Research Article

Spatial Analysis of Vegetation, Water Stress and Land Surface Temperature in Baghdad Using Landsat Data

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Abstract | The agricultural areas in Baghdad governorate is facing increasing environmental and climatic challenges, including drought and a noticeable increase in surface temperatures. This study aimed to assess the state of agricultural vegetation cover and water resources and their relationship to land surface temperature (LST) in Baghdad governorate for the year 2025, based on remote sensing data. Indicators such as Normalized Difference Vegetation Index (NDVI), a modified Soil Adjusted Vegetative Index (SAVI) – due to the semi-arid nature of the region – as well as a Modified Normalized Difference Water Index (MNDWI) were used. The results showed that dense agricultural spaces were concentrated in the peripheral parts of the governorate, while land surface temperatures (LST) recorded values ranging from 21°C to 77°C. Statistical analysis revealed a strong inverse correlation (coefficient of determination R^2 = 0.641) between (NDVI) and Land Surface Temperature (LST), suggesting that crops experience thermal stress. The MNDWI index also showed reduced surface water and lower soil moisture in areas with high LST. The study concluded the SAVI index was more accurate than NDVI for identifying sparse agricultural vegetation in Baghdad's semi-arid environment. The research recommends the need to adopt agricultural adaptation strategies and mitigate heat islands to maintain food security in the province.

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Keywords | Remote sensing, Land surface temperature, SAVI, MNDWI, NDVI, Baghdad

Introduction

Agriculture in Iraq is extremely vulnerable to climate change because it depends on limited water supplies and temperature-sensitive crops. Observed warming from 1993-2023 has already raised maximum and minimum temperatures while slightly reducing annual precipitation, leading to projected increases of up to 80 % in net irrigation water requirements (NIWR) for many crops by 2075 Alsamarray *et al.*, 2025. By utilizing satellite images and a Geographic Information System (GIS) platform, change detection can be significantly achieved Mohammed, 2021. LST is one of the physical parameters of land surface processes from local through global scales. LST importance is being increasingly recognized and there is a strong interest in developing methodologies to measure LST from space Li *et al.*, 2013.

The normalized difference vegetation index (NDVI) based mixture model is widely used to estimate FVC from remotely sensed data. However, the efficiency and accuracy of FVC estimation require the precise measurement of two key factors: NDVI of fully covered vegetation and bare soil Zhao *et al*., 2026. SAVI is a powerful tool for assessing vegetation in arid or semi-arid regions, where NDVI can be misleading due to the influence of soil Abdulrahman Ali *et al*., 2026.

The increase of impervious surfaces and the decrease of vegetative cover are both contributing indicators to estimated temperatures in urban regions, particularly in regions with hot desert climate. Studies have shown that such growth of built-up areas and the decline in vegetation contribute to environmental challenges, such as increasing in LST in many urban regions Abulibdeh 2021 and Patel, 2025. MNDWI also measured according to its important in like this study Zhanga *et al*., 2015.

Materials and Methods

The spatial framework was established using ArcGIS Pro, with all data projected to WGS 1984 UTM Zone 38N for geometric precision. A point feature class was constructed for the 50 monitoring sites, linked to a geodatabase containing multi-temporal field measurements. Buffer analysis was applied around each site to quantify the surrounding urban fabric characteristics, while Kriging interpolation was utilized to generate continuous spatial distribution maps of the city's microclimatic variables.

Location of the study area

The study was conducted in the city of Baghdad, the capital of the Republic of Iraq. The city is located within the hot and dry climatic zone. The boundaries of the administrative study were determined as shown in the attached map Figure 1, since the Tigris River cuts through the city and affects its climatic characteristics.

Data collection

The research was based on a network of field monitoring points distributed over 50 locations (S1 to S50) covering all neighbourhoods' and districts of Baghdad to ensure the accuracy of spatial representation, as shown in the map of locations.

The study's scientific contribution lies in providing a sophisticated spatial analytical framework that linksnewly developed spectral indices (SAVI,

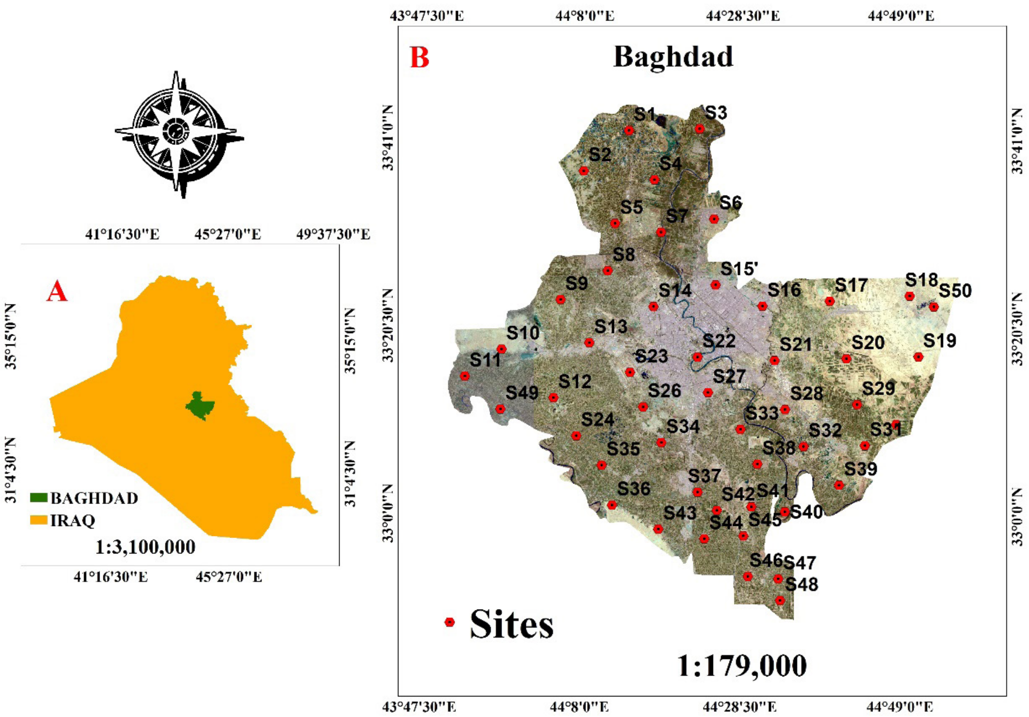

Figure 1: *Location of the study area and distribution of monitoring points. (A) map of Iraq with a scale of 1: 3,100,000 showing the location of Baghdad governorate in green. (B) a detailed map of Baghdad at a scale of 1:179,000, showing the spatial distribution of 50 monitoring sites (S1 to S50) covering all neighbourhoods of the city and the urban fabric network.*

MNDWI) with surface temperatures (LST). The research demonstrated the efficiency of the SAVI index as a more accurate tool than NDVI in monitoring sparse vegetation cover in semi-arid environments. It also quantitatively revealed the cooling role of green belts and the Tigris River in mitigating urban "heat islands" in Baghdad in 2026.

Results and Discussion

Normalized difference vegetation index (NDVI)
NDVI is a satellite-derived measure of greenness, calculated as in equation 4; it ranges from -1 to +1, with higher values indicating healthier vegetation, denser and lower values indicating barren areas (rock, sand, or snow), making it crucial for monitoring climate, agriculture, natural disasters, and drought (Figure 2) (Gidey, Mhangara *et al*., 2025).

$$NDVI = \frac{(NIR - Red)}{NIR + Red}$$

Landsat soil adjusted vegetation index (SAVI)
SAVI used to correct NDVI for the influence of soil brightness in areas where vegetative cover is low.

Landsat 9 Operational Land Imager (OLI)/Thermal Infrared Sensor (TIRS) collection 1 and collection 2 scenes that have been processed to Landsat Level-2 surface reflectance products. *Landsat 9 = Collection 2 only

SAVI is used to enhance NDVI for the influence of soil brightness in areas where vegetative cover is low. SAVI measured as a ratio between (R and NIR) values with a soil brightness correction factor (L) defined as 0.5 to accommodate most land cover types as shown in Figure 3.

$$SAVI = \left(\frac{(NIR - R)}{(NIR + R + L)}\right) * (1 + L)$$

Modified normalized difference water index (MNDWI)
MNDWI uses green and SWIR bands for the enhancement of open water features. It also diminishesbuilt-up region features that are often correlated with open water in other indices Linrong (Li *et al*., 2021) (Figure 4).

$$MNDWI = \frac{(Green - SWIR)}{(Green + SWIR)}$$

Land surface temperature (LST)
LST describes how cold or worm surfaces on earth are and its related processes, such as the exchange of water and energy between the Earth's atmosphere and the land surface. LST influences the rate and timing of plant growth and is affected by the albedo

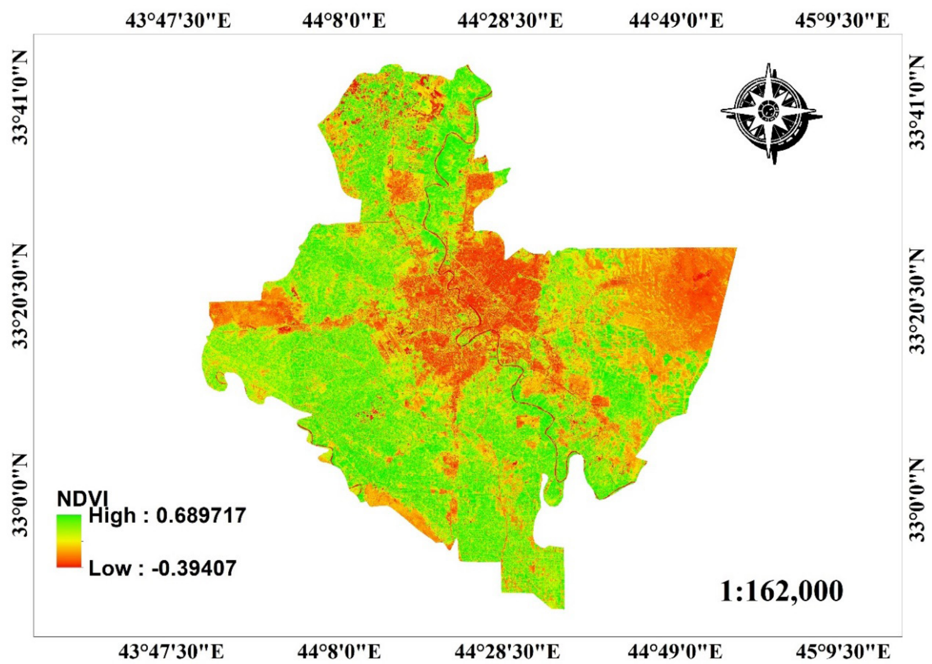

Figure 2: *Spatial distribution of normalized difference water index (NDVI).*

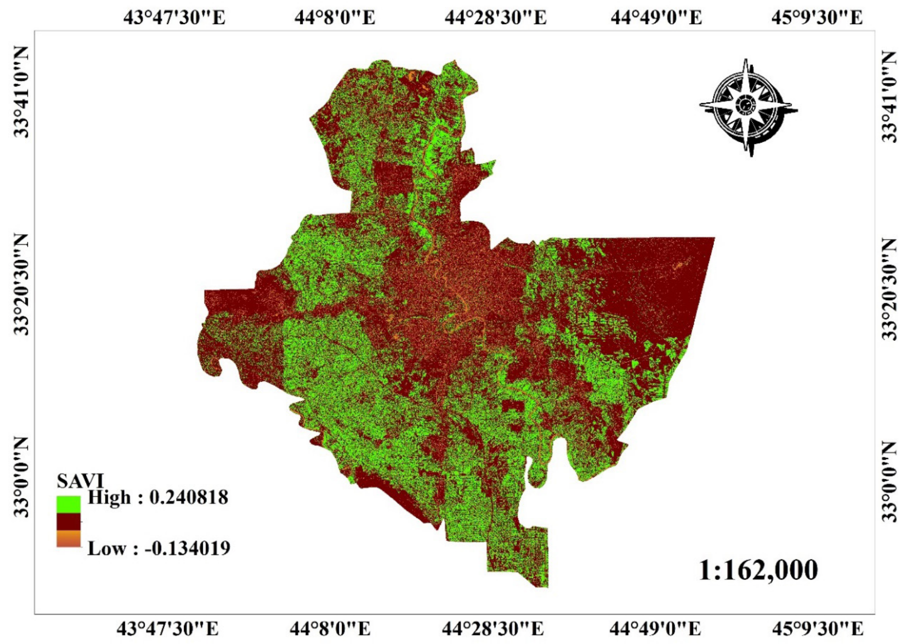

Figure 3: *Spatial distribution of normalized difference water index (SAVI).*

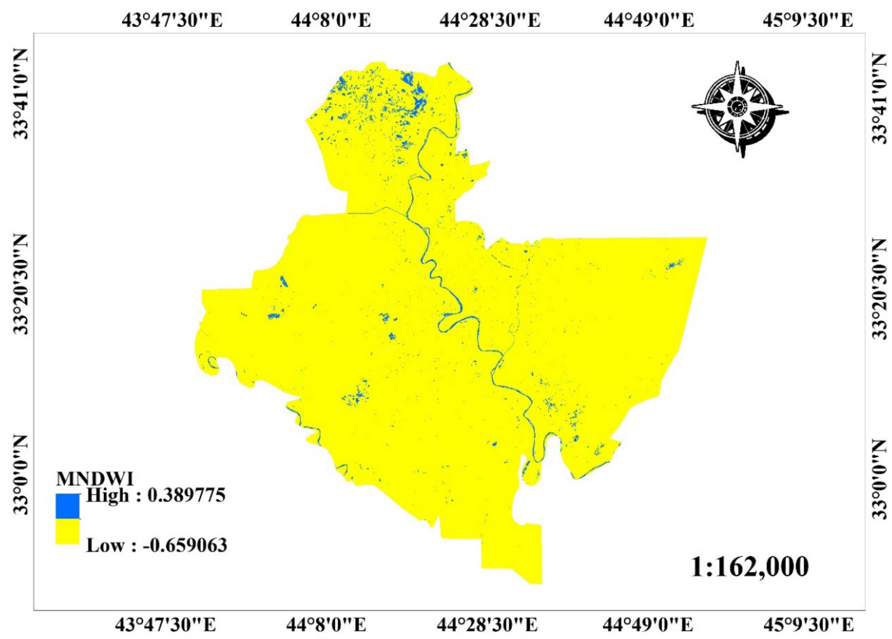

Figure 4: *Spatial distribution of normalized difference water index (MNDWI).*

(the reflectance of the surface). These data can improve decision making for water use and irrigation strategies, and are also an indicator for crop health and water stress Cheda *et al*., 2026, and Thakur *et al*., 2026.

lST = BT/(1+ ω* (BT/p)* *In*(ε))

BT: Brightness Temperature, calculated from satellite radiance data.
ω: Wavelength of the emitted radiance, which is specific to the satellite sensor band used:

A: constant value related to Planck's constant
P: A constant value related to Planck's constant (*h*×*c*/*s*)
ε: Land Surface Emissivity, which accounts for the radiative properties of the land surface. This is often calculated separately using other information like the Normalized Difference Vegetation Index (NDVI).

After the production of spectral index maps and LST maps, a multi-level spatial analysis was carried out to

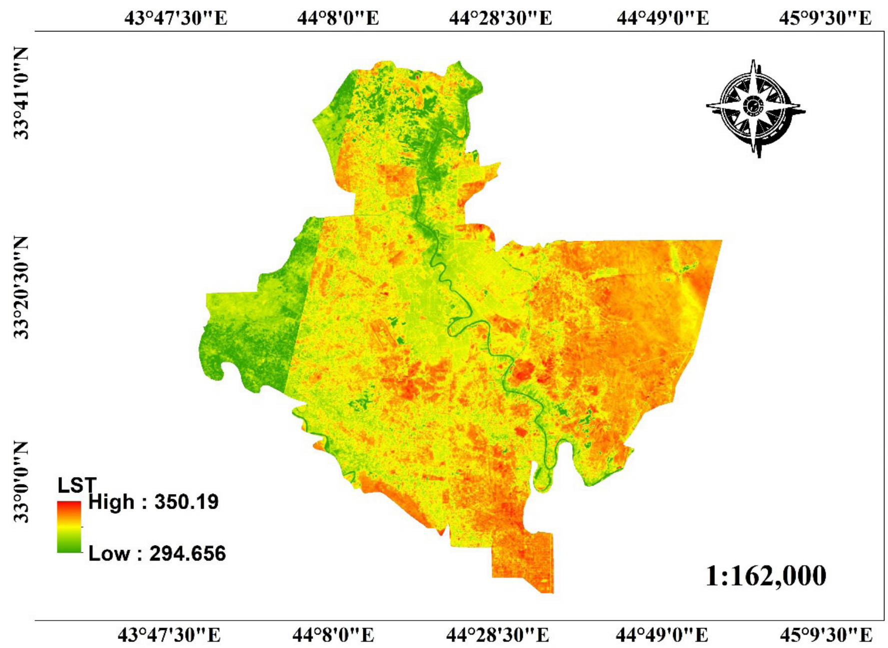

Figure 5: *Spatial distribution of land surface temperature (LST) in baghdad governorate*

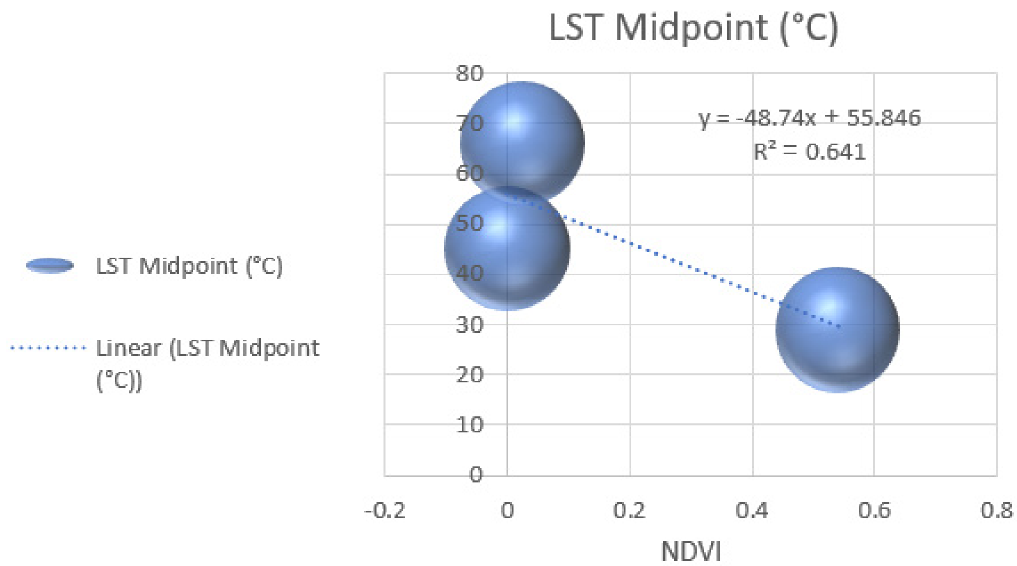

Figure 6: *Scatter plot showing the correlation between Mean NDVI and LST across different land cover classes in Baghdad.*

understand the relationships between urbanization and environmental and thermal characteristics. The analysis included a comparison of the spatial distribution of LST values with urbanization indicators SAVI on the one hand, and natural cover indicators (NDVI, MNDWI) on the other. Statistical cjanalysis was used to measure the degree of correlation between LST and each spectral index, allowing to identify the most influential indicators of the formation of urban heat islands. The results were also classified into different thermal categories to determine the most thermally stressed areas within the city. The results in Figure 6 showed that there is inverse correlation between mean NDVI and average LST across different land cover classes in Baghdad. The coefficient of determination R^2 = 0.641 indicates a significant impact of vegetation cover on mitigating surface heat.

Both of the barren soils and urban areas record the highest temperatures and the greatest thermal unevenness, reflecting their high ability to absorb

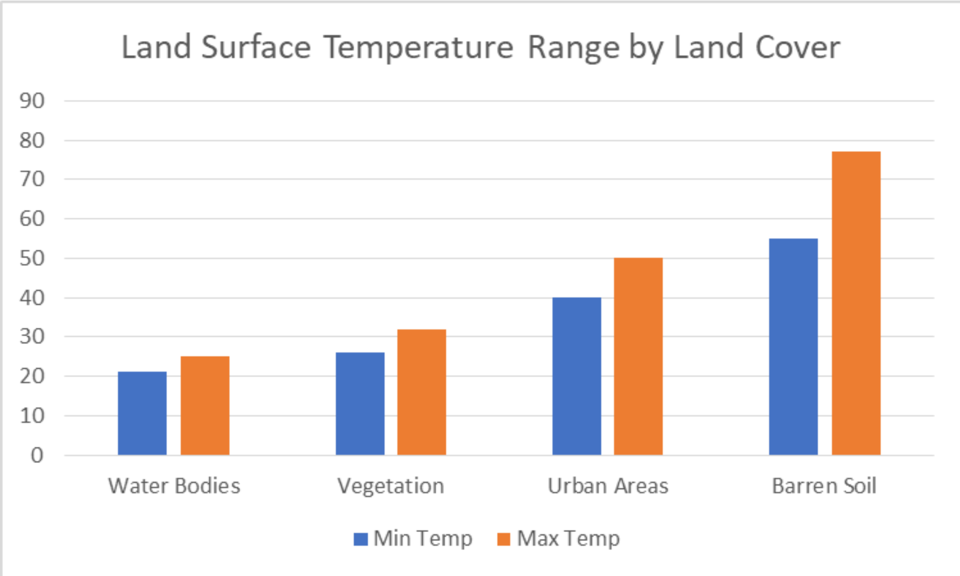

Figure 7: *The influence of the nature of the surface on the minimum and maximum temperatures*

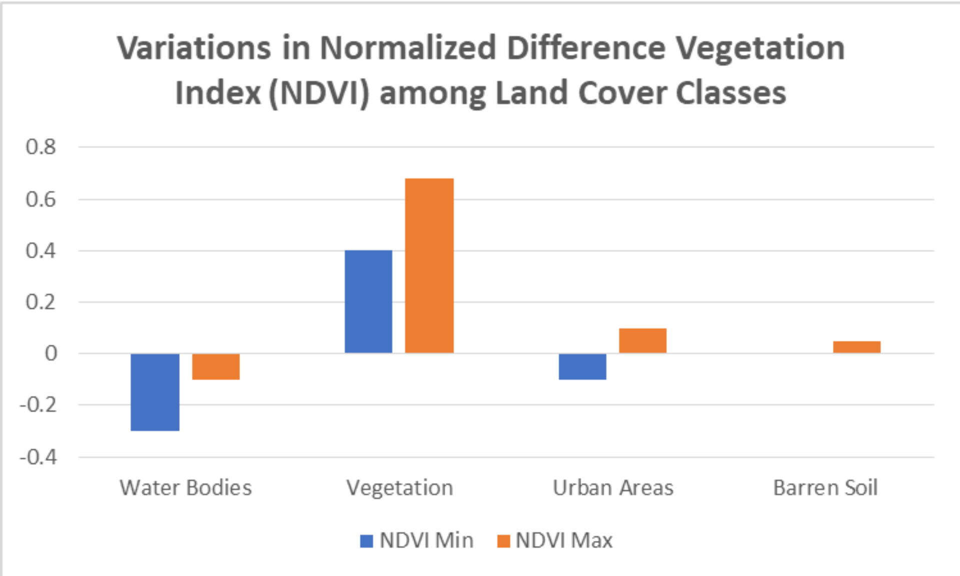

Figure 8: *Analysis of the variation of the vegetation cover index (NDVI) by land cover categories*

and store heat.In turn, water bodies and vegetation maintain relatively low and stable temperatures, thanks to such natural cooling properties as evaporation and transpiration.

The results in Figure 8 showed that the higher the NDVI value as in vegetation, the lower the surface temperature and stabilized.

Spatial distribution of agricultural vegetation cover (NDVI & SAVI)

Figure 2 and Figure 3 show the spatial distribution of the NDVI and SAVI indicators for Baghdad governorate for the year 2025. The values of the natural vegetative difference index (NDVI) ranged between (-0.394) for water bodies and built-up areas, and (0.689) for areas with dense vegetation cover. Through visual analysis of the map, it turns out that agricultural lands (green color) are concentrated mainly in the northern extremities (Taji and Tarmiyah districts), the western extremities (Abu Ghraib district), and the southern parts (Mada'in and Mahmudiyah districts), forming an agricultural belt surrounding the urban center.

As for the map of the modified soil vegetative index (SAVI), it showed values ranging from (-0.134 to 0.240). This indicator is characterized by a clearer isolation of the agricultural patch from the background of neighboring barren soils, since the central and eastern regions of the province (dark red color) appear as vegetatively degraded lands with

Links Researchers

high soil reflectivity, which confirms the accuracy of SAVI in semi-arid environments for assessing sparse cover compared to NDVI, which may be affected by soil brightness.

Spatial assessment of water bodies (MNDWI)
Figure 4 shows the map of the modified water index (MNDWI), where the values ranged from (-0.659) for dry areas, to (0.389) for water bodies and high soil moisture. The spatial distribution (blue color) shows a sharp decline in surface water bodies, the positive indicator of which is limited to the course of the Tigris River and some scattered water bodies in the northern and western extremities. The predominance of negative values (yellow color) over the vast majority of the area of the province clearly indicates the exposure of agricultural lands and urban areas to significant water stress, a sharp decrease in the moisture content of the topsoil during the visible capture period.

Spatial variation of surface temperatures (LST)
The spatial distribution of surface temperature (LST) shown in Figure (W) is a direct reflection of the state of the ground cover. The recorded temperatures ranged between (21.5 and 77) C^0.

High thermal foci (red and orange color) are intensively concentrated in the center of the capital Baghdad (Karkh and Rusafa sides) as a result of high structural density and heat-absorbing surfaces, in addition to the eastern parts with barren soil devoid of vegetation. In contrast, the lowest surface temperatures (green color) were recorded in the areas of the agricultural belt surrounding the city and along the Tigris River.

Spatial correlation between heat stress and agricultural cover
By spatial Overlay (spatial Overlay) of the four maps, it becomes clear that there is a complete inverse correspondence between surface temperatures (LST) and vegetation cover indicators (SAVI and NDVI). The areas with the highest vegetation degradation and the lowest moisture content values (MNDWI) are the same ones that formed extreme "surface heat islands". This discrepancy, which reaches a thermal difference of more than 50 degrees Celsius (Kelvin) between bare/urban surfaces and irrigated agricultural lands, quantitatively proves the crucial role of orchards and agricultural crops in dispersing solar energy through the evapotranspiration process, and alleviating heat stress in Baghdad governorate for the year 2025.

The results showed substantial agreement with Abulibdeh's (2021) study, which demonstrated that the growth of built-up areas and the degradation of vegetation cover are the two main drivers of rising surface temperatures in desert-climate cities. The findings also support Zhao *et al.* (2026) assertion regarding the importance of accurate vegetation cover indices for precise temperature estimation, as evidenced by the superiority of the SAVI index in Baghdad's semi-arid environment.

Conclusions

- Through spatial analysis of land cover indicators and surface temperatures in Baghdad governorate using remote sensing techniques, the analysis demonstrated a strong inverse relationship (R^2 = 0.641) between vegetation cover and surface temperature, confirming that the arid urban areas in central Baghdad are the most vulnerable to heat stress. the study reached the following main conclusions: -
- LST showed a sharp spatial contrast, with the highest temperatures concentrated in the eastern and central parts of the capital (areas with high building density and barren soils), confirming the formation of the phenomenon of "urban heat islands" as a direct result of the absorption of solar radiation by asphalt and concrete surfaces.
- The inverse relationship between plant and heat: the spatial distribution of the NDVI and SAVI indicators revealed a clear inverse correspondence with temperature levels. The areas with the highest vegetation values (such as the Baghdad agricultural belt and the periphery areas) recorded the lowest surface temperatures, proving the effective role of vegetation as" cooling Islands " (Cooling Islands) temper the microclimate through the process of evapotranspiration.
- Thermal effect of water bodies: the map of the water index (MNDWI) showed that the course of the Tigris River and its accompanying water bodies play a pivotal role in breaking the thermal expansion intensity within the urban fabric, as these areas recorded the lowest temperatures (the coldest) within the scope of the study area.
- The impact of urban expansion: the combined indicators indicate that the indiscriminate urban

sprawl and the bulldozing of orchards and green spaces inside the capital Baghdad is the main cause of the deterioration of thermal characteristics and the increase in the harshness of the local climate.

Recommendations

- Based on the results produced by maps and environmental indicators, the study recommends the following:
- Reviving the green belt: the urgent activation of laws and legislations that prevent the bulldozing of orchards and agricultural lands on the outskirts of Baghdad, and the start of projects to revive the green belt to act as natural heat and dust storms.
- Sustainable urban planning: the need to oblige the planning and municipal authorities in Baghdad to include the criteria of" sustainability " in new urban projects, by increasing the proportion of open green spaces and distributing them fairly and balanced within crowded residential neighborhoods.
- Use of reflective materials (cool surfaces): encourage the use of building materials and colors reflective of solar radiation (Albedo) in paving roads and building surfaces to reduce the amount of heat absorbed during daylight hours, especially in commercial city centers.
- Optimal utilization of the banks of the Tigris River: protecting the river banks from concrete encroachments, increasing afforestation along its length to enhance its role as a natural channel for cooling and replenishing the city's air.

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Novelty Statement

This study studies the disconnect between meteorological data and architectural application by introducing a novel spatial climate map. Unlike traditional datasets, this framework is specifically engineered to function as a decision-support tool, enabling architects and planners to integrate energy efficiency and thermal comfort strategies directly into early-stage design.

Author's Contribution

Susan Abed Hassan: Conceptualization, data Curation, formal analysis, methodology, Visualization.
Aaya W. Al-Azzawi: Resources, Writing - original draft, writing - review & editing.

Code and data availability

All code and data in this study can be found in the body of the manuscript.

Generative AI and AI-assisted technology statement

The authors declare that no generative AI and AI assisted technology was used in the creation of this manuscript.

Conflict of interest

The authors have declared no conflict of interest

References

Abulibdeh, A. 2021. Analysis of urban heat island characteristics and mitigation strategies for eight arid and semi-arid gulf region cities. Environ. Earth Sci., 80(7): 259. https://doi.org/10.1007/s12665-021-09540-7

Ali, A.B., M.A. Mohammed, A.F. Abed, B.A. Alrazaq and B.A. Ahmed. 2026. Optimizing Vegetation Cover Classification Accuracy by Assessing the Impact of Atmospheric Corrections on Spectral Reflectivity Using Remote Sensing Data. Iraqi Geolog. J., 59(1A). https://doi.org/10.46717/igj.2026.59.1A.15

Alsamarray, R.S., M.S. Al-Khafaji and K. Shemal. 2025. Compatibility of Crop Patterns with Climate Change for Irrigation Projects in Semi-Arid Regions: The Case Study of the Abu Ghraib Project in Iraq. Engineering, Technol. Appl. Sci. Res., 15(5): 27519-27529 https://doi.org/10.48084/etasr.11967.

Cheda, A., A. Tetzlaff, J. Blannin, E. Good, V. Sharma, I. Trigo, J. Schwaab, A. Riihelä, C.M. Grams and M. Schröder. 2026. Heat Indices for Europe Derived from Satellite Data: A Proof of Concept. Remot. Sens., 18: 589. https://doi.org/10.3390/rs18040589

Gidey, E. and P. Mhangara, 2025. Exploring the relationship between annual soil loss and formation rate in different land use scenarios using support vector machine (SVM) learning models in Tigray Highlands. Scient. Report., 15: 39146. https://doi.org/10.1038/s41598-025-26881-6

Li, L., H. Su, Q. Du and T. Wu. 2021. A novel surface water index using local background information for long term and large-scale Landsat images. ISPRS J. Photogramm. Remote Sens., 172: 59-78. https://doi.org/10.1016/j.isprsjprs.2020.12.003

Li, Z.L., B.H. Tang, H. Wu, H. Ren, G. Yan, Z. Wan, I.F. Trigo and J.A. Sobrino. 2013. Satellite-derived land surface temperature: Current status and perspectives. Remote Sens. Environ., 131: 14-37. https://doi.org/10.1016/j.rse.2012.12.008

Mohammed, D.A. 2021. Integrated remote sensing and GIS techniques to delineate groundwater potential area of Cham Chamal basin, Sulaymaniyah, NE Iraq. Kuwait J. Sci., 48(3): 1-16. https://doi.org/10.48129/kjs.v48i3.9699

Patel, S., M. Indraganti and R.N. Jawarneh. 2025. Comparative analysis of land cover changes on outdoor thermal comfort in Doha, Dubai, Kuwait City, Manama, Muscat, and Riyadh. Ann., GIS: 1-18. https://doi.org/10.1080/19475683.2025.2453548

Thakur, P.K., R.K. Verma and P.K. Thakur. 2026. Assessing Landscape Dynamics and Variations in Land Surface Temperature in the Parbati Watershed of the Himalayas. International J. Environ. Res., 20: 79. https://doi.org/10.1007/s41742-025-01030-z

Zhang, H. and H. Chen. 2015. The application of modified normalized difference water index by leaf area index in the retrieval of regional drought monitoring. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XL-7/W3, 36th International Symposium on Remote Sensing of Environment, 11–15 May 2015, Berlin, Germany. https://doi.org/10.5194/isprsarchives-XL-7-W3-141-2015

Zhao, T., W. Song, X. Mu, Y. Xie, Y. Wang, H. Ren, D. Xie and G. Yan. 2026. Normalized difference vegetation index maps of pure pixels over China for estimation of fractional vegetation cover. Earth Syst. Sci. Data., 18(1). https://doi.org/10.5194/essd-18-551-2026