Seasonal Assessment of Land Use Impacts on Daytime and Nighttime Urban Heat Island Intensity Patterns in a Hot and Arid Region: A Case Study of Ahvaz, Iran

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Keywords: Daytime urban heat island, Nighttime urban heat island, Land use, Hot and arid areas, Thermal remote sensing.

Abstract

This study aims to assess the seasonal impact of land use on daytime normalized urban heat island (DNUHI) and nighttime normalized UHI (NNUHI) in Ahvaz, one of the hottest cities in Iran. To this end, 63 corrected Landsat images acquired in 2024 were used, and daytime land surface temperature (DLST) and nighttime land surface temperature (NLST) were derived for the four seasons. Thereafter, DNUHI, NNUHI, and normalized UHI (NUHI) indices were derived by normalizing the temperature differences between urban and non-urban areas. A land use layer consisting of 14 classes was overlaid with the thermal data to investigate the role of land use type in controlling thermal patterns. The results showed that the highest DNUHI values were observed in industrial (0.14-0.20) and oil (0.12-0.19) areas, which generated the highest daytime heating. At night, the highest NNUHI values were recorded in industrial (0.12-0.24), military (0.07-0.20), and oil (0.08-0.18) land uses, indicating the strong heat storage capacity of these areas. In contrast, green spaces, orchards, and agricultural lands showed the lowest DNUHI and NNUHI values (about 0.01-0.06). These findings can inform the design of sustainable climate strategies, the development of green spaces, and land use management to reduce urban heating.

1. Introduction

The urban heat island (UHI) phenomenon is one of the most important environmental challenges in cities in hot and arid regions, where the combination of very high temperatures, intense solar radiation, low humidity, and limited vegetation cover creates conditions for increased surface temperatures and heat accumulation in urban spaces (Abulibdeh, 2021; Kamal et al., 2023). Rapid urbanization, the expansion of impervious surfaces, the concentration of industrial and service activities, and extensive land use change have altered urban energy exchange patterns and intensified temperature differences between urban and suburban areas (An et al., 2025; Chen et al., 2022; Zhang et al., 2025). In extremely hot cities such as Ahvaz, this effect is observed not only during the day but also at night, because man-made surfaces store large amounts of energy during the daytime and release it during night.

The intensity and behavior of the UHI during the daytime and nighttime in different seasons are directly influenced by land use type and its associated physical surface characteristics (Firozjaei et al., 2018; Firozjaei et al., 2023; Li et al., 2024; Siddiqui et al., 2021). Each urban land use reflects a set of surface properties, such as the percentage of impervious surfaces, the amount and type of vegetation cover, the type and heat capacity of materials, the density of structures, and the pattern of energy consumption. Increasing impervious surfaces and reducing vegetation cover decrease evapotranspiration, increase solar radiation absorption, and enhance heat storage during the day (Firozjaei et al., 2020; Kiavarz et al., 2022; Morabito et al., 2021). On the other hand, land use type, for example industrial, commercial, or residential, reflects different patterns of human activity and energy consumption that directly affect the thermal behavior of the surface. Therefore, land use can act as an effective proxy for these surface characteristics and play a decisive role in shaping urban thermal patterns (Nadizadeh Shorabeh et al., 2020; Xiang et al., 2024; Zou et al., 2021). Hence, analyzing the relationship between land use and UHI intensity (UHII), especially in hot regions, plays a fundamental role in urban management, land use planning, and designing climate-adapted solutions.

Li et al. (2024) examined how seasonal differences in SUHII across cities worldwide are related to surface cover and changes in surface energy budget components (e.g. net radiation, sensible and latent heat fluxes, land use/land cover properties). Their results show that the patterns and UHII strongly depend on season; for example, in some cities UHII is stronger in summer, while in others in the transitional season, with these differences driven by land cover composition, background climate, and seasonal variations in surface energy fluxes. Liou et al. (2024) investigated the spatiotemporal patterns of SUHII and its influencing factors in Taiwan, coinciding at daytime/nighttime and seasonal scales. Their findings indicate that SUHII is on average stronger during the day than at night in all seasons. They further show that during the day, SUHII is negatively related to vegetation and normalized difference latent heat index (NDLI) and positively related to built-up intensity and anthropogenic heat, whereas at night the roles of air temperature, built-up intensity and anthropogenic heat become more prominent. Wang et al. (2025) focused on Chengdu city and used LST derived from ECOSTRESS data to investigate the effect of urban morphological details, including landscape patterns and building forms on the UHI across four seasons and between day and night. Their results showed that impervious surfaces are the most important factor in increasing LST, and that a high sky view factor plays a prominent role in reducing LST during the day in autumn and winter and at night in spring and summer. Shape diversity of impervious surfaces can have a cooling effect, whereas on summer days tall and dense buildings significantly increase surface temperatures. The shape diversity and density of impervious surfaces played the greatest role in changing surface temperature in spring, summer and autumn, whereas in winter building-related indices were dominant. Grasslands and water bodies also significantly affected LST at most times, except on winter and summer nights.

Despite numerous studies on the UHI, there is still no comprehensive understanding of the seasonal and diurnal differences in the interaction between land use patterns and UHII in hot and arid climates. Most studies have focused either on the thermal behavior of a season, or only on daytime or nighttime temperatures. However, in cities such as Ahvaz, large seasonal temperature differences, variations in incoming radiation, and changes in energy consumption patterns cause the role of urban land uses in generating heat to vary from one season to another. Therefore, simultaneous analysis of the daytime normalized UHI (DNUHI), nighttime normalized UHI (NNUHI), and normalized UHI (NUHI) indices can provide a more accurate picture of the city's thermal dynamics throughout the year. The main objective of this study is to investigate the seasonal impact of land use on daytime and nighttime UHII in hot and arid regions.

2. Study area

Ahvaz is the capital of Khuzestan Province in southwestern Iran and is one of the hottest and driest cities in the country (Figure 1). The city is located between 31°10′ and 31°25′ N and 48°35′ and 48°46′ E and covers an area approximately 188 km^2. According to the Köppen-Geiger climate map, Ahvaz has a subtropical semi-arid hot desert climate (BWh), characterized by extremely hot summers, with air temperatures sometimes exceeding 50°C and mild, relatively dry winters. The remarkable diversity of land uses and surface patterns, including extensive impervious surfaces in industrial and central areas, limited vegetation cover across most of the city, and agricultural land and orchards in the surrounding countryside makes Ahvaz a suitable case study for analyzing the relationship between land use and thermal behavior in a hot and arid climate. Moreover, the difference between the physical structure of the eastern and western parts of the city, the significant changes between daytime and nighttime temperatures, and variations in energy consumption patterns provide a valuable opportunity to examine the seasonal intensity of daytime and nighttime UHI.

(a) (b)

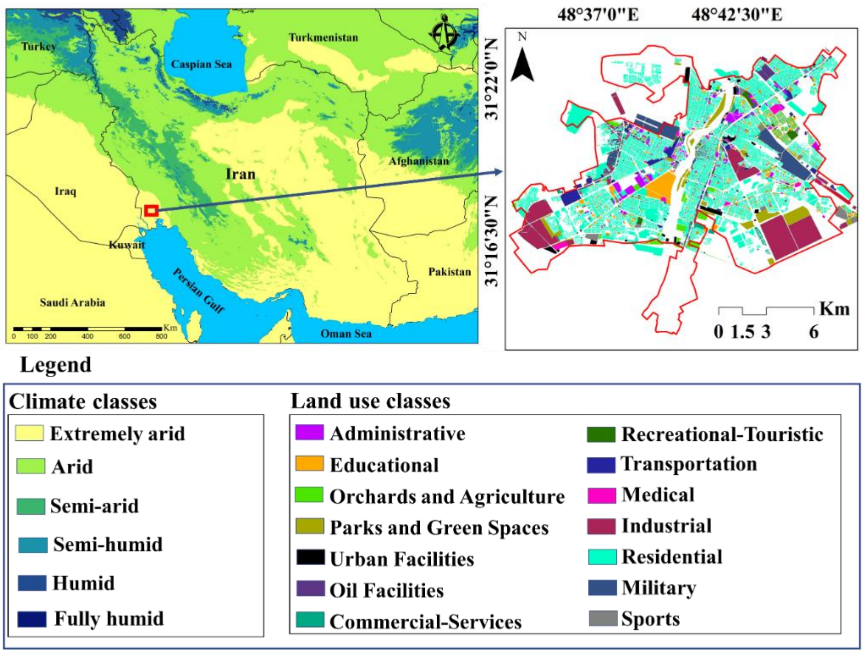

Figure 1. (a) Geographical location of the study area in Iran on the climate classification map and (b) land use map of the study area.

3. Data Source and Processing

In this study, a combination of remote sensing data and land use information was used to investigate the seasonal intensity of daytime and nighttime UHI in Ahvaz. First, Landsat 8 and 9 images from 2024, including OLI reflectance and TIRS thermal bands at the corrected level (Collection 2, Level-2), were collected. A total of 63 daytime and nighttime images with minimal cloud cover were selected, and a combination of daytime land surface temperature (DLST) and nighttime land surface temperature (NLST) was produced for each season. The land use layer was also prepared based on updated urban management data and high-resolution imagery and includes 14 main classes (Figure 1). This layer was converted to a 30 m raster and spatially matched to the thermal data. To improve data quality, all pixels affected by clouds and cloud shadows were removed, the coordinate system was unified, and all datasets were prepared for pixel-based analysis.

4. Methodology

The methodology of this research consists of four main steps: data preparation, thermal parameter extraction, calculation of daytime and nighttime UHII indices, and analysis of their relationship with land use across the four seasons. In the first step, Landsat 8 and 9 images at the corrected level (Level-2) for the year 2024 were collected and initial processing including removal of cloud and cloud shadow pixels using the CFMask mask was performed. Next, daytime and nighttime images were combined for each season and used to derive seasonal mean DLST and NLST. In the third step, UHII indices, including DNUHI, NNUHI, and NUHI were calculated using equations (1)-(3) (Wu et al., 2023) for uniform comparison between seasons and land uses types. For this purpose, first, the difference between daytime and nighttime LST of urban pixels and the mean LST of surrounding non-urban areas was computed. Then, these thermal differences were rescaled to a standard range using linear normalization to make thermal changes comparable across seasons and land uses. The NUHI index was obtained as the average of DNUHI and NNUHI to represent the combined daytime and nighttime thermal behavior.

$$DNUHI = \frac{T_d^u - \overline{T_d^r}}{T_d^{max} - T_d^{min}} \quad (1)$$

$$NNUHI = \frac{T_n^u - \overline{T_n^r}}{T_n^{max} - T_n^{min}} \quad (2)$$

$$NUHI = \frac{DNUHI + NNUHI}{2} \quad (3)$$

where T_d^u represent the daytime urban LST, $\overline{T_d^r}$ is the mean daytime rural LST, T_d^{max} and T_d^{min} correspond to the maximum and minimum DLST values within the study area, respectively. Here T_n^u and $\overline{T_n^r}$ represent the nighttime urban LST and mean nighttime rural LST, respectively. T_n^{max} and T_n^{min} represent maximum and minimum nighttime LST values, respectively. Finally, the land use layer, consisting of 14 different classes, after rescaling and converting it to a 30 m raster, the layer was overlaid with heat index maps. For each season, the mean DNUHI, NNUHI, and NUHI values were extracted for each land use class to determine the impact of land use type and its associated surface characteristics on urban thermal behavior. This analysis allowed the identification of heat-generating and cooling land uses. Finally, the seasonal results were displayed using graphs and thermal maps to accurately assess daytime and nighttime differences and the effect of seasonal variation on the UHI in Ahvaz.

5. Results

The spatial distribution of LST maps indicates that the city center and industrial-commercial zones with high building density exhibit higher temperatures than surrounding areas, particularly those with vegetation cover and agricultural lands. These high-temperature zones are mainly concentrated in the central and southeastern parts of the study area (Figure 2). During winter, DLST values are relatively low across large portions of the city, with surface temperatures mostly falling into medium to low classes. However, as the seasons transition into warmer periods, particularly in summer, surface temperatures rise sharply, and a significant portion of the city area shifts to high and very high temperature classes. This increase is directly related to intense solar radiation, reduced surface moisture, and a scarcity of vegetation cover in Ahvaz. Areas with higher surface temperature values were more prevalent in the eastern half of the city across all four seasons compared to the western half. The differences between the maximum and minimum DLST values in Ahvaz were approximately 16, 20, 22, and 20 K in winter, autumn, spring, and summer, respectively. The differences between the maximum and minimum NLST values were around 12, 10, 12, and 10 K for winter, autumn, spring, and summer, respectively. At night, the heat stored in urban construction materials, particularly in the city center, is slowly released, maintaining the temperature difference between urban and rural areas. As a result, the surface UHI effect persists during the night. The highest NLST values in winter, autumn, spring, and summer were approximately 282, 289, 299, and 305 K, respectively.

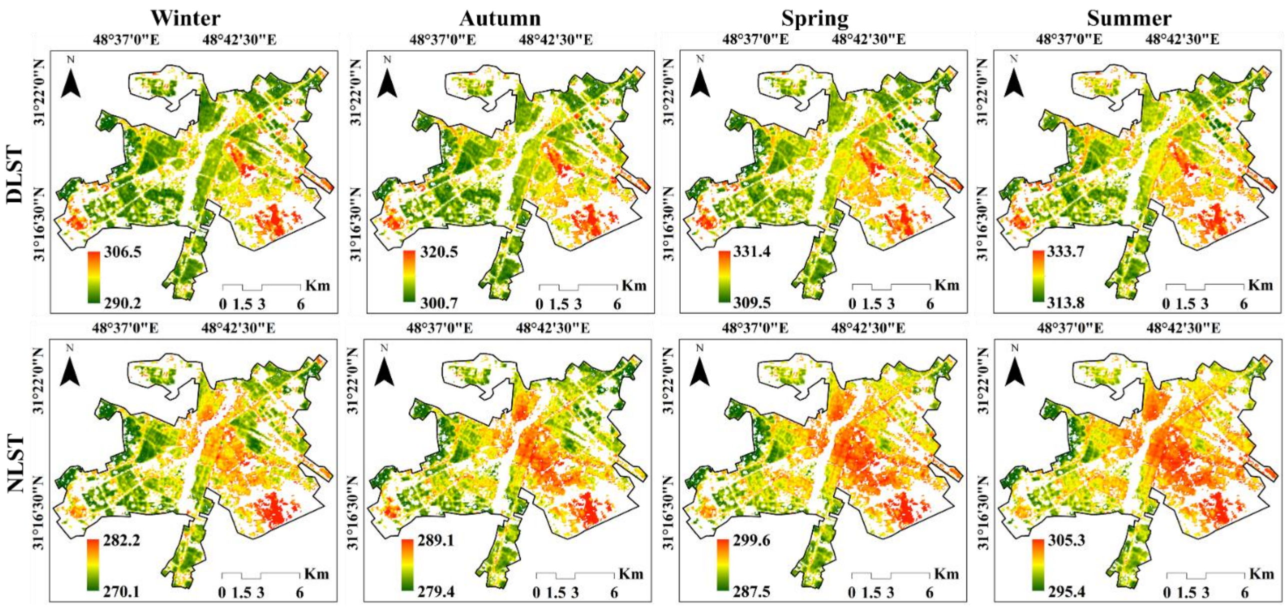

Figure 2. Maps of DLST and NLST in Ahvaz city across different seasons.

The DLST in Ahvaz consistently increases from winter to summer, rising from approximately 295.3 K in winter to 323.1 K in summer, indicating a substantial temperature rise during the warm seasons (Table 1). The standard deviation of DLST also increases from spring to summer (from 2.31 in winter to 2.90 in summer), reflecting greater thermal fluctuations during the daytime in hotter seasons. Similarly, the NLST shows an upward trend, increasing from 275.8 K in winter to 299.8 K in summer. However, its standard deviation remains relatively stable (ranging between 1.29 and 1.56), suggesting that nighttime thermal variations are less pronounced than those observed during the day. Given the significant increases in both DLST and NLST, the overall cooling effect of higher albedo appears to be limited.

Factors/Seasons		Winter	Autumn	Spring	Summer
DLST	Mean	295.3	306.7	318.9	323.10
	Standard Deviation	2.310	2.650	2.600	2.900
NLST	Mean	275.8	283.1	292.3	299.80
	Standard Deviation	1.520	1.290	1.560	1.330

Table 1. Mean and standard deviation of DLST and NLST (K) for Ahvaz city across different seasons.

https://doi.org/10.5194/isprs-archives-XLIX-B3-2026-387-2026

The spatial distribution of the NUHI during the day, night, and day-night average across the four seasons is illustrated in Figure 3. The observed patterns indicate significant seasonal variations and a clear concentration of heat in the central and densely built-up areas of the city. In winter, most parts of the city fall into the low-intensity categories, with only a few hot spots in the urban core. As the seasons transition toward warmer periods, particularly from autumn to spring, daytime heat intensity increases, and areas with moderate to high intensity expand. During summer, the maps reveal that daytime heating reaches its maximum extent, with the urban core, industrial zones, and densely constructed areas exhibiting the highest intensity levels. This pattern highlights the dominant role of intense solar radiation, increased anthropogenic heat emissions, and high building density in amplifying the daytime SUHI effect. At night in winter, the temperature difference between urban and rural areas decreases, and the city is mostly covered by low and very low intensity classes, indicating rapid heat loss. However, from autumn and especially in spring, warmer zones begin to appear within the city center. In summer, high and very high intensity areas become prominent due to the gradual release of stored heat from low-albedo and high-thermal-capacity materials. This trend suggests that nighttime urban heating remains persistent and reaches its peak in summer. Overall, the NUHI maps demonstrate a continuous and increasing trend in UHII from winter to summer. In winter, heat accumulation is primarily confined to the central districts, but as summer approaches, warmer zones expand, encompassing the entire urban core. During summer, both the highest intensity and the widest spatial extent of urban heating are observed, even extending into some peripheral areas.

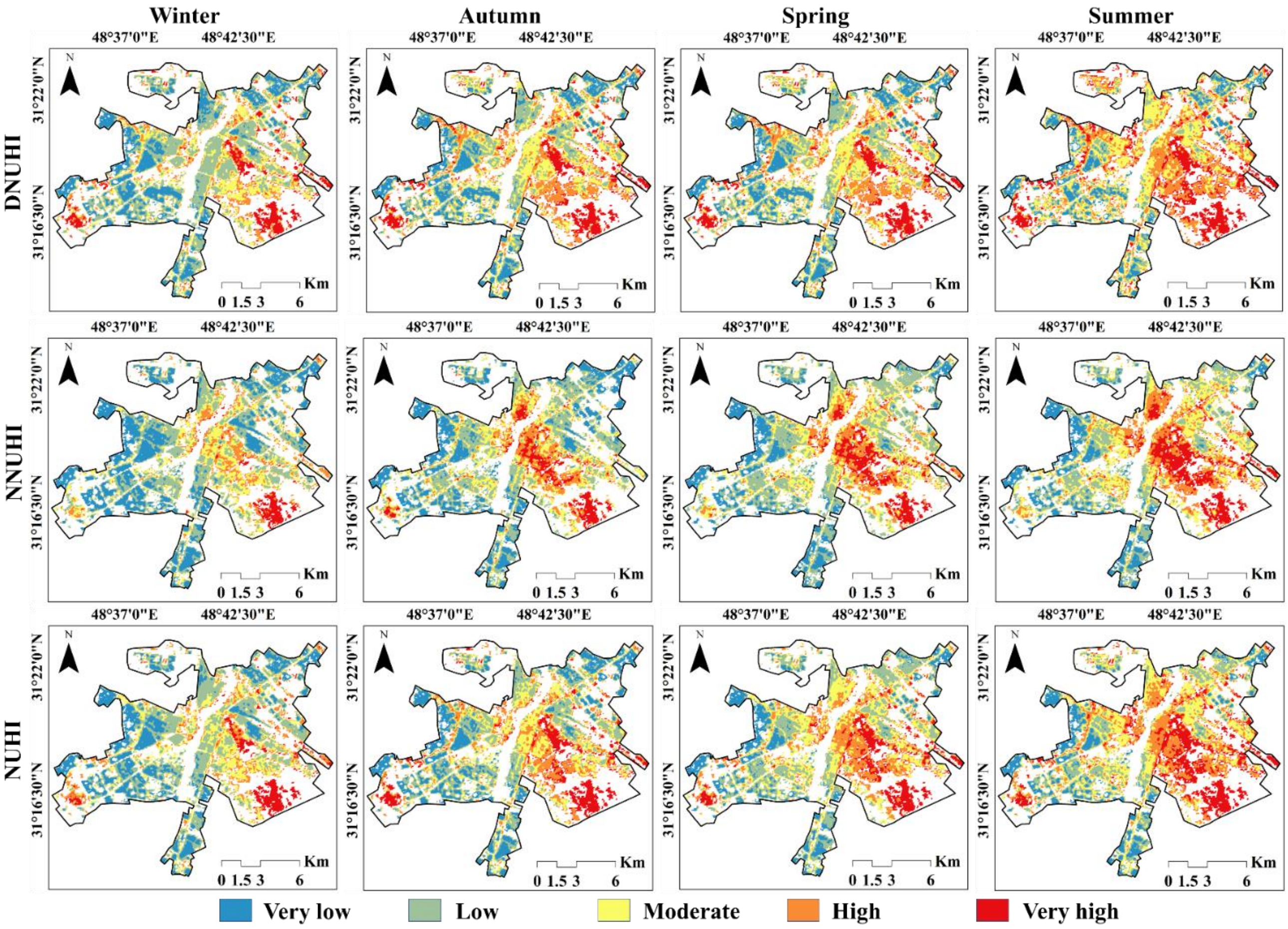

Figure 3. Maps of DNUHI, NNUHI, and NUHI for Ahvaz city across different seasons.

In winter, the low DNUHI class covers the largest area, approximately 33.57 km², indicating low heating intensity during the cold season (Figure 4). With the onset of autumn, the medium-intensity class expands to 27.50 km², marking the beginning of a gradual intensification of heat accumulation. This trend continues into spring, where the medium class reaches its peak extent of 32.89 km². During summer, the heating effect reaches its maximum, with the medium (30.44 km²) and high (30.46 km²) intensity classes becoming dominant. Moreover, the very high class increases from 9.14 km² in winter to 20.93 km² in summer, representing more than a twofold rise in severe daytime heating. Regarding the NNUHI, the nocturnal urban heat pattern is more variable and concerning. In winter and autumn, the low-intensity class still covers the largest areas (38.86 km² and 36.67 km², respectively), reflecting efficient dissipation of heat stored during the day. However, in spring and especially in summer, stored heat in urban materials is released more intensely at night, leading the medium class to expand to 27.91 km². Notably, the area of the very high class increases from 3.99 km² in winter to 15.76 km² in summer, nearly a fourfold rise. This indicates that the thermal effects associated with high heat capacity and limited energy exchange in Ahvaz manifest as a persistent nighttime phenomenon, posing a serious threat to human health and thermal comfort during hot seasons.

The NUHI, which integrates both daytime and nighttime effects, further highlights the persistence and intensity of the heat island in Ahvaz. In winter, the low-intensity class dominates with an area of 40.60 km², indicating a weak SUHI effect. However, from autumn onward, the heating pattern shifts, and in spring and summer, the medium-intensity class expands to around 29.54

km² and 29.00 km², respectively, showing a transition of heat concentration toward moderate and high levels. Additionally, the very high-intensity class increases from 6.90 km² in winter to 19.22 km² in summer almost a threefold rise demonstrating the growing persistence and intensity of urban heat accumulation across seasons.

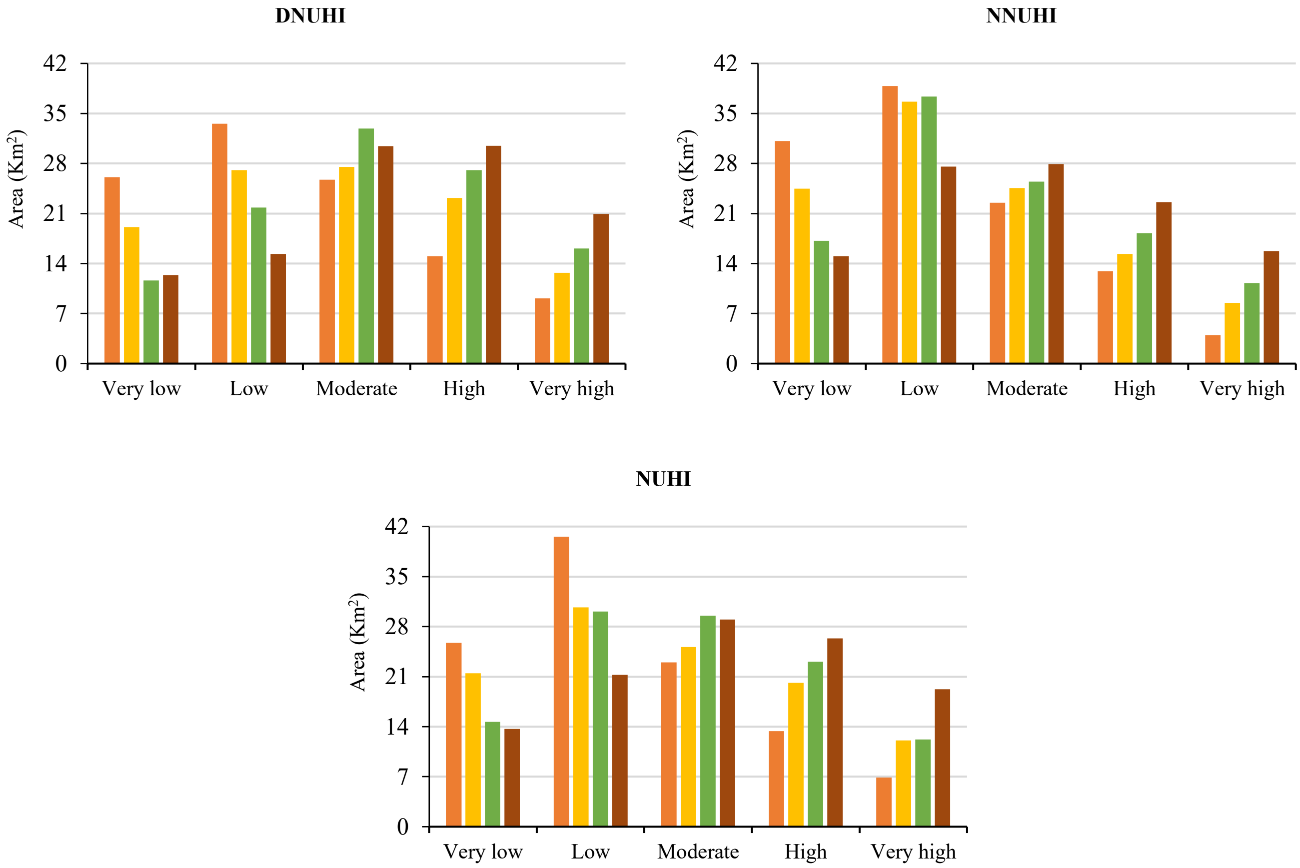

Figure 4. Area of DNUHI, NNUHI, and NUHI classes in Ahvaz city across different seasons (km²).

The analysis of the mean values of the DNUHI, NNUHI, and NUHI urban heat island indices across various land use types in Ahvaz reveals that the spatial pattern of urban heat is highly dependent on land use, human activity, and seasonal variations (Figure 5). During the day, the highest DNUHI values are observed in industrial (0.14-0.20) and oil facility areas (0.12-0.19), indicating their strong contribution to surface heat generation and accumulation. Continuous energy consumption and industrial operations, particularly in summer, intensify surface temperatures and UHI effects. Following these, military zones (0.10-0.16) and urban utilities and transportation areas (0.08-0.13) also exhibit considerable heat levels. Conversely, green spaces, gardens, and agricultural lands (0.03-0.05), along with residential areas (0.01-0.03), record the lowest daytime heating.

At night, the heat distribution pattern changes notably. NNUHI remains high in industrial (0.12-0.24) and military (0.07-0.20) areas, reflecting the persistence of stored heat. Construction materials with high thermal capacity such as concrete and asphalt contribute to slow nighttime cooling in these zones. Oil facilities also maintain relatively high NNUHI values (0.08-0.18), underscoring their role in nocturnal heat retention. In contrast, green areas, gardens, and farmlands exhibit very low NNUHI (0.01-0.06), while residential zones (0.02-0.13) demonstrate moderate cooling effects, emphasizing the nighttime mitigation capacity of vegetated land uses.

Overall, the highest NUHI values occur in industrial (0.13-0.22) and oil facility areas (0.10-0.19), confirming their dominant role in both daytime and nighttime heat accumulation. These are followed by military, transport, and urban utility areas with moderate to high NUHI (0.07-0.18). Residential, green, and agricultural lands have the lowest NUHI (0.02-0.08), contributing least to urban heat enhancement. From a seasonal perspective, the highest UHII is observed during summer, driven by intense solar radiation and increased energy use. Mean DNUHI, NNUHI, and NUHI values all rise significantly in summer, with industrial and densely populated zones experiencing the most severe heat stress. In autumn and spring, DNUHI and NUHI values decrease slightly, though industrial and oil-related land uses remain comparatively warmer. Winter exhibits the lowest DNUHI and NNUHI values, coinciding with reduced solar input and seasonal heating demands. Furthermore, the smaller difference between DNUHI and NNUHI in industrial and oil areas indicates sustained heat retention from day to night. In contrast, larger day-night temperature differences in green and agricultural areas reflect their strong capacity for nocturnal cooling.

Although the analysis focuses on a specific urban area, the observed thermal behavior of different land use classes is consistent with patterns reported in other UHI studies. In particular, industrial and densely built-up areas tend to exhibit higher land surface temperatures due to low albedo materials, limited vegetation cover, and high heat storage capacity.

Conversely, urban green spaces demonstrate greater thermal stability and lower temperature variability because of evapotranspiration and shading effects. Therefore, the results of this study may be indicative of thermal dynamics commonly observed in medium-density urban environments with comparable climatic and morphological conditions. These findings contribute to the broader understanding of how land use composition influences spatial temperature variability and may support urban planners in designing mitigation strategies for UHIs in similar cities.

	DNUHI				NNUHI				NUHI			
	Winter	Autumn	Spring	Summer	Winter	Autumn	Spring	Summer	Winter	Autumn	Spring	Summer
Administrative	0.06	0.09	0.07	0.09	0.06	0.06	0.13	0.19	0.06	0.07	0.10	0.14
Educational	0.05	0.06	0.05	0.06	0.05	0.04	0.10	0.15	0.05	0.05	0.08	0.11
Orchards and Agriculture	0.03	0.05	0.03	0.05	0.02	0.01	0.04	0.06	0.03	0.03	0.03	0.05
Parks and Green Spaces	0.04	0.05	0.03	0.04	0.05	0.04	0.11	0.15	0.05	0.05	0.07	0.10
Urban Facilities	0.08	0.11	0.09	0.12	0.08	0.07	0.13	0.19	0.08	0.09	0.11	0.16
Oil Facilities	0.12	0.16	0.12	0.19	0.08	0.04	0.12	0.18	0.10	0.10	0.12	0.19
Commercial-Services	0.05	0.07	0.06	0.08	0.05	0.06	0.12	0.18	0.05	0.06	0.09	0.13
Recreational-Touristic	0.08	0.10	0.07	0.08	0.08	0.06	0.12	0.17	0.08	0.08	0.09	0.12
Transportation	0.08	0.11	0.09	0.13	0.06	0.06	0.11	0.17	0.07	0.08	0.10	0.15
Medical	0.05	0.07	0.05	0.07	0.06	0.05	0.11	0.16	0.05	0.06	0.08	0.11
Industrial	0.14	0.19	0.15	0.20	0.12	0.10	0.18	0.24	0.13	0.15	0.16	0.22
Residential	0.01	0.02	0.02	0.03	0.02	0.03	0.08	0.13	0.02	0.03	0.05	0.08
Military	0.10	0.13	0.10	0.16	0.07	0.05	0.13	0.20	0.09	0.09	0.12	0.18
Sports	0.09	0.11	0.08	0.12	0.08	0.06	0.13	0.19	0.08	0.09	0.11	0.15

Figure 5. Heatmap of the mean values of DNUHI, NNUHI, and NUHI across different land use classes in Ahvaz for each season.

6. Conclusion

This research investigated the seasonal effect of land use on the daytime and nighttime UHII in Ahvaz city, one of the hot and arid regions of Iran. The results showed that UHI in Ahvaz is strongly influenced by both season and land use type. The largest areas with very high intensity in the DNUHI, NNUHI, and NUHI indices were observed in summer, indicating the intensification of urban heating during the warm period of the year. In particular, the mean DLST and NLST increased to 323.1 K and 299.8 K, respectively, and the daytime and nighttime temperature differences were greater in industrial and oil areas, indicating the high capacity of these land uses to store and release heat. The study of the relationship between thermal indices and land use showed that industrial and oil uses play the greatest role in increasing surface temperature and enhancing the UHI, whereas green spaces, orchards, and agricultural lands with their high evapotranspiration and shading capacity effectively reduce surface temperature and moderate urban heating. Beyond confirming the cooling role of urban green spaces, this study quantitatively demonstrates the differences in thermal amplitude between land use types during daytime and nighttime conditions. The results indicate that industrial areas not only exhibit higher absolute temperatures, but also larger diurnal temperature variations compared with vegetated surfaces. This suggests that vegetation contributes not only to cooling but also to thermal regulation within the urban environment. These findings highlight the importance of preserving and expanding green infrastructure as a strategy to reduce thermal stress and stabilize urban microclimates. Also, the significant differences between daytime and nighttime temperatures across land use types further highlight the importance of spatial design and land use management for reducing thermal impacts. These findings suggest that urban planning measures such as development of green spaces can effectively reduce the UHII and improve the thermal comfort of residents. In addition, the use of remote sensing data for simultaneous analysis of daytime and nighttime temperatures and land use classification provides a powerful tool for identifying high-risk areas and prioritizing urban heating mitigation strategies. One limitation of this study is that the analysis relies primarily on Landsat-derived land surface temperature data for a specific time period. Although satellite-based measurements are widely used in UHI studies, future research could integrate in situ air temperature measurements to further validate satellite observations. Additionally, extending the analysis to multi-year datasets and multiple cities would provide a more comprehensive understanding of long-term thermal dynamics and improve the generalizability of the results. Nevertheless, the current study provides a detailed snapshot of the spatial relationship between land use and urban thermal patterns. Overall, the results of this study provide scientific and practical guidance for designing climate-resilient strategies, land use management, and urban development resilient to extreme heat in cities in hot and arid regions.

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