

Assessing the Impact of Urban Heat Island on Air Quality in Rajshahi City

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ABSTRACT

Urban heat islands (UHI) and air quality are significant concerns in rapidly urbanizing areas, particularly in metropolitan Bangladesh. This research investigates how UHI impacts air quality in Rajshahi City using satellite-derived data, including MODIS Land Surface Temperature (LST) and Aerosol Optical Depth (AOD), along with ground-based observations. Spatiotemporal analysis reveals that UHI intensity ranges from 1.09 to 4.7, with the highest values in central and southern zones. The Air Quality Index (AQI) values varied from 101 to 200, mostly categorizing these areas as "unhealthy for sensitive groups" or "unhealthy." The analysis shows a strong correlation ($r = 0.682$) between higher UHI intensity and increased PM_{2.5} levels, reflecting poorer air quality in densely built-up areas. Elevated UHI temperatures accelerate pollutant formation, particularly PM_{2.5}. In contrast, peripheral zones with more vegetation cover had lower UHI and AQI values. These findings inform sustainable urban development strategies to mitigate the effects of urban heat islands and air pollution in the future.

Keywords: Urban Heat Island, Air Quality Index, MODIS, PM_{2.5}, Urban Environment

1. INTRODUCTION

Urbanization and the ensuing city expansion significantly alter the natural environment, often leading to the occurrence of an Urban Heat Island (UHI). The "urban heat island" (UHI) effect occurs when the temperature in a city is greater than that of a nearby rural area (Hulley, 2012). Urban heat islands are an increasing concern because they can affect communities by elevating greenhouse gas emissions and air pollution due to heightened air conditioning usage, along with an increased occurrence of heat-related illnesses and potentially even higher death rates (Leal Filho et

al., 2018). One of Bangladesh's fastest-growing cities, Rajshahi, is becoming much more urbanized, which could change the city's microclimate and environmental conditions (Sadat et al., 2024a).

The city of Rajshahi, located in northwest Bangladesh, has seen tremendous changes owing to increased industrial activity and a growing population. The creation of UHIs is facilitated by excessive warming of impervious surfaces and increased anthropogenic heat release (Vujovic et al., 2021). Air pollution emissions are increased by human activity, which affects the chemical

composition of the air in cities (Fallmann et al., 2016). Between 1998 and 2018, vegetated areas dropped significantly from 50.8% to 4.03%, while built-up areas expanded, causing an average Land Surface Temperature (LST) increase of up to 6°C in developed zones of Rajshahi City (Sadat et al., 2024b). This study aimed to assess the urban UHI patterns in Rajshahi and their relationship with air quality. Through a multidisciplinary approach involving satellite imagery, meteorological data analysis, and ground-level air quality monitoring, the study seeks to clarify the complex links between air pollution and the UHI effect in this metropolitan area.

The UHI effect in Rajshahi is particularly pronounced due to factors such as limited vegetation in urban cores, extensive impervious surfaces, and concentrated industrial and vehicular emissions (Rahman and Hasan, 2024). Elevated urban temperatures enhance atmospheric stability, inhibiting pollutant dispersion and creating a conducive environment for the accumulation of air pollution (Nejad et al. 2023). This combination of factors underscores the urgent need to examine the interactions of urban heat islands (UHI) and their effects on air quality, as they have profound implications for public health and urban planning (Elmarakby and Elkadi, 2024).

A study investigates Hangzhou's urban heat island (UHI) impact on inorganic aerosols, revealing a 33% drop in PM_{2.5} concentrations in the boundary layer, largely due to UHI circulation (Kang et al., 2022). A study conducted from 2015 to 2019 in the Yangtze River Delta shows the spatiotemporal distribution of UHI intensity and six air pollutants, revealing regional differences

in UHI and correlations with O₃ concentrations (Wang et al., 2021). The UHI intensity increased in the afternoon, peaking at night, highlighting the need for integrating meteorological and air quality data to understand urban environmental dynamics and revealing important insights into UHI's temporal variations in Tali (Lai and Cheng, 2009). The study emphasizes the significant relationship between land use and land cover (LULC) and land surface temperature (LST), indicating that urban heat islands (UHIs) are associated with increased air pollution in the market area of Tabriz City (Feizizadeh and Blaschke, 2013). Ozone is negatively related to urban heat islands, while CO, NO₂, SO₂, and PM show a positive correlation, with stronger pollutant interactions in winter (UHI, NO₂, PM₁₀) and fall (SO₂, CO, PM_{2.5}) (Ngarambe et al., 2021).

This study addresses this knowledge vacuum by analyzing the spatial and temporal patterns of UHI in Rajshahi City and its correlation with air quality parameters, particularly aerosols and particulate matter. By leveraging remote sensing data from MODIS satellites and integrating ground-based observations, this research provides a comprehensive assessment of UHI's impact on air quality. The objectives of this study were to identify UHI hotspots, evaluate air pollution levels, and establish correlations between urban heat intensity and pollutant concentrations.

The findings from this research are expected to contribute significantly to urban climate studies, offering insights to urban planners and policymakers to mitigate UHI effects and improve air quality. By focusing on a rapidly urbanizing city like Rajshahi, this study not only bridges a critical research gap but also provides a

model framework for addressing similar challenges in other urban areas across developing countries. The study highlights the significance of assimilating green infrastructure, promoting sustainable urban planning practices, and developing adaptive plans to tackle the simultaneous challenges of rising urban temperatures and poor air quality.

Although research on urban heat islands (UHI) and air quality is increasing, there is still a significant knowledge gap regarding analyzing individual UHI and air quality in Rajshahi City. This research aims to bridge the gap between UHI and air quality analysis and provide useful data for the scientific community and for regional policymakers.

2. METHODS

2.1 Data source

This study primarily used remote sensing datasets from MODIS satellite sensors.

Specifically, the study relies on LST and AOD data. LST data provides land surface temperature measurements at moderate spatial resolutions, allowing researchers to identify urban heat island hotspots and analyze temporal temperature variations in Rajshahi City and its surroundings. Similarly, AOD data offers insights into aerosol concentrations in the atmosphere, aiding in the assessment of air quality and its correlation with urban heat island intensities. This research initiative utilizes remote sensing datasets to explore the complex interplay between urban heat islands and the air quality. By doing so, it aims to enhance the understanding of environmental dynamics specific to Rajshahi.

To carry out this research, we used MODIS satellite imagery featuring 1-kilometer spatial resolution and spectral bands of 31 and 32 (Table 1). This allowed us to effectively evaluate land surface temperature (LST) and detect urban heat island (UHI) phenomena in the area.

Table 1: Characteristics of Satellite imageries

Satellite	Sensor	Spatial Resolution (m)	Temporal Resolution	Spectral Bands	Products	Date of Acquisition
TERRA	MODIS	1000	Daily	Thermal Infrared bands (31 & 32)	LST	April to June, 2023
TERRA	MODIS	1000	Daily	Blue band (0.47 μm), Green band (0.55 μm).	AOD	April to June, 2023

To analyze the impact of the UHI effect on the air quality of Rajshahi City, satellite imageries were obtained from Google Earth Engine (GEE). The data acquisition period for both satellite images was from April to June of 2023 (Table 1).

LST data from MODIS is vital for identifying and mapping UHI trends because of its intermediate geographic resolution and frequent revisits. AOD data were analyzed with a focus on aerosols and particulate matter. Accessing data over an

appropriate period ensures a comprehensive understanding of temporal trends and seasonal variations in Rajshahi City.

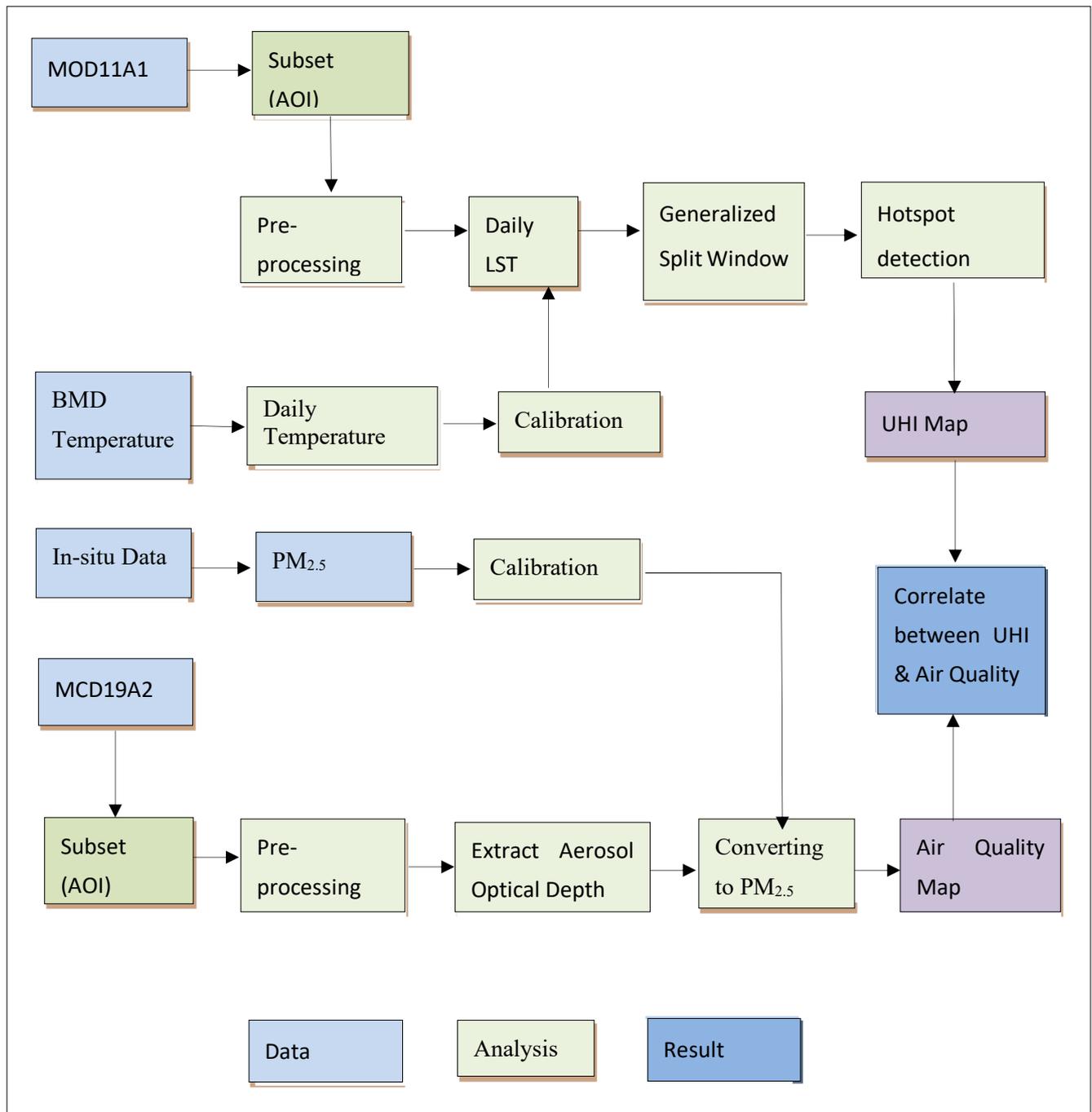


Figure 1: Methodological flowchart of the study.

2.2 Methodology

This study was conducted through geospatial methods integrated with the in-situ data. The entire process of this study is illustrated in the following flowchart (Figure 1). A UHI map was created through land surface temperature data,

with the calibration using daily temperature data from the Bangladesh Meteorological Department. Air quality data was prepared by analyzing aerosol optical depth data. After obtaining the aerosol value, it was converted into PM_{2.5} by the calibration of the Department of Environment

data of PM_{2.5}. Then, the UHI map and the air quality map were overlapped to identify the relationship between them in specific areas. Finally, a Pearson's correlation analysis was conducted between UHI intensity and PM_{2.5} concentration values to validate the spatial relationship and assess the impact of UHIs on air quality.

2.2.1 Data pre-processing

Our study emphasizes the pre-processing stage, which is essential for guaranteeing the precision and quality of satellite data, to assess the effect of the UHI on air quality in Rajshahi City. We used atmospheric correction algorithms on MODIS data to minimize air interferences, thus enhancing the precision of Land Surface Temperature (LST) measurements. Additionally, we applied temporal and geographic filtering to the Aerosol Optical Depth (AOD) data to remove noise and outliers, providing a clearer picture of atmospheric composition, including aerosols and particulate matter. This thorough pre-processing step lays the groundwork for informed air quality analyses, facilitating deeper insights into the interplay between urban heat dynamics and air pollution in Rajshahi.

2.2.2 Data analysis

2.2.2.1 UHI calculation

Spatially integrated LST data were used to determine UHI-related indices and discover urban heat islands (UHIs). This is a crucial step in understanding temperature dynamics. These indices are important markers of the changes in temperature trends between urban and rural areas of the country. The LST was derived from the generalized split-window algorithm, primarily using thermal infrared bands (T31 and T32) of the

MODIS sensor (Wan, n.d.), as shown in Eq. (1).

$$LST = BT31 + (a \times (BT31 - BT32)) + (b \times (BT31 - BT32)^2) + c + d \times \varepsilon + e \times \Delta\varepsilon \quad (1)$$

Where

- **BT31**: Brightness temperature from MODIS band 31 (centered at ~11 μm).
- **BT32**: Brightness temperature from MODIS band 32 (centered at ~12 μm).
- **a, b, c, d, e**: Coefficients derived from atmospheric and surface emissivity characteristics. These coefficients are pre-calculated and provided with the MODIS LST product based on atmospheric models and surface properties.
- **ε**: Mean emissivity of bands 31 and 32.
- **Δε**: Emissivity difference between bands 31 and 32.

The urban heat island intensity value (ΔT) was calculated by identifying representative urban and rural pixels, as shown in Eq. (2). UHI maps are produced using the computed data from the land surface temperature data, offering a clear depiction of temperature changes throughout Rajshahi City's complex metropolitan environment.

$$\Delta T = T_{urban_mean} - T_{rural_mean} \quad (2)$$

2.2.2.2 Assessment of Air Quality

The air quality of Rajshahi City was categorized based on the concentration of PM_{2.5} derived from the satellite data of the AOD with the calibration of in-situ data from the Department of Environment, Bangladesh. PM_{2.5} values were estimated from AOD data using regression analysis to calibrate PM_{2.5} data with AOD data, establishing a reliable relationship

between the two. Following this, a PM_{2.5} map was created to illustrate the geographical spread of PM_{2.5} in Rajshahi City. Eq. (3) shows the simple linear regression analysis between PM_{2.5} and AOD.

$$Y = 272.3X - 127 \quad (3)$$

Where

- Y = PM_{2.5} value
- X = Aerosol optical depth (AOD) value

After obtaining the PM_{2.5} concentration values,

Table 2: Air quality index (AQI) and breakpoint prescribed by environmental protection agencies.

2024 AQI for Fine Particle Pollution (Breakpoints are in micrograms per cubic meter)			
AQI Category and Index Value	Previous AQI Category Breakpoints	Updated AQI Category Breakpoints	What changed?
Good (0 - 50)	0.0 to 12.0	0.0 to 9.0	EPA updated the breakpoint between Good and Moderate to reflect the updated annual standard of 9 micrograms per cubic meter.
Moderate (51 - 100)	12.1 to 35.4	9.1 to 35.4	
Unhealthy for Sensitive Groups (101 - 150)	35.5 to 55.4	35.5 to 55.4	No change, because EPA retained the 24-hour fine PM standard of 35 micrograms per cubic meter.
Unhealthy (151 - 200)	55.5 to 150.4	55.5 to 125.4	EPA updated the breakpoints at the upper end of the unhealthy, very unhealthy, and hazardous categories based on scientific evidence about particle pollution and health. The Agency also collapsed two sets of breakpoints for the Hazardous category into one.
Very Unhealthy (201 - 300)	150.5 to 250.4	125.5 to 225.4	
Hazardous (301+)	250.5 to 350.4 and 350.5 to 500	225.5+	

they are classified according to the Air Quality Index (AQI) and specific breakpoints prescribed by the Department of Environment (DoE) in Bangladesh. These breakpoints are largely based on the United States Environmental Protection Agency (US EPA) standards, which calculate air quality using five criteria pollutants: Particulate Matter (PM₁₀ and PM_{2.5}), NO₂, CO, SO₂, and Ozone (O₃). In Bangladesh, the AQI breakpoints for PM_{2.5} are aligned with those of the US EPA (Table 2).

2.2.2.3 Conceptual Framework and Sampling Design for Correlation Analysis

The conceptual interdependence between Urban Heat Island (UHI) intensity and PM_{2.5} concentrations was examined in relation to air pollution and urban climate theory before conducting the correlation analysis. Cities that are characterized by increased intensity of UHI are normally characterized by dense built-up environments, high anthropogenic heat sources, diminished vegetation covers, and amplified traffic and industrialization, which are also principal components of PM_{2.5}. Moreover, high surface temperatures may affect the stabilization of the atmosphere and distribution of pollutants

and cause an increase in PM_{2.5} concentrations closer to the surface. Thus, it is theoretically anticipated that there exists a positive correlation between UHI and PM_{2.5}.

In the correlation analysis, 30 sampling units were selected using a random sampling method in the study area. Random sampling was employed to eliminate selection bias and ensure that all locations in the study area had an equal chance of being selected. This will increase the representativeness of the sample and enable generalization of the findings. The sample size (N = 30) is considered sufficiently large to conduct parametric statistical analysis and provide a trustworthy estimation of the Pearson correlation.

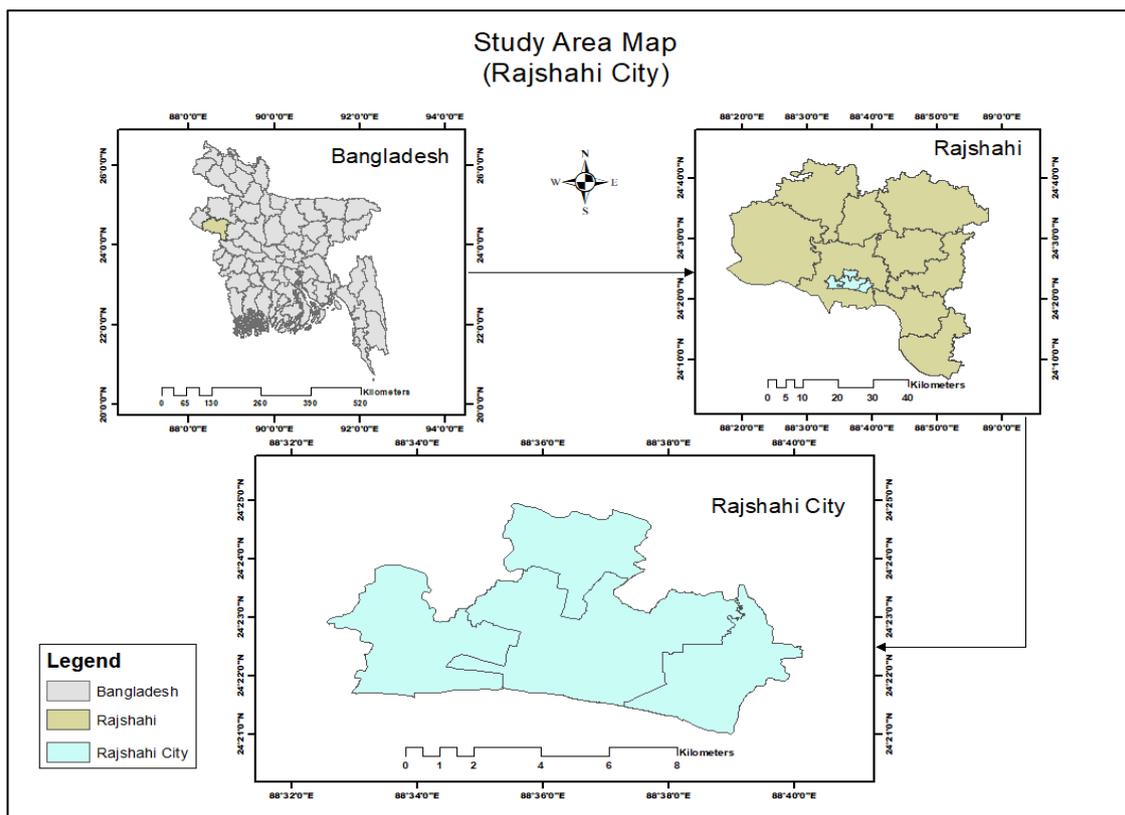


Figure 2: Locational Map of the Study Area.

2.3 Study Area

The city of Rajshahi was chosen as a center of the given study because of its unique climatic, urban, and environmental factors that

precondition its appropriateness to be considered as the case to investigate the correlation between Urban Heat Island (UHI) and air quality. Rajshahi, which is in the northwestern region of

Bangladesh (Figure 2), is considered one of the hottest towns in the state, where the summer temperatures are quite extreme, and heat stress is common. Over the last few years, the city has experienced a high rate of urban sprawl characterized by the advancement of built-up areas, decreased vegetation cover, and increased traffic and business, all of which enhance the effects of UHI.

Besides these, Rajshahi is experiencing new air quality challenges, which are stimulated by the city's air emissions, brick kilns around the urban centers, car pollution, and seasonal weather. Imperfections notwithstanding, the city of

Rajshahi has not received much scientific concern in the research of UHI-air quality as other major metropolitan cities like Dhaka and Chattogram. Thus, the study of Rajshahi is informative in terms of learning the urban climate and environment of medium-sized cities in Bangladesh and helps to bridge an existing research gap.

In addition, the fact that data on land surface temperature and air quality parameters obtained via satellites are constant allows effective spatial analysis; thus, Rajshahi is a feasible and scientifically viable case study.

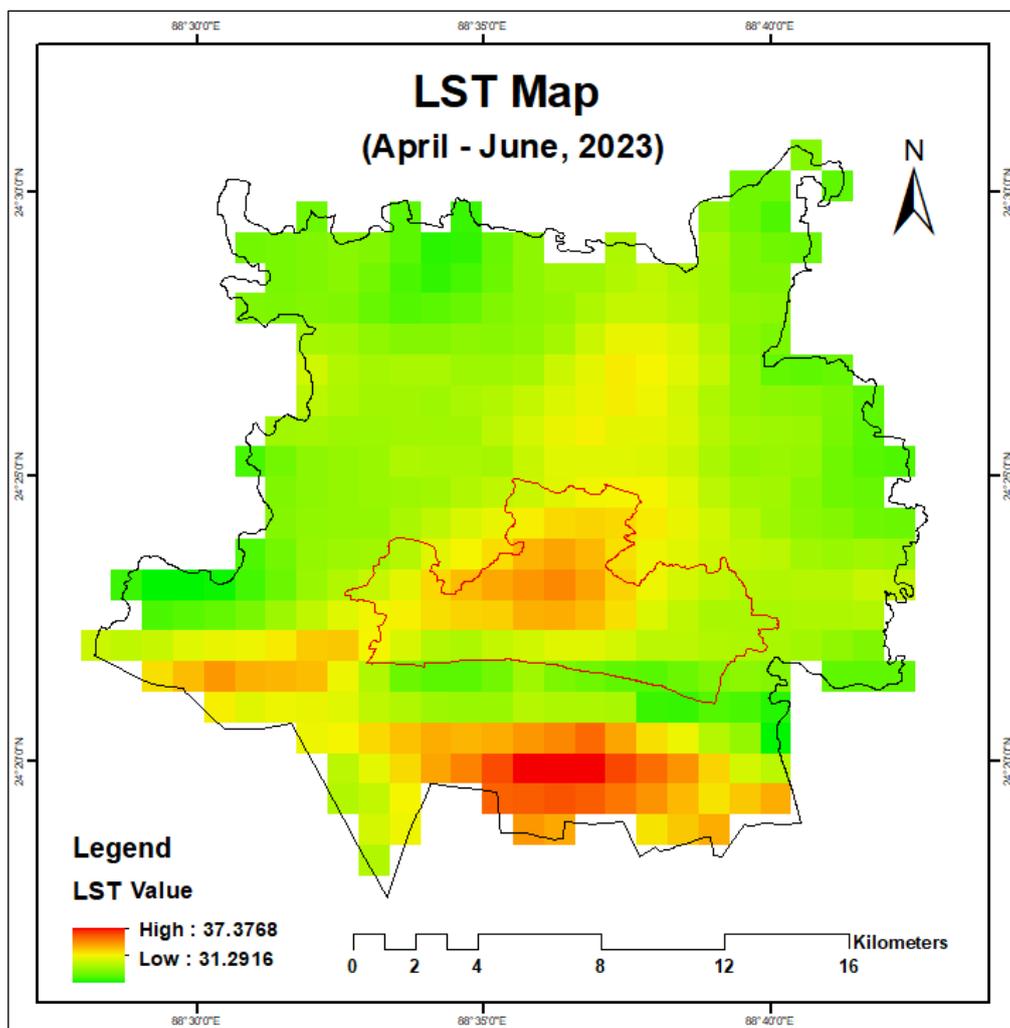


Figure 3: Land Surface Temperature Map of Rajshahi City and the surrounding rural area.

3. RESULTS

3.1 Detection of UHI

The Land Surface Temperature (LST) maps analysis (Figure 3) provides an understanding of the surface temperature distribution pattern across the Rajshahi City. The map indicates that the minimum temperature observed was 31.29°C and the highest observed was 37.38°C, with the average LST of 33.45°C in the studied area

(Figure 3).

The highest LST was also found in the southern parts of the cities, where the southern part has the highest LST value due to the charland of the Padma River, and in the central parts of the city. These zones, marked by red and orange colors on the map (Figure 3), are primary thermal-accumulation zones.

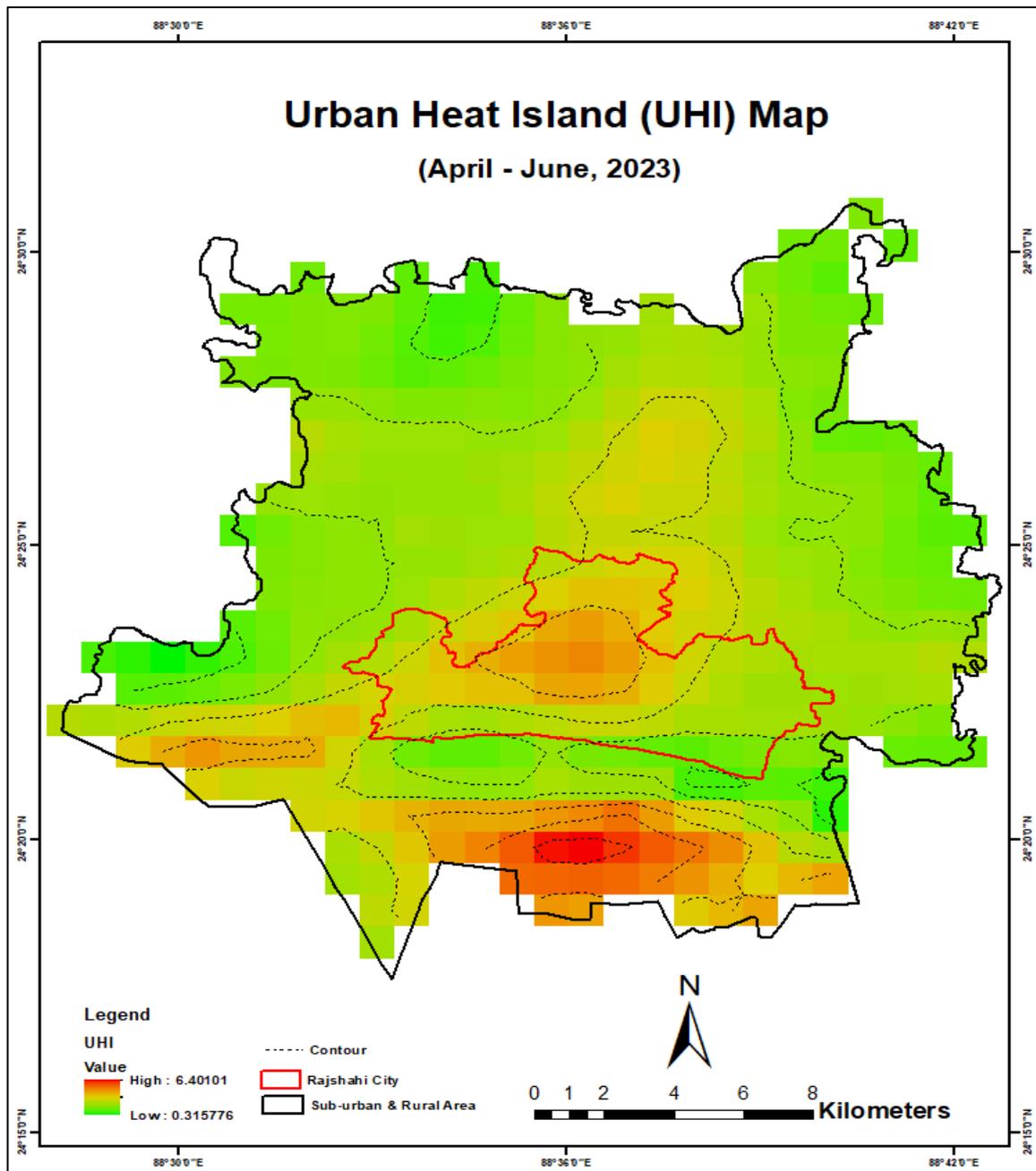


Figure 4: Urban Heat Island Map of Rajshahi City and the surrounding rural area.

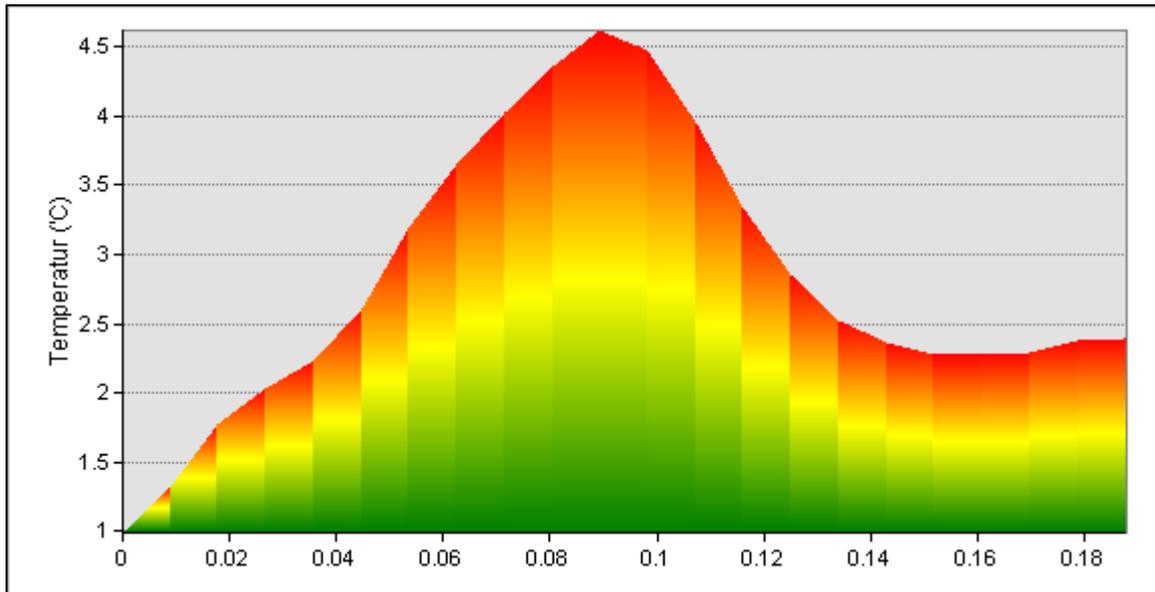


Figure 5: Urban Heat Island Stack Profile.

The UHI Intensity Values on the map (Figure 4) varied from 0.32 in the suburb to 6.40, which are outside of the city boundary. In the city core, the value is 4.70, which depicts the significant variations in heat retention and heat release capacity by urban parts and peripheral areas of the area.

The UHI map also revealed a spatial gradient, with UHI intensity decreasing progressively from the city center to the outskirts (Figure 5). The temperature increases dramatically as one moves closer to the metropolitan areas (shown by the red region), reaching a peak of about 4.7°C (Figure 5). Temperatures are higher in the urban core, suggesting the existence of a UHI effect.

3.2 Air Quality Assessment

The PM_{2.5} map of Rajshahi City (Figure 6) provides a spatial visualization of particulate matter concentrations across different areas of the city. PM_{2.5}, representing particulate matter with a diameter of 2.5 micrometers or less, is a critical indicator of air quality. According to the map (Figure 6), PM_{2.5} values in Rajshahi City range

from a minimum of 51.66 µg/m³ to a maximum of 118.94 µg/m³. The highest concentrations are represented by red and orange shades and are mostly found in the central and western parts of Rajshahi city.

The Air Quality Index (AQI) map for Rajshahi City (Figure 7) presents a clear view of air quality across various parts of the city. AQI values in this map range from 101 to 200, categorized primarily into two zones: moderate (101-150) and unhealthy for sensitive groups (151-200) based on the US EPA standards (Table 2). These categories are visualized through orange and red shades, respectively, indicating areas where air pollution levels may pose health risks to the residents.

The majority of Rajshahi City falls within the "unhealthy for sensitive groups" category, with AQI values between 151 and 200, as indicated by the red color (Figure 7). This indicates poor air quality in the area. The pockets of lower AQI values (101-150), represented in orange color (Figure 7), are distributed in certain peripheral

regions. Although these areas still fall within the "moderate" category, they suggest slightly better air quality than the city's core.

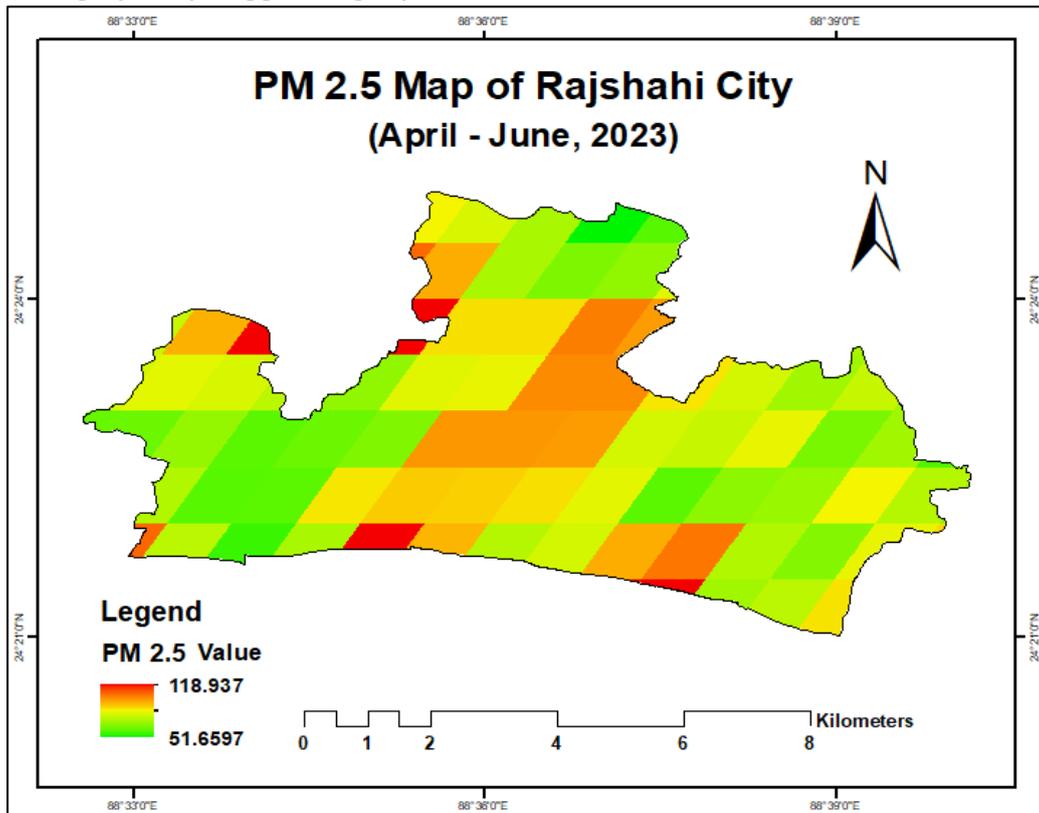


Figure 6: PM_{2.5} Concentration Map of Rajshahi City.

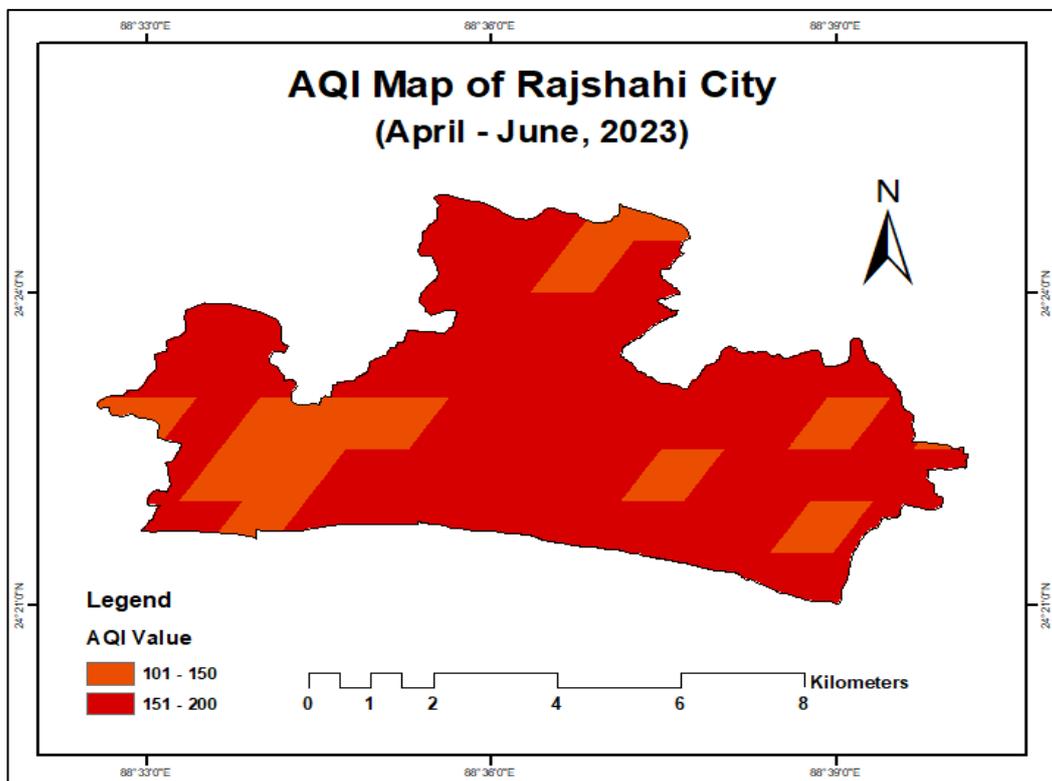


Figure 7: Air Quality Index Map of Rajshahi City.

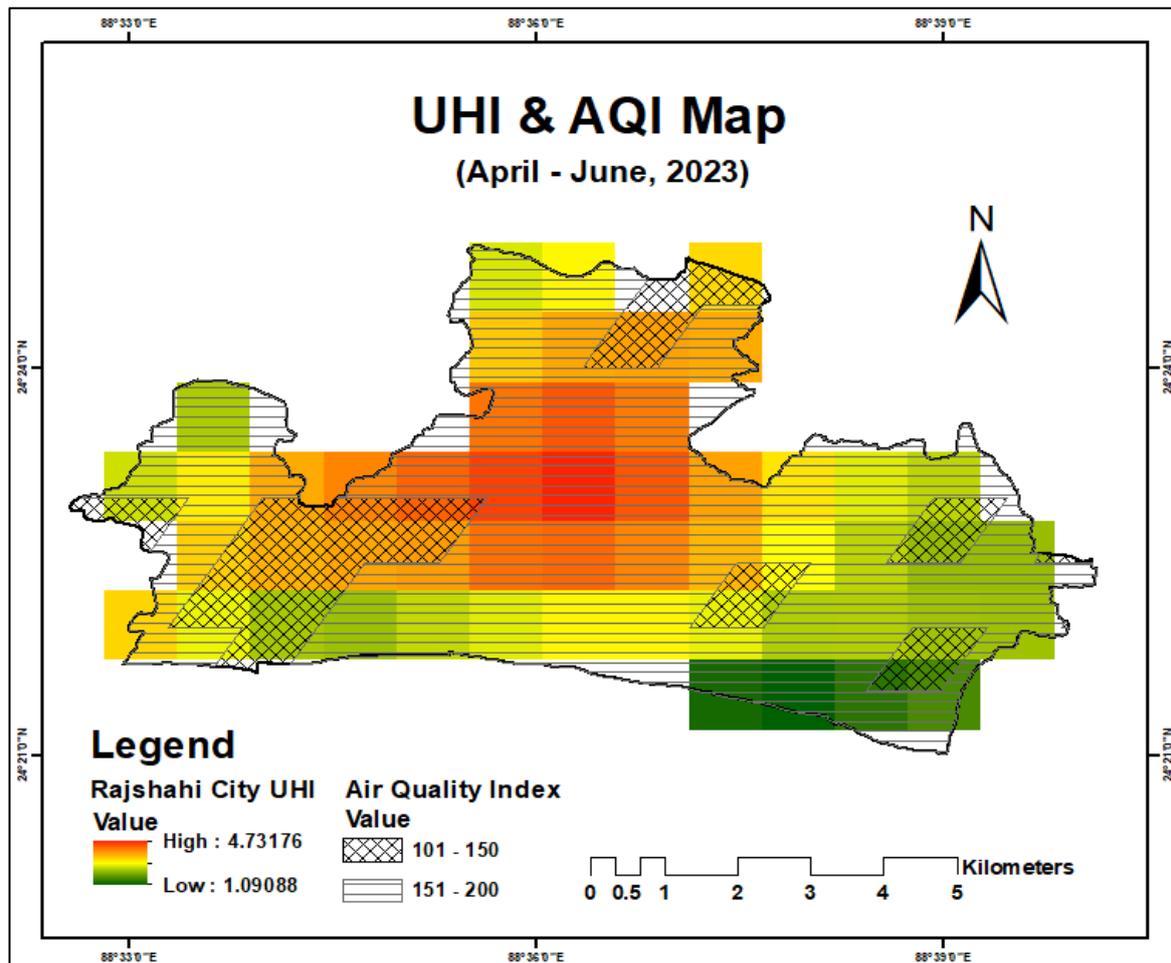


Figure 8: Overlapping of UHI and AQI Map of Rajshahi City.

Table 3: Correlation between UHI and PM_{2.5}

Correlations			
		UHI	PM _{2.5}
UHI	Pearson Correlation	1	.682**
	Sig. (2-tailed)		.000
	N	30	30
PM _{2.5}	Pearson Correlation	.682**	1
	Sig. (2-tailed)	.000	
	N	30	30

** . Correlation is significant at the 0.01 level (2-tailed).

3.3 Relationship between UHI and Air Quality

The combined UHI and AQI map for Rajshahi City (Figure 8) visually represents the spatial relationship between UHI intensity and air

quality levels. The UHI values in the map (Figure 8) range from 1.09 to 4.73. The highest UHI intensities were concentrated in the central and western regions of Rajshahi. These zones, marked

by yellow to red shades, align closely with areas exhibiting poor air quality (AQI values of 151-200, shaded with crosshatching). This map illustrates the regions where high urban heat island (UHI) values coincide with poor air quality.

To further validate this spatial observation, Pearson’s correlation analysis was performed between UHI intensity and PM_{2.5} concentration values. The result revealed a strong positive correlation ($r = 0.682$, $p < 0.01$, $N = 30$) (Table 3), confirming that areas with higher UHI intensities (2.8 to 4.7) tended to have higher PM_{2.5} levels (65 $\mu\text{g}/\text{m}^3$ to 118.94 $\mu\text{g}/\text{m}^3$) and reinforces the observation of spatial pattern (Figure 8). This statistically significant relationship supports the spatial evidence that urban heat contributes to the deterioration of air quality in Rajshahi City. The

positive correlation implies that as surface temperature rises owing to intensified UHI effects, the concentration of fine particulate matter (PM_{2.5}) also increases, likely owing to reduced atmospheric dispersion and pollutant accumulation in warmer zones.

This overlap indicates that regions with higher UHI effects also experience elevated levels of air pollution, suggesting a potential relationship between urban heating and pollutant accumulation in these areas. The UHI effect occurs when urban infrastructure and limited green spaces lead to higher temperatures, as illustrated in the land use and land cover map of Rajshahi City (Figure 9), which can influence atmospheric stability, leading to pollutant trapping and reduced dispersion in the air.

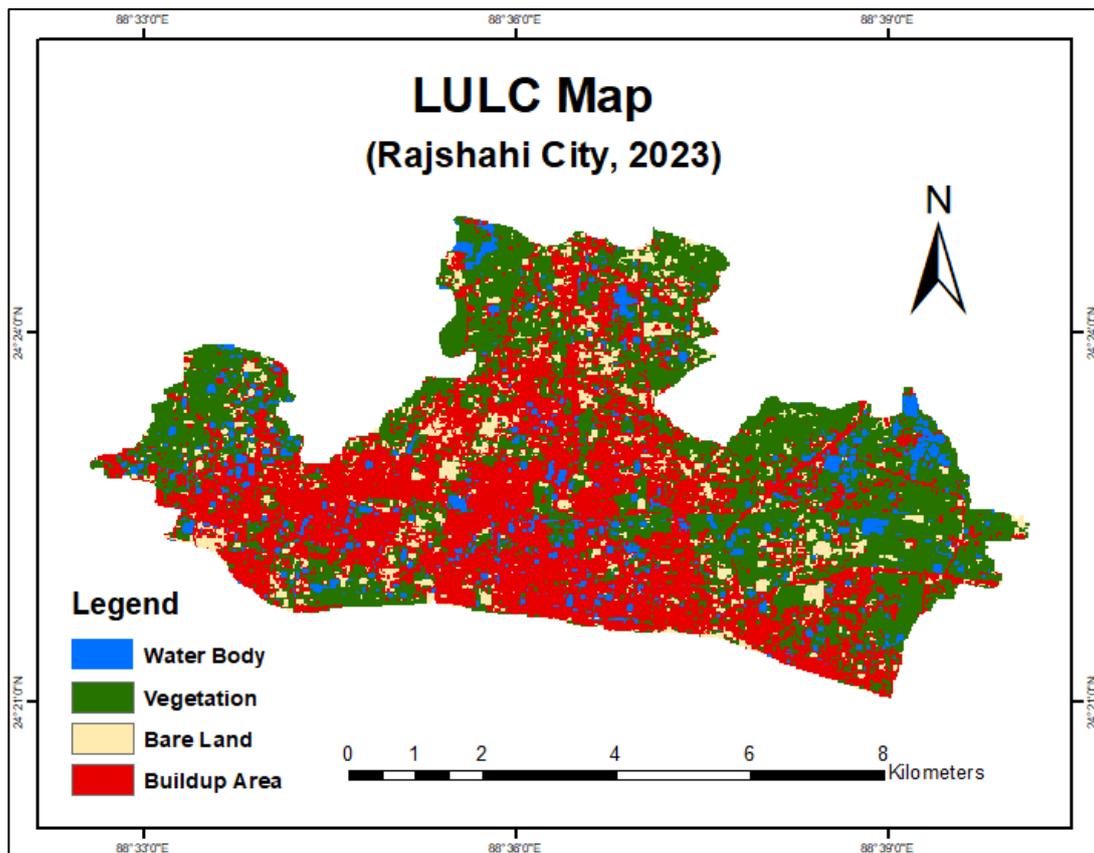


Figure 9: Land Use and Land Cover Map of Rajshahi City.

The areas with lower UHI values, mostly located in the city's eastern and southern areas,

were associated with better air quality, as shown by AQI values in the "Unhealthy for Sensitive Groups" range (101-150) or lower. These zones benefit from relatively lower temperatures, likely owing to increased vegetation cover and the presence of open spaces (Figure 9).

4. DISCUSSION

The quantitative analysis revealed a statistically significant and moderately strong positive correlation between Urban Heat Island (UHI) intensity and PM_{2.5} concentration in Rajshahi ($r = 0.682$, $p < 0.01$, $N = 30$). The coefficient of determination ($R^2 = 0.465$) indicates that approximately 46.5% of the spatial variation in PM_{2.5} concentration can be explained by variation in UHI intensity. High-UHI zones (≤ 4.73) were predominantly associated with AQI levels within the 151–200 range, reflecting unhealthy air quality conditions, which are in the densely built-up urban core (Figure 9). These findings directly confirm that increased surface temperature is significantly associated with deteriorating air quality.

Scientifically, this relationship suggests that elevated land surface temperatures modify local atmospheric dynamics in ways that favor pollutant accumulation. Urban materials such as concrete and asphalt absorb and retain solar radiation, reducing nighttime cooling and enhancing near-surface thermal stability (Ziaemehr et al., 2023). This thermal stratification can suppress vertical mixing of air masses, limiting pollutant dispersion (Wen et al. 2022) and increasing particulate concentration. The UHI effect is defined by increased temperatures resulting from urban development and a lack of greenery (Marando et al., 2022),

which weakens evapotranspiration and natural filtration processes (Jin et al., 2017), further intensifying localized warming and contributing to higher pollutant persistence in densely urbanized zones.

The analysis of this integrated map offers critical insights into how urban heat exacerbates air pollution and contributes to health risks within the city (Cichowicz and Bochenek, 2024). The observed positive correlation between high UHI intensity and poor air quality in Rajshahi is consistent with the results from studies conducted in urban regions like Hangzhou, China, Seoul, South Korea, and Chennai, India. The study in Hangzhou demonstrated that UHI significantly increased particulate matter concentrations in urban zones by altering atmospheric conditions (Kang et al., 2022). Similarly, in Rajshahi, high UHI zones corresponded with elevated PM_{2.5} levels, particularly in densely developed areas.

A significant connection exists between densely populated urban areas and elevated land surface temperatures (Rashid et al., 2022), which is consistent with our first findings. Similar studies conducted in Dhaka, Bangladesh, have revealed that rapid urbanization has contributed to increased LST and air pollution (Faisal et al., 2022). A study in Chennai, India, showed that urban heat islands (UHIs) and humidity significantly affect PM_{2.5} and NO₂ levels (Swamy et al., 2020).

Another study found that higher daytime temperatures in urban areas increased ozone concentrations, while high PM_{2.5} levels persisted because of limited pollutant dispersion (Wang et al., 2021). A study from Berlin indicated that urban areas experience the Urban Heat Island

(UHI) effect and the Urban Pollution Island (UPI) (Li et al., 2018). The growth of urban areas in Bangalore has led to higher land surface temperatures and heightened air pollution, primarily because natural surfaces have been converted into impermeable land (Suthar et al., 2023).

Based on the analysis of the findings from this study and other contemporary studies, the common cause responsible for the poor living environments in cities is rapid urbanization (Environment, 2009). This leads to urban expansion that retains heat in built-up areas (Hao et al., 2025). By retaining heat, cities become an Urban Heat Island, which then affects air pollutants (Wu et al., 2024). These air pollutants worsen air quality and pose significant risks to human health (Tran et al., 2023). However, the correlation strength observed in Rajshahi ($r = 0.682$) underscores that even mid-sized cities can exhibit a pronounced linkage between UHI intensity and particulate pollution, reinforcing the broader relevance of this environmental interaction.

The demonstrated relationship between UHI intensity and $PM_{2.5}$ concentration has significant societal implications for urban sustainability and public health. Since nearly half of the observed variability in particulate concentration is explained by UHI intensity, thermal mitigation strategies could simultaneously reduce heat stress and improve air quality. A comparative analysis with similar research shows that targeted interventions, such as increasing greenery (Zhang et al., 2014), applying reflective roofing (Saqib et al., 2024), and controlling emissions, could be equally beneficial in Rajshahi as they have been in other cities worldwide. Because the cooler

areas allow for improved air circulation, reducing pollutant concentrations and enhancing air quality (Niza et al., 2024).

This study did not use advanced atmospheric dispersion or transport models due to data limitations. With better meteorological datasets and modeling tools, the estimation of pollutant dynamics and their interaction with urban thermal patterns could be improved. The analysis was based on a limited dataset of 30 observations from a specific time frame; a more extensive multi-seasonal dataset would deepen our understanding of UHI intensity and particulate pollution variability. Key meteorological factors like wind speed and humidity were not included in the analysis, despite their potential effects on pollutant dispersion. Although the study highlighted the UHI–air quality relationship under typical conditions, long-term and multi-parameter investigations would bolster the findings' reliability and generalizability.

5. CONCLUSIONS

This study set out to examine whether Urban Heat Island (UHI) intensity significantly influences air quality in Rajshahi. A statistically significant and moderately strong positive correlation was identified between UHI intensity and $PM_{2.5}$ concentration ($r = 0.682$, $p < 0.01$, $N = 30$), demonstrating that higher surface temperatures (34 to 37°C) are associated with elevated particulate pollution levels. Furthermore, the coefficient of determination ($R^2 = 0.465$) indicates that approximately 46.5% of the spatial variability in $PM_{2.5}$ concentration can be explained by variation in UHI intensity. This confirms that UHI is not merely coincident with poor air quality but represents a substantial

contributing factor.

Spatial analysis further supports this conclusion, as densely built-up zones with high UHI values (2.8 to 4.73) correspond predominantly to AQI levels within the unhealthy category (151–200), whereas vegetated areas exhibit lower surface temperatures (31 to 33°C) and comparatively improved air quality. These results collectively confirm the study's primary objective by quantitatively demonstrating that thermal accumulation in urbanized areas intensifies particulate pollution in Rajshahi City.

By providing empirical evidence from a mid-sized urban center in Bangladesh, this study contributes to the broader understanding that the interaction between urban heat and air pollution is not limited to megacities but is also significant in emerging cities. The findings highlight the importance of integrating heat mitigation strategies—such as expanding urban greenery and reducing impervious surface coverage—into urban planning policies, as such measures may simultaneously reduce thermal stress and improve air quality. Overall, the study clearly answers its research question by confirming that UHI intensity plays a statistically significant and meaningful role in shaping PM_{2.5} distribution patterns in Rajshahi City.

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DECLARATIONS

The authors declare that they have no competing interests.

AUTHOR'S CONTRIBUTIONS

Md. Asadujjaman Reon: conceptualization, methodology, data collection and analysis, visualization, writing. Md. Rahedul Islam: conceptualization, methodology, visualization, review and editing, supervision. Nishat Tasnim Ananna: data collection and analysis, visualization.

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