Proceedings of the Eighteenth International Conference on
Civil, Structural and Environmental Engineering Computing
Edited by: P. Iványi, J. Kruis and B.H.V. Topping
Civil-Comp Conferences, Volume 10, Paper 17.1
Civil-Comp Press, Edinburgh, United Kingdom, 2025
ISSN: 2753-3239, doi: 10.4203/ccc.10.17.1

The Impact of Land Use Changes on UHI Intensity in Kuwait City

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Abstract

The urban heat island (UHI) effect, characterised by elevated temperatures in urban areas due to heat-absorbing surfaces, poses significant environmental challenges, particularly amid climate change This study examines the relationship between Land Surface Temperature (LST), Normalized Difference Vegetation indices (NDVI), and land use type to understand the factors contributing to temperature increases and UHI formations. The dataset includes Landsat 8 satellite images of Kuwait City for 2013, 2018 and 2024. Statistical analysis, including linear regression, is performed to assess the correlation between LST and NDVI. Water bodies and UGS can significantly reduce LST, while the cooling effect is likely influenced by various factors such as vegetation density, water body size, and weather conditions. The UHI intensity in Kuwait City has increased by 13.5% from 2013 to 2024, highlighting the urgent need for urban planning strategies to combat this growing environmental challenge. UHI hotspots are primarily located in bare lands and industrial areas.

These findings highlight the importance of integrating green spaces and water bodies into city planning to mitigate the UHI effect and improve residents' overall quality of life.

Keywords: UHI, LST, remote sensing, NDVI, Kuwait City , land-use change, Landsat 8.

1. Introduction

Urbanization has led to significant transformations in many cities globally, particularly in environmentally sensitive regions like deserts, where vegetation is naturally sparse and ecosystems are more susceptible to change. Urban growth has significantly changed land use and cover, transforming natural soil and desert vegetation into roads and buildings made from concrete and asphalt [1]. These materials absorb more heat and reflect less solar radiation than natural land cover (e.g., trees and grass) [2]. This alteration disrupts the surface energy balance, causing surface radiance and infrared temperature variations between urban and rural areas [3]. The variation in air temperature between urban and rural areas can lead to the Urban Heat Island (UHI) effect [4], where cities experience higher temperatures than their rural surrounding area [5]. This effect is primarily caused by increased land surface temperature (LST) due to urban development [6], [7], [8]. Several factors influence UHI, including weather conditions such as rainfall availability, urban design elements like narrow streets between tall buildings, and population dynamics [9]. Studies have shown a direct link between UHI intensity and urban expansion, indicating that greater urban growth leads to a more intense UHI effect [10]. This intensified effect can increase temperature by approximately 2-4°C during heat waves [11]. Large-scale urbanization has been demonstrated to significantly elevate land and air temperatures, reinforcing the strong positive relationship between UHI intensity and the size of urban areas [12].

These temperature increases lead to adjustments in the surface energy balance, resulting in higher net surface long-wave radiation and sensible heat flux [13]. Additionally, the reduction in vegetation decreases cooling through evapotranspiration, causing heat absorbed during the day to be released slowly at night, leading to higher nighttime temperatures [14]. The UHI effect is further intensified by pollutants such as Carbon monoxide (CO), Nitrogen dioxide (NO2), Sulfur dioxide (SO2), and Particulate matter (PM), while ozone (O3) has been found to negatively correlate with UHI intensity[15] . These factors complicate the challenges related to air quality and public health, increasing mortality rates and global discomfort in very hot areas [16], [17]. Therefore, studying and analysing the UHI effect is important for developing mitigation strategies to improve air quality, reduce health risks, and enhance the livability of urban environments.

Kuwait City, an area experiencing rapid urbanization in an arid climate, faces challenges from the UHI effect, including elevated local temperatures, increased energy consumption, and damage to infrastructure. These temperatures linked to the UHI effect will have implications for environmental sustainability. These effects conflict with Sustainable Development Goals (SDGs) 11 and 13, which aim to create sustainable cities and take climate action [18], [19]. Addressing the UHI effect in Kuwait City is crucial for improving liveability and reducing energy costs in arid regions [20].

This study investigates the influence of vegetation on UHI effects by analysing the spatiotemporal correlation between LST and NDVI in Kuwait City in 2013 and 2024. Additionally, the study shows how various land use types contribute to the UHI effect. This paper is organized as follows: Section 2 materials and methods, Section 3 describes the results, Section 4 draws the conclusions and contributions.

2. Material and Methods

2.1 Study Area and Dataset

Kuwait City, covering 145 km², is a rapidly urbanizing arid region characterized by dense development, sparse vegetation, and high summer temperatures, making it ideal for UHI analysis. This study utilised three Landsat 8 (OLI/TIRS) images from July 2013, 2018 and 2024 with less than 10% cloud cover [21]. Land use data from 2018, including buildings, vegetation, roads, and industrial areas, was sourced from the Kuwait Institute for Scientific Research (KISR, 2018) to support spatial analysis Figure 1.

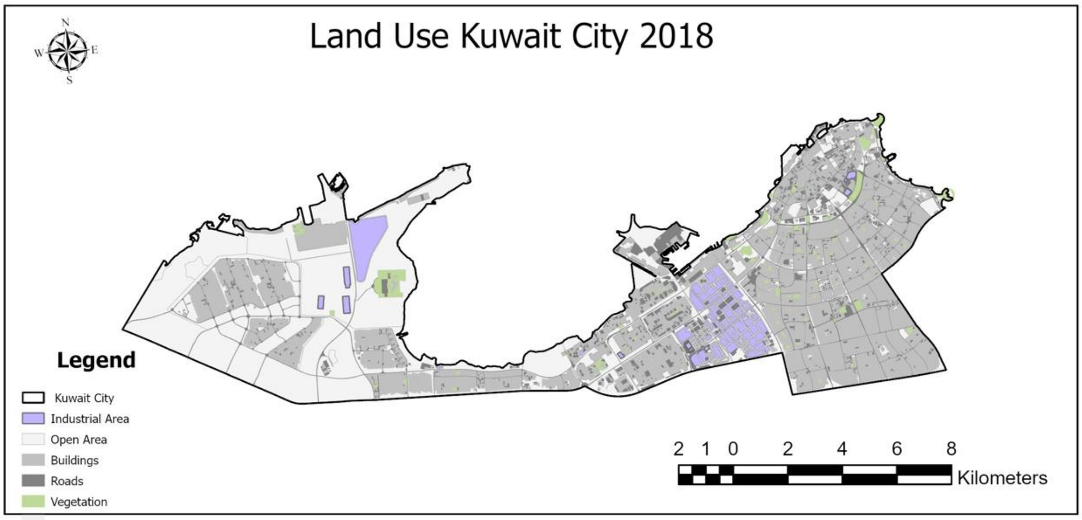

Figure 1. The land use distribution map of the study area, Kuwait City, illustrates major land cover categories such as industrial areas, open spaces, buildings, roads, and vegetation. This map defines the spatial extent used in the UHI analysis. (Data source KISR; map created by the author.)

2.2 Method Overview

Satellite imagery preprocessing and analysis were performed in ArcGIS Pro. LST was derived using standard radiative transfer algorithms [22] [21] [23]. The process involved computing radiance (Eq.1), brightness temperature (Eq.2), NDVI (Eq.3), NDBI (Eq.4), Proportion of vegetation (Eq.5), surface emissivity (Eq.6), and LST (Eq.7).

$L\lambda = ML \times Qcal + AL$ (1)
$BT = \ln(L\lambda K1 + 1)K2$ (2)
$NDVI = (Band5 - Band4)/(Band5 + Band4)$ (3)
$NDBI = (Band6 - Band5)/(Band6 + Band5)$ (4)
$Pv = (NDVImax - NDVImin/NDVI - NDVImin)2$ (5)
$\varepsilon = 0.004 \times Pv + 0.986$ (6)
$LST = BT/(1 + (\lambda \cdot BT/\rho)\ln\varepsilon)$ (7)

2.3 UHI and Land Change Analysis

UHI zones were identified using the mean (μ) and standard deviation (σ) of LST, with pixels classified as UHI [24] if:

UHI areas: $LST > \mu + 0.5 * \delta)$ (8)

Non- UHI areas: $0 < LST < \mu + 0.5 * \delta)$ (9)

2.4 Visual and Statistical Analysis

Visual and statistical analyses were performed to interpret the UHI dynamics and assess the relationship between UHI intensity and land use changes in Kuwait City. Random samples were extracted from the raster layer for statistical analysis, including descriptive statistics and regression, to evaluate the relationships between LST and NDVI in 2013 and 2024, assessing the link between UHI intensity and land use changes.

3 Results

UHI effects are influenced by human activities [25] and modifications in land use and land cover (LULC). The UHI dynamics map in Figure 2 illustrates the spatial distribution of UHI zones in 2013 and 2024. The findings indicate that the establishment of Al-Shaheed Park has contributed to a noticeable localised reduction in UHI intensity (Figure 3c). However, despite this cooling effect, the UHI area expanded from 40.5 km2 in 2013 to 46 km2 in 2024, marking approximately a 13.5% increase in affected area. Aerial images also highlighted UHI intensity zones in critical areas such as Shuwaikh Port, industrial zones, and bare lands Figure 3. This study demonstrates that industrial zones and bare lands in arid and semi-arid regions can significantly contribute to the UHI effect Table 1.

The study aimed to assess whether vegetation could reduce the UHI effect in Kuwait City. Results show that while introducing Al-Shaheed Park effectively reduced LST locally, the overall analysis of Kuwait City indicated an unexpected positive but negligible correlation between NDVI and LST in 2013 and 2014, R2 of 0.095 and 0.012, respectively (Figure 4a and 4b). However, when the data is filtered for temperatures below a threshold, such as 40°C in 2013, a positive correlation is found R2 = 0.315 (Figure 4c). This finding aligns with Uddin et al. (2010) study, which found that temperatures are higher even with higher NDVI values in arid cities [26].

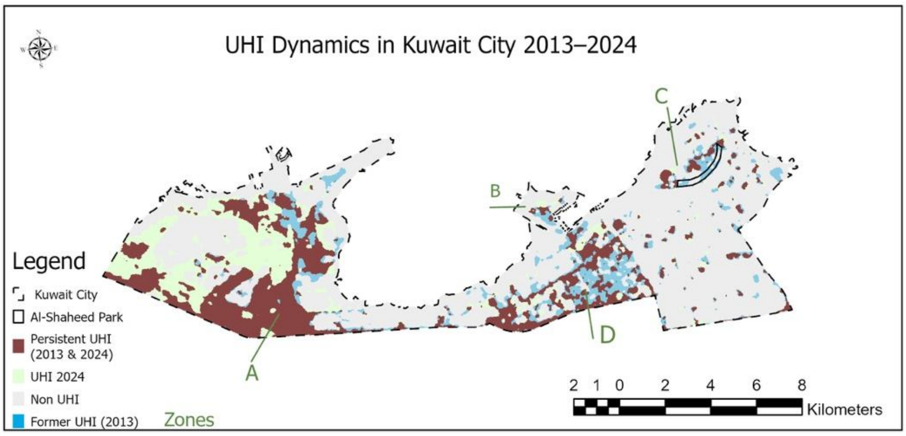

Figure 2a. UHI Dynamics in Kuwait City (2013-2024). Al-Shaheed Park reduced UHI intensity, but the overall UHI area expanded by 5.5 km2. Persistent UHI zones (A, B, C, D) remain hot (Figure 3)

Figure 3. Aerial images from Google Earth showing UHI hotspots in Kuwait City. (a) Bare lands around a residential area. (b) Newly constructed bridge and bare lands near Shuwaikh Port. (c) Al-Shaheed Park, surrounded by bare lands and tall buildings. (d) Industrial areas.

Table 1. Summary statistics of LST categorised by land use in Kuwait City (2018). This table shows various land use categories' maximum and minimum temperatures, including vegetation, buildings, roads, open areas, and industrial areas. (Land use map 2018 sources KISR)

Land Use Type	Min Temp (°C)	Max Temp (°C)	Mean Temp (°C)	Std Dev (°C)	Median Temp (°C)
Vegetation	32.96	48.28	44.03	2.49	44.54
Buildings	30.85	49.84	44.96	1.35	44.89
Roads	34.45	51.20	45.76	1.67	45.90
Open Area	30.50	52.55	46.89	3.05	47.38
Industrial Area	42.77	50.55	46.93	1.09	46.95

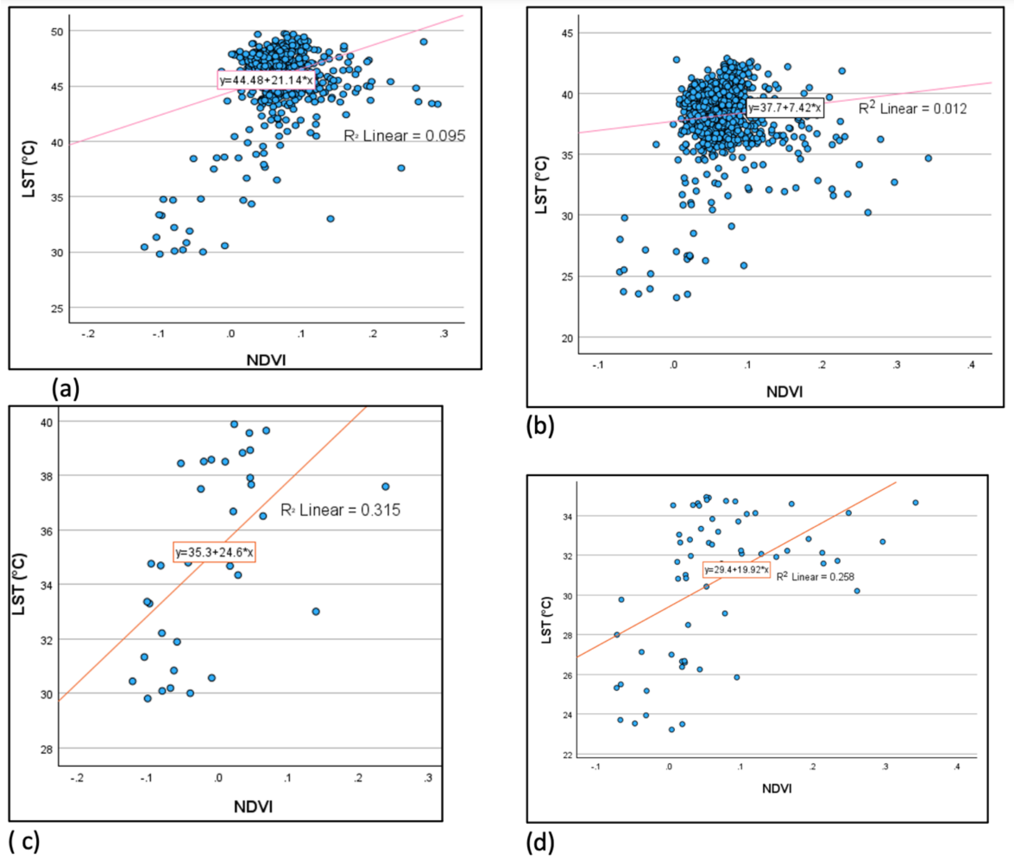

Figure 4. Linear regression models showing the relationship between LST and NDVI in Kuwait City for the years 2013 and 2024. **(a)** Overall linear regression for 2013 ($R^2 = 0.095$, $n = 993$, $p < 0.001$). **(b)** Overall linear regression for 2024 ($R^2 = 0.012$, $n = 993$, $p < 0.001$). **(c)** Linear regression for 2013 with temperatures below 40°C, where the orange line represents the filtered data, showing a stronger correlation ($R^2 = 0.315$). **(d)** Linear regression for 2024 with temperatures below 35°C, where the orange line represents the filtered data, showing a stronger correlation ($R^2 = 0.258$).

4 Conclusions and Contributions

This study utilises remote sensing and GIS tools, specifically Landsat 8 imagery, to evaluate the impact of vegetation and urbanization on LST and UHI effects in Kuwait City for 2013, 2018 and 2024. The study finds no clear correlation between NDVI and LST above 40°C. However, a weak negative correlation was detected below this temperature threshold, highlighting the limited cooling capacity of vegetation under extreme heat conditions. Conversely, urban parks (e.g., Al-Shaheed Park) and areas near water bodies recorded the lowest LSTs, confirming that vegetation and strategic urban planning can reduce local temperature and mitigate UHI effects. UHI hotspots are primarily located in Industrial areas and bare lands.

The findings highlight the importance of implementing government strategies in Kuwait, such as incorporating green spaces, strategically locating parks, using high-albedo materials, and optimizing urban designs. These efforts will improve urban sustainability and enhance the quality of life in arid cities.

Acknowledgements

This paper is part of my MSc thesis at the University of Glasgow. I thank the Kuwait Institute for Scientific Research (KISR) for providing the 2018 land use map, and my supervisor, Dr. Cristina Persano, for her guidance and insights.
We wish to acknowledge the support of Kuwait Foundation for the Advancement of Sciences (KFAS).

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