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Influence of the Land Surface Temperature and Urban Heat Island Effect on $PM_{2.5}$ in Faisalabad during the Summer of 2023

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Abstract

The relationship between Land Surface Temperature (LST), Urban Heat Island Intensity (UHII) and $PM_{2.5}$ air pollution in Faisalabad is being explored in the summer (June, July and August, JJA) of 2023. Kriging interpolation, buffer zones and regression models were applied using the combined data from MODIS, CAMS reanalysis and GIS approaches to look at heat and pollution dynamics. LST values during the day exceeded 42˚C and UHII was as high as 1.95˚C in the middle and industrial parts of the city. At night, the air's $PM_{2.5}$ levels increased above 275 μg/m^3 which occurred because of conditions caused by monsoon weather and inversions. LST and UHII were linked with a moderate degree of correlation ($r \approx 0.53$), though their effect on $PM_{2.5}$ and the consistency of this relationship showed that other factors, such as human activities and weather are involved. Even though it focuses only during summer, the study gives practical information about areas hit by both thermal and pollution stress. The integrated geospatial method can be applied to urban environmental planning in other cities in South Asia.

Keywords

Urban Heat Island Intensity, Land Surface Temperature, $PM_{2.5}$, Urbanization, Air Quality

1. Introduction

Urbanization in South Asia is progressing at an unprecedented pace, reshaping landscapes and placing increasing pressure on urban ecosystems. The rapid expansion of built-up areas in cities such as Faisalabad, Pakistan, is associated with significant changes in land use and surface properties. As a result, there are critical challenges such as the Urban Heat Island (UHI) effect, elevated Land Surface Temperature (LST) and increased air pollution, mainly from $PM_{2.5}$ particles. The replacement of natural vegetation and permeable surfaces with impervious materials such as concrete and asphalt disrupts urban energy balances and microclimatic conditions (Zhang et al., 2015). The UHI effect is a major result of changing land into urban spaces quickly. The excessive heat in the city during the day and slower cooling at night is a result of both urban materials and the heat put out by people. Faisalabad's build-up surfaces can absorb much heat from the sun in the day and slowly release it during the night, resulting in higher temperatures in the city at night and less of a daily gap between high and low temperatures (Di Bernardino et al., 2023). Often, the plants that moderate air temperature through perspiration are missing from urban areas, which makes it harder for cooler outdoor air to reach buildings and can increase local heat retention (Zeeshan et al., 2024). At the same time, $PM_{2.5}$ is very concerning for air quality because of the dangerous health problems it causes. Particles in $PM_{2.5}$ which measure less than 2.5 microns, can enter deep into the lungs, resulting in problems for the heart, lungs and nerve system. Among its various sources are vehicles, factories, the burning of plant matter, dust in construction and aerosol that forms from atmospheric chemical reactions (Jhun et al., 2015; Yin et al., 2023). It is especially important to note that the increased heat in cities intensifies $PM_{2.5}$ accumulations by slowing down the normal mixing in the atmosphere, holding pollutants near the ground late at night (Wu et al., 2017). Faisalabad shows how industrial progress in South Asian cities brings multiple types of environmental problems. It is developing very rapidly in Pakistan, thanks to its textile, farming and logistics industries. Despite the booming economy, lots of green space and farmland have been lost over the past years, as shown by research based on remote sensing (Kausar et al., 2023). Now, most of Faisalabad's scenery is made up of structures which has caused the air to become hotter and less able to recover from disruptions (Parveen et al., 2019). Climatic and air quality reflect that changes are taking place in Faisalabad's environment. Readings from satellites in the summer of 2023 showed temperatures of more than 41˚C in the central city, but lower levels were found in the fringes because of less heat being trapped by vegetation and soil moisture. During the day, the Urban Heat Island Intensity reached 1.95˚C, while at night it was 0.66˚C, showing that there were big differences in temperatures across the urban-rural boundary. These situations accompanied high $PM_{2.5}$ numbers, reaching a high of 275 μg/m^3 near big industries and congested roads, much greater than the 15 μg/m^3 standard set by the World Health Organization (WHO, 2023). LST, UHI and $PM_{2.5}$ have not been assessed in an integrated way, together with data-scarce, mid-scale cities, although they are all linked. Special attention is typically given to air pollution and temperatures, but it's less common to consider the places these factors actually overlap. By being split, policy efforts often do not work well, particularly in developing countries that have poorly developed spatial planning, environmental monitoring and healthcare infrastructure (Hoek et al., 2008). Geospatial technologies are now advancing faster, offering a chance to solve the gap. Using MODIS LST products, imagery from Sentinel-2 and CAMS-EAC4 air quality models, it is possible to observe the link between urban heat and pollution over time. By working with statistical models like Pearson correlation, regression analysis and spatial interpolation, these data permit a detailed and quantified assessment of sources of environmental pressure (Zhang et al., 2015). This study, therefore, adopts a multidisciplinary and geospatial approach to evaluate the interactions between LST, UHI, and $PM_{2.5}$ in Faisalabad during the summer season of 2023. The study delineates four principal research objectives for attainment. 1) To investigate the spatial and temporal maps of LST at day and night times of JJA-23 and calculate UHI intensity across Faisalabad. 2) To analyze variation in $PM_{2.5}$ concentrations through spatial interpolation maps. 3) To detect the $PM_{2.5}$ levels at day and night times through buffer analysis over LULC. 4) To access the influence of LST and UHI on $PM_{2.5}$ by performing correlation analysis. This research not only advances academic knowledge but also informs data-driven urban development strategies aimed at mitigating heat stress and pollution exposure in rapidly expanding cities. This study focuses on the summer season (JJA-2023) since this time includes the highest heat and pollution levels in cities. Though it misses some seasonal shifts, this approach makes it easier to watch bees when they encounter the most difficulties. Even though the findings relate to Faisalabad in particular, they are relevant by concept to other South Asian cities with similar industries, city layouts and climate. Bringing together LST, UHII and $PM_{2.5}$ data with geospatial tools establishes a valuable pattern that can be applied to urban climate studies outside the region.

Study Area

The city of Faisalabad in the plains of northeastern Punjab, Pakistan (31˚24'N, 73˚04'E), has grown into one of the most industrialized and crowded areas in the country. This high volume of textile activity makes Dhaka a center of urban environmental challenges. The city's climate is subtropical semi-arid, marked by hot summers, cool and dry winters and swinging day-to-night temperature changes, with summer temperatures often reaching 45˚C. Expanding cities, a lack of green spaces and much car and industry pollution have worsened the UHI problem in Faisalabad. Surveys demonstrate that sealants, less vegetation and fuel combustion have made LST increase and harmed air quality in cities. Large differences in temperatures and pollution occur in Faisalabad due to the differences in land use found in the areas and zones shown in **Figure 1**. Similarly, Zeeshan et al. (2024) found that summer LST was increased because of both plants losing cover and a rise in hard surfaces. The authors also pointed out that a decrease in evapotranspiration from plants causes higher temperatures in cities. Rauf et al. (2024) proved that Faisalabad's hot zones commonly occur near $PM_{2.5}$ hotspots, showing the two are related. Researchers Yang et al. (2021) also found that increases in $PM_{2.5}$ levels make UHI problems more severe by altering both the radiation and energy distributions of the planet's surface. In addition, Santamouris (2015) supported these results in his own meta-analysis by pointing out that cutting down natural vegetation outside cities contributes to consistent urban temperature rise. Consequently, issues such as trapped air and heat-trapped conditions in the city's streets make pollution issues worse because pollutants can't move away quickly and are more likely to form photochemical pollutants (Zhang et al., 2024; Di Bernardino et al., 2023).

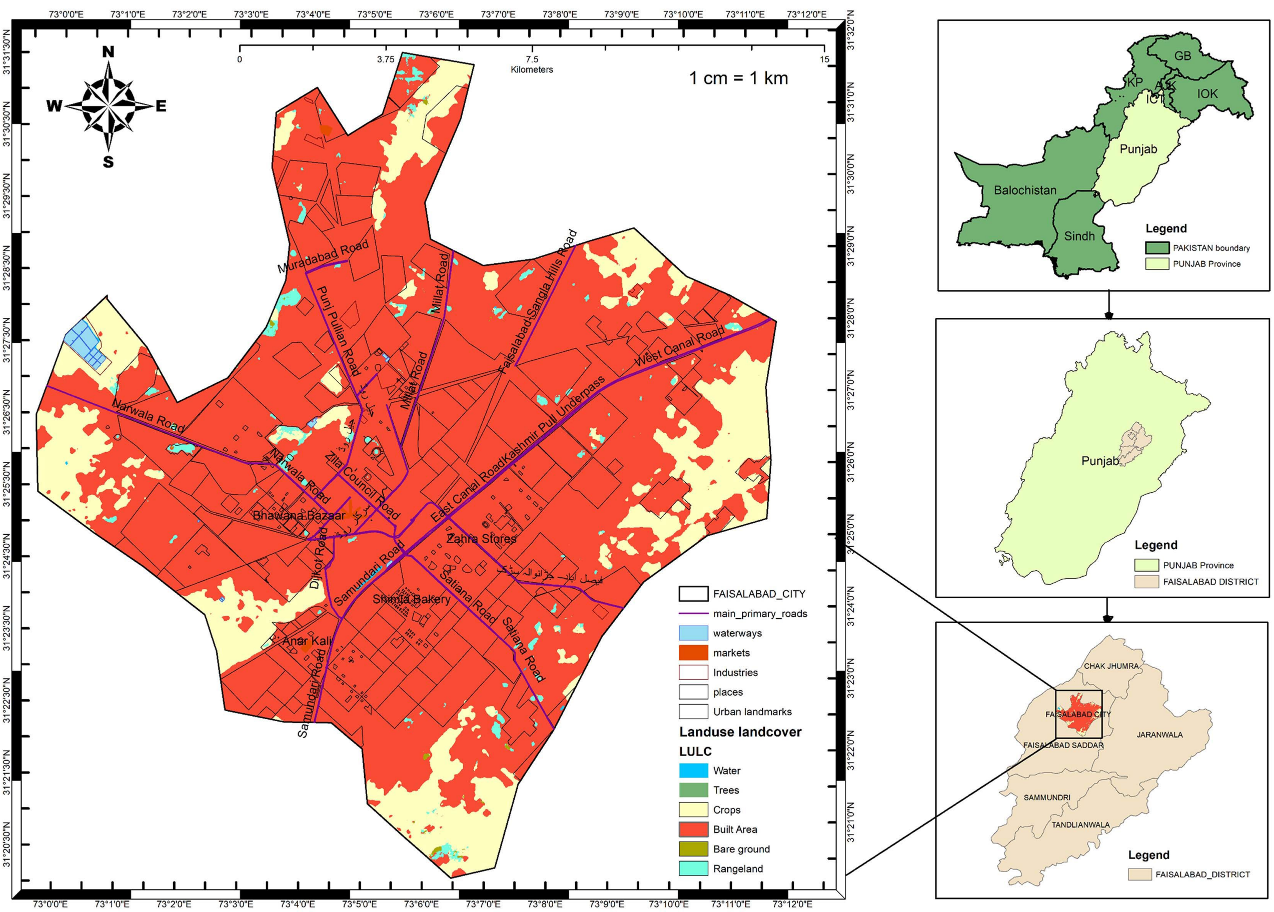


Figure 1. Study area map of Faisalabad along land use land cover (LULC) of 2023 and national administrative boundaries.

2. Materials and Methods

2.1. Data Sources

This study employed a combination of satellite-based remote sensing datasets and reanalysis products to perform comprehensive geospatial and statistical analyses. Land Surface Temperature (LST) data were obtained from the MODIS Terra

MOD11A1 daily product, which provides daytime and nighttime LST values at a spatial resolution of 1 km. These data enabled detailed mapping of thermal patterns across Faisalabad. To assess air quality, surface-level $PM_{2.5}$ concentration data were sourced from the CAMS-EAC4 reanalysis model. The gridded $PM_{2.5}$ outputs were converted into micrograms per cubic meter (μg/m³) for interpretability and compliance with World Health Organization (WHO) air quality standards. Land Use and Land Cover (LULC) classifications were derived from Sentinel-2 imagery and validated using Esri/Impact Observatory datasets, allowing for accurate delineation of different urban land types. These multi-source datasets provided the foundation for spatial interpolation, buffer analysis, and statistical correlation used in this study.

2.2. Methodology

Remote sensing, GIS mapping and statistical methods were used to investigate the link between Land Surface Temperature, Urban Heat Island Intensity and $PM_{2.5}$ levels in Faisalabad last summer. A complete description of datasets, the sources used, the spatial resolution and analytical processes is in Table 1.

Table 1. Methodology for assessing LST, UHI, and $PM_{2.5}$ in Faisalabad (JJA-2023).

Dataset	Source	Resolution	Time Period	Processing & Methodology
Land Use/Land Cover	Sentinel-2 (Esri, Impact Observatory)	10 m resolution	2023	Faisalabad reclassified into urban (built-up) and rural (non-built-up) zones, pixel counts converted to km² for spatial analysis
Land Surface Temperature	MODIS Terra (MOD11A1 Version 6)	1 km resolution	1st June - 31st August, 2023	Downloaded 92 granules, extracted subdataset (day/night), reprojected to GCS_WGS_1984, converted to ˚C using Raster Calculator, clipped to study area
Urban Heat Island	Derived from LST & LULC	Raster (Zonal statistics)	June-August 2023	Urban and rural LST extracted via Zonal Statistics; UHI intensity calculated using mean LST difference (urban - rural) for both day and night periods
$PM_{2.5}$ Concentration	CAMS Global Reanalysis (EAC4), Copernicus ADS	0.75˚ × 0.75˚, 3-hourly	June-August 2023	Extracted via Python (xarray), unit converted to μg/m³, spatially interpolated using kriging, buffer analysis around roads, industrial zones, overlaid on LULC
Infrastructure Data	OpenStreetMap (Geofabrik), PBS Census 2023	Shape files (Vector)	2023	Includes road networks, land use, buildings; aligned to WGS84/UTM, used for buffer analysis, proximity to pollution hotspots, and overlay with environmental indicators

2.2.1. Preprocessing

Before using the data, both the MODIS Terra (MOD11A1) and Sentinel-2 datasets were carefully preprocessed using usual GIS techniques such as mosaicking, converting to the same coordinate system, cloud masking and computing NDVI. Rural and urban zones were marked using a supervised classification of land use/land cover (LULC) and buffer-based methods.

2.2.2. $PM_{2.5}$ Surface Interpolation

Using Python (xarray), $PM_{2.5}$ was extracted from the EAC4 data from CAMS Global Reanalysis. To use the kriging method, the data were converted to units μg/m^3 and added to ArcGIS. These surfaces were combined with information on industries and roads to allow for studies on hotspots and their relationship with certain places (Zhang et al., 2015; Yang et al., 2022).

2.2.3. UHI and LST Analysis

Mean temperatures for urban and rural zones were found using zonal statistics after processing day and night LST raster's for UHI and LST analysis. UHIs were calculated using the formula (urban LST - rural LST) for night and during the day, using the approaches adapted by Di Bernardino et al., (2023) and described by Oke (1982).

2.2.4. Correlation and Regression Modeling

Correlation and regression analysis were used to study the relationships between LST, UHII and $PM_{2.5}$ concentrations. Second-degree polynomial regression models were also applied to study any non-linear ties and detect the types of temperatures that impact how pollutants are spread out.

2.2.5. Vegetation Impact Assessment

The percentage of vegetation was determined by reading NDVI values from Sentinel-2 images in various parts of the study area. Using PCA, the study team investigated the connection between vegetation, LST and the level of $PM_{2.5}$ particles, pointing out that urban green spaces both cool the area and filter some pollutants.

2.2.6. Visualization

ArcGIS was used to show the final products of the study, including the UHI intensity maps, interpolated $PM_{2.5}$ heat maps and overlays of vegetation. By creating these spatial views, it became possible to recognize hotspots of risk linked to urban microclimates over time.

For both climate and pollution, the approach made it possible to analyze many factors in depth, providing advice on urban planning in South Asian cities.

3. Results and Discussion

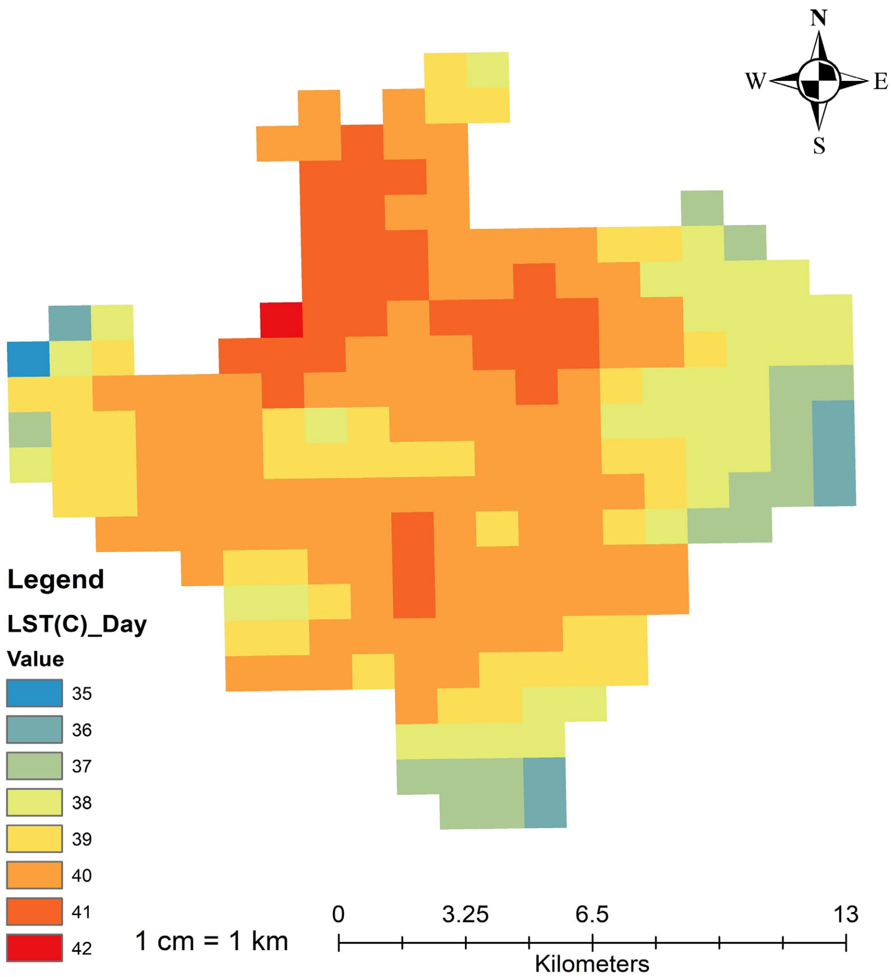
3.1. Spatial and Temporal Analysis of Land Surface Temperature (LST) and Urban Heat Island Intensity (UHII)

3.1.1. Daytime and Nighttime LST

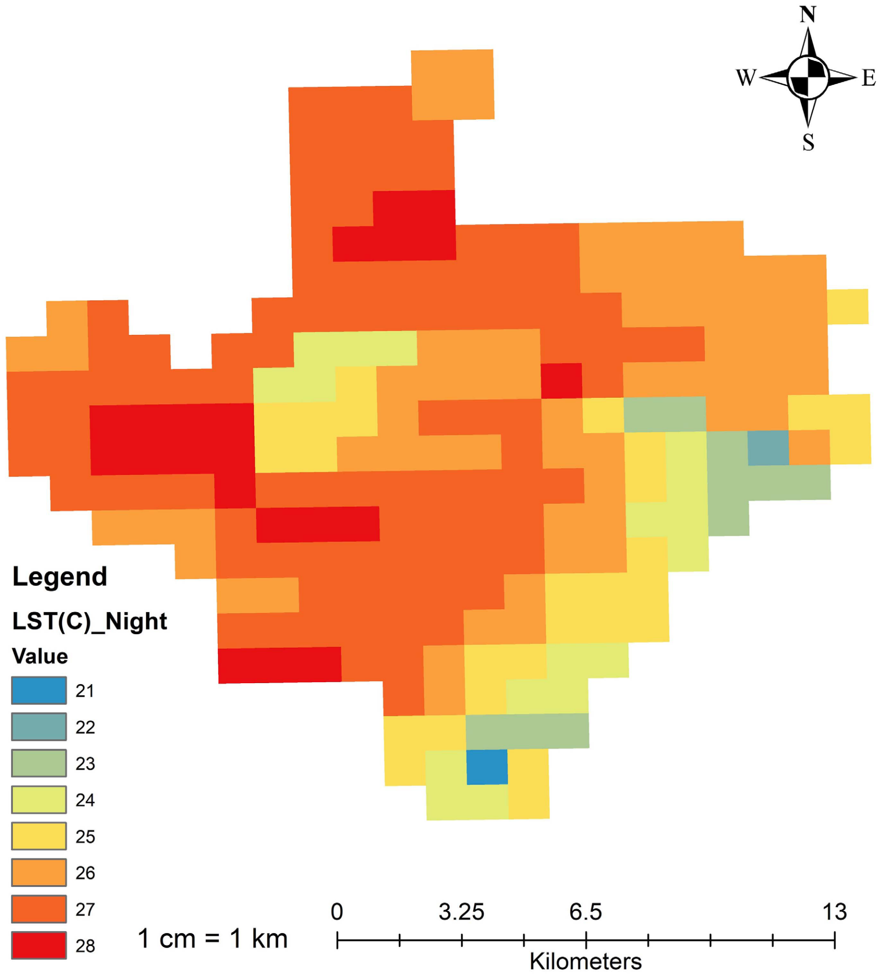
The evaluation of daytime and nighttime Land Surface Temperature (LST) for

Faisalabad during the summer of 2023 (June-August) showed that differences are strongly related to the city's urban layout and land types. Because of replacing natural surfaces with hot materials like concrete, asphalt and rooftops, together with dense cities and industrial activity, urban zones always have warmer surface temperatures. In the city, the daytime city area temperature reached between 39˚C and 42˚C, mainly over the commercial, administrative and industrial sections. In Figure 2(a), central regions are mostly colored red and orange, marking the main urban areas. In areas outside cities, including rural and peri-urban regions, typical temperatures range from 35˚C to 38˚C and are highlighted in green and blue on the map. The highest number of pixels in Figure 2(c) is for the 40˚C class, with 96 pixels, then 39˚C class with 33 pixels, 41˚C with 30 pixels and 38˚C with 24 pixels. There were few pixels captured in the range of 35˚C to 37˚C, suggesting that little vegetation or reflective surfaces are found in large parts of our urban areas.

Heating the measured surface confirms the impact of urban development and shows that the UHI effect is stronger during the day. From the data, it's clear that places with the most urban surface are found in the 40˚C extreme which

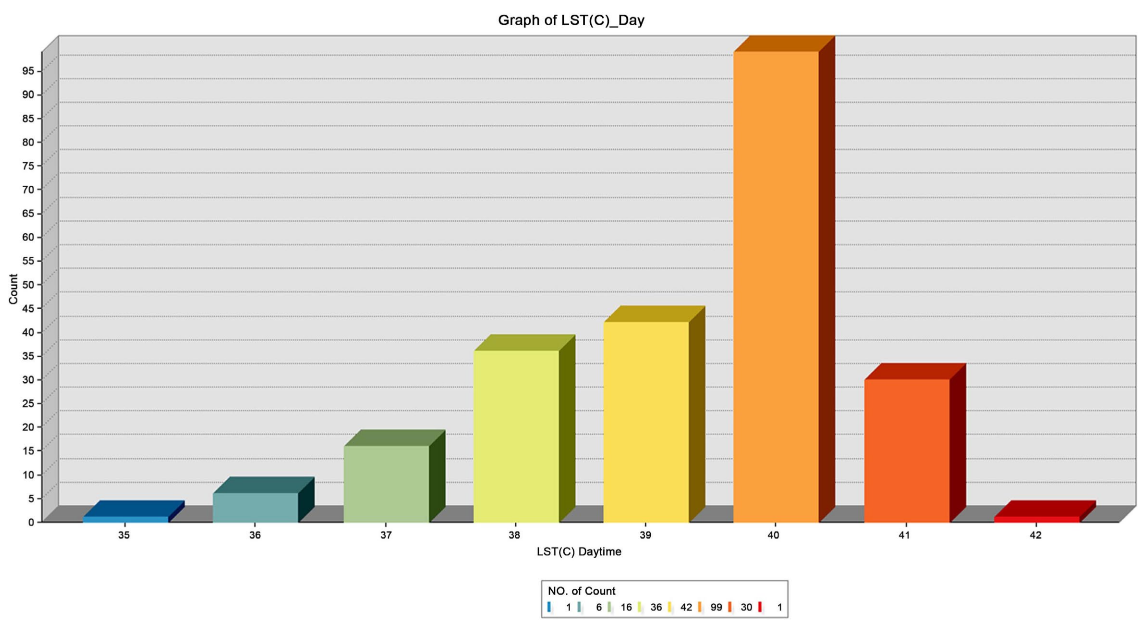


(a)



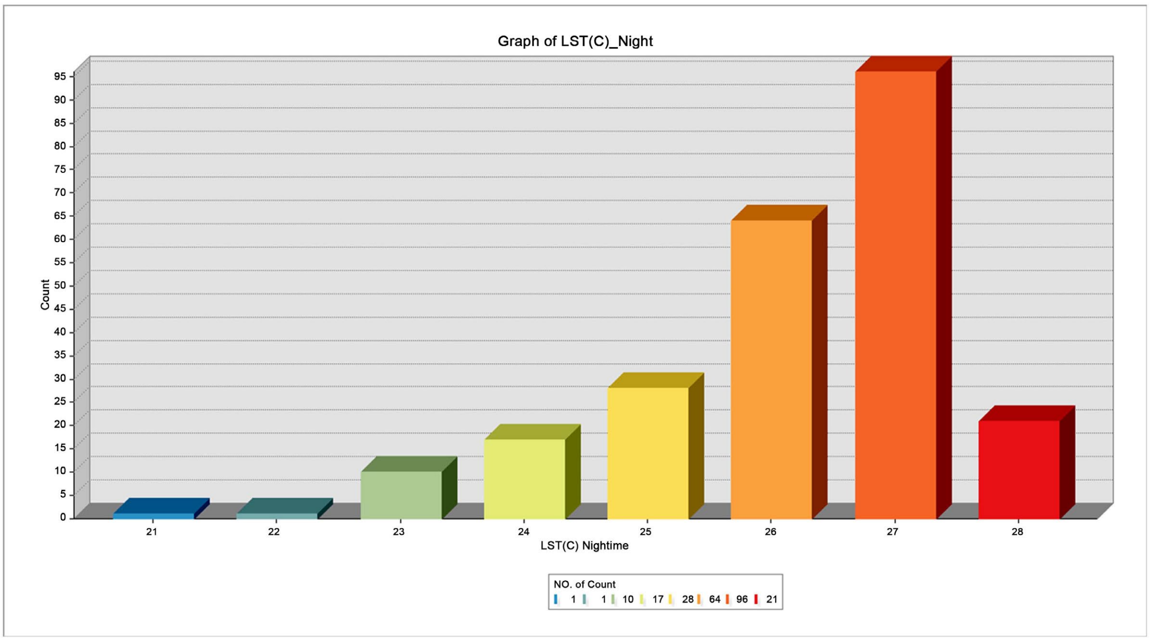
N
W
E
S
Legend
LST(C)_Night
Value
21
22
23
24
25
26
27
28
1 cm = 1 km
0
3.25
6.5
13
Kilometers

(b)



Graph of LST(C)_Day
Count
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
35
36
37
38
39
40
41
42
LST(C) Daytime
NO. of Count
1
6
16
36
42
99
30
1

(c)



(d)

Figure 2. (a) Spatial distribution of daytime LST across Faisalabad during June-August 2023 (Higher temperatures (39˚C - 42˚C) are concentrated in the urban core, shown in red and orange hues, while cooler rural zones appear in green and blue), (b) Spatial distribution of nighttime LST across Faisalabad during June-August 2023 (Urban areas retain heat overnight, with dominant temperatures 26˚C - 28˚C), (c) Frequency distribution of LST pixel values in daytime, showing the dominant occurrence of 40˚C, followed by 39˚C and 41˚C, indicating the prevalence of extreme heat in urban areas, (d) Bar chart showing the frequency distribution of nighttime LST values, with 27˚C as the most frequent class, reflecting thermal inertia and reduced cooling in built-up areas.

demonstrates a powerful buildup of heat during the day because there is high absorption of sun and not much evaporation due to low humidity. There is also evidence of ongoing thermal stress for urban areas at night. From Figure 2(b), we can see that Faisalabad's center was warmer at night (26˚C to 28˚C) while the outlying sectors were much cooler. The central areas in these images are marked by domination of red and orange, opposed by green and blue in the periphery. According to Figure 2(d), there were 84 urban pixels classified as 27˚C, the next most common was 26˚C with 52 pixels and 19 pixels at 28˚C. Nighttime cooling was usually low in urban settings since the use of impervious materials trapped heat and green areas were rarely present (Yang et al., 2022; Li et al., 2017). Holding onto heat during the night affects both energy costs, personal health and common comfort, especially for those who are fragile.

3.1.2. Urban and Rural LST Distributions

The LST analysis for Faisalabad from June to August 2023 shows that urban locations are much hotter than the surrounding countryside. In urban areas, daytime surface temperatures rose to 39˚C and 42˚C, peaking in the city center, industry zones and main commercial areas (Figure 3(a)). The higher temperatures were caused by an abundance of built infrastructure, little green cover and mostly impervious surfaces that reduced the ability of plants to cool the air naturally. In contrast, LST values in rural locations recorded between 35˚C and 38˚C (**Figure 3(b)**) and the lowest values were found over agricultural fields and green spaces urban periphery. The temperature in these areas was lowered by evapotranspiration, by surfaces that reflect more heat and by being more open. At night, urban and rural LST values again showed significant thermal contrast, reflecting difference between them. As shown in **Figure 3(c)**, built-up neighborhoods retained heat, with nighttime LSTs ranging from 26˚C to 28˚C. Central, industrial and densely populated neighborhoods, where restricted airflow, were the regions where nighttime temperatures were most clustered. Conversely, nighttime conditions in rural zones exhibited more effective, with LST levels at 22˚C to 25˚C (**Figure 3(d)**). The presence of open land, vegetation, and moisture-retaining soils enhanced radiative heat loss, supporting lower nighttime temperatures even during peak summer conditions. The charts outlined by frequency distribution showed that urban zones had mostly higher temperatures, while rural areas' LST broader range across cooler bands. Land cover and urban morphology have the most influence on this heat gradient. These findings show that urban design in Faisalabad contributes significantly to the generation and maintain surface heat variations. Asphalt and concrete quickly absorb heat from the sun and then release it more slowly and there's not much shading or evaporation from trees. As a result, the Urban Heat Island (UHI) effect is made worse at all times, making it hard for natural cooling to occur. The results match previous studies that indicate increased LSTs and lower thermal resilience in cities with few plants and lots of built-up land (Zhang et al., 2015; Santamouris, 2015). The cooling effect noted in rural areas reinforces the ecological importance of green and agriculture zones. Land with plants increases transpiration, but open land makes it easier for land to reflect sunlight and absorb nearby heat (Avdan & Jovanovska, 2016; Mirzaei & Haghighat, 2010). Their stable thermal properties make agricultural areas great locations for checking UHI intensity which shows why preserving them is necessary during urban development. The results for the summer of 2023 indicate that urban development leads to local climate changes at the surface. Preserving vegetated areas close to urban areas and including green spaces and shiny surfaces in planning can help keep Faisalabad's growing people cooler.

3.1.3. UHI Intensity Calculation

The Urban Heat Island Intensity (UHII) in Faisalabad during the summer months was calculated by comparing the average temperature in urban and rural areas. There is noticeable difference in temperature patterns, with a peak in the day and continuous heat at night in zones with many buildings. According to **Figure 4(a)**, the UHII for daytime reached 1.96˚C and these areas are indicated by the red shading, highlighting zones with the highest intensity. Most of these zones are in the central, western and southern areas of Faisalabad, sheltering thriving commercial, industrial and administrative areas. There is less evaporating water

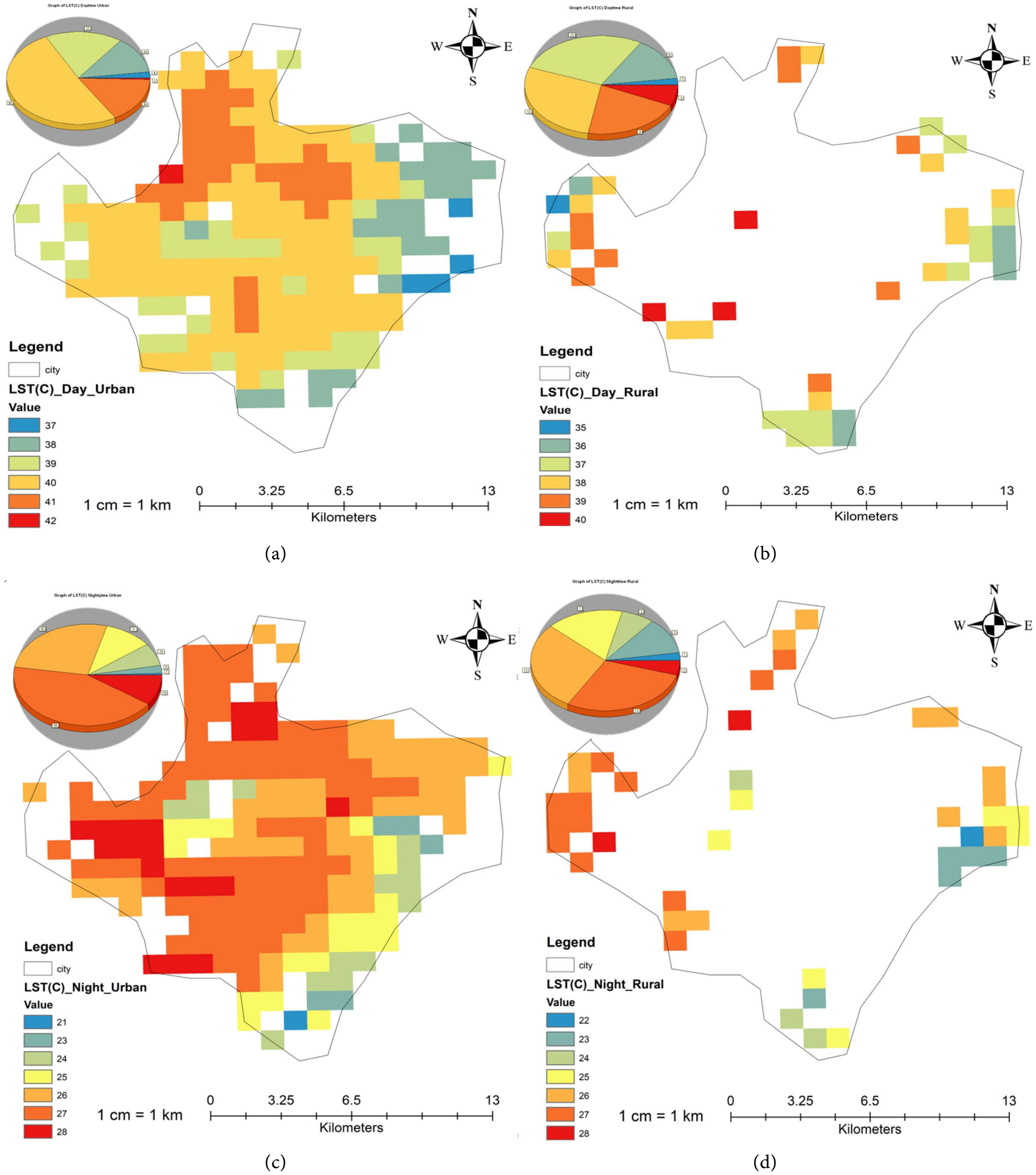
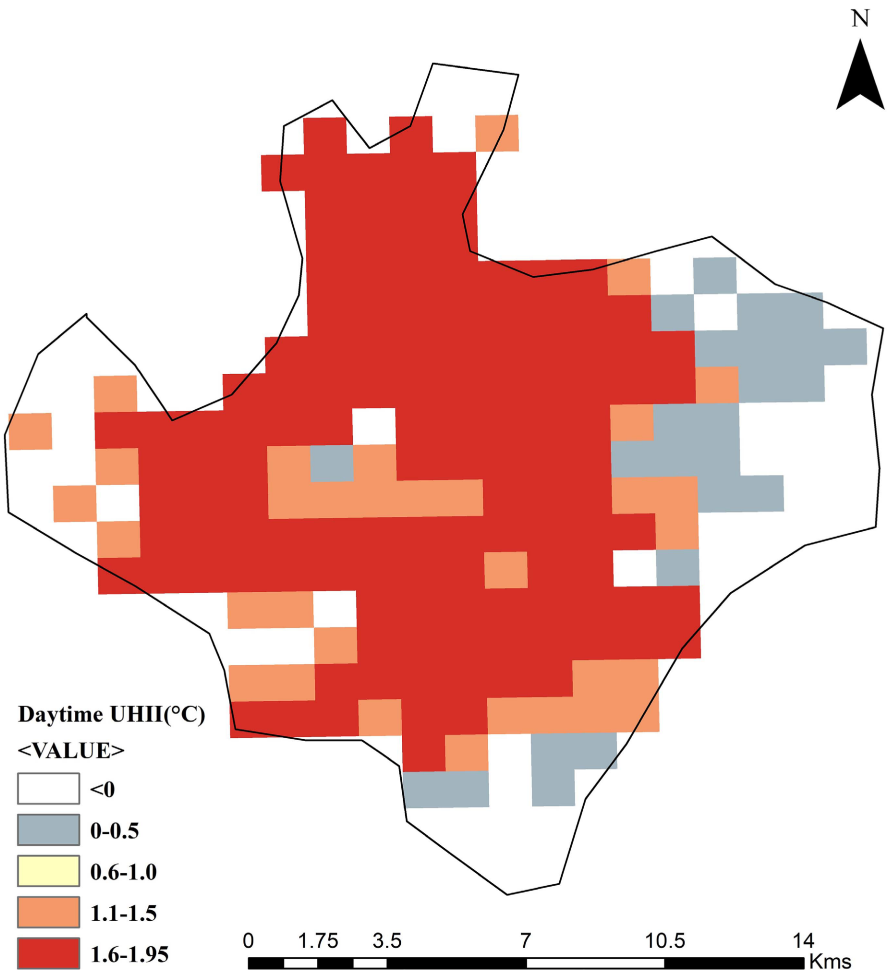


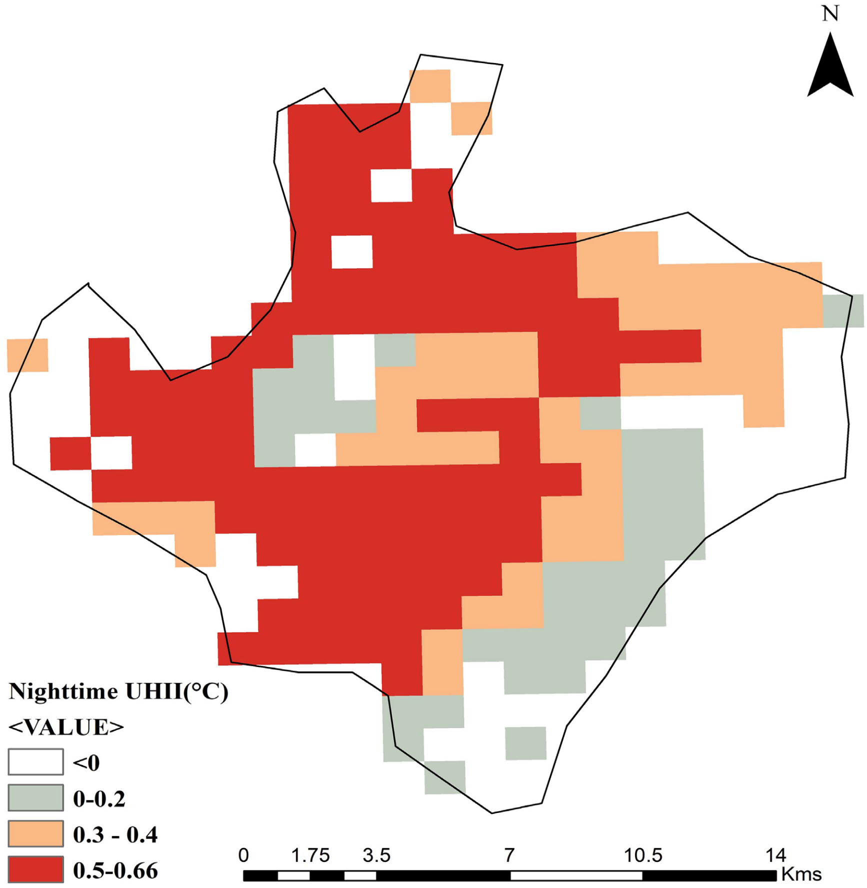
Figure 3. (a) Spatial distribution of daytime LST (˚C) in urban zones of Faisalabad during June-August 2023, with highest intensities (39˚C - 42˚C) concentrated in the central business district and industrial corridors, (b) Daytime LST in rural zones, showing reduced temperatures (35˚C - 38˚C) associated with vegetation and agricultural land cover, (c) Nighttime LST distribution in urban zones, revealing strong heat retention with temperatures ranging from 26˚C - 28˚C, particularly in built-up and low-emissivity zones, (d) Nighttime LST in rural areas, where widespread cooling results in values as low as 22˚C - 25˚C, indicating efficient radiative and evaporative heat loss. Pie charts reflect pixel frequency for each temperature class, supporting statistical comparisons between urban and rural thermal behavior.

and more surface heat due to all the concrete, asphalt and roofs, as well as far less vegetation cover. The results from these factors fit well with observed urban LST maps, showing that urban areas are much hotter than rural surroundings. UHII values showed in gray and mild pale orange on the map point to vegetation or limited vegetation at the edges of the zone, so thermal relief wasn't very strong near them. The pattern in Figure 4(a) demonstrates that green areas and mixed-use zones in urban areas play a big role in controlling temperatures during the day.

Figure 4(b) shows the distribution of nighttime UHII in the city. Although the temperatures were lower at night than during the day, with a top reading of 0.66˚C, many urban locations still saw higher than usual temperatures. The presence of reddish and orange areas in the city's center and south points to continued heat stored at night. The heat lasting for many hours is caused by the thermal inertia of buildings and not enough circulating air at night, mostly where construction is dense. Due to the vegetation and moisture in their soil, rural and peri-urban areas in gray or light green on the map were able to cool better. The regions showed lower values than 0.2˚C for UHII or were even negative, showing they are



(a)



(b)

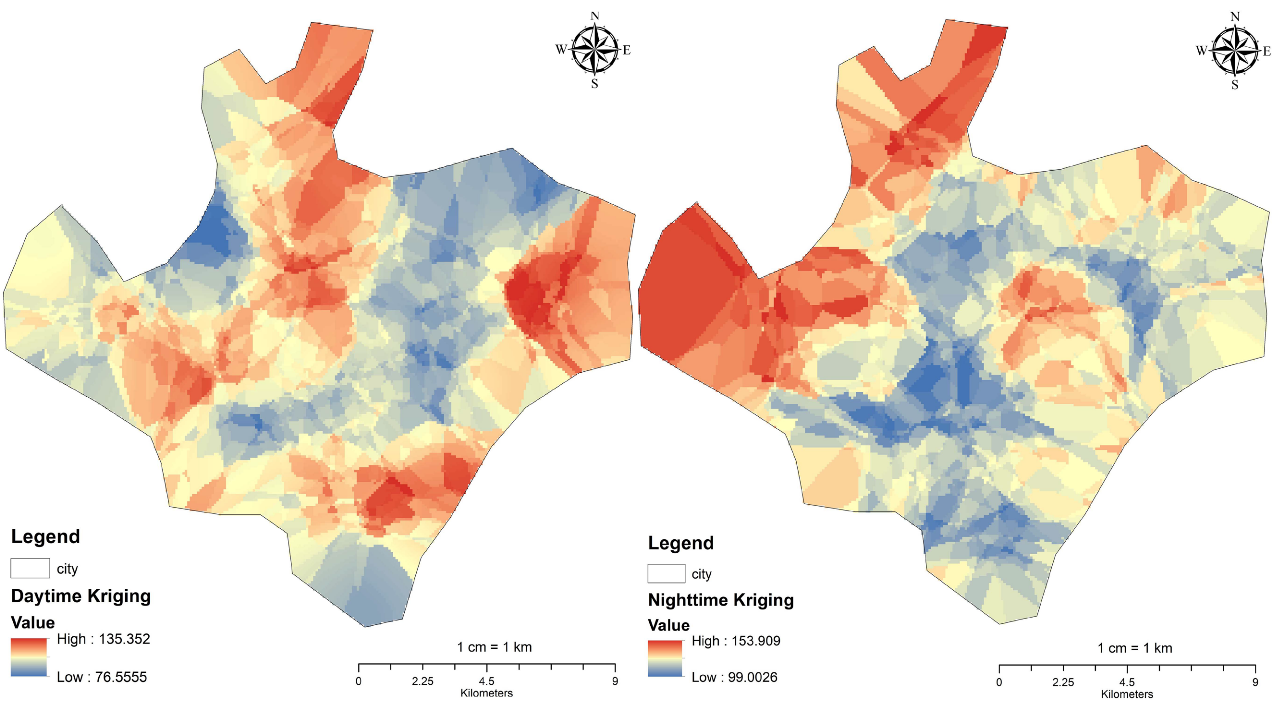
Figure 4. (a) Daytime UHI intensity map for Faisalabad during JJA 2023 (UHI intensity exceeding till 1.96˚C, Red shows the highest UHII while Gray or while color shows less or no UHII), (b) Nighttime UHI intensity map for Faisalabad during JJA 2023 (UHI intensity exceeding, 0.66˚C, Red shows the highest UHII while Gray or while color shows less or no UHII).

better at getting rid of heat and resulting in cooler evenings. It is evident from Figure 4(a) and Figure 4(b) that the distribution of excessive heat increases consistently over time and stays centralized in urbanized areas. During the day, how much UHII you get depends on direct sunlight and the materials used, but in the evening, it is affected by what energy your surroundings hold and how the lack of natural cooling affects it. The evidence unanimously shows that the pattern of land use, land cover diversity and what vegetation is found influence UHI in cities. Since the research points to rising temperatures, Faisalabad needs urban plans that include schemes to cool the city by adding trees, reflective materials and building corridors that help with air circulation. Keeping rural green belts intact and controlling the growth of urban edges provides an important barrier against heat waves expected in the future.

3.2. $PM_{2.5}$ Concentration Patterns

An assessment of $PM_{2.5}$ levels in Faisalabad during June-August 2023 found regular excesses past the WHO recommended amount, with a clear difference in $PM_{2.5}$ values at various locations and times. Maps showing the daytime and nighttime $PM_{2.5}$ distributions were made using kriging and clearly illustrate how different urban shapes, pollution sources and atmospheric situations affect $PM_{2.5}$ levels. From morning until evening, $PM_{2.5}$ levels were found to vary from 76.55 to 135.35 μg/m^3, the highest levels occurring in the northwestern and southwestern urban areas mainly because of vehicles, manufacturing plants and construction activities. Figure 5(a) demonstrates that the concentrations are lower in the central and eastern parts of the image. In the same way, nighttime $PM_{2.5}$ values in Figure 5(b) indicate that concentrations rose throughout the city, ranging from 99.00 μg/m^3 to 153.91 μg/m^3. The increase results from temperature inversions, a lack of wind and air pollution from vehicles, industrial processes and homes at night.

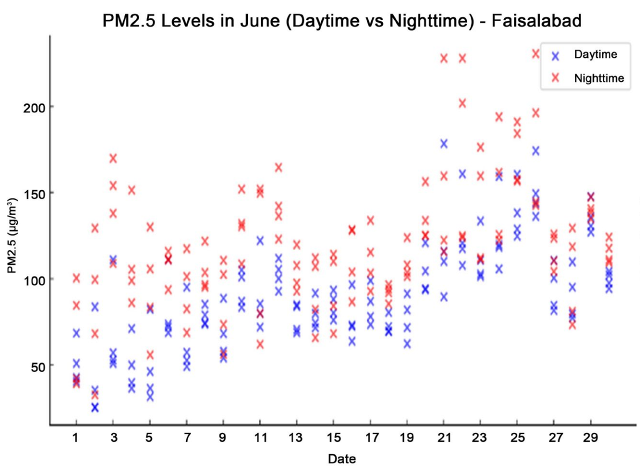
The temporal graphs in Figures 6(a)-(d) reveal that $PM_{2.5}$ concentrations were highest during August, mainly at night and often over 275 μg/m^3, much higher than the amounts seen in previous and later months. The higher particulate pollution in August is mainly because of a change in meteorology and ongoing human activities. At this time in Faisalabad, because of the extreme monsoon conditions, there is not much mixing in the air due to very humid and stagnant weather. Due to stagnation, pollutants are not spread as freely and especially at night when temperature inversions raise the level of these pollutants. Because air cools so rapidly at night, air near the ground is trapped, allowing emissions to



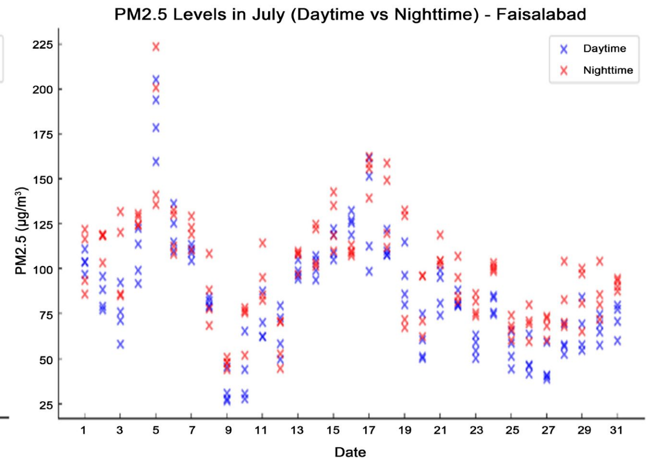
(a) (b)

Figure 5. (a) Daytime Kriging Map of $PM_{2.5}$ Concentrations in Faisalabad during JJA (June-July-August) 2023, (b) Nighttime Kriging Map of $PM_{2.5}$ Concentrations in Faisalabad during JJA (June-July-August) 2023.

stay concentrated and increasing the chances of exposure to pollution. Furthermore, because humidity is high at this time, $PM_{2.5}$ particles grow larger, so they are more harmful for health. In addition, ongoing emissions from transportation, industry and homes add to these constraints, leaving behind rising levels of pollutants. While pollution spikes were caused by weather episodes in July, August shows that pollution continues to affect air quality without stop. During August, it's most obvious that nighttime $PM_{2.5}$ concentrations are consistently above daytime concentrations. Such a pattern presents major health concerns, especially for more sensitive populations and requires air quality management strategies that take into account both the influence of weather at different times of day and night emission levels.



(a)



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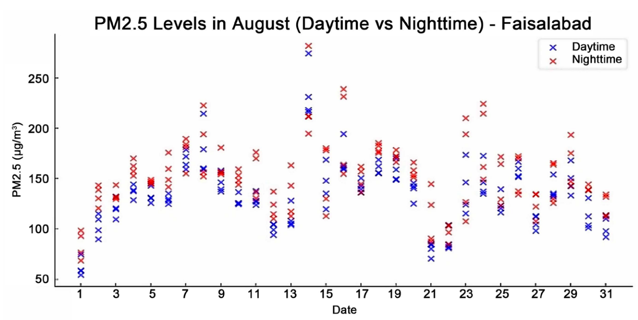
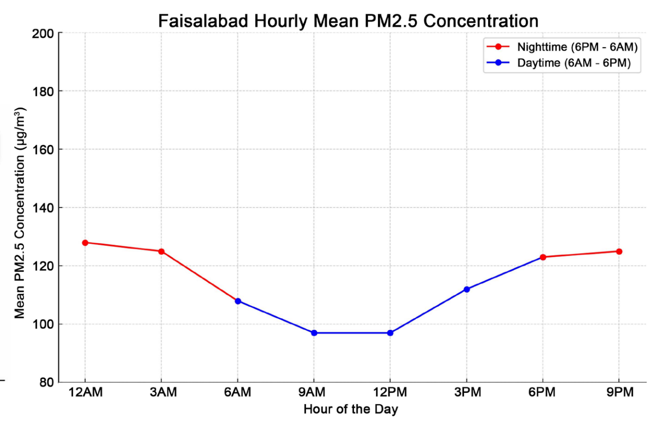


(c)



(d)

Figure 6. (a) Scatter graph of Daily PM2.5 Levels in June-2023 Faisalabad, (b) Scatter graph of Daily PM2.5 Levels in July-2023 Faisalabad, (c) Scatter graph of Daily PM2.5 Levels in August -2023 Faisalabad, (d) Line Graph of hourly Mean PM2.5 Levels in June, July and August 2023, Faisalabad.

Spatial analysis of $PM_{2.5}$ concentrations displayed that both the times of day and the location within Faisalabad differed between urban and rural areas. As the graph in **Figure 7(a)** shows, daytime levels of $PM_{2.5}$ were the highest in the central business and northwestern industrial areas, areas where heavy traffic, construction and industry are found. Most of these hotspots registered high levels of $PM_{2.5}$ particles, mainly where urban activity was most constant. However, similar to Figure 7(a), some rural areas in areas close to factories or places where open biomass burning takes place exhibited high $PM_{2.5}$ concentrations during the daytime too. $PM_{2.5}$ was released and spread more at nighttime across the urban area which is shown in Figure 7(c). Active radiative concentrations appeared in both the northwestern and central regions, probably caused by the same hot temperatures and bad mixing seen during the night. It was shown in Figure 7(d) that $PM_{2.5}$ levels rose at nighttime over the rural zones, mainly in the northwestern and southern regions. Domestic solid fuel use in places with poor ventilation created the most elevated levels of pollution in low-lying spots. The results indicate that cities and rural areas in Faisalabad struggle with high $PM_{2.5}$ values and although the sources are not the same, both locations suffer.

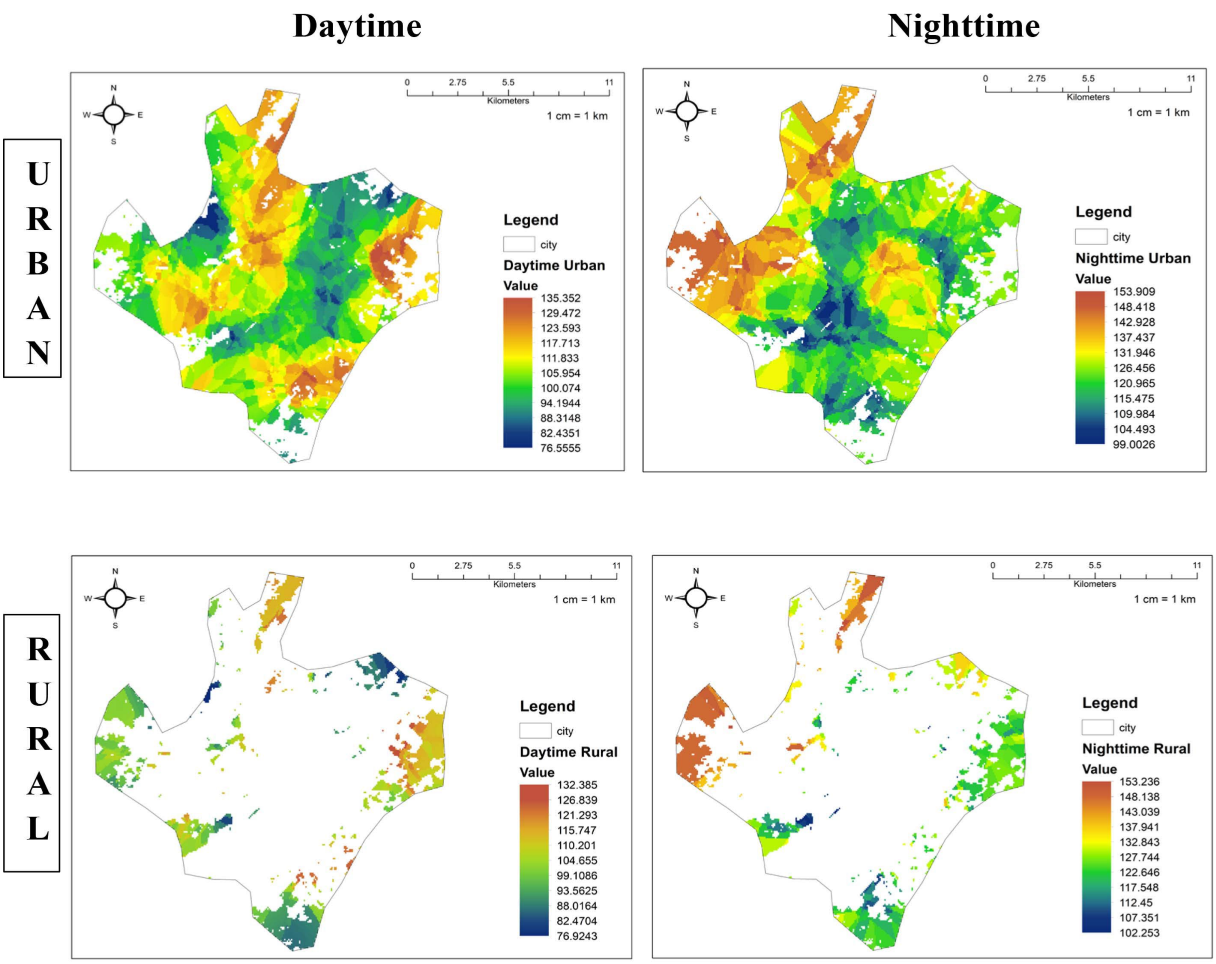


Figure 7. (a) Spatial interpolation of daytime $PM_{2.5}$ concentrations across Urban Areas of Faisalabad, (b) Spatial interpolation of daytime $PM_{2.5}$ concentrations across rural areas surrounding the city, (c) Spatial interpolation map showing nighttime $PM_{2.5}$ concentrations across the urban landscape, (d) Spatial interpolation of nighttime $PM_{2.5}$ concentrations in rural areas.

During the daytime, urban zones are heavy human activity, slow-moving vehicles and industry are largely responsible for air pollution, while late at night, trapped warm air and continuing energy use hold the pollution near the ground. Although the pollution level during the day in rural areas is partly because of industry, nighttime spikes of pollution often come from biomass fuel used for household heating and cooking. Further comparison of **Figure 7(a)** with **Figure 7(b)** urges us to note that rural areas experience occasional outbreaks of pollution at specific hotspots. In addition, the night contrasts in **Figure 7(c)** and **Figure 7(d)** point out that local weather makes pollutants gather more easily in both crowded city areas and far-off fields. According to these results, various approaches are needed to address these problems. Urban strategies should target keeping emissions down from traffic and ensuring that industry complies, while rural initiatives would be wise to improve clean technologies for cooking and air ventilation inside homes. Both scenarios require following the latest data and preparing specific plans to lower the urban-rural difference in $PM_{2.5}$ exposures.

Spatial buffer analysis of $PM_{2.5}$concentrations among various LULC classes pointed out that Faisalabad's pollution levels are quite different during the day time compared to the nighttime. The blue circles show daytime $PM_{2.5}$ measurements and the red circles represent nighttime $PM_{2.5}$ in **Figure 8**. In addition, there are many large and red circles in places with densely packed cities, such as the urban center, road intersections, suburban zones and city amenities, emphasizing how $PM_{2.5}$ levels increase at night. The daytime roadway $PM_{2.5}$ readings appeared to stay at moderate levels because the blue circles were spread and located close to

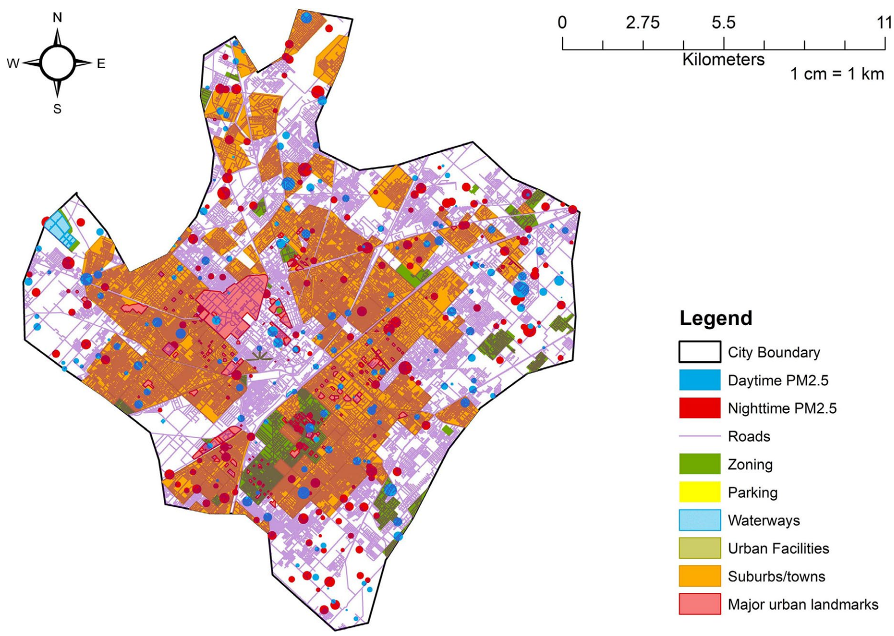


Figure 8. Buffer analysis on $PM_{2.5}$ over LULC during day and nighttime of June, July and August (JJA), 2023, Faisalabad.

one another. They were scattered in urban areas, along major roads and in residential plus commercial zones. Still, areas around green zones, along waterways and in open parking lots almost always had fewer and less crowded $PM_{2.5}$ particles, meaning they experienced better air quality both during the day and night. There were higher $PM_{2.5}$ levels in the air at night mostly found in crowded areas, including along main roads and in popular locations. The red lines around these zones suggested that the levels of fine particulate matter were high. This study demonstrates that how land is used is closely related to $PM_{2.5}$ accumulations and its spread around different areas under different weather conditions. Nighttime pollution in cities and areas dominated by roads is caused by human activities plus temperature inversion and reduced winds. High pollutant concentrations near surfaces result from these conditions, especially in poorly ventilated places. Major differences in appearance between city centers and nearby green or watery areas only prove the purifying influence of greenery. As a result, these areas act as air filters and also ensure better airflow. In urban areas, the areas near zoning, waterways and parking have consistently lower $PM_{2.5}$ values, which illustrates the usefulness of including green and open infrastructure in city planning. The grouping of $PM_{2.5}$ around most roads and main tourist attractions shows that traffic and dense movement areas are major sources of particulate pollution. Residential, industrial and commercial activities mixed in some districts resulted in comparable emissions, especially at night when household and industrial energy rises. The analysis confirms that the risk of exposure to $PM_{2.5}$ varies place to place, making it necessary to address the problem locally. It is important to give main emphasis to road corridors, nighttime pollution in urban centers and environmentally beneficial buffers in cities. At the same time, planning bodies need to use air quality simulations to address the health problems caused by long-term urban particle pollution.

3.3. Spatial Influence of LST and UHII on $PM_{2.5}$

3.3.1. Spatial Distribution of LST and $PM_{2.5}$

The maps of Land Surface Temperature (LST) and $PM_{2.5}$ for June-June-August 2023 (JJA-23) in Faisalabad indicate that very hot weather and increased incidence of fine particles tend to happen together during the day. Figure 9(a) indicates that the areas with the most extreme daytime LSTs are found largely in the central, industrial and highly developed business areas. The places where air temperatures rose most also showed higher readings of $PM_{2.5}$, with some spots having levels above 300 μg/m^3. There was very little vegetation in these spaces and concrete and asphalt were the most common materials used for the ground. On the other hand, those urban regions where the LST was in the middle range between 38˚C and 40˚C had increased $PM_{2.5}$ levels-usually between 150 μg/m^3 and 200 μg/m^3. Both districts had a combination of residential and light commercial real estate, with medium population levels. While agricultural and urban fringe regions registered LST between 35˚C and 37˚C, most days of these $PM_{2.5}$ concentrations were under 100 μg/m^3. There was a great deal of open space, plants and fields here, making it easier to both cool down and spread out harmful particles. In the evening after sundown, as seen in Figure 9(b), LST values dropped by a lot since radiative cooling occurred, from 21˚C to 28˚C. $PM_{2.5}$ concentrations were still very high in city centers and industrial zones, happening again above a normal daily level and at times even passing 300 μg/m³. Lowest nighttime $PM_{2.5}$ concentrations (below 120 μg/m³) were found in suburban and residential zones with lots of plants, yet a few local hotspots were also observed due to nearby emissions and still air.

According to the results, higher daytime LST is linked with a rise in $PM_{2.5}$, so regions with more surface heat are more susceptible to severe pollution. The decrease is mostly because the atmospheric boundary layer is lower during heat, energy use increases and emissions from industrial and vehicles are high. The rise of pollutants close to the ground is exacerbated by surfaces that stay hot but do not evaporate water. Nighttime is when it is easy to notice that LST and $PM_{2.5}$ are less connected. Even though less sun means a loss of LST, particle pollution levels can still be high or increasing in most city areas. Air pollution is mostly created by the continued existence of stable weather conditions with inversions in temperature and pollution from biomass burning, generators and factories. Even when the surface isn't warm enough, cooler air prevents pollutants from going high in the atmosphere, making them stay near the ground. So, even some colder

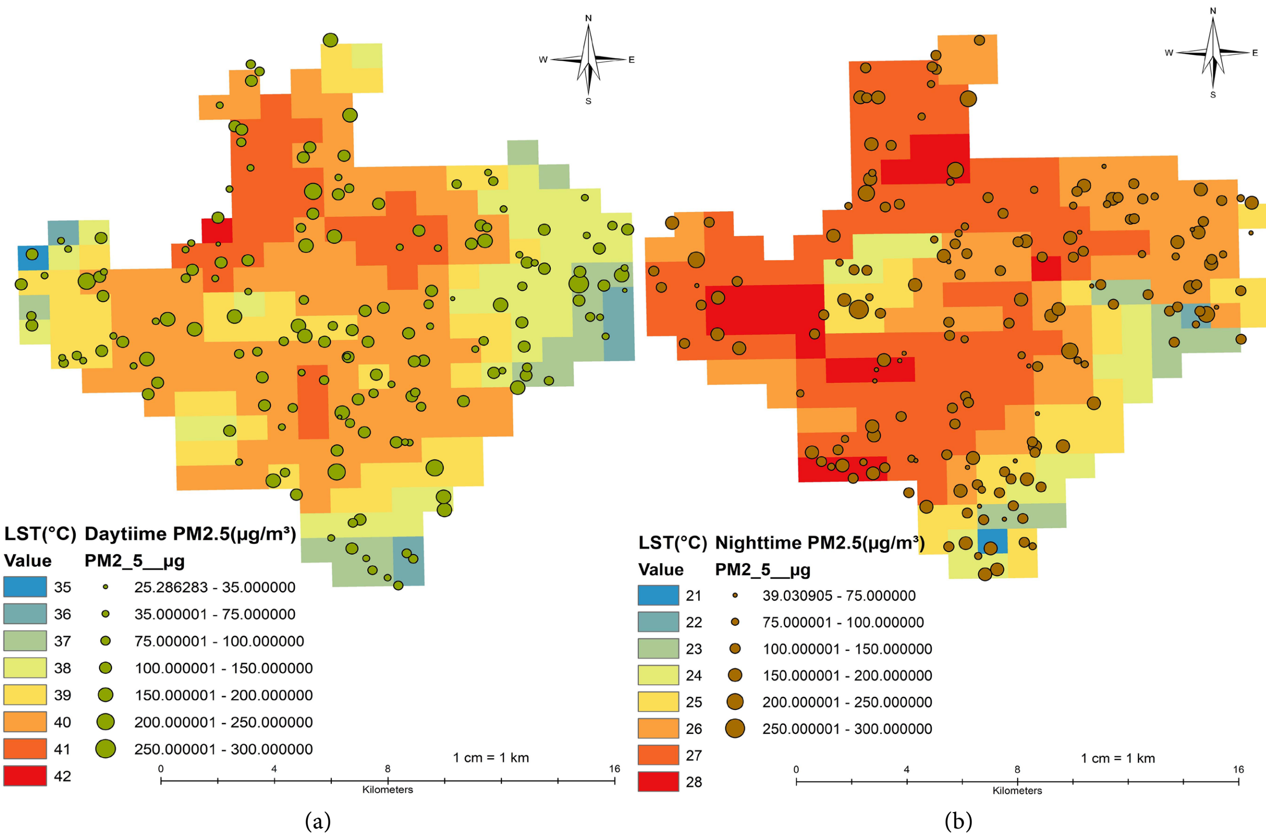


Figure 9. (a) Spatial Distribution of Daytime LST and $PM_{2.5}$ during JJA-23, (b) Nighttime Spatial Distribution of LST and $PM_{2.5}$ during JJA-23.

places can have high $PM_{2.5}$ because nearby emissions cause them, rather than heat. Maps reveal that temperature and pollution are most closely linked during the daytime and at night, it is the density of emissions and air conditions that matter more for pollution. From these results, it is apparent that both temperature conditions and pollution sources should be handled, mainly through efforts including urban greening, controlling emissions and designing improved urban ventilation. It is important to note that nighttime pollution exposure is a big risk to human health, so there should be constant measures in place to lessen this risk.

3.3.2. Spatial Distribution of UHII and $PM_{2.5}$

In summer 2023 of Faisalabad, areas with high temperatures showed a strong association with areas affected by air pollution. Daytime temperatures in UHII can go as high as 1.95˚C and the strongest heat islands are found along Narwala Road, Jhang Road and Sargodha Road, as seen in Figure 10. Similarly, the zoning is based on prominent modern places like Clock Tower, Gol Bazar and Karkhana Bazar which have close city buildings and little green space, helping heat stay trapped for longer. During the day, levels of $PM_{2.5}$ are highest in the city's center and northwestern areas and sometimes go above 200 μg/m³. The pattern of greater $PM_{2.5}$ circles shows that buildings, traffic and commercial activities help build up pollution. Both UHII and $PM_{2.5}$ levels are seen to spike together at places with lots of fuel stations and parking, pointing to the role of land cover, temperature and

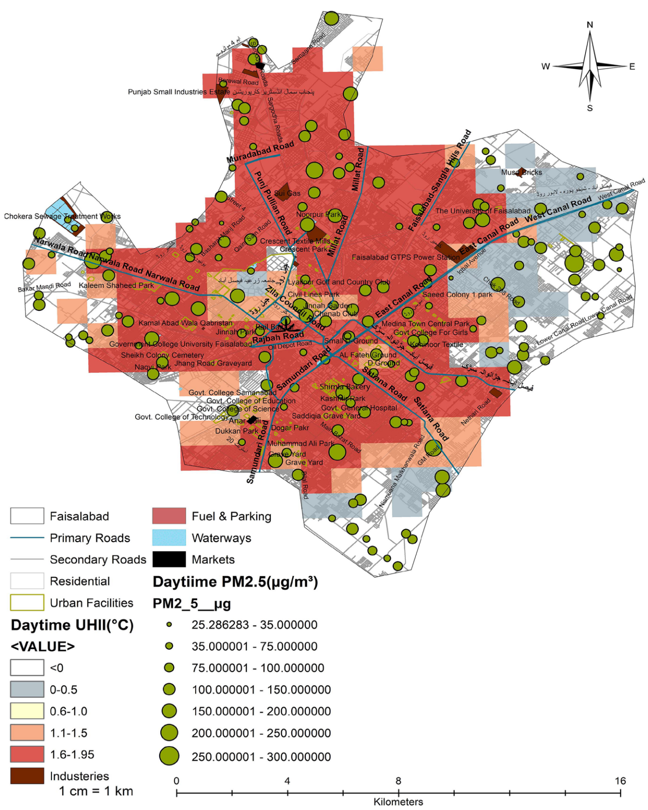


Figure 10. UHII and $PM_{2.5}$ Spatial Distribution over Faisalabad at daytimes of Summer (JJA), 2023.

man-made sources. Near the Punjab Small Industries Estate, the industrial area is a dual hotspot marked by intense heat and large $PM_{2.5}$ levels, usually more than 150 and less than 250 μg/m^3. Alternatively, Millat Town, Eden Valley and the east along Canal Road have comparably small changes in temperature (<1˚C) and very low $PM_{2.5}$ concentrations (below 100 μg/m^3). Having lower development, more green areas and being by water bodies means these areas are better at getting rid of heat and pollution. In Peoples Colony No. 2, indicators both fall in the moderate ranges, indicating that its land use is changing from suburban to urban.

Figure 11 demonstrates that thermal and pollutant stress is still present at night, just slower. While rates of UHII drop at night, there is still clearly heated air in places such as Gulberg, Jhang Road and the Punjab Small Industries neighborhood. $PM_{2.5}$ readings continue to climb overnight, mainly in the southern and eastern regions around Millat Road, Madina Town and Samundri Road. The values go above 250 μg/m^3 here, due to things such as biomass burning, generators used for homes and factories working all night. Nighttime $PM_{2.5}$ levels tend to diverge more from the zoning pattern outlined in the UHII program. While heat stays in dense cities, it is stability in the air and light winds at night that allow pollutants to grow. The lower UHII in Madina Town and Gulshan-e-Madina still results in sharp rises of $PM_{2.5}$ at night, indicating that sources close to the ground, as well as pockets of bad air due to the terrain, are more important than heat in

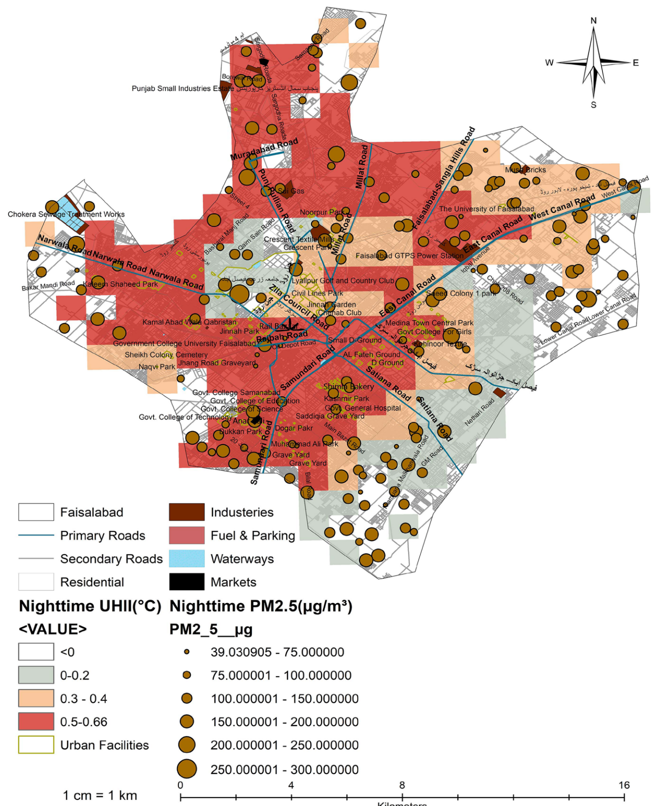


Figure 11. Nighttime UHII and $PM_{2.5}$ Spatial Distribution over Faisalabad during JJA-23.

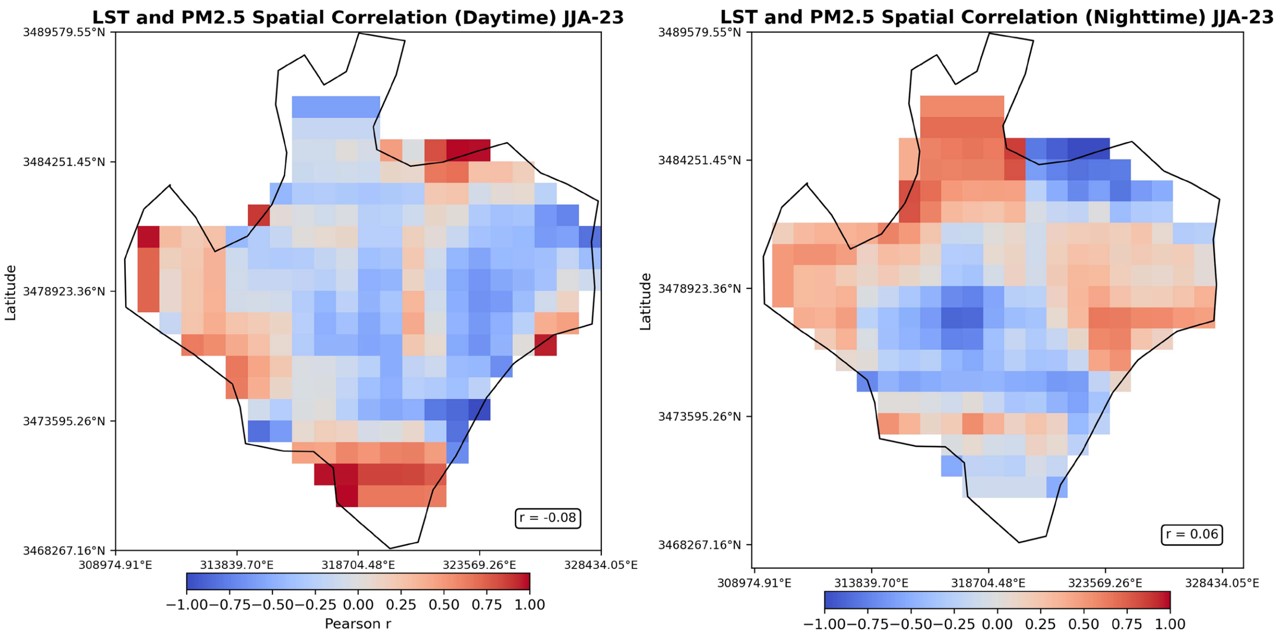
raising pollution during the hours of darkness. The correlation between UHII and $PM_{2.5}$ is highest during the day because land cover, hotter surfaces and emission sources are affecting each other closely. At night, how stressful air quality is having more to do with household and industry activity and calmer air than with heat. Based on the findings, it is recommended to consider special planning and pollution measures for hot and emission sectors of Faisalabad.

3.4. Interactions between Urban Thermal Patterns and Air Pollution in Faisalabad

3.4.1. Day-Night Temperature Effects on $PM_{2.5}$ Distribution

The interaction between Land Surface Temperature (LST), Urban Heat Island Intensity (UHII) and $PM_{2.5}$ during the summer months (June-July-August 2023) in Faisalabad exhibits unique patterns in space and time, clearly seen in **Figure 12** and **Figure 13**. Most of the study area displays a slight negative and weak correlation between daytime LST and $PM_{2.5}$, as seen in **Figure 12(a)**, with an overall Pearson's r of −0.09. Therefore, when temperatures on the surface get higher, $PM_{2.5}$ concentrations tend to decrease, especially in the western, southwestern and industrial districts of many cities. The daily decrease in pollutants is probably because sunlight during the day mixes air vertically, carrying pollutants up. Cooling effects are more noticeable where there is lots of greenery or a low amount of development, as these areas also absorb air pollution. Also, **Figure 13(a)** indicates a weak negative association between daytime UHII and $PM_{2.5}$, having an average r value of −0.11. Even with high heat islands in Clock Tower, Jhang Road and Punjab Small Industries, the amount of $PM_{2.5}$ does not always increase. Instead, the increase in UHII seems to correspond with better vertical motion that disseminates pollutants. The results suggest that hotter surface temperatures and greater heat in cities at midday are not always linked to worse air quality because there is also a rise in turbulence in the air. There were still important patterns found in Faisalabad, even though some of the correlations between temperatures and $PM_{2.5}$ levels were not very strong. More specifically, high $PM_{2.5}$ concentrations being grouped with hot and urban areas highlights risk patterns that cannot be fully explained by just using linear models. On the contrary, this proves that understanding urban environmental stress is complicated because emissions, land cover and weather all interplay in the city.

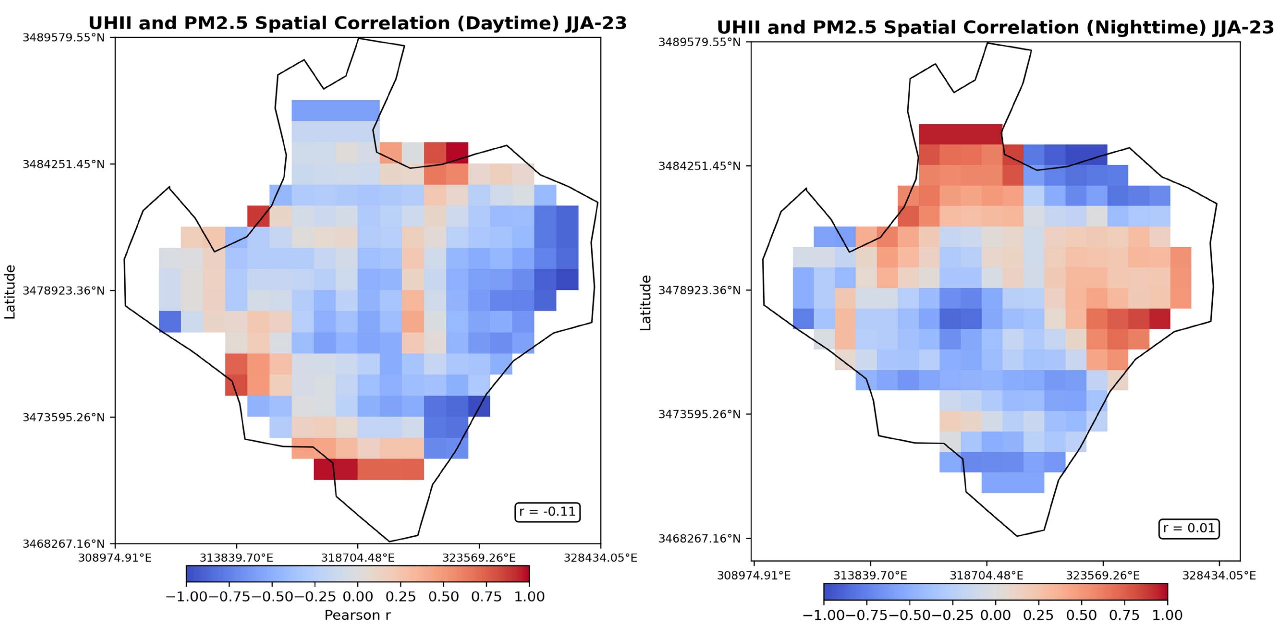
On the other hand, we see nighttime behaviors heading in the opposite direction from what we see during the day. A weak but positive link between LST and $PM_{2.5}$ concentrations during the night is visible in **Figure 12(b)**, with an average value of r = 0.06. The difference comes from solar convection being absent at night which results in the heights of the boundary layers being lower and more stable air. Urban materials that keep heat do not cool down, stopping pollutants from rising and making $PM_{2.5}$ accumulate worldwide. High positive correlations are found in most central and northern regions of Faisalabad because generator use and night-time factories cause continuous emissions there. **Figure 13(b)** also shows that during the night, there is a weak but positive relationship between



(a) (b)

Figure 12. LST and $PM_{2.5}$ Spatial Correlation daytime (a) and nighttime (b) of JJA-23 in Faisalabad.

urban heat intensity and measured $PM_{2.5}$ ($r \approx 0.03$). Despite the fact that the relationship is generally weak, it is clearer in parts of the north and northeast where the UHII is high. Because these zones are tightly packed with buildings and have little plant cover, heat collection happens higher than usual and air circulation slows. So, even slight rises in UHII at night are linked to clearly measurable $PM_{2.5}$ accumulations.



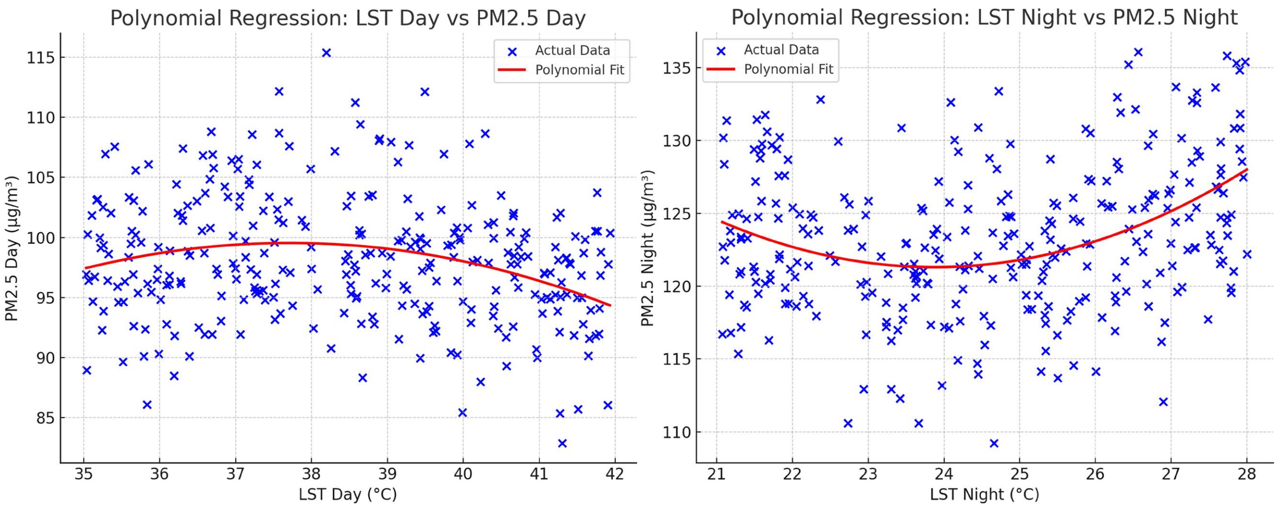
(a) (b)

Figure 13. UHII and $PM_{2.5}$ spatial correlation daytime (a) and nighttime (b) of JJA-23 in Faisalabad.

Spatial correlation analysis shows that while there is not much of a direct connection between LST, UHII and daily $PM_{2.5}$ concentrations, this changes with different times of the day. During the day, convective activity sends pollutants across the sky which weakly reduces their concentrations, while at night their accumulation from a stable atmosphere weakly increases their levels. It is easiest to see the impact of LST and UHII where nearby temperature and emission sources join. The findings demonstrate that multiple urban factors such as type of emissions, land use, the amount of vegetation and atmospheric conditions work together with metrics like LST and UHII to predict $PM_{2.5}$ variations. Air quality strategies for cities must take into account both day and night and focus especially on controlling emissions in areas with heavy development. Although temperature and urban heat are significant factors, pollutant levels are mainly influenced by the sources of air pollution, how stable the air is and land activities. That is why policies should be formulated carefully by considering many different environmental and socio-economic factors.

3.4.2. Temperature Thresholds and Non-Linear $PM_{2.5}$ Response

As thermal variables and $PM_{2.5}$ concentrations do not always line up in a simple way, a second-degree polynomial regression model was applied to help reveal special patterns and non-linear edges that linear methods miss. Both the linear and squared terms for Land Surface Temperature (LST) were part of the polynomial model to reflect the common concave or convex shapes in the ties between pollution and heat in cities. As shown in **Figure 14(a)**, the analysis of our data during the day produced an inverted U-shaped regression curve. The $PM_{2.5}$ concentrations remained much the same from 36˚C to 38˚C daytime temperature, but they began to drop a lot if the daytime temperature rose above 39˚C. Above this line, turbulent rises and the thickening boundary layer work to take pollutants up and reduce the levels of tiny particles at ground level. The results are consistent with previous work showing that more solar radiation increases the buoyancy of city air which helps reduce the concentration of pollutants (Zhang et al., 2015; Hoek et al., 2008). Alternatively, there was a convex (U-shaped) pattern during the night regression shown in **Figure 14(b)**. Air quality was better at moderate temperatures between 24˚C and 25˚C, but worsened noticeably at both the coldest and hottest temperatures. Various nighttime weather processes explain why we get these dual effects. When it's cool outside, the strong inversion layer keeps air and pollutants closer to the ground. Because concrete and asphalt absorb heat during the day and then let it off slowly, they extend warm air and keep pollutants trapped near the ground on warm nights. From the data, it appears that both U-shaped and inverted U-shaped relationships show $PM_{2.5}$ levels follow heat thresholds instead of going up with every temperature increase. Polynomial regression helps explain these non-linear patterns in a first study, yet further research could use additional models to look deeper into the relationship among heat, pollution and land use. Even so, the data from the study suggests that temperature affects



(a) (b)

Figure 14. Polynomial regression curves showing the relationship between Land Surface Temperature (LST) and $PM_{2.5}$ concentrations in Faisalabad during JJA 2023. (a) Daytime curve displays a concave (inverted U-shaped) pattern, with $PM_{2.5}$ concentrations peaking around 38˚C and declining at higher temperatures due to enhanced convective mixing. (b) Nighttime curve follows a convex (U-shaped) trend, where $PM_{2.5}$ levels reach a minimum around 24˚C - 25˚C but rise at both cooler and warmer extremes due to thermal inversions and heat retention.

pollution in cities which matters greatly to how cities plan for the future. Because of this dual response, it is clear that nighttime $PM_{2.5}$ is strongly affected by both people and weather (Stone et al., 2012; Guttikunda and Calori, 2013; Wu et al., 2017; Yang et al., 2022).

A summary of these regression outcomes is presented in **Table 2**, which identifies the turning points for each curve and provides interpretations. The daytime trend confirms that above ~39˚C, strong convective activity significantly reduces $PM_{2.5}$ exposures, while the nighttime pattern indicates that both extremely low and high temperatures exacerbate pollution levels due to limited atmospheric mixing. Regression analysis illustrated that spatial patterns in urban areas can be quite different in different sub-regions. $PM_{2.5}$ levels in highly populated and industrial areas were highest at night when LST and UHII values were both high. Yet, patterns seen in peri-urban and vegetated areas were weak or changed, probably due to differences in land cover, nearby emissions and microclimate. The significant differences in pollution exposure across areas point out the need to include diverse land uses, sources of emissions and airflow in pollutant modeling. Even though polynomial regression shows certain threshold behaviors, the interpretation is still straight forward. Multi-variate or AI-based improvements are likely to reveal more about how various factors interact and impact one another, mostly when there are shifts in weather conditions.

In conclusion, the model based on second-degree polynomials accurately explained the changes and thresholds observed in LST and $PM_{2.5}$ over the day. This analysis shows, as previous studies did, that temperature does influence $PM_{2.5}$, but so does the pattern of urban heat distribution and when it occurs. It is necessary to model air pollution with care to focus mitigation on parts of the world and specific time periods with low air quality.

Table 2. Summary of polynomial regression analysis for LST and $PM_{2.5}$ (JJA 2023).

Time	Regression Equation	Curve Shape	Turning Point (˚C)	Observed Trend	Interpretation
Daytime	$PM_{2.5} = \alpha_0 + \alpha_1 \cdot LST + \alpha_2 \cdot LST^2$	Concave (Inverted-U)	~38˚C - 39˚C	$PM_{2.5}$ relatively stable until ~38˚C, then declines sharply	High LST enhances convective mixing, reducing $PM_{2.5}$ concentrations
Nighttime	$PM_{2.5} = \alpha_0 + \alpha_1 \cdot LST + \alpha_2 \cdot LST^2$	Convex (U-shaped)	~24˚C - 25˚C	$PM_{2.5}$ reaches a minimum at ~24˚C −25˚C; rises at both cooler and warmer ends	Cooler nights trap $PM_{2.5}$ due to inversions; warmer nights retain heat and trap $PM_{2.5}$

3.4.3. Statistical Strength of Temperature-Pollution Linkages

The connections between Land Surface Temperature (LST), Urban Heat Island Intensity (UHII) and $PM_{2.5}$ concentrations during 24 hours in Faisalabad in the summer of 2023 were analyzed using Pearson correlation and *p*-value matrices.

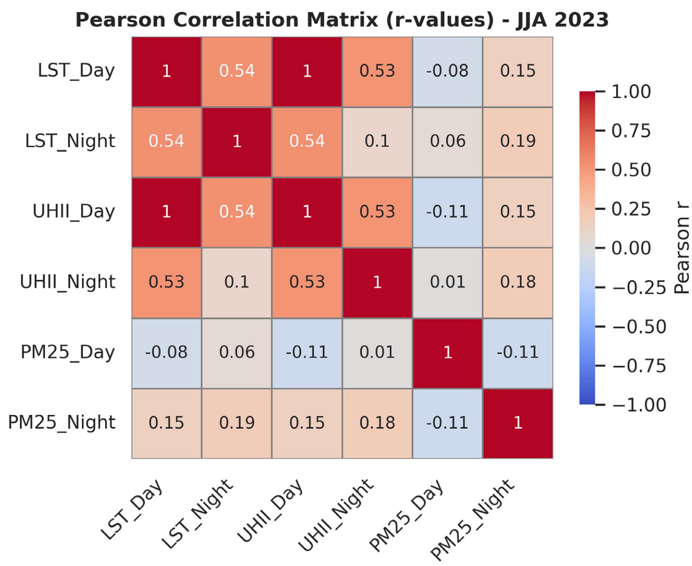


Figure 15. Pearson correlation matrix (r-values) showing linear relationships among LST, UHII, and $PM_{2.5}$ during JJA 2023 in Faisalabad.

LST and UHII were found to be strongly connected by the Pearson correlation matrix (Figure 15), with a result of 0.53 both day and night, proving that higher temperatures on the surface increase the effect of urban heat island. There was a moderate relationship found between surface temperatures during the day and at night and this indicates that urban materials help keep the area warm at night. Meanwhile, the strength of the connections between $PM_{2.5}$ and thermal variables tended to be low. During the day, there was a small, non-significant negative link between daytime LST and $PM_{2.5}$ and during the night, there was a slightly bigger but still weak link between amount of UHII and $PM_{2.5}$ ($r = -0.08$, $p = 0.14$; $r = -0.11$, $p = 0.043$). It's possible that the high trends show how convection carries pollutants further up into the atmosphere during hot afternoons (Hoek et al., 2008). Things did not happen the same during the night. There is a statistically significant, although weakly positive link between $PM_{2.5}$_night and LST_night (0.19, $p = 0.014$) and UHII_night (0.18, $p = 0.015$) temperatures. These findings indicate that keeping heat on the surface and stable air during the night increases the concentration of air pollutants close to the ground.

In the *p*-value matrix (**Figure 16**), statistically significant associations are shown by marking *p*-values below 0.05. The matrix demonstrates that LST and UHII, measured daily and nightly, are strongly related, confirming the importance of urban thermal linkages. Nevertheless, most relationships between thermal factors and $PM_{2.5}$ were not properly supported by the data, especially between LST_night and $PM_{2.5}$_day ($p = 0.20$). The findings of these analyses are listed in **Table 3**, with Pearson r-values and p-values given for all of the variable combinations. The table breaks down how strong and which way thermal-pollution interactions occurred, as well as their trustworthiness.

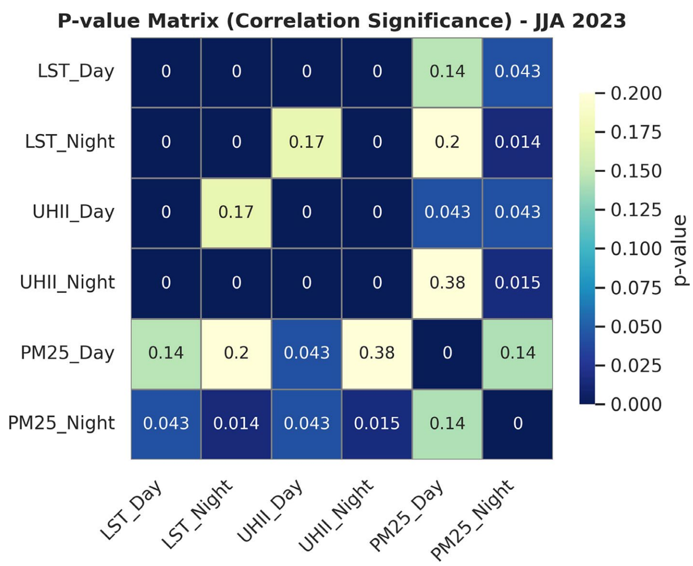


Figure 16. *P*-value matrix for correlation significance in June-July-August (JJA), 2023.

Table 3. Summary of Pearson correlation coefficients (r) and *p*-values for LST, UHII, and $PM_{2.5}$ (JJA 2023-Faisalabad).

VARIABLES COMPARED	PEARSON R	*P*-VALUE	INTERPRETATION
LST VS UHII (DAYTIME)	0.53	0.000	Strong positive, highly significant

Continued

LST VS UHII (NIGHTTIME)	0.54	0.000	Strong positive, highly significant
LST (DAY) VS LST (NIGHT)	0.54	0.000	Moderate positive, highly significant
UHII (DAY) VS UHII (NIGHT)	0.51	0.000	Moderate positive, highly significant
LST VS $PM_{2.5}$ (DAYTIME)	−0.08	0.14	Weak negative, not statistically significant
UHII VS $PM_{2.5}$ (DAYTIME)	−0.11	0.043	Weak negative, statistically significant
LST VS $PM_{2.5}$ (NIGHTTIME)	0.19	0.014	Weak positive, statistically significant
UHII VS $PM_{2.5}$ (NIGHTTIME)	0.18	0.015	Weak positive, statistically significant
LST (DAY) VS $PM_{2.5}$ (NIGHT)	0.15	0.043	Weak positive, statistically significant
UHII (DAY) VS $PM_{2.5}$ (NIGHT)	0.15	0.043	Weak positive, statistically significant
LST (NIGHT) VS $PM_{2.5}$ (DAY)	0.06	0.20	Very weak, not statistically significant

3.5. Limitations and Future Directions

This research concentrated on the first three summer months in 2023 (June-June-August), since these are when urban heat and pollution usually peak, so broader seasonal comparisons could not be made. Instead, the results should be understood as an expert look into a brief period rather than a description for an entire year. Although Pearson correlation and polynomial regression helped with uncovering key aspects and possible links between zones, they might not uncover all the complex and non-straight relationships found in urban ecology. Further studies should include both cool and transitional times of year, along with new advanced data methods, for example, Random Forest, Support Vector Machines or deep learning models. They could make it easier to consider several variables, achieve better results in prediction and expand our knowledge of causes. Additionally, analyzing cities in South Asia that are of similar size to Pakistan's can help make the results more generalized. Nevertheless, this study provides a framework for understanding and diagnosing climatic and pollution challenges in cities that can easily be used and applied to support sustainable efforts.

4. Conclusion

The study focused on finding the link between Land Surface Temperature (LST), Urban Heat Island Intensity (UHII) and $PM_{2.5}$ air pollution in Faisalabad, Pakistan during the peak summer months of June to August 2023. With the help of MODIS data, kriging, spatial buffers and statistical methods such as polynomial regression and Pearson correlation, the study explored the thermal and pollution exposure in an urbanizing city.

Results showed that there were heat islands surrounding the city, with day and night temperatures being unusually high. Central and industrial areas had the highest UHII values which averaged 1.95˚C during the day and 0.58˚C at night. There were a lot of paved surfaces and very little city vegetation which greatly influenced this pattern. Limited by the season it was carried out, the study still analyzes heat and pollution interactions very effectively in South Asia and provides findings useful for other developing urban centers. Nighttime $PM_{2.5}$ concentrations were much higher than during the day, with levels from 76 to 135 μg/m^3 during the day and concentrations often above 150 μg/m^3 at night, mostly in areas where people drive and heat their homes with wood, which are more common. In August, the peak value was recorded at 275 μg/m^3 most likely because of monsoon conditions that slowed mixing in the air. Some hotspots of $PM_{2.5}$ did show up in areas with high LST/UHII, but the strong link between these features was lacking, so it is not possible to say that pollution is caused mostly by temperature or urban layout. The pattern from polynomial regression suggests that the presence of $PM_{2.5}$ lowers at daytime high temperatures, but increases at both lower and higher temperatures at night. Urban areas close to roads and with less vegetation experienced more heat and pollution, but the greener and waterfront regions were calmer, cleaner and supported the urban green spaces' function in making air cleaner and temperatures lower. It is apparent from the findings that Faisalabad regularly deals with two big risk factors: hot temperatures and highly polluted air, mainly in the evening hours. They are mostly affected by what humans release into the atmosphere, as well as atmospheric state, rather than just the temperature. These results point to the importance of stronger climate resilience which can come from more green spaces, improved city planning, tighter nighttime regulations and efforts to increase clean energy mainly in surrounding and rural areas that require protection. To conclude, this study displays where air and thermal pollution overlap in a city in South Asia when the weather is at its highest temperature. It mainly depends on using remote sensing, spatial modeling and statistical analysis together to identify risks that are present in the same parts of urban areas. The approaches can be followed by others, the findings are helpful for practical changes and the results help in improving academics and city policy. With this research, the need to focus on effective urban environmental planning becomes clear and it opens the door for similar research done throughout the year.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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