Journal of Posthumanism
2025
Volume: 5, No: 5, pp. 1218–1240
ISSN: 2634-3576 (Print) | ISSN 2634-3584 (Online)
posthumanism.co.uk

DOI: https://doi.org/10.63332/joph.v5i5.1434

The Role of Remote Sensing and GIS in Monitoring the Impact of Green Areas on Temperatures and Improving the Quality of Life in Dammam City

Nourah M. Alamri[1]

Abstract

Climate change emerges as one of the most significant challenges facing the world, prompting various plans to mitigate its causes and minimize its effects. The Kingdom of Saudi Arabia has pursued this through numerous initiatives outlined in Vision 2030 and other development plans, aiming to achieve the Sustainable Development Goals, particularly those related to quality of life, the environment, and climate. Dammam, in the Eastern Province, is a key city in the Kingdom, serving as the region's petroleum production hub and a major industrial center. Variations in land use due to urban and industrial activities in cities create notable environmental challenges, particularly the formation of heat islands, especially those resulting from industrial activities. This impacts urban quality of life. Therefore, the use of remote sensing and Geographic Information Systems (GIS) technologies is crucial for monitoring, analyzing, and evaluating the Kingdom's projects aimed at reducing local temperatures through urban planning, including afforestation and increasing green spaces.This study relied on Landsat satellite imagery to monitor vegetation cover changes and surface temperature distributions between (2014:2024). Indicators such as the Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST), along with per capita green space, were used to assess the relationship between vegetation density, temperatures, and quality of life in industrial and urban areas of Dammam. The goal was to conduct a spatial assessment of the impact and effectiveness of green space and vegetation projects in mitigating thermal effects in the city and its surrounding areas.The results highlight the importance of integrating remote sensing and GIS technologies in environmental planning and monitoring climate impacts in cities with dense urban and industrial activities. The study also demonstrates that afforestation and increasing green spaces contribute significantly to reducing temperatures in surrounding areas, particularly industrial zones, and major roads, thereby strengthening their role as sustainable environmental solutions. This reinforces the recommendation to expand afforestation and green spaces as part of environmental and climate policies that enhance the quality of life in Dammam and achieve the goals of the Kingdom's Quality of Life Document in accordance with Vision 2030.

Keywords: *Dammam, Climate Change, Quality of Life, Thermal Impact, Green Areas, Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI).*

Introduction

The characteristics of the city's environment are changing because of rapid urban expansion and increased human activities, which lead to higher surface temperatures and the emergence of the Urban Heat Island phenomenon, which is reflected in the quality of life of its residents. The city of Dammam in the Eastern Province of the Kingdom of Saudi Arabia is considered one of the largest cities witnessing urban, economic and service changes, which has been reflected in both its natural environment and its human environment, as the demand for infrastructure services and urban facilities increases in parallel with the increase in population, and this may come at

[1] Department of Geography & GIS, College of Arts, Imam Abdulrahman Bin Faisal University, Dammam, Kingdom of Saudi Arabia, Email: noalmary@iau.edu.sa, https://orcid.org/0000-0002-8729-8975.

CC BY NC ND

the expense of the city's green spaces, which reduces them, and thus affects the per capita share of green spaces, which is one of the indicators of quality of life in cities, where the target according to the Quality of Life Program document is to reach 9 square meters per person by 2030 (The Quality Life of Program). Therefore, it is important to search for sustainable environmental solutions that increase the area of green spaces, reduce the impact of hot temperatures, and improve the climatic conditions in the city, which reflects on the overall quality of life in the city.

Green spaces play a key role in mitigating the impact of Urban Heat Islands in densely populated urban areas like the city of Dammam, as they contribute to regulating temperatures, improving air quality, and enhancing environmental sustainability, where vegetation works to absorb solar radiation, reduce heat reflection, and increase evaporation rates, leading to lower temperatures in urban areas. The city of Dammam faces a developmental challenge represented in the decrease of green spaces due to increased urban expansion and economic and service activities, which motivates the need for precise geographic monitoring using remote sensing and geographic information systems to monitor the development and impact of this phenomenon on the quality of the environment and life in the city.

Remote sensing and geographic information systems programs are scientific tools employed by geographers to monitor and analyze environmental changes in the city of Dammam accurately and effectively, as these technologies provide various capabilities to monitor vegetation cover, measure surface temperatures, and analyze the spatial and temporal changes of green areas, which contributes to providing accurate data that supports sustainable urban planning processes. This study relies on analyzing satellite images, and analyzing environmental indicators, such as the Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST), to assess the relationship between the distribution of green spaces and analyze their role in mitigating temperatures in the city of Dammam and the reflection of that on improving the environmental quality of life in the city of Dammam, and providing supporting results for urban planning decisions, enhancing the use of green spaces as a sustainable solution to face environmental challenges, in alignment with Saudi Vision 2030 to achieve sustainable development and improve the quality of life for urban residents..

Research Problem

Dammam, like other major cities in arid urban areas, is witnessing a significant rise in temperatures due to rapid urban expansion, a decrease in green spaces, and an increase in artificial surfaces that absorb and store heat. These factors exacerbate the urban heat island effect, which negatively impacts the quality of life, energy consumption, and thermal comfort of the city's residents. Although scientific studies have proven that green spaces play a fundamental role in regulating the urban climate by providing shade, increasing the process of evaporation and transpiration, and improving air quality, the impact of these spaces in reducing temperatures in Dammam has not been studied using remote sensing techniques and geographic information systems.

Objectives of the Study

This study aims to demonstrate how remote sensing techniques and geographic information systems can be employed to monitor and analyze the role of green areas in improving surface temperatures in cities, and the impact of this on enhancing the quality of life in Dammam City. To achieve this, the study seeks to accomplish the following objectives:

1- Using some modern methods and tools in remote sensing programs and geographic information systems to study the relationship of surface temperature and some influencing variables, and its impact on the quality of life in Dammam city.

2- Analyzing the relationship between green area coverage and surface temperatures in the city of Dammam using satellite data, by comparing the Normalized Difference Vegetation Index (NDVI) with Land Surface Temperature (LST) data.

3- Studying the impact of vegetation distribution and density on the urban heat island phenomenon and identifying the areas most affected by rising temperatures in the city of Dammam and the reflection of this on the quality of life and the environment.

4- Analyzing the relationship between vegetation cover and urban climate using various technical methods such as Geographically Weighted Regression (GWR), coefficient of determination R^2, and others to produce an analytical model that can be utilized and generalized to other cities.

Study Area

The city of Dammam is located between the latitudes 26° 07' N and 26° 31' N, and the longitudes 49° 50' E and 50° 14' E. It is the headquarters of the Eastern Province and one of its most important cities. Geographically, the city overlooks the coast of the Arabian Gulf to the east, making it an important maritime center, as it houses King Abdulaziz Port, one of the most important ports in Saudi Arabia. To the west, it is bordered by the Riyadh region, while to the north, it is bordered by the governorates of Qatif and Seihat, and to the south, it is bordered by the city of Khobar (Figure 1).

Dammam is considered an administrative, urban, and commercial center for the Eastern Province in general, with a population of 1.53 million, accounting for 29.9% of the total population of the Eastern Province according to the latest census in 2022(General Authority for Statistics, Saudi Census, 2022).

Approaches and Methods of Study:

The study relied on the use of several geographical approaches, such as historical, objective, and analytical approaches. It also employed cartographic and quantitative methods, remote sensing tools in Geographic Information Systems (GIS), and satellite images to process digital elevation models (DEMs) to monitor, analyze, and evaluate the relationship between surface temperature, vegetation cover area, and elevations in Dammam, comparing the years 2014 and 2024 to demonstrate the evolution of the phenomenon. The following steps were as follows:

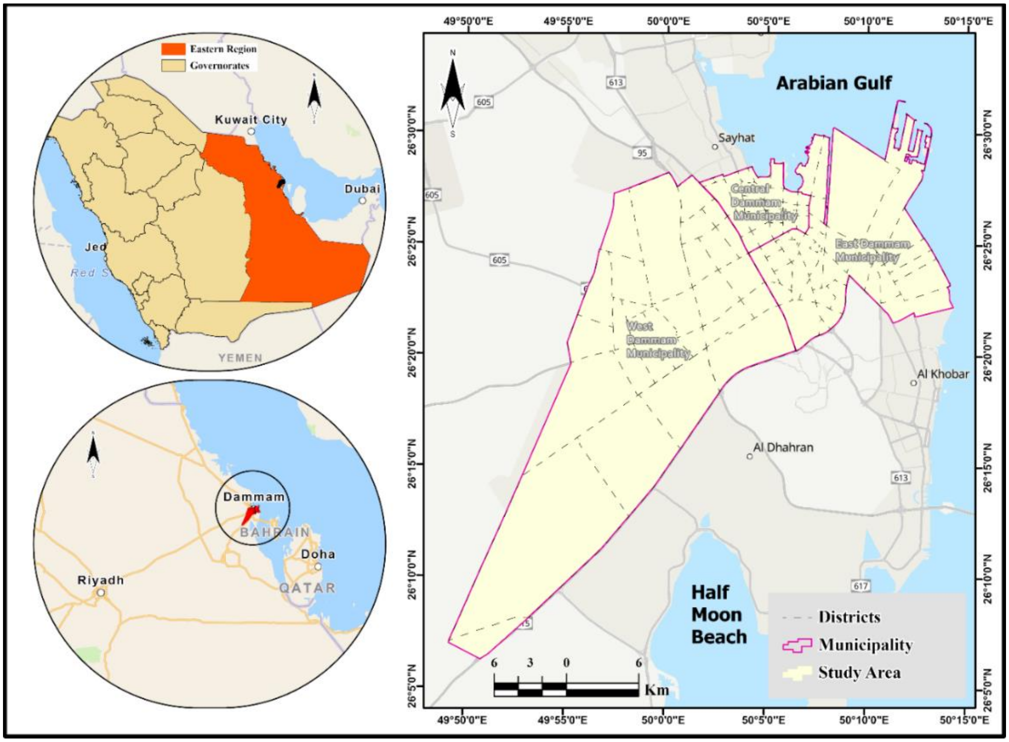

Figure (1) The Geographical Location of Dammam City.

- Processing of multi-spectral satellite images (Landsat) for the years 2014 and 2024:

Two satellite images were obtained from the Landsat 8 satellite dated 24/12/2014 and Landsat 9 dated 17/12/2024, which are multispectral images, chosen from the same source (USGS Earth Explorer) to ensure consistency in spatial and temporal analysis. These images were used to extract the NDVI vegetation index for both years, allowing for an accurate comparison of changes in green areas over a decade.

-Monitoring Land Surface Temperature (LST) during the four seasons:

Four thermal bands were processed for each year, representing the four seasons (winter, spring, summer, autumn) to accurately monitor annual temperature changes throughout the year. Equations to convert digital values were then used to convert the digital values to actual temperatures, and the average annual surface temperature was calculated for each year, with the aim of producing two maps representing LST for the years 2014 and 2024.

-Designing a digital elevation model (DEM):

A digital elevation model (DEM) of Dammam City with a 30-meter resolution was downloaded from USGS Earth Explorer. It was processed using ArcGIS Pro tools to prepare it as a primary input for the analysis, aiming to study the effect of topography on thermal variations in the city, as elevations affect temperature distribution.

- Building spatial layers:

Several spatial layers were created to represent the urban structure, factors affecting heat distribution, and to identify specific locations representing factories in industrial areas of

Dammam City. These also included points representing urban density areas, and points representing green spaces and parks. These layers helped clarify the spatial distribution of factors affecting temperatures and contributed to the completion of the spatial analysis and the accuracy of its results.

- Creating random points and extracting spatial values:

The Create random points tool was used to generate 600 random points within the administrative boundaries of the city of Dammam. The extracting spatial values tool was also used to extract the NDVI value from Landsat images, the Land Surface Temperature value from heat maps, and the DEM elevation value. These points were linked to the district boundary layer, so that each point is associated with an administrative area, facilitating spatial analysis and its connection to the urban area.

-Analyzing the relationship using Geographically Weighted Regression (GWR):

The GWR (Geographically Weighted Regression) tool was used to analyze the relationship between the dependent variable represented by the Land Surface Temperature (LST), and the independent variables represented by the NDVI vegetation cover and the DEM elevation. This analysis was conducted using ArcGIS Pro, resulting in analytical maps that illustrate the regression coefficients, the Local R^2 value, and the distribution of residual errors, which helped in deriving results about the impact of each variable on surface temperature in a precise spatial manner.

Previous Studies

Many studies have analyzed the relationship between green spaces and surface temperatures using remote sensing techniques and geographic information systems in various regions around the world, and the following are the most important ones:

-A study by **Ali and Mohammed (2016)** in the city of Jubail, Saudi Arabia, observed that industrial areas lead to an increase in surface temperature by up to 80 ° in some locations, thereby expanding the scope of the urban heat island effect. **Almalki and Al-Namazi (2019)** expanded on this in a similar study, confirming that industrial growth contributed to higher temperatures compared to residential areas.

-A study by **Nayak and Mandal (2019)** monitored the impact of land use changes on thermal trends in India, indicating that converting forests to agricultural land contributed to cooling temperatures, while conversion to built-up areas increased them.

-The study by **Verma and Kundapura (2020)** focused on developing the "urban green weight" index and linking it to temperatures in the city of Lucknow, confirming that a decrease in this index by one unit is associated with an increase in temperature by 2.5 °.

-A study by **Naikoo et al. (2020)** monitored urban growth in the suburbs of Delhi, showing that the expansion of built-up areas came at the expense of agricultural and green areas, negatively impacting the thermal environment.

-Guha et al. (2020) demonstrated in their seasonal study that the relationship between land surface temperature and the urban building index varies by season, with the strongest correlation recorded in the post-monsoon period.

-The study by **Wang et al. (2021)** focused on assessing the thermal benefits of green spaces using a geographic detector, indicating that the diversity and distribution of vegetation play a role in improving the thermal environment.

-The study by **Kebede et al. (2022)** relied on spectral indices to extract impervious surfaces in Addis Ababa, noting that changes in land use contributed to increased urban heat.

-The study by **Halder et al. (2022)** discussed vegetation dynamics in the city of Kolkata, showing that a reduction in green spaces by 8.62% was accompanied by a noticeable increase in heat.

-The study by **Degefu et al. (2023)** linked the decline of green cover to increased intensity of heat islands in Ethiopian cities, confirming the role of spatial analysis in explaining thermal differences between regions.

-**Maskulrath et al. (2023)** showed in their study of Thailand that green spaces helped reduce thermal energy flows, while Gyimah et al. (2023) focused on the impact of converting vegetation to build areas in Accra, which raised temperatures by 0.8 ° over 25 years.

-The study by **Basu and Das (2023)** indicated that fragmentation of vegetation in the city of Raiganj led to a reduction in its thermal efficiency, while **Zahir et al. (2024)** proved that the MSAVI index is the best for assessing vegetation in the Colombo area. **Salan et al. (2024)** clarified that the loss of vegetation in Rajshahi reduced climate comfort quality.

-**Aghazadeh et al. (2024)** showed that urban expansion in Tabriz was accompanied by a decline in per capita green space and an increase in heat island effects, while **Rodríguez-Gómez et al. (2025)** focused on building an intelligent system to simulate the impact of green infrastructure on temperatures using data analysis techniques. The study by **Sun et al. (2025)** highlighted that the formation of green spaces in Beijing is a decisive factor in reducing temperatures, showing that larger and more diverse areas achieve clear cooling results. Finally, **Liu et al. (2025)** clarified that climate, city shape, and NDVI index have a direct impact on daytime and nighttime thermal changes in the Yangtze River area, while **Ünsal et al. (2025)** focused on the importance of accessibility to green spaces in improving thermal indicators in Turkish cities.

The previous studies indicate a close relationship between urban vegetation and land surface temperature, as most of them focus on using vegetation indices or analyzing spatial relationships using geographic information system tools. This study matched most of the processes and methodological steps addressed by previous studies, but its distinctive addition lies in applying the Geographically Weighted Regression (GWR) method to measure the relationship between the dependent variable surface temperature (LST) on one hand, and the vegetation index (NDVI) and digital elevation model (DEM) on the other hand. It also produced maps showing the spatial variation of these relationships, enhancing the precise spatial understanding of the factors affecting the thermal environment of the city of Dammam, and the relationship of that to environmental quality and its reflection on the quality of life of the city's residents.

Study Terminology

- Geographically weighted regression (GWR): is an advanced spatial analytical technique designed to address spatial non-stationarity by allowing the relationships between explanatory variables (such as climatic conditions, demographic attributes, and physical environmental characteristics) and a dependent variable to vary across geographic space. This method facilitates the exploration of localized patterns and spatial heterogeneity in the data**.** (Esri GIS Dictionary).

- The Normalized Difference Vegetation Index (NDVI): is a widely used remote sensing metric for quantifying vegetation greenness. It serves as a valuable indicator for assessing vegetation density and monitoring ecological and land cover changes over time. (Landsat Normalized Difference Vegetation Index)

- Land Surface Temperature (LST) refers to the temperature of the Earth's surface as measured by remote sensing techniques. It plays a critical role in understanding surface-atmosphere interactions, including the exchange of energy and moisture, and is a key parameter in studies related to climate change, urban heat islands, and environmental monitoring. (NASA Earth science data)

- **R squared (R^2)**: is a statistical measure used to assess how well a regression model fits the actual data. Its values range between 0 and 1, where values close to 1 indicate that the model explains a large proportion of the variance in the dependent variable, indicating higher accuracy of the model. Therefore, a high R^2 value reflects the model's ability to represent the data comprehensively. (Esri GIS Dictionary)

- **Residuals**: are defined as the difference between observed and estimated values in regression analysis. The values observed above the regression line have a positive residual value, and observed values below the regression line have a negative residual value. The regression line should lie along the center of the data points, and the sum of the residuals should be zero. (Esri GIS Dictionary)

First: The Development of Green Spaces in Dammam City (2014-2024):

The area of green spaces in Dammam City has undergone significant changes, as observed through satellite imagery analysis from 2014 to 2024 using remote sensing tools and geographic information systems. Figure (2)shows a change in the spatial distribution and geographical extent of vegetation cover within Dammam City limits. While the area of green spaces in 2014 was approximately 6.5 square kilometers, it increased to approximately 18.9 square kilometers in 2024, representing an increase of approximately 190.8% over ten years. This growth can be attributed to a combination of interconnected factors, most notably the implementation of projects for implementation of Vision 2030 objectives, particularly those related to improving the quality of life. This was achieved through various national projects and initiatives, such as the Saudi Green Initiative and the Quality of Life Program, in addition to municipal projects, including the Eastern Province Municipality, which has actively sought to increase green vegetation cover within the cities of the Eastern Province.

The increase in green spaces can also be explained by the structuring of urban planning priorities in Saudi cities, including Dammam. Green spaces have become a fundamental element in the development of new districts, alongside the rehabilitation of some unused open spaces within the urban area. The spatial distribution of green spaces demonstrates that the expansion of green areas was not random, but followed a geographical pattern along several axes, most notably the southwestern extensions of the city due to the presence of industrial areas and some residential areas in the city center. This indicates the deliberate integration of landscaping and the cultivation of green spaces into the urban and service planning systems of residential districts, aiming to serve the city's residents and enhance their environmental quality, which in turn reflects indicators of their quality of life.

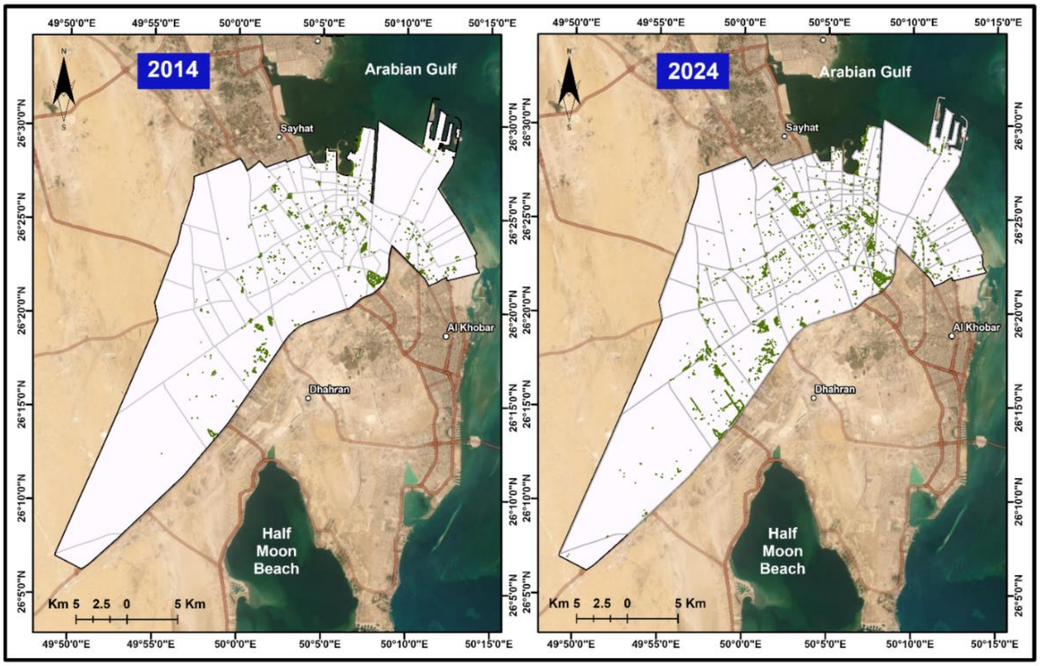

Figure (2) The Geographical Distribution of Green Areas in Dammam City, Compared Between 2014 And 2024.

The increase in vegetation cover has led to a reduction in the city's surface temperature (as will be detailed further), and a decrease in the impact of the urban heat island effect, in addition to improving air quality, absorbing pollutants, and reducing noise. It also enhances the mental and physical health of Dammam residents by providing areas for sports and recreational activities. The vegetation cover has also enhanced the city's aesthetics and increased the property value in surrounding areas, demonstrating that environmental policies not only contribute to improving the environment, but also enhance the investment attractiveness, economic, urban, and tourism appeal of Dammam City.

Secondly: Monitoring Surface Temperatures Compared Between 2014 and 2024

Urban surface temperatures, or what is known as the urban heat islands effect, arise from several factors, such as the significant absorption of solar radiation by dark surfaces like roads, streets, buildings, and soil. Also contributing are heat generated by vehicles, machinery, building air conditioners, and industrial activities (Younes, Ghali, Ghaddar, 2022). This leads to higher city temperatures, such as in Dammam, compared to surrounding rural areas.

Analysis of surface temperatures in Dammam during 2014 and 2024, as shown in Figure (3), reveals a change in the spatial distribution of surface temperatures. Results from 2014 show a concentration of hot temperature categories in the central and southern parts of the city, ranging from 42° to 52°. Some coastal areas maintained moderate temperatures between 28° and 38°. In 2024, a noticeable increase in the area covered by dark red zones representing hot temperature categories was observed. Values in some areas reached between 48° and 55°, particularly in the southwestern and central areas with high population and building density. This change indicates an increase in the intensity of the urban heat islands phenomenon, despite the expansion of green cover.

The observed increase in surface temperature categories in 2024 may be attributed to several factors, including rapid urban growth and urban expansion into open areas, such as the Al-Faisaliah, Bader, and Airport districts. This has led to an increase in non-porous surfaces that absorb solar radiation, such as roads and buildings. The expansion of industrial areas in Dammam, such as the First and Second Industrial Cities, also contributed to raising average surface temperatures due to heat generated from factories and the density of asphalt and concrete surfaces. Furthermore, population growth and associated activities increased urban heat loads due to traffic and other heat emissions.

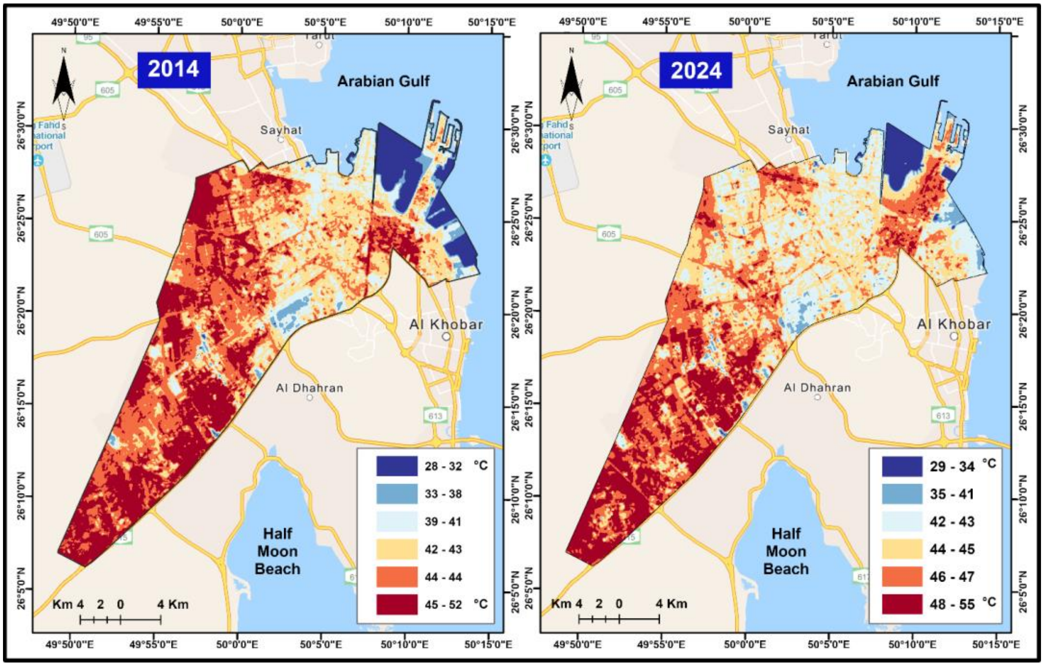

Figure (3) The Geographical Distribution of Surface Temperatures in Dammam City Compared to the Years 2014 And 2024.

Despite the increase in vegetation in some Dammam districts, the city still experiences higher surface temperatures compared to neighboring rural areas in Al- sayhat and Al-Qatif. This highlights the importance of effective spatial planning and distribution of green cover, not just increasing their area. Maps indicate that industrial areas, particularly the First and Second Dammam Industrial Cities (northeast and southwest, respectively), are among the highest urban heat islands areas in Dammam, reflecting the thermal impact of industrial activities.

The topography and geographical location of Dammam have also significantly influenced surface temperatures. Analysis combining digital elevation models (DEMs) with temperature data showed that relatively low-lying areas within industrial and residential clusters had the highest surface temperatures, while coastal areas associated with the waterfront, such as Dammam Corniche and districts along the Arabian Gulf, had relatively lower temperatures compared to other parts of the city.

Thirdly - Factors Affecting the Surface Temperature in Dammam City

The factors affecting the surface temperature in cities are numerous, as human activities intertwine with environmental phenomena. Dammam City is one of the largest cities with diverse and intertwined activities, such as urban activities represented in urban plans, construction, and building, as well as economic activities like industrial areas, and mining activities represented in the extraction of crude oil, its processing, refining, and exporting from the ports. Below are the most prominent factors affecting surface temperatures in Dammam City:

1- Industrial Areas:

Dammam City is an industrial center in eastern Saudi Arabia, due to its natural and human resources. The city's factories are concentrated in three industrial areas, the first of which is the first industrial area established in 1973, covering an area of about 2.44 km^2, with 184 factories. The second industrial area covers 25 km^2, with 1133 factories. The third industrial area includes 251 factories distributed over an area of 10 km^2. Additionally, there is a workshop area located in the Al-Khadhriya district, and small factories south of the Al-Faisaliay district.

Based on the analysis of satellite imagery and maps, an industrial density map of Dammam city (Figure 4) was produced. The map reveals that the highest concentration of industrial establishments is concentrated in the southwestern areas of the city, specifically around the Second Industrial City. Lower industrial concentrations are found around the First Industrial City, followed by mixed workshops within residential districts.

This varied geographical distribution can be explained by a combination of interconnected factors. These areas have been designated as industrial zones for decades, possessing the necessary infrastructure such as road networks, energy, and water supplies, making them attractive to investors. Their location on the city's outskirts minimizes interaction between industrial and residential areas, while proximity to major highways, such as the Dammam-Riyadh highway, and the Kingdom's key ports on the Arabian Gulf (King Abdulaziz Port), facilitates transportation and logistics.

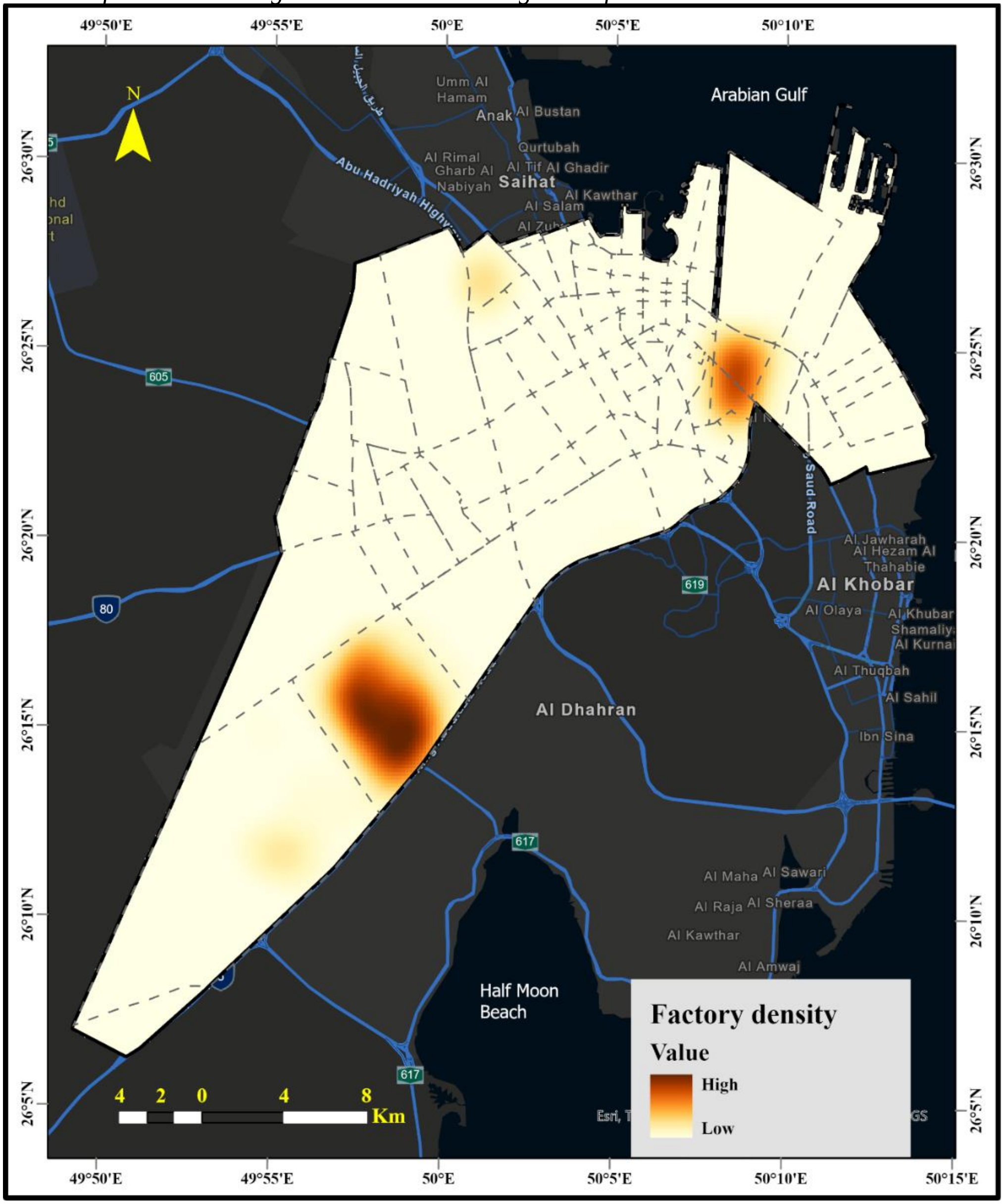

Figure (4) The Density of Industrial Facilities in Dammam.

An analysis of surface temperatures from Dammam city imagery using remote sensing software revealed that, in general, the industrial cities of Dammam, and particularly the Second Industrial City, recorded the highest surface temperatures, ranging from 46° to 55°. This is evident in the LST maps (Figure 3) for 2014 and 2024, representing some of the highest readings within the city. This is primarily due to the lack of vegetation cover in these areas. NDVI maps (Figure 2) show a scarcity of green spaces within these areas, exacerbating the urban heat island effect.

Furthermore, the materials used in factory construction and the concrete surfaces absorb and store heat radiation, increasing temperatures, and intensifying the impact in the absence of trees and buffer zones. Limited efforts to increase green spaces and planting in recent years have had a limited impact, as they have focused on residential and commercial areas, rather than being implemented extensively in industrial zones.

2- Green Space Density in Dammam City:

The vegetation cover density in Dammam varies, as shown in Figure (5). A geographical and density disparity is evident between residential and industrial areas. The map shows that areas with higher green space density are concentrated in the northern and eastern parts of the city, particularly in residential districts like Al-Faisaliah, Bader, and Al-Jama'een. Density significantly decreases in industrial areas, such as the First and Second Industrial Cities. This difference reflects the urban planning pattern of the city, which prioritizes increased green spaces in residential areas due to the inclusion of parks and public gardens, as well as street and private yard landscaping, which is less common in industrial zones.

Conversely, the lower green space area in industrial zones may be attributed to the maximum utilization of space for existing industrial activities. Industrial establishments typically expand at the expense of open spaces and green areas, relying on solid construction materials like concrete and metal, which absorb solar radiation, contributing to higher surface temperatures in these areas. This is clear in the Dammam thermal map (Figure 3), which shows a high heat concentration in the Second Industrial City, which corresponds to a low density of green spaces, as shown in density of green spaces map (Figure 5).

It is noteworthy that attempts to plant trees and increase green spaces around and within industrial areas are limited to small areas and scattered trees, which do not significantly affect measured surface temperature changes, and are not sufficient to effectively modify the local climate. Mixed urban areas, including small workshops, exhibit higher vegetation density compared to Dammam's industrial zones. This is due to the integration of these workshops with residential districts, which contain green spaces.

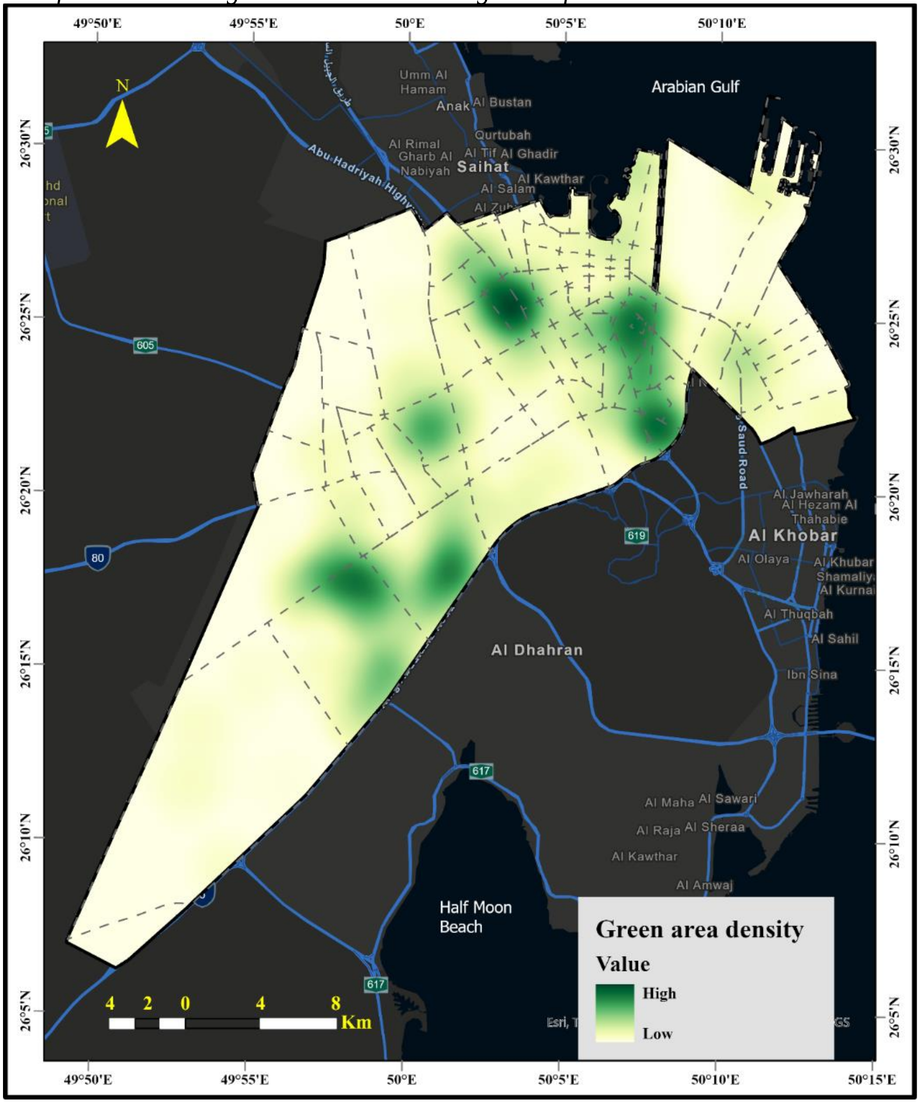

Figure (5) The Density of Green Spaces in Dammam.

3- Urban Density in Dammam City:

Urban density varies across Dammam's districts, comparing older districts and newer districts, as shown in Figure (6). The highest urban density is concentrated in the northeastern and central districts of Dammam, particularly in older, densely populated districts like Al-Nakheel, Al-Zuhour, Al-Khalij, Al-Faisaliah, Al-Muhammadiah, and Al-Adamiyah. The urban density map shows that these areas have the highest population and building density, creating an intertwined environment characterized by a high rate of solar radiation absorption and, consequently, a high surface temperature.

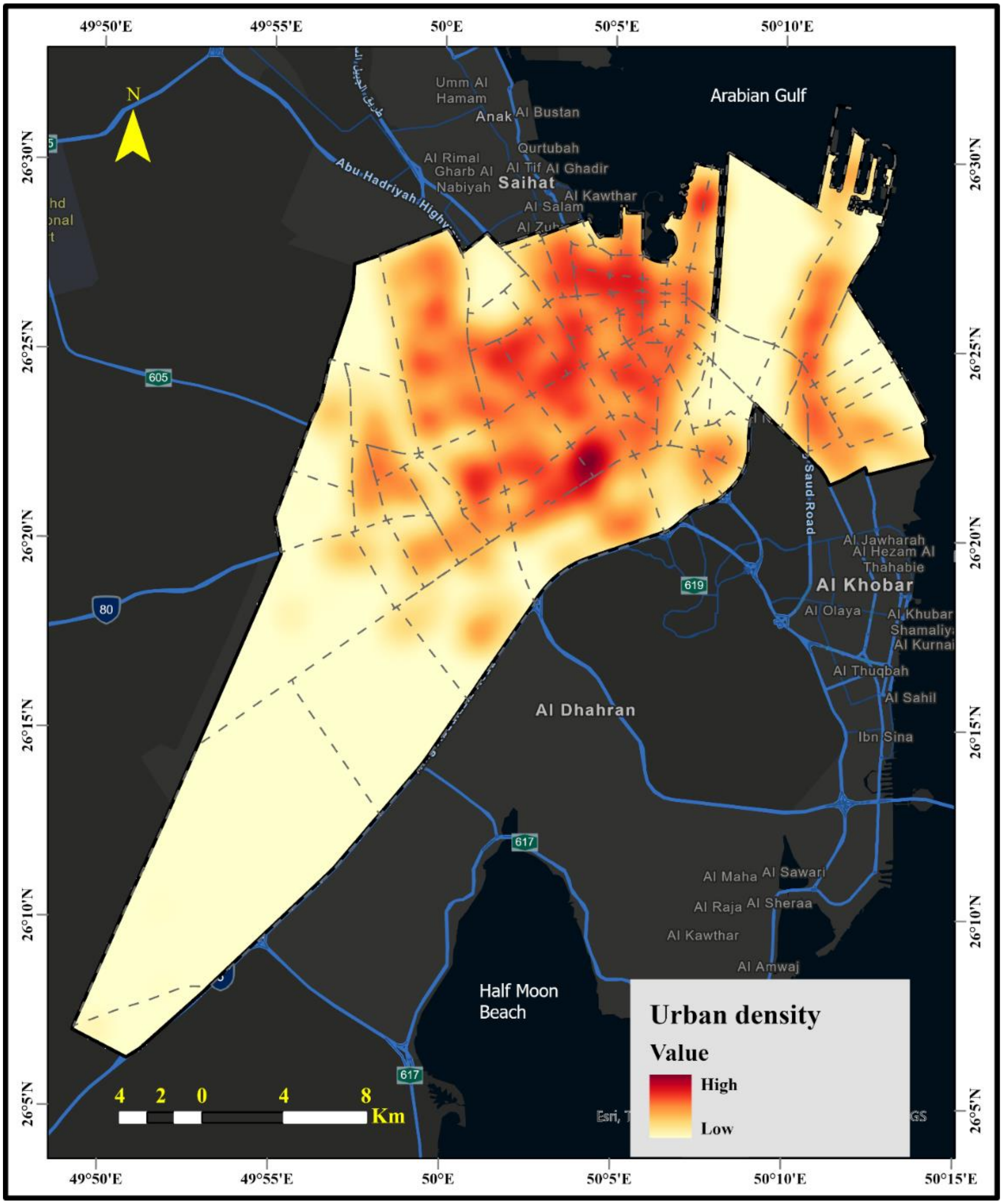

Figure (6) The Density of Urban Areas in Dammam.

Urban concentration is associated with high surface temperatures, as shown by LST maps, which explains the direct relationship between urban density and reduced ventilation, as well as the multiple sources of thermal emissions. This is due to the density of buildings, narrow streets, and the absence of large gardens that contribute to air cooling. This urban pattern enhances the phenomenon of thermal islands, especially in areas lacking sufficient vegetation cover, as indicated by the NDVI map. It has been found that some industrial districts, despite their high economic activity, record lower temperatures in certain areas due to reduced urban density around them, indicating that urban clustering is a crucial factor in explaining thermal variations more than economic activity itself.

Districts with high population density lack a reasonable area of vegetation, making them more susceptible to exacerbated thermal effects, which reduces the sense of thermal comfort, defined as "a person's awareness of the thermal atmosphere and their feeling of thermal balance towards a specific thermal environment" (Moses, 2022), affecting the quality of life indicators for the residents of Dammam City. Additionally, some new urban expansions to the west and south, such as in Al-Amana and the Airport district, currently show a less dense pattern, providing an opportunity to adopt planning solutions that consider environmental balance from the outset of urban planning for residential districts.

Fourth: The Effect of Green Spaces and Elevations on Surface Temperatures in Dammam Using Geographically Weighted Regression Analysis

Some Geographic Information Systems (GIS) and remote sensing techniques are used to study the relationship between several variables, including green spaces, elevation, and their impact on surface temperature values, to derive spatial analyses and relationships that may not be accessible through traditional methods. One of the most important of these methods is geographically weighted regression analysis (GWR), which was applied to the studied phenomenon in Dammam city, and its output is represented in Figure (7).

The Geographically Weighted Regression model (GWR) was used to explain the distribution of land surface temperatures in Dammam city, based on two variables: the Normalized Difference Vegetation Index (NDVI) and the Digital Elevation Model (DEM), in addition to the Intercept and Standardized Residuals. Using spatial variance analysis to monitor the effect of each of these variables on surface temperature, highlighting their statistical significance and distribution within the urban and industrial fabric of Dammam city. The results of this analysis were as follows:

Figure (7A) shows that the GWR coefficients associated with NDVI show a clear variation in the effect of vegetation cover on land surface temperatures in Dammam city. Some industrial areas, particularly the eastern parts of the Second Industrial City, have recorded negative coefficients with statistical significance, indicating a limited temperature-moderating effect of limited green spaces in these areas, due to the local distribution of some green spaces or light vegetation cover. Northern and western areas recorded positive coefficients, reflecting a positive

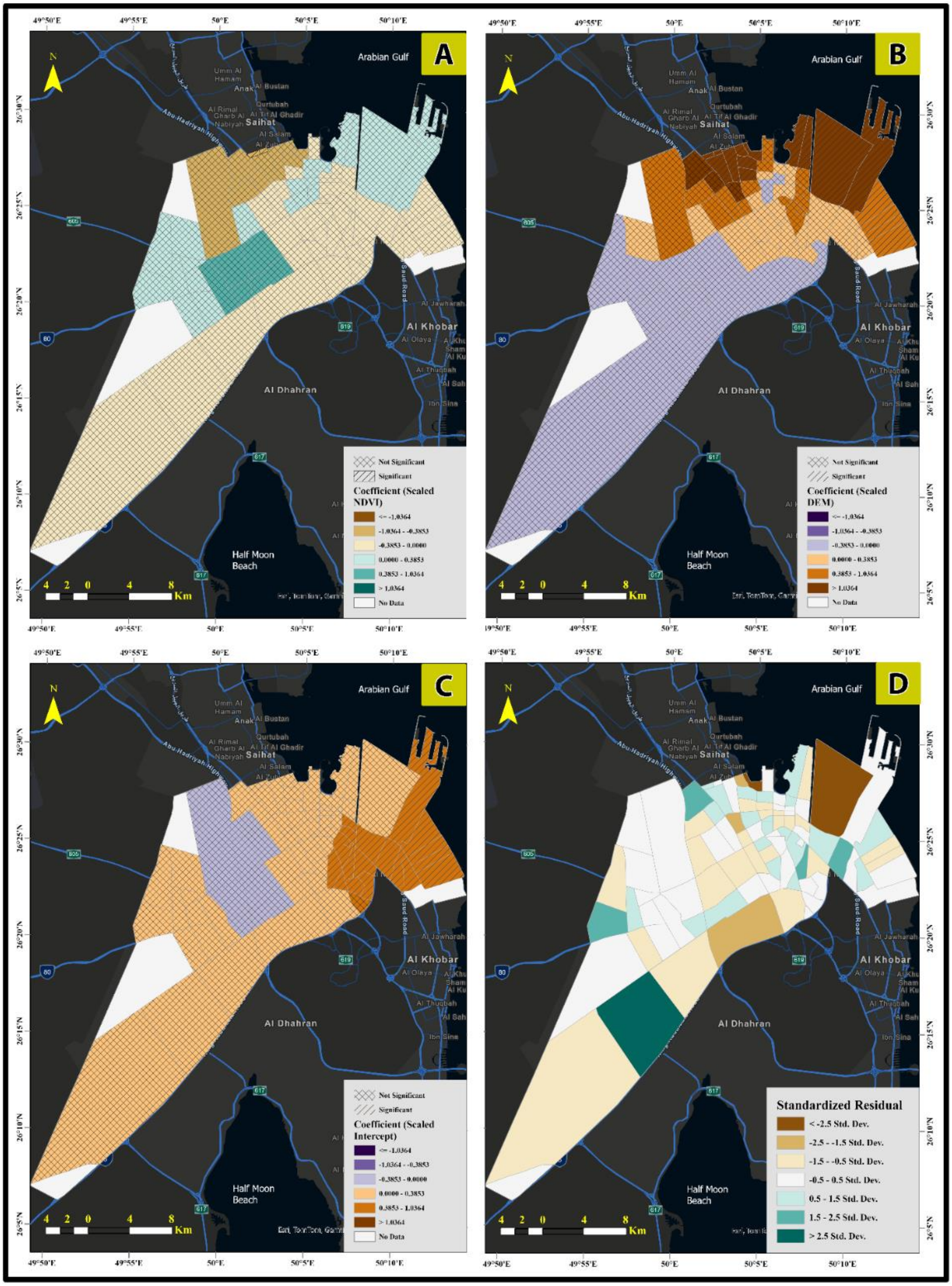

Figure (7) Results of Applying The (GWR) Model to the Distribution of Land Surface Temperatures (LST) in the City Of Dammam.

relationship between NDVI and LST, which is attributed to the presence of sparse vegetation covering over exposed soil, or the interference of NDVI with the built-up area represented by asphalt surfaces and construction materials. Areas that showed coefficients close to zero or were not statistically significant are usually solid industrial areas lacking vegetation cover, which limits NDVI's ability to explain temperature changes in these areas.

2- Figure (7B) shows spatial variation in the effect of the elevation variable (DEM) on surface temperatures in Dammam. Northern and eastern areas of the city, as well as areas bordering the Arabian Gulf coast, recorded positive coefficients with statistical significance, indicating that relatively higher areas contribute to higher temperatures, especially in densely urbanized areas. Southern and western areas, including the Second Industrial City, recorded negative significant coefficients, reflecting a slight correlation between topographic depressions and a relative decrease in temperatures. This is due to the nature of these flat desert areas that allow greater heat exchange. Values close to zero in the central and residential areas indicate the absence of a direct effect of elevation, due to the interaction between building density and land use. This highlights the importance of considering DEM as a secondary explanatory factor, not for its independent effect, but for its interaction with other factors in shaping the local thermal pattern.

3- The spatial distribution of the Intercept, shown in Figure (7C), reveals the basic expected temperatures if the effect of other variables remains constant. It is observed that most areas, especially the southwest sector extending towards the Second Industrial City, recorded positive coefficients with statistical significance, reflecting a high basic temperature resulting from dense urban and industrial activities lacking environmental elements that moderate temperatures. This is due to the use of solid concrete and metal building materials, and non-permeable roofs that retain thermal radiation. Industrial areas also show higher interceptive values, indicating latent thermal conditions requiring specific planning interventions. Some northern and northeastern coastal areas show negative coefficients, due to the marine effects of the Arabian Gulf and the dispersion of the built-up area.

4- The spatial analysis of the Standardized Residuals of the GWR model (Figure 7C) reveals the accuracy of the model in explaining surface temperatures in Dammam. Some areas, particularly the Second Industrial City, record positive residuals, indicating that the model was able to explain the significant increase in temperatures, due to the scarcity of vegetation cover and the effect of intensive industrial activity. Residential areas show lower residuals despite their high density, indicating the effect of increased green spaces and vegetation cover on temperatures and the quality of life in the area. The statistical analysis of the relationships between the variables confirms that NDVI is inversely related to LST, while DEM shows a positive relationship, which reinforces the natural distribution of residuals and the suitability of using the GWR model in studying local thermal distribution.

-Local R^2 values for GWR model in Dammam city districts:

Figure (8)shows the spatial variation in the explanatory power of the GWR model for Land Surface Temperature (LST) in Dammam city, based on the independent variables (Normalized Difference Vegetation Index NDVI and Digital Elevation Model DEM). This variation is measured using the Local R^2, which represents the proportion of LST variance explained by the variables at each location. This resulted in classifying Dammam districts into several zones based on the Local R^2 value:

- Areas with a high determination coefficient (0.71 – 0.91):

High R^2 values are concentrated in the northern and eastern districts of Dammam, particularly in coastal areas adjacent to the Arabian Gulf and some modern industrial areas with modern urban planning. This increase in R^2 is attributed to the effectiveness of the relationship between vegetation cover or elevation and their impact on surface temperatures. These results indicate that the local variation in LST in these areas can be well explained by NDVI and DEM, confirming the effective cooling effect of vegetation cover or the direct effect of elevation in areas with lower urban density and better ventilation.

- Areas with an average determination coefficient (0.47 – 0.70):

Medium R^2 values are distributed in the central districts of Dammam and areas located between residential and industrial districts. This medium R^2 value is due to the role of vegetation and elevation in reducing surface temperatures.

- Areas with a low determination coefficient (0.18 – 0.40):

Low R^2 values are found in the southern and western districts of Dammam, particularly in the Second Industrial City. The low R^2 value in these areas is due to the weak influence of vegetation and elevation, given the nature of the flat industrial land, the scarcity of vegetation and green spaces, and the increase in paved and concrete surfaces, which contribute to raising temperatures.

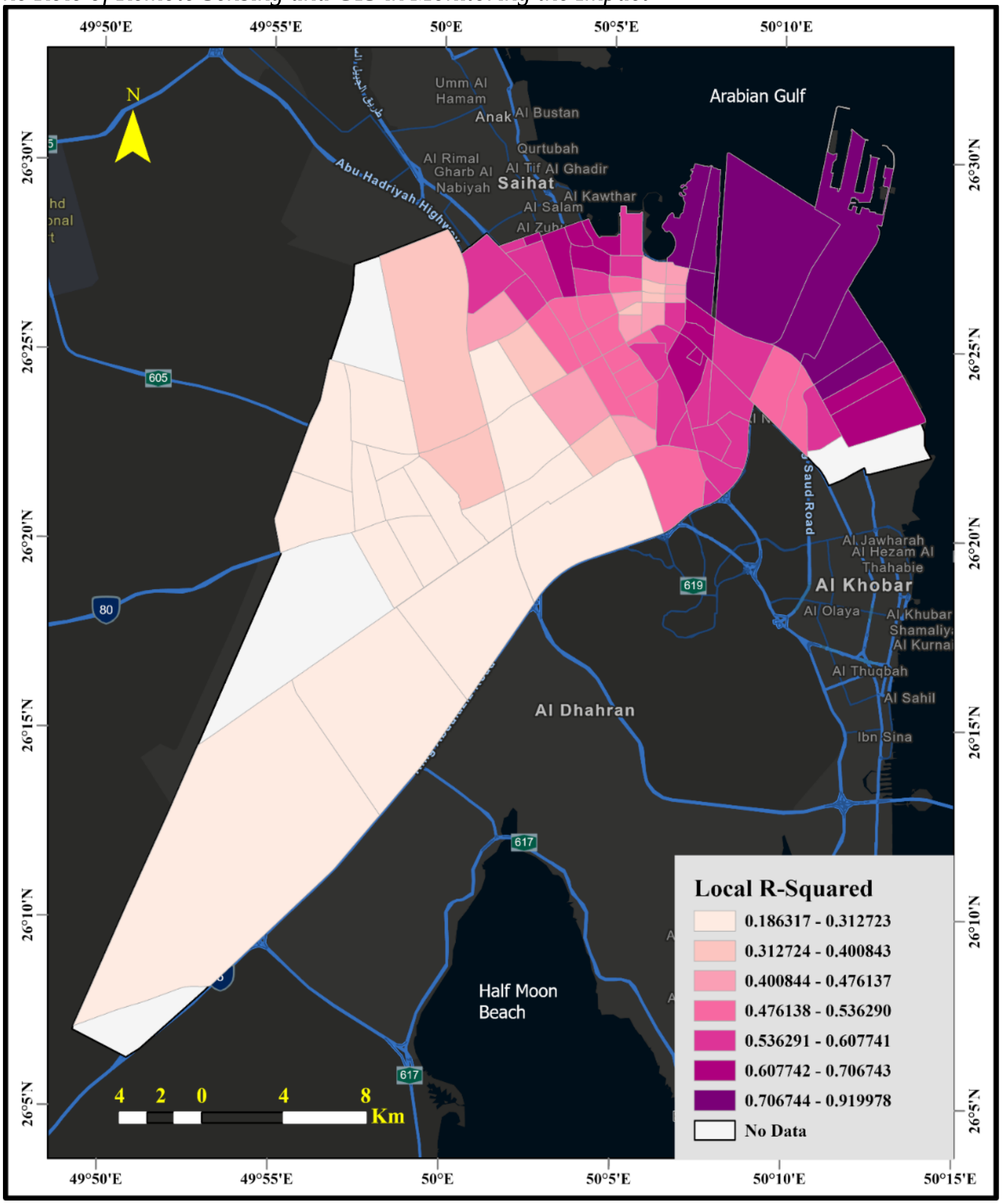

Figure (8) Distribution of The Results of the Local Determination Coefficient (R^2) for the GWR Model in the Districts of Dammam City.

-Spatial analysis of predicted land surface temperatures in Dammam using a geographically weighted regression (GWR) model:

Figure (9) shows the spatial distribution of predicted land surface temperatures (LST) in Dammam, as produced by the geographically weighted regression (GWR) model, which was created using the Normalized Difference Vegetation Index (NDVI) and Digital Elevation Model (DEM) variables. The results show a clear

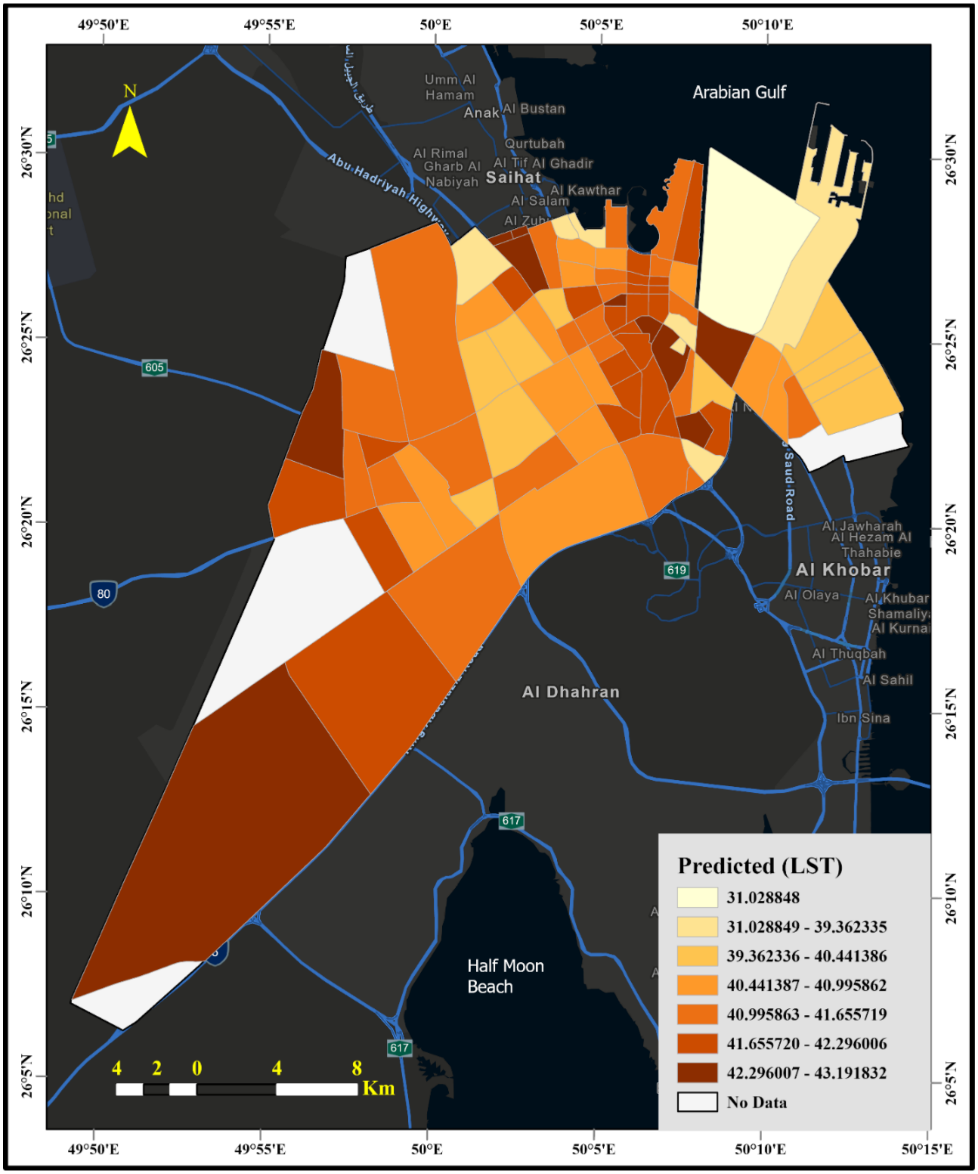

Figure (9) Analysis of the Spatial Distribution of Expected Land Surface Temperatures (LST) Using GWR.

thermal variation between the districts of Dammam, indicating the effect of various environmental and urban areas. factors on the local thermal pattern. Based on the results of the spatial analysis of predicted land surface temperatures in Dammam using the geographically weighted regression (GWR) model, Dammam can be divided into three categories as follows:

-Areas With High Predicted Temperatures:

Predicted hot temperatures (over 42.3°) are concentrated in the southern and western districts of the city, particularly in the second industrial zone, as well as in some central areas with high urban density. This increase is due to several intertwined environmental and urban factors, most notably the scarcity or absence of vegetation in these areas, in addition to the intense industrial activity that generates significant local heat. The widespread presence of hard surfaces, such as asphalt, concrete, and metal structure, contributes to the absorption of solar radiation, increasing surface temperatures, exacerbating the urban heat island effect.

-Areas With Moderate Predicted Temperatures:

This category includes transitional areas between industrial and residential districts, especially in the city center, where predicted temperatures range between 39.3° and 41.6°. These areas have a mixture of hard surfaces and green spaces, along with variations in urban density, resulting in moderate thermal effects. There may be green spaces, trees, or partial vegetation cover that contributes to reducing temperatures, but its effect is not sufficient to create a completely moderate thermal environment.

-Areas With Low Predicted Temperatures:

This category, with low predicted temperatures (below 39°), is found in the northern and eastern districts of the city, particularly in coastal areas overlooking the Arabian Gulf, such as Al-Zuhour neighborhood. This is because of marine ventilation resulting from proximity to the coast and low urban density. A relative abundance of vegetation cover or undeveloped land contributes to improving the thermal energy balance and reducing the absorption of solar radiation, leading to a localized natural cooling effect.

Results

- Analysis of satellite imagery and the Normalized Difference Vegetation Index (NDVI) reveals a significant difference in vegetation distribution between residential and industrial areas in Dammam. Green spaces are primarily concentrated in the northern and eastern residential districts, thus improving the quality of life due to the availability of thermal comfort conditions and a higher per capita area of green spaces. Conversely, major industrial areas, particularly the first and second industrial cities, suffer from a scarcity of vegetation.

- Land Surface Temperature (LST) maps comparing 2014 and 2024 show a rise in temperatures, particularly in industrial areas, and more specifically in the second industrial city, which is a prominent heat source with 2000 facilities. Temperatures there ranged between 46 and 55 °. This increase is attributed to the density of concrete and asphalt surfaces, coupled with the lack of vegetation cover, which leads to increased heat absorption and exacerbates the urban heat island effect.

- Results from the geographically weighted regression (GWR) model indicate a cooling effect of vegetation on surface temperatures, especially in some green spaces within residential districts. However, this effect remains limited and does not extend to industrial areas. This is attributed to the absence of urban greening strategies and a low level of compliance with environmental regulations requiring green spaces within these areas.

- Analysis of the relationship between the digital elevation model (DEM) and surface temperatures revealed a limited effect, with positive statistically significant coefficients observed in some elevated areas north of the city. These results suggest a secondary role for topographic elevation in shaping the thermal pattern.

- The intersection coefficient in the GWR model shows high baseline temperatures in industrial areas, even without clear statistical significance for NDVI and DEM variables. This is due to the nature of impermeable building materials and solid urban fabric, reflecting the presence of underlying thermal conditions requiring direct planning intervention for their resolution.

- The Local R^2 map shows a clear spatial variation in model efficiency. Higher values were concentrated in the northeastern districts and coastal areas, indicating the model's ability to explain temperatures there based on vegetation and elevation. Conversely, values decreased in industrial and southern areas, highlighting the need to incorporate additional variables to explain thermal phenomena more accurately in these areas.

- The study demonstrated the ability of the GWR model to explain thermal patterns in Dammam in a spatially varying manner. Densely populated industrial and urban areas show higher predicted temperatures, while coastal and open areas exhibit lower temperatures.

- Industrial areas in Dammam are characterized by a complex thermal structure, combining high urban density, low green space, and high surface temperatures. These factors together exacerbate thermal stress and negatively impact on environmental quality of life.

Recommendations

- Direct urban planning efforts towards enhancing vegetation cover and increasing green spaces and tree planting in high-temperature areas, particularly industrial areas, by integrating sustainable green spaces into industrial infrastructure. This includes allocating areas for urban tree planting and creating green belts around industrial complexes, using plant species suitable for local climatic conditions, to reduce surface temperatures, enhance ecological balance, and improve the quality of the urban environment in the city.

- Activate partnerships and cooperation between the industrial sector and government agencies to achieve environmental sustainability goals and ensure alignment of local policies with the Kingdom's Vision 2030. This is a gateway to achieving balanced industrial development, considering the environmental dimension, and contributing to reducing thermal effects and improving the quality of life in Dammam.

- Increase the per capita area of green spaces beyond the targets set by Vision 2030 to enhance quality of life indicators in Dammam.

References

Alshehri, A., Almana, L. (2021) Khobar City Plan and the New Public Space in Saudi Arabia, The Journal of Public Space, 6(1), 215-234. DOI 10.32891/jps. v6i1.1323

Bianca Biagi, Maria Gabriela Ladu, Marta Meleddu, Vicente Royuela (2020), Tourism and the city: the impact on residents' quality of life, International Journal of Tourism Research: Volume 22, Issue 2 March/April, Pages 168-181. https://doi.org/10.1002/jtr.2326

doi:10.1016/j.scs.2022.103932. S2CID 248588547.

Genene, A., & Meten, M. (2021). Landslide Susceptibility Mapping Using GIS-based Information Value and Frequency Ratio Methods in Gindeberet area, West Shewa Zone, Oromia Province, Ethiopia. https://doi.org/10.21203/rs.3.rs-219331/v1

Gotlib, D., & Olszewski, R. (2017). conceptual modeling to a map. International Cartographic Association ICA https://doi.org/10.5194/ica-proc-1-49-2017

Griffith, D. A. (2019). Negative spatial autocorrelation: One of the most neglected concepts in spatial statistics. MDPI Journal. Vol.2-Issu3, 2, Basel, Switzerland. https://doi.org/10.3390/stats2030027

Jiangfu Liao, et al., (2019). Urban sprawl scenario simulations based on cellular automata and ordered weighted averaging ecological constraints, Ecological Indicators, Vol. 17.

https://doi.org/10.1016/j.ecolind.2022.108538
Lei, C. A. O., Yiqun, H. A. N., & Zixuan, L. I. (2023). Spatial Pattern Construction of the Grand Canal National Cultural Park in Tianjin from the Perspective of Narrative Space. Landscape Architecture, 30(2), 65-72. https://doi.org/10.12409/j.fjyl.202208030464
MOMRAH. (2022). Kingdom of Saudi Arabia's Report on the Implementation of the New Urban Agenda. Ministry of Municipal, Rural Affairs & Housing. Kingdom of Saudi Arabia.
Moses. Eterigho Emetere (2022), Typical environmental challenges -Numerical Methods in Environmental Data Analysis, Elsevier, Pages 41-51. https://doi.org/10.1016/B978-0-12-818971-9.00004-1.
Saudi authority for Industrial Cities and Technology Zones (2024), Cities and industrial areas in the regions of the Kingdom of Saudi Arabia.
Seifolddini-Faranak, M. Shabani Fard and Hosseini Ali (2009), Distribution and Determining of Tourist Attractions and Modeling of Tourist Cities for the City of Isfahan-Iran, American Journal of Economics and Business Administration 1 (2): 160-166.
Semple, R.K., Green, M.B. (1984). Classification in Human Geography. In: Gaile, G.L., Willmott, C.J. (eds) Spatial Statistics and Models. Theory and Decision Library, vol 40. Springer, Dordrecht. https://doi.org/10.1007/978-94-017-3048-8_4
Stéphanie Truchet, Virginie Piguet, Francis Aubert, Jean-Marc Callois. (2016) Spatial influence of attractions on tourism development. Tourism Geographies, 18 (5), pp.539-560.
Younes, Jaafar; Ghali, Kamel; Ghaddar, Nesreen (August 2022). "Diurnal Selective Radiative Cooling Impact in Mitigating Urban Heat Island Effect". Sustainable Cities and Society. 83:103932.