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Remote Sensing-based Land Surface Temperature Retrieval in Kirkuk City, Iraq Using GIS and TES Algorithm: A Climatic Concern

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Abstract
One of the largest signifiers of the climatic changes that can define the general state of thermal characteristics of the earth as well as the urban and metropolitan regions is Land Surface Temperature (LST). Remote sensing and Geographic Information Systems (GIS) can be used to assess the trends of the urban heat and the determination of variation in LST which is important in other sustainable climate-based planning. The increasing climatic pressures on the Kirkuk city will be viewed due to the elevated level of the urbanization process, as well as altered temperature patterns. Satellite imagery was used to access and analyze the LST data and achieve the following aims: measuring the temporal and spatial variability of the temperature. From the generation of maps of high resolutions that can be used to give the distributions of surface temperature in the urban and the rural areas as well as the suburbs, interaction between GIS tools was employed. It has shown, as the results state, there has been a large acceleration of LST during the course of the year 2024 and that has been the greatest in the urbanized regions. This paper shows the importance of the application of both TES-based remote sensing and GIS analysis of variables that have been quantified in the environment. The conclusion can be made about the outcomes of the research giving the new directions toward the sustainable development of the cities and flexible approaches that could help Kirkuk City to avoid the adverse impact of climate change.

Keywords: Remote Sensing, TES, GIS, LST, Kirkuk city

1. Introduction

The shift in the global environment in recent decades actually accelerated due to an advanced interplay between human activities and natural processes (Jumaah *et al*., 2023a; Mahmood *et al*., 2025; Jumaah *et al*., 2025) [10, 15, 11]. One of the most apparent and urgent indicators of the change is the Land Increment of the Land Surface Temperature (LST) (Jamal *et al*., 2023) [8]. LST Radiative skin temperature of the land is founded on the current set of thermal infrared satellite measurements, and it is an incredibly strong indicator of regional, regional, and global climatic changes (Li *et al*., 2023) [14]. LST is especially sensitive concerning the assessment of the Urban Heat Island (UHI) effect where the urban regions experience higher temperatures than the rural ones due to the anthropogenically caused transformation of land cover, energy usage, and contemporary urban designing (Sadiq Khan *et al.*, 2020) [17]. Urbanization is gaining currency in the majority of the areas of the world with developing nations taking the bridle in such activities hence in environmental planning, urban development, energy forecasting and population wellbeing, it is crucial to be conscious of the spatial and temporal characteristics in LST (Sinha, 2024) [18].

The application of the high technology in remote sensing has made it unavoidable in the exploration of landmass and the atmosphere of the earth (Zhang *et al*., 2022) [19]. The researchers may be able to determine land surface characteristics of the earth using multispectral and thermal images on satellite platforms to monitor changes in specific intervals and large spatiotemporal scales (Li *et al*., 2023) [14]. Specifically, some of the satellites including Landsat, Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), and Moderate Resolution Imaging Spectroradiometer (MODIS) offer Thermal

Infrared (TIR) sensors that have been providing useful data to retrieved LST (Abrams *et al*., 2015) [1]. Nevertheless, proper LST measurement based on satellite-derived data requires decomposing the temperature and emissivity channel into component a process well managed using Temperature/Emissivity Separation (TES) algorithm (Mohamed *et al*., 2017) [16]. A better retrieval of the LST can be done using the TES algorithm using the decoupling of the effect of land surface emissivity which depends on surface type, moisture, vegetation and texture (Zhang *et al*., 2025) [20]. When combined with Geographic Information Systems (GIS), these remote sensing data could be spatially analyzed, visualized, and interpreted, and it was easy to identify vital patterns and relations (Jumaah *et al*., 2019; Hamed *et al*., 2021; Ajaj *et al*., 2025) [9,6,3]. The use of TES algorithm in the instance of Kirkuk provides a plausible approach to measurement of LST in numerous land cover categories that covers urban areas, green sceneries, sterile landscapes, and a waterway (Ahmed, 2017) [2]. The GIS and the software associated with it, such as data management and the use of symbology, have the potential to heighten the chances of creating high-resolution temperature maps, which are substantive to mapping hot regions, gauging thermal gradients, and imparting knowledge on the local stakeholders (Jumaah *et al*., 2023b) [12]. The use of satellite data on temperate and GIS based spatial analysis is a complex phase of environmental monitoring, an aspect that is highly significant in low resource jurisdictions including Iraq where ground networks on monitoring temperature is either flat or outdated (Ameen *et al*., 2021). In addition, it is also possible to use the GIS tools in classifying and symbolically displaying the thermal data as well as interpolating the data spatially to create a collection of maps, which are aesthetically valuable methods of maximizing the thermal records as evidence of the warming tendency in the city (Jumaah *et al*., 2024; Jumaah *et al*., 2025) [13, 11]. The maps can be used as decision support to the urban planners, regulators of the environment and local governments (Jumaah *et al*., 2023b) [12]. They are able to advise about what interventions they should put first like creating more green cover, change building codes to incorporate heat-reflective materials or even create heatwave early warnings (Devanathan & Devanathan, 2011) [5].

The expansion of urban area in Kirkuk has entailed a pattern of climatic stresses that has influenced the nature of both its environment and infrastructure. An increase in impervious surfaces, or those surfaces that do not allow water through such as roads, rooftops, pavements, causes the absorption and the retention of heat during the day and a slower cooling at night. This alters the surface thermal balance and this has been found to associate with high temperatures on the surface and air. The loss of vegetative cover and natural water bodies also aggravates thermal comfort in the city further compromising thermoregulation capacity of the city, especially in the hottest months in the summer season when average temperatures may reach above 45 ̊C. Therefore, more people will be affected by the heating and will face the risks of heat stress, dehydration, cardiovascular load, and loss of work quality. The most susceptible include children and the elderly as well as outdoor laborers.

Infrastructurally, the effect of high LST on deteriorating building materials, asphalt roads and other public utilities increases the cost of maintaining the infrastructure and reduces the life time of the infrastructure facilities. Also, the warmer climate reduces the number of energy sources, thus straining local energy infrastructures, adding to the carbon footprint of the city. Such inter-related problems develop into the relevance of active and evidence-based climate-sensitive urban planning interventions. This paper aims at presenting such evidence by extracting and analyzing LST in Kirkuk city by using the remote sensing data processed into the TES algorithm and also using the spatial analysis tools in GIS. In achieving these goals, the research advances to a greater comprehension of how to accomplish the urban climate in a Middle Eastern setting- a region that is not well represented by worldwide climatic studies.

2. Methodology

2.1. Study area

The Kirkuk City in the North of Iraq (Figure 1), can serve as an effective case study concerning the thermal impact of the quick urbanization.

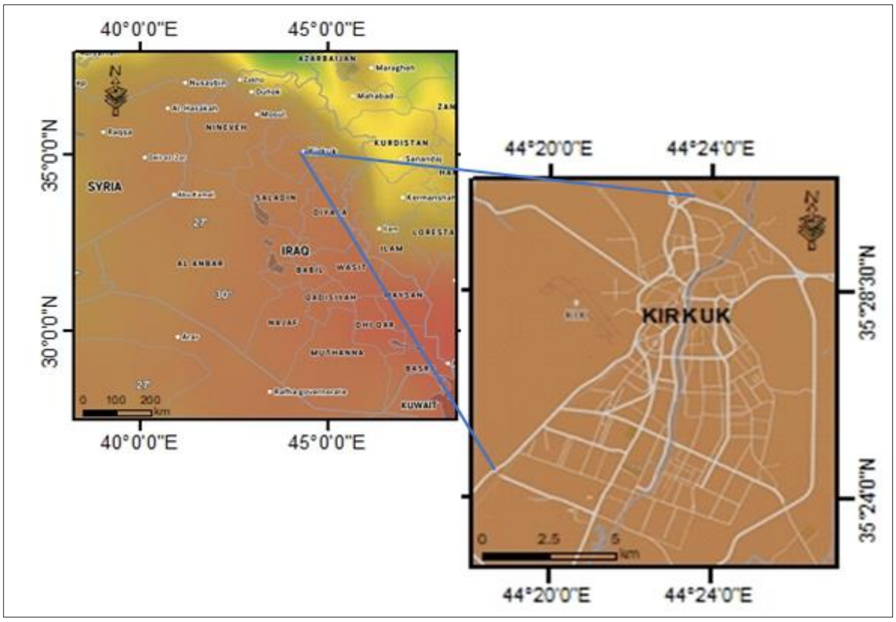


Fig 1: Study area Kirkuk city

Kirkuk is located in a semi-arid climatic zone and in the last several decades, large-scale land use and land cover changes have occurred as a result of populating, radial expanse of constructed features, and development of infrastructural facilities. The land pressure on the territory of the city, the lack of green zone and incorrect organization of urban territory created the conditions, which led to the growth of the surface temperature and developing the environmental vulnerability. Although the physical increase of the city is obvious, the climatic implications of this development, and especially the increase of the LST values need to be researched urgently. The evaluation of LST within this context can not only result in local environmental knowledge, but it is the scientific basis of the policies focusing on sustainable urban development and protection against climatic changes.

This research creates a baseline knowledge which will help researchers pursue more studies while enhancing data-based decision-making interventions for climate adaptation and sustainable urban development throughout Kirkuk.

2.2. Data and methods

The data was collected in three types; remotely sensed images of Land Surface Temperature for 6 months represented July to December of the year 2024. The data was downloaded as satellite images from worldview application of NASA Earth data by the link (https://worldview.earthdata.nasa.gov/). Satellite images were Terra/MODIS and it shows the temperature of the land surface in Kelvin (K)**.** Units' conversion from Kelvin to Celsius degree used as shown on the maps. Figure 2 represents field measurements.

Fig 2: Fild measurements along Kirkuk city

Field measurements was applied in each month using Air Quality Tester device which involve Temperature measure in ˚C. These data used for evaluating presented maps and validate measurements by comparison with satellite-based points of temperatureThe temporary analysis point is taken as the year 2024 since major changes have been experienced both environmentally and in development patterns within the following period. The thermal maps and temperature measures are drawn based on this year satellite records. These are then spatially cross referenced to field data to find places of intense thermal change. A particular focus is paid to the difference between core city districts, peri-urban development areas, and rural background in order to outline the process of differentiated energy of thermal impacts created due to human impact. The TES algorithm that has the possibility of overcoming the emissivity effects, and the ability to make little improvement on temperature accuracy, makes the LST values extracted to be robust, and that the values can be used in policy-oriented analysis. Figure 3 represents LST points along Kirkuk city.

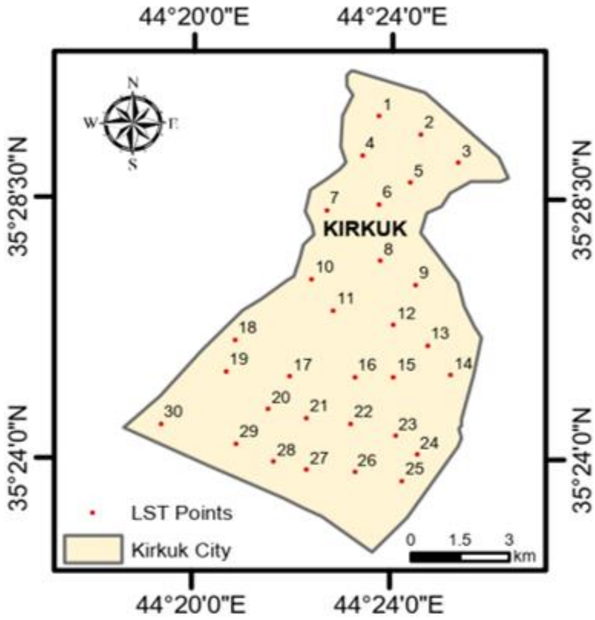


Fig 3: LST points along Kirkuk city

In this study 30 points were selected within the study area. The temperature of each point was determined based on remotely sensed images, and field measurements were taken at the same points for evaluation purposes.

The equation used in this study which represents TES for estimating Mean Emissivity $\acute{\varepsilon}$ from Minimum Maximum Difference (MMD) can be written as (Hulley *et al*., 2016) [7]:

$$\acute{\varepsilon} = a + b\,.\,MMD \tag{1}$$

It important to know that **TES** algorithm involve empirical coefficients (a and b) which varies for each satellite.

For TERRA satellite, the TES was firstly established for ASTER sensor. This sensor known as TIR bands with high resolution. So, the equation can be written as:

$$\acute{\varepsilon}_{ASTER} = 0.982 - 0.072\,.\,MMD \tag{2}$$

here, empirical coefficients (a= +0.982, and b= +0.072).

For MODIS satellite, which has wide-ranging bands and less TIR channels, So, the equation can be written as:

$$\acute{\varepsilon}_{MODIS} = 0.970 - 0.060\,.\,MMD \tag{3}$$

here, empirical coefficients (a = + 0.9***70***, and b = **–** 0.0***60***) (Hulley *et al*., 2016) [7].

3. Results

LST spatial distribution-based RS and TES algorithm were mapped based on GIS. The resultant maps are shown in Figure 4. While Figure 5 represents LST evaluation in: July, August, September 2024.

Based on Figure 5, LST maps of Kirkuk city in the year 2024 indicate a definite seasonal variation in the temperature with a sharp rise in the summer months. LSTs recorded over 50 Celsius degrees and 47 Celsius degrees on 15 July and 15 August of the year, portraying a situation of high heat in central and western zones of urbanization.

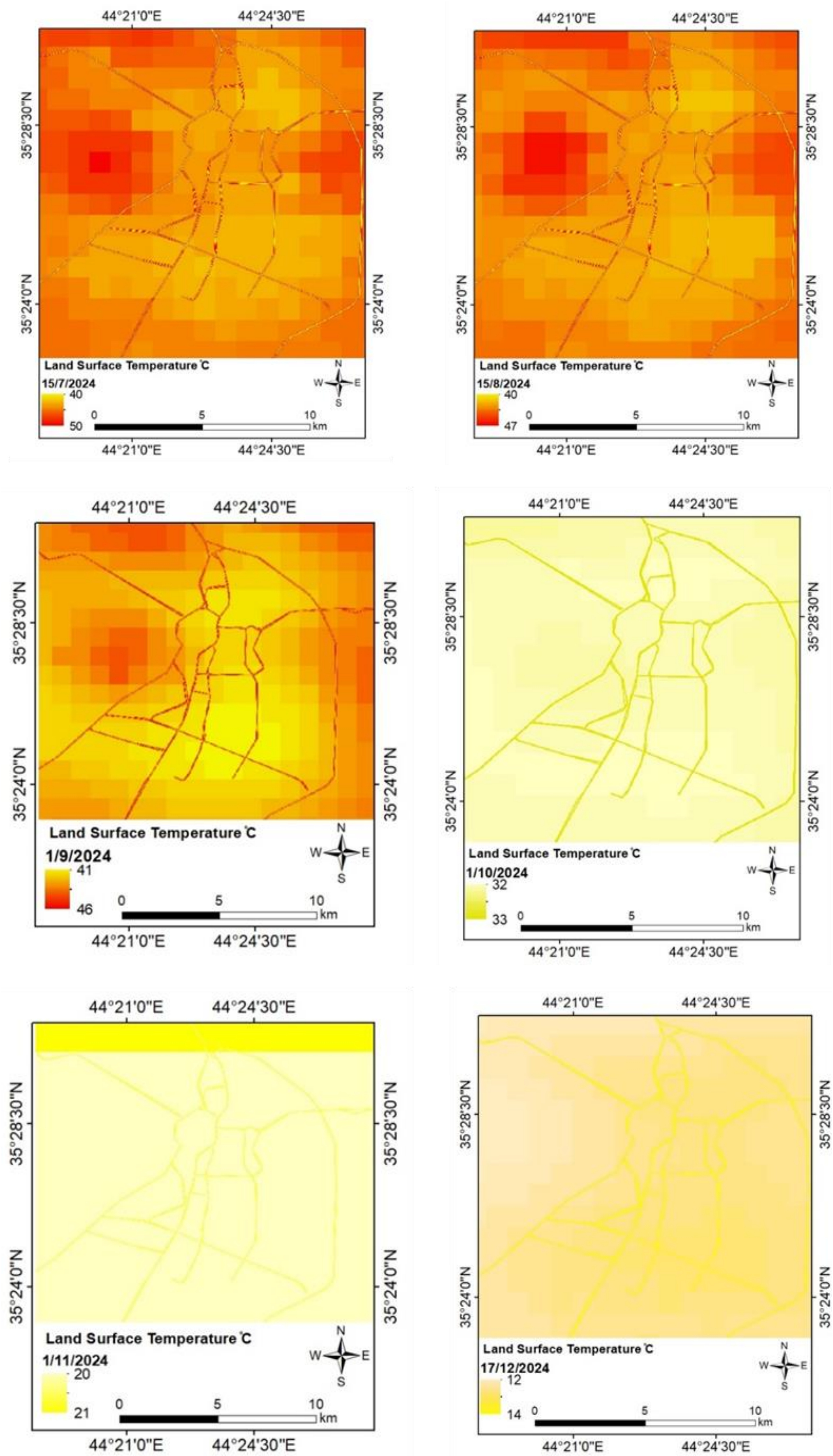
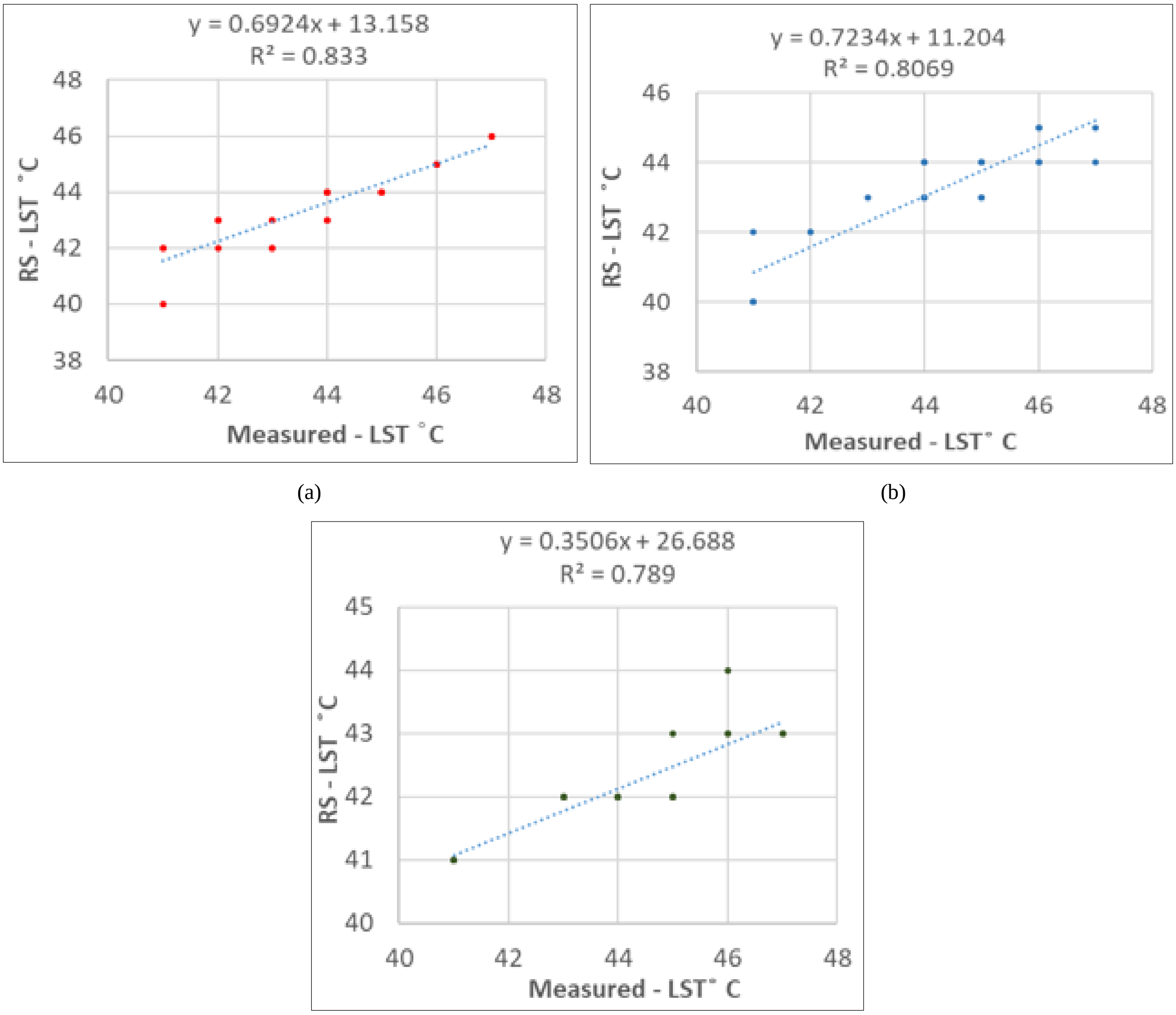


Fig 4: Spatial maps of LST based on RS and TES algorithm.



(a) (b)

(c)

Fig 5: LST evaluation in: July 2024 (a), August 2024 (b), September 2024(c).

By 1 September, temperatures slightly dropped however they still varied between 41℃ and 46℃ due to the prolonged heat of summer. There is a cool season which starts in the month of October and the temperature drops to the level of 32-33℃ and it also rises down in the month of November with ranges between 20-21℃. The minimal LST was recorded on 17 December when it hit 14-16℃, in accordance with the winter weather conditions. Idiotically, the greatest heat was spatially represented by the highly built-up areas, but the open land and vegetative areas were relatively cool. This interannual difference in thermal makes sense with the semi-arid climate of Iraq and the urban heat island effect in Kirkuk. The findings support the ability of TES and GIS combination to monitor LST changes and map thermally strained urban areas.

The validation plots of satellite-derived LST by remote sensing (RS) against measured LST values on the ground are shown in the scatter plots and the correlation is uniformly high in all datasets. In the first graph Figure 5(a), the topmost coefficient of determination ($R^2 = 0.833$) is found and here the regression line equation obtained is $y = 0.6924x+13.158$, which reveals a high, strong and stable relationship between the measured LST and RS-derived LST, although a slight underestimation of LST at lower extremes. There is significant consistency and accuracy of the model since the second plot Figure 5(b) indicates high agreement with $R^2 = 0.8069$ and regression $y = 0.7234x + 11.204$. The third chart Figure 5(c) has a slightly reduced correlation ($R^2 = 0.789$), but still has a good predictive result $y = 0.3506x + 26.688$ but the slope brings a certain tendency of compression of thermic range. In general, the outcomes of the validation reveal the efficiency of the TES algorithm in approximating LST using satellite data with reasonable errors. Such high R^2 values will complement the trustworthiness of remote sensing outputs, which can be relied upon to carry out additional climate and urban planning analysis in Kirkuk. The evaluation of the rest three months is difficult to apply as the remotely sensed LST seems same value for all points.

4. Discussion

The study proves that Kirkuk City reveals substantial changes in temperature patterns across different areas and time periods because of its fast urbanization and changing land uses. Climate stress in Kirkuk City continues to grow at an alarming rate which affects both environmental quality and human health together with urban infrastructure systems.

The study's findings showed Kirkuk City temperatures spanned from 12°C to 50°C as remotely obtained data tracked seasonal along with spatial changes throughout urban and rural spaces. A strong relationship and concordance between satellite-acquired data and recorded meteorological measurements appeared in this evaluation procedure. A validation procedure demonstrated that the remote sensing analysis produced accurate temperature readings at a rate of (78-83) % thus showing strong reliability patterns. Satellite-derived Land Surface Temperature measurements have proved accurate enough for urban thermal pattern monitoring and environmental and climatic research especially when field-based data collection is restricted.

The results demonstrate the strong correlation between temperature changes and land use/land cover (LULC) alterations in Kirkuk city. regions that underwent urban expansion demonstrate elevated surface temperatures because they swapped vegetation into buildings combined with asphalt and concrete installations. Surface temperatures remained lower in areas filled with dense vegetation as shown by remote sensing data in parks and farmlands because of evapotranspiration processes. Removing vegetation from urban areas through construction of impervious surfaces causes the natural cooling mechanism to dissipate thus resulting in higher temperatures and higher thermal pressure.

5. Conclusion

To sum up, this study demonstrates the burning necessity of evaluating and comprehending the thermal environment of Kirkuk in terms of new geospatial technologies. With cities increasingly becoming large and with climatic trends changing unsystematically, it is good to have tools, such as TES and GIS, which can provide platforms to make proper decisions in real time based on evidence. The research contextually lies at the crossroad of technology, environment, and urban planning that can enhance a more sustainable and climate-resilient future of Kirkuk and other cities of its kind. Measurement, spatial and contextual interpretation of LST data used in precise visualization of a warming world, sheds light into the challenges, as well as opportunities faced by change towards adaptation of the realities. The climate change problem in Kirkuk has no isolation. The situation in cities throughout Iraq and the larger Middle East is quite similar in its pressure formed by rise in temperatures, water shortages and degradation of land. This research, through examination of Kirkuk, brings forth information/expertise that can be of use across other city settings in the arid/semi-arid world, where environmental weaknesses are supplemented with socio-political-financial limitations. The combined approach of TES-based LST recovery and GIS provides an exemplary model that can be reproduced by cities that want to develop resilience in the aspect of increased temperature conditions.

Noteworthy, the study also highlights the value of remote sensing as a cost-efficient, scalable, and repeatable method of environmental monitoring, at a time when post-conflict cities such as Kirkuk need options where the traditional meteorological infrastructure is limited.

Local authorities should implement data-driven strategies based on GIS and remote sensing data because it will help address increasing air temperature along with its associated effects. The reduction of urban heat island intensity will result from developing more green space areas combined with sustainable construction practices and the installation of reflective or green roofs. A system for continuous environmental observation must be developed to identify emerging changes in the climate. The public needs public awareness campaigns which help build public support for climate resilience programs. The integration of technology with sustainable practices throughout city planning will help Kirkuk adapt to climate changes as it enhances resident quality of life.

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