer, NLST classes 10, 9, and 8 occupied over 96% of the study space, with a value of more than 0.7. However, when

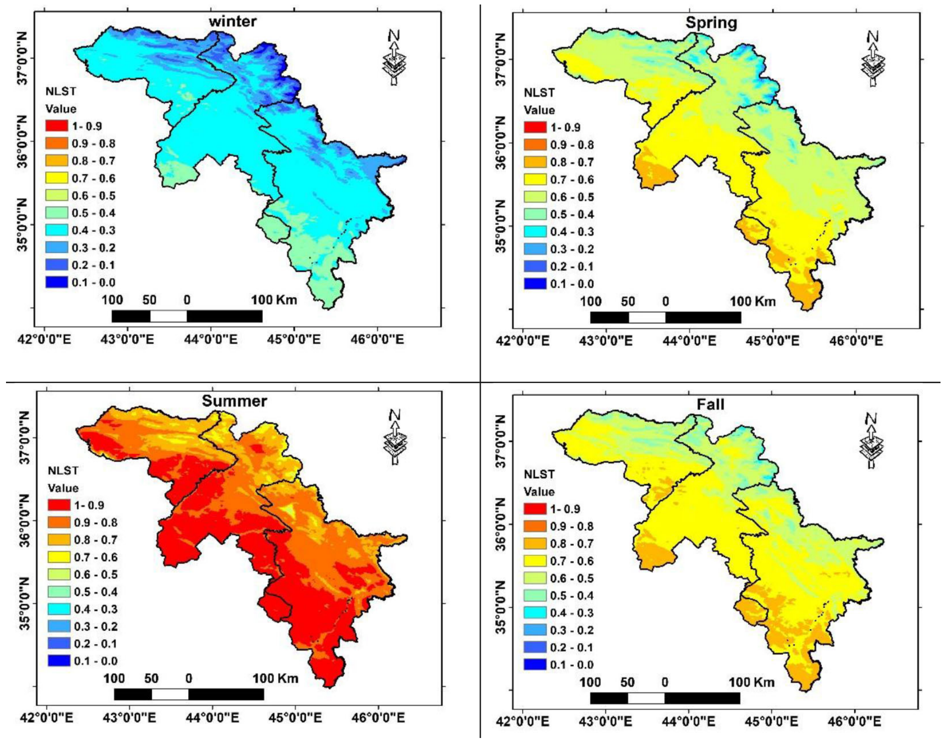

Fig. 3: Seasonal daytime normalized land surface temperature (NLST) in Kurdistan region

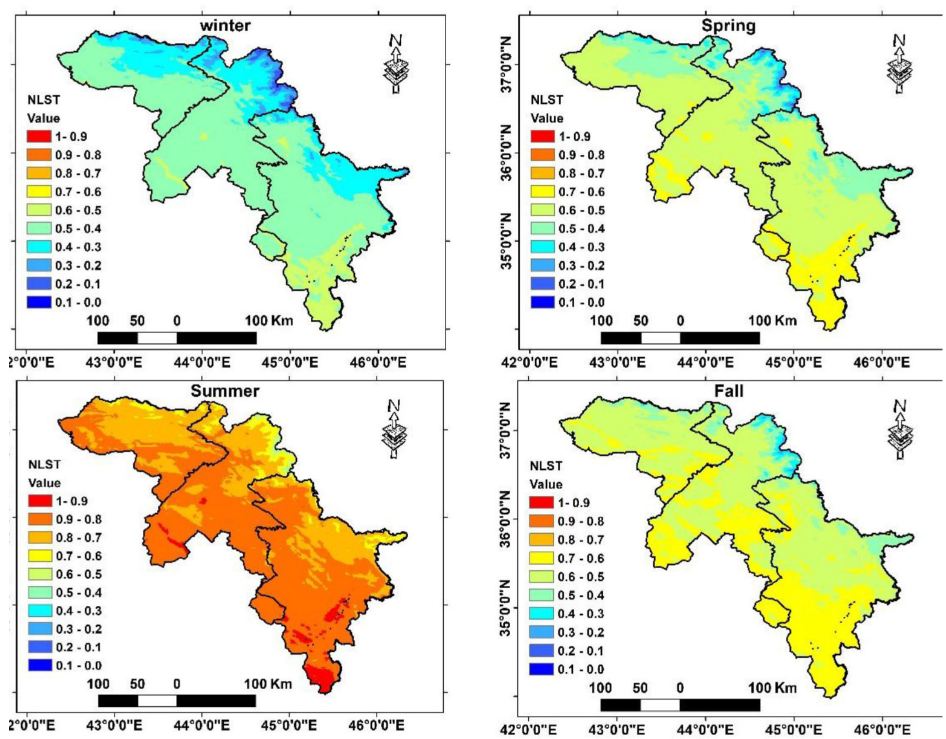

Fig. 4: Seasonal nighttime normalized land surface temperature (NLST) in Kurdistan region

it came to nighttime, only classes 8 and 9 occupied over 90% of the study area. Results from fall and spring exhibited a similar distribution for both times, with classes 5 to 8 mostly occupying the study area. The highest disparity in spatial distribution occurred during the summer and winter seasons. According to the annual results, about 80% of the study area has an NLST score ranging from 0.6 to 0.7.

Table 1 shows statistical difference tests conducted for each governorate. The Erbil governorate reveals higher mean LST values in urban and suburban areas, with a maximum of 49.87 ^{0}C during summer daytime in urban areas, indicating the impact

Table 1: Daytimes and nighttime LST (^{0}C) during different seasons of the three governorates in Kurdistan region

Season	Daytime LST (^{0}C)			Nighttime LST (^{0}C)		
	Urban	Rural	Differences	Urban	Rural	Differences
			Duhok			
Winter	13.54	12.49	1.05	3.44	1.05	2.39
Spring	28.67	27.23	1.44	13.65	11.02	2.63
Summer	46.19	45.90	0.29	26.91	24.62	2.29
Fall	30.52	30.51	0.01	15.15	13.15	2.00
			Erbil			
Winter	15.12	12.46	2.66	4.12	1.05	3.07
Spring	32.91	27.81	5.1	14.93	11.27	3.66
Summer	49.87	46.9	2.97	28.21	24.83	3.38
Fall	33.5	31.02	2.48	16.03	13.08	2.95
			Sulaimanih			
Winter	14.88	12.12	2.76	3.98	0.98	3.00
Spring	30.49	27.03	3.46	14.28	10.97	3.31
Summer	47.88	46.2	1.68	27.83	24.75	3.08
Fall	32.48	30.56	1.92	15.97	13.08	2.89

of urbanization and city location. Generally speaking, towering buildings and urban structures absorb heat, decrease airflow, and produce hot air when air conditioners are used. The lowest mean values of LST appeared in the northern part of Sulimaniyah governorate, especially in the nighttime of the Rural area, with a mean value reaching 0.98 ^{0}C, and this is due to the impacts of dense vegetation cover and the topographic nature of this city. The highest difference in LST values between urban and rural regions was shown in the spring season for all governorates of the study area, with a maximum difference appearing in the daytime of Erbil city (5.1 ^{0}C). The fall season revealed a lesser difference in LST values between urban and rural regions for all of the study area governorate, and the daytime of Duhok indicated a lower difference, reaching 0.09 ^{0}C.

Our observations of a diminished and elevated heat island effect during the day and night align with studies conducted in proximate cities exhibiting similar desert climates, such as Tehran, Iran (Haashemi *et al.,* 2016), and Dubai and Abu Dhabi, United Arab Emirates (Lazzarini *et al.,* 2012; Frey *et al.,* 2007). There are a number of ways to stop urban warming around the world. When exposed to sunlight, low-albedo surface materials such as concrete and asphalt may maintain lower temperatures if substituted with high-albedo and high-emissivity surfaces (Wang *et al.,* 2015). Vegetation may have a higher albedo than concrete, and it may also absorb solar radiation, provide shade, and help cool the environment by releasing water vapor (Ng *et al.,* 2011). Green roofs may also help lower the urban heat island effect.

This study has a number of limitations. First, we did not compare the satellite data to observed data from ground facilities because we did not have any reference surface temperature data. Second, even though satellites can see a lot of land and history, we could only do so at a spatial resolution of one km. Before 2001, we couldn't get historical LST data from Google Earth Engine to compare our results with those of the previous studies done in the study area. A one km spatial resolution might not be able to show the small differences between hot and cold places in a city.

CONCLUSIONS

This study examined the spatial distribution of land surface temperature in the Kurdistan region of Iraq and analyzed the existence of an urban heat island during both daytime and nighttime in the study area. The results showed that the southern part of the study area, which was the urban area, had the highest LST values. The average value was 32.2 during the day. Erbil had the highest temperature (49.5 ^{0}C) in the summer, and Sulimaniyah had the lowest (0.98 ^{0}C). The most significant disparity in LST mean values between urban and suburban regions occurred during the summer daytime in Erbil city. Conversely, the least differences were observed in the fall season across all governorates in the study area. This study can assist in directing initiatives to adapt to climate change, especially concerning urban planning regulations. Our geographical analysis of the land surface temperatures in the Kurdistan region of Iraq can assist in evaluating temperature exposure for population health research. This study may assist Iraqi policymakers and urban planners in devising strategies to mitigate the urban heat effect.

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Data availability: Data to be provided on request

Author contribution: **Yaseen Al-Timimi**: Draft writing and Data analysis; **Alaa AL-Lami:** Planning the experiments and reviewing the manuscript; **Ali Al-Salihi**: Collecting data.

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