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A CORRELATION ANALYSIS OF LAND SURFACE TEMPERATURE AND EVAPOTRANSPIRATION IN AN URBAN SETTING

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ABSTRACT

Urbanisation is found to increase the Land Surface Temperature (LST), which results in the formation of Urban Heat Islands (UHI). This effect is a result of the natural land cover being replaced with impermeable surfaces like buildings, roads, and pavements, which absorb and hold onto heat more. As a result, metropolitan regions frequently experience substantially hotter temperatures than their nearby rural counterparts, especially during heat waves. This arises partly due to reduction in Actual Evapotranspiration (AET). AET and LST have a close relationship. AET rates are greatly influenced by the amount of vegetation and their transpiration capacity, which in turn can have an influence on LST in urban regions. The type of Land Use and Land Cover (LULC) has a significant impact on how LST affects the interchange of energy between the earth's surface and the atmosphere. Vegetation AET has a huge potential to reduce both temperatures. The temperature of a water body is lower than that of the nearby urban. The objective of this research is to determine the variation in AET and LST with regards to varying types of land cover by finding correlation between them. The spatio-temporal analysis is done for the summer and winter season of 2020. The correlation is studied between LST and AET for each land cover class and for both seasons for 2020 and results are plotted. The green areas and lakes of the city showed a higher AET and lower LST, whereas the built environment behaved in just the opposite manner. It can be inferred that it is essential to comprehend the local context to effectively determine the relationship between LST and AET in a particular scenario.

1. INTRODUCTION

Land Use and Land Cover (LULC) patterns in developing countries have undergone significant transformations due to anthropogenic activities. These changes in LULC have had a substantial impact on the environment, leading to various forms of environmental degradation (Shukla & Jain, 2021). Urbanisation is found to increase the local Land Surface Temperature (LST), which results in the formation of urban heat islands (Mazrooei, Reitz, Wang, & Sankarasubramanian, 2021). This effect is a result of the natural land cover being replaced with impermeable surfaces like buildings, roads, and pavements, which absorb and hold onto heat more. As a result, metropolitan regions frequently experience substantially hotter temperatures than their nearby rural counterparts, especially during heat waves (Ullah et al., 2023). This arises partly due to reduction in the actual evapotranspiration. LST and Actual Evapotranspiration (AET) are related to each other in the context of urban environments. In urban areas, where impervious surfaces like buildings, roads, and concrete dominate the landscape, the land surface behaves differently compared to natural vegetated areas. Urban areas typically exhibit higher surface temperatures due to the urban heat island effect, which is caused by the absorption and re-radiation of heat by the built environment. Evapotranspiration rates are greatly influenced by the amount of vegetation and their transpiration capacity, which in turn can have an influence on land surface temperatures in urban regions. Large green areas, such as parks, have a significant impact on the temperature in urban environments due to the presence of vegetation. The vegetation in these areas plays a crucial role in improving the thermal environment (Shashua-Bar & Hoffman, 2000).

In a city, AET and LST are close related. The relationship between them is mostly an inverse relation. The environment, especially the ground surface, supplies the energy that is required by vegetation to transpire. Thus, by lowering the temperature, evapotranspiration can lessen the effects of the Urban Heat Island (UHI).

Green spaces have a cooling effect that can enhance residents' general health and living conditions as well as the thermal comfort of highly populated areas (Ii, 2010). Different vegetation coverings and different types of urban land development may show considerable regional variation in actual evapotranspiration (Tu et al., 2016). Understanding environmental changes requires an understanding of how LST affects the interchange of energy between the earth's surface and the atmosphere. The type of land cover also has a significant impact on this. High LST values are often associated with the presence of heat-retaining materials, lack of vegetation, and increased energy consumption, among other factors. Vegetation evapotranspiration has a huge potential to reduce both urban and global temperatures. Water bodies in urban areas also have a major influence on the UHI effect due to the thermal properties of water and evaporation. Typically, the temperature of a body of water is lower than that of the nearby urban area (Robitu, Inard, Groleau, & Musy, 2004).

In a city, evapotranspiration and LST often have an inverse relationship due to obvious reasons. Due to the heat stress on vegetation and faster evaporation from exposed surfaces like pavements and rooftops, high LST values imply elevated surface temperatures, which can lead to increased evapotranspiration rates. The contribution of transpiration to evapotranspiration may, however, be negligible compared to the overall evaporation process in densely populated areas with little vegetation cover. The relationship between LST, AET and LULC is still a topic of research. Therefore, the present study explored the relationship between LST and ET for each of the LULC classes. The objective of this research is to determine the variation in AET and LST for varying types of land covers in urban settings by finding correlation between them. By studying the relationship between LST and AET, researchers and urban planners can gain insights into the heat dynamics of cities. These insights can inform decisions related to urban design, green infrastructure planning to improve the livability and sustainability of cities.

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2. STUDY AREA

The present study focuses on the examination of the Bhopal city, situated in the Madhya Pradesh state of India, as illustrated in Figure 1. Bhopal is characterized by a high population density, serving as the capital of Madhya Pradesh. It is positioned between longitudes 77°12' and 77°40' east and latitudes 23°07' and 23°54' north. With an average elevation of 1400 feet, Bhopal receives an annual rainfall of approximately 1140 mm. The period between mid-March and early June, preceding the monsoon season, is marked by high temperatures, while the city turns considerably cold from mid-November to late February.

Bhopal, positioned as the twentieth-largest urban agglomeration globally and the sixteenth-largest city in India, is also included among the twenty-one cities with the highest growth rates worldwide (Singh & Jain, 2022). Owing to the ongoing and continuous development as the state capital, Bhopal's population is experiencing rapid growth, leading to a substantial expansion of the city's boundaries. The Master Plan 2030 for Bhopal encompasses a planning area larger than that of the Bhopal Municipal Corporation (BMC) (Government of MP, 2020). For our research, we specifically focused on the planning area of Bhopal, which covers a vast expanse of 814 km^2. By considering this expanded planning area, our aim was to capture a more comprehensive and representative sample of regions with diverse patterns of different LULC classes and urban development. This broader scope allows us to gain valuable insights into the spatial and temporal aspects of Bhopal's growth and development.

3. DATASETS USED

The boundary of the Bhopal planning area and the locations of water bodies were acquired from the Bhopal Municipal Corporation office. Both datasets were uniformly projected using the Geographic Coordinate System, specifically WGS84, UTM Zone 43N.

LULC Classification: To obtain the land use land cover data, the study utilized Landsat 8 Level 2 data. The surface reflectance data used here was atmospherically adjusted and readily available for use. The specific data used was from Collection 2, which offers improved data quality compared to Collection 1. Tier 1 data was chosen, ensuring the highest radiometric and positional quality. In this study, the mean images from mid-February to mid-March for the year 2020 were selected due to the reduced foliage during this time of the year. This seasonal characteristic facilitated the distinction between various land cover classes, making the analysis simpler and more accurate.

Land Surface Temperature: The MODIS (Moderate Resolution Imaging Spectroradiometer) daily LST data is used to compute the monthly composites and a single dataset for summer and winter season of 2020 at 1 km resolution.

Actual Evapotranspiration: The monthly AET data is obtained from the USGS FEWS NET (United States Geological Survey Famine Early Warning Systems Network) website for hydroclimatic data (https://earlywarning.usgs.gov/fews/product/). It uses the operational simplified surface energy balance (SSEBop) model for evapotranspiration computation. The provided dataset includes monthly composites (measured in mm/month), which were subsequently utilized to calculate the average values for both seasons of the year 2020.

For detailed information about all the datasets utilized, please refer to Table 1, which outlines their specifications.

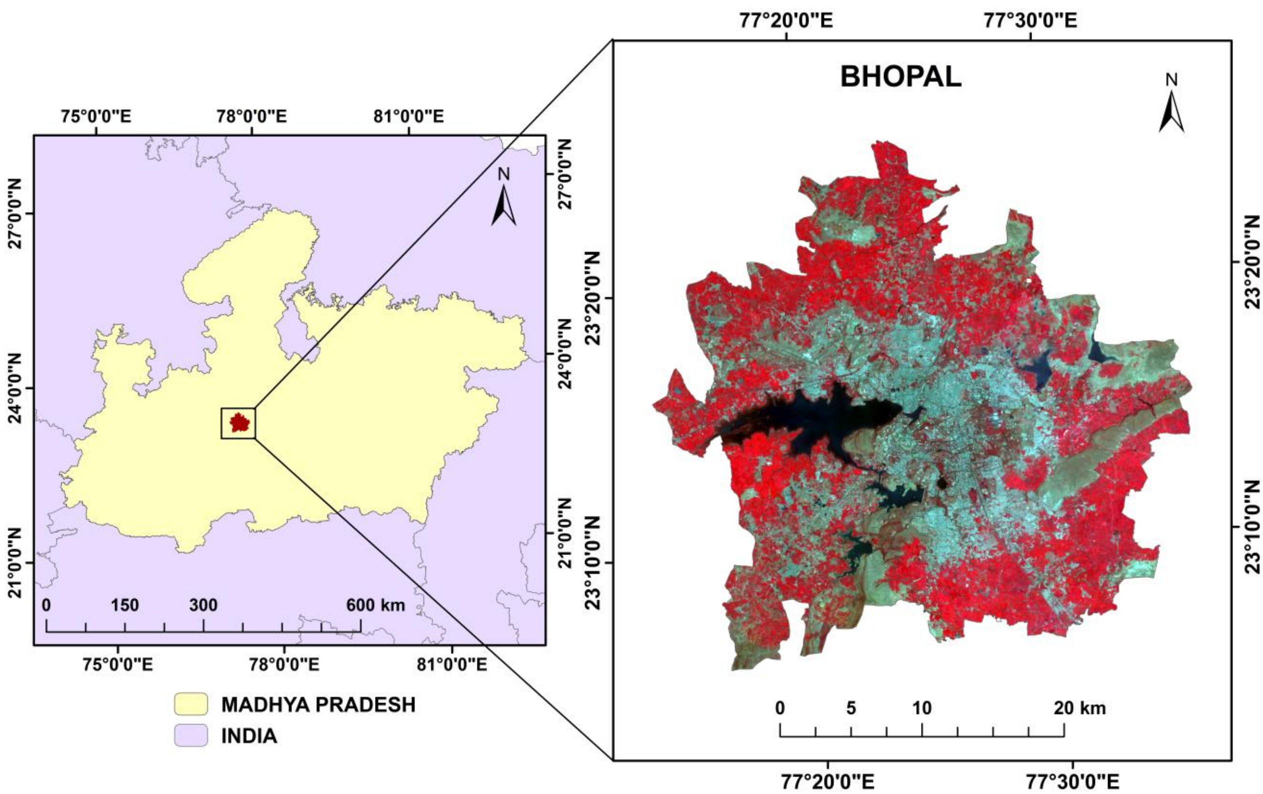

Figure 1. Study Area

Table 1. Datasets used

Data	Satellite/Sensor	Resolution	DOA	Remarks
LULC	Landsat8/OLI	30m	Mid-Feb - Mid-March	Row/Path (145/044)
LST	MOD11A1v006	1000m	1 April – 31 May	Summer
	(Daily data)		1 December – 31 January	Winter
AET	https://earlywarning.usgs.gov/fews/product/	1000m	1 April – 31 May	Summer
	(Monthly Data)		1 December – 31 January	Winter

4. METHODOLOGY

The flowchart of the methodology adopted is shown in Figure 2.

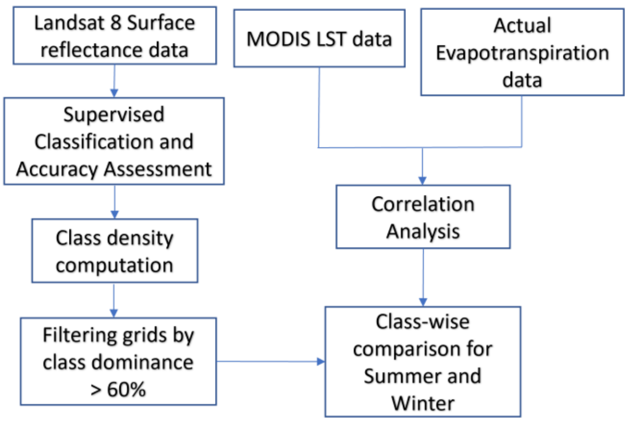

Figure 2. Methodology

To analyze the LST and AET across various LULC categories, four specific LULC types were chosen within the study area. These categories encompassed (a) vegetated lands (comprising agricultural lands, trees, shrubs, and all greenery), (b) water bodies (such as lakes and rivers), (c) urban areas (spanning low, medium, and high-intensity developments in the form of buildings, roads, etc.), (d) bare land (comprising of open non-irrigated land). The spatio-temporal analysis is done for the summer and winter season of 2020 at a spatial resolution of 1km. The months chosen for the summer season are April and May 2020, and that for winter season are December 2020 and January 2021. For downloading these data and LULC classification, cloud-based computing platform Google Earth Engine (GEE) is used, and rest of the process is done in ArcGIS 10.3. The MODIS LST data is also downloaded for the mean values of the daily land surface temperature data through GEE. The monthly AET data is downloaded directly and averaged for the months for both the seasons.

Initially, the analysis involves computing the area and proportion of land for each land cover class. Subsequently, the density of each class is determined. To accomplish this, a grid with dimensions of 1km x 1km is superimposed on each land cover class, as the LST and AET data used in this study are also provided per square kilometer. The total area of all the classes within each grid is calculated. Following that, the grids that have at least 60% of their area covered by a specific class are filtered out. In other words, the grids with a class density exceeding 0.60 km^2/km^2 of the grid are selected. Finally, the seasonal average values of LST and AET are computed for each land cover class that satisfies the criterion of having a class density equal to or greater than 0.60 km^2/km^2. Rest other grids having mixed classes and not following the aforementioned criteria are ignored in the analysis.

Correlation analysis

The study includes the computation of the correlation between LST and ET for the entire study area. Additionally, the correlation between LST and ET is examined for each individual land cover class. The respective scatter plots are plotted to understand the trend for each land cover and for both the seasons. The results obtained for the summer and winter seasons are compared and investigated to analyze the seasonal variations and changes.

5. RESULTS AND DISCUSSIONS

Figure 3 showcases the Land Use and Land Cover classification of the Landsat 8 image for the year 2020.

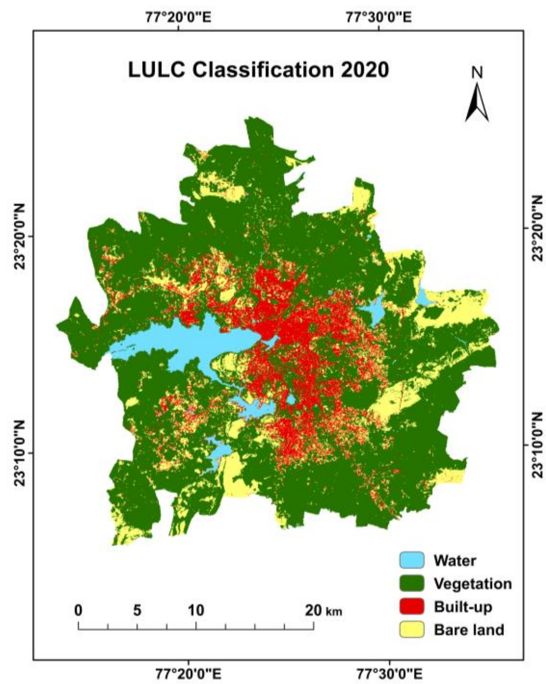

Figure 3. LULC Classification 2020

The findings from our study indicate that the overall classification accuracy and kappa value were 85.38% and 84.12% respectively. This demonstrates a reliable performance of the classification method and indicates substantial agreement between the classified maps and the reference data. Table 2 provides the corresponding area and proportion of each land cover class based on the LULC classification depicted in Figure 3. In the total planning area of Bhopal, the land cover composition consists of 5.52% water, 64.22% vegetation, 11.30% built-up land, and 18.96% bare land. These percentages represent the relative distribution and coverage of each land cover class within the study area.

Figure 4 and Figure 5 illustrate the LST and AET for the summer and winter seasons, respectively. During the summer season, the range of LST values varies from 29.74 to 48.46 degrees Celsius. In contrast, during the winter season, the LST values range from 20.27 to 30.42 degrees Celsius. Similarly, the AET values for the summer season fall within the range of 2 to 219 mm per month, while for the winter season, the AET values range from 17 to 100 mm per month.

Table 2. Proportion of land in each land cover class

Class	Area (km^2)	% Area
Water	45	5.52
Vegetation	526	64.22
Built-up	89	11.30
Bare land	154	18.96

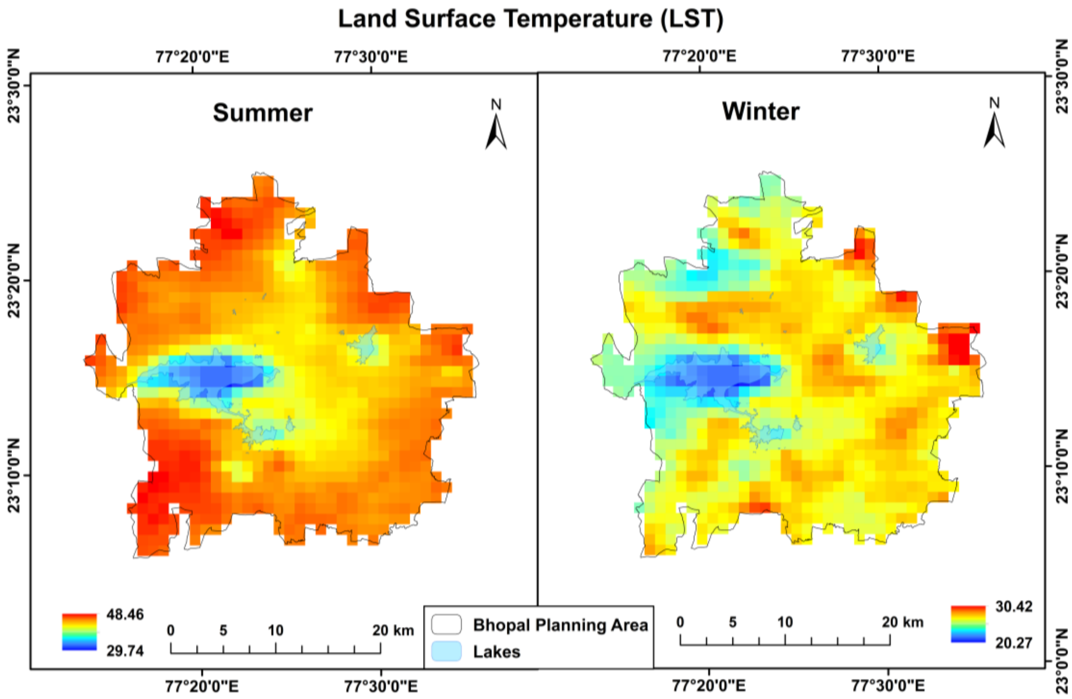

Figure 4. Summer and Winter LST variations

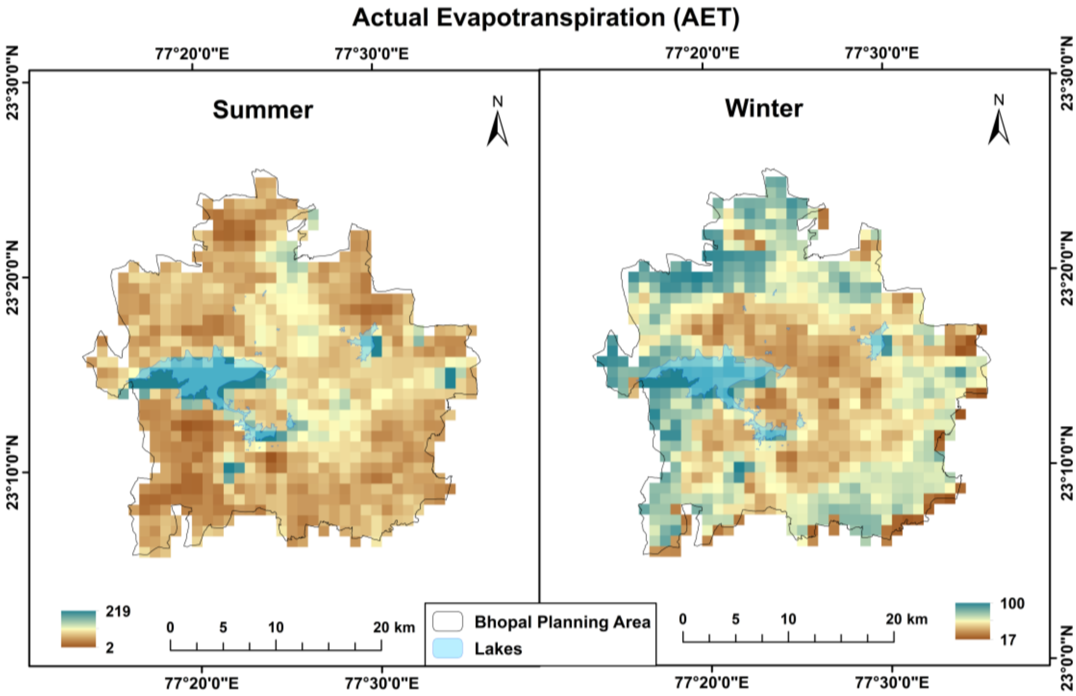

Figure 5. Summer and Winter AET variations

This contribution has been peer-reviewed.
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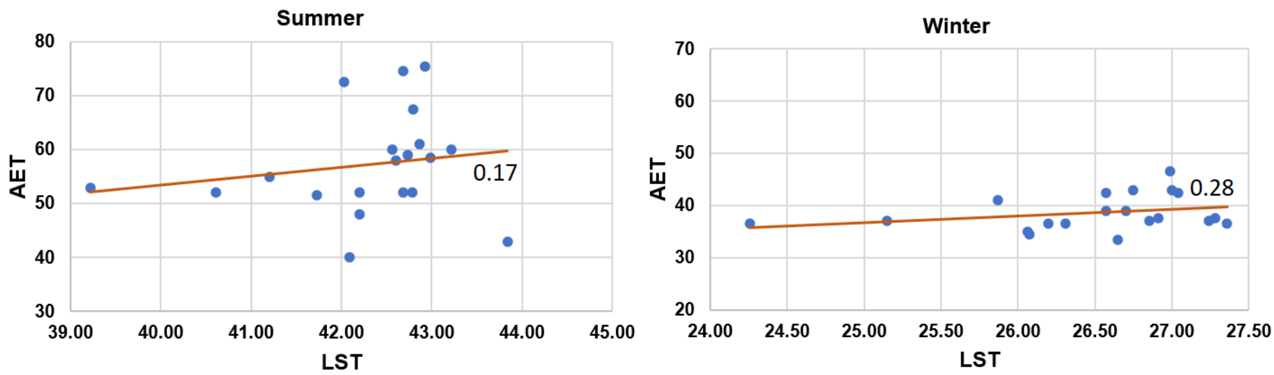
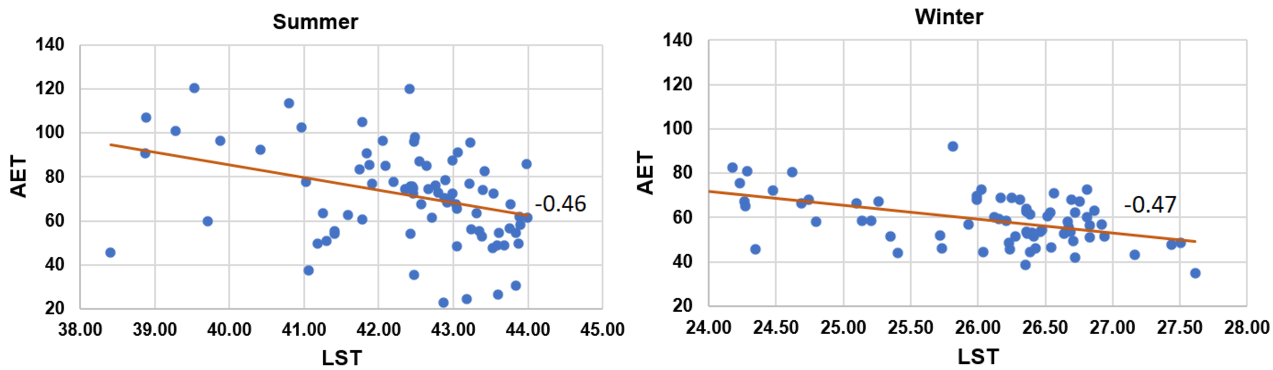
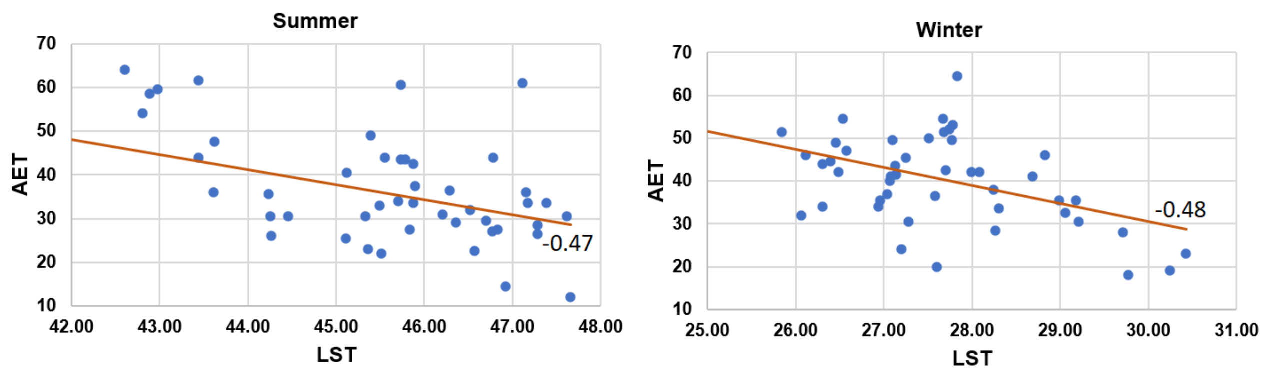


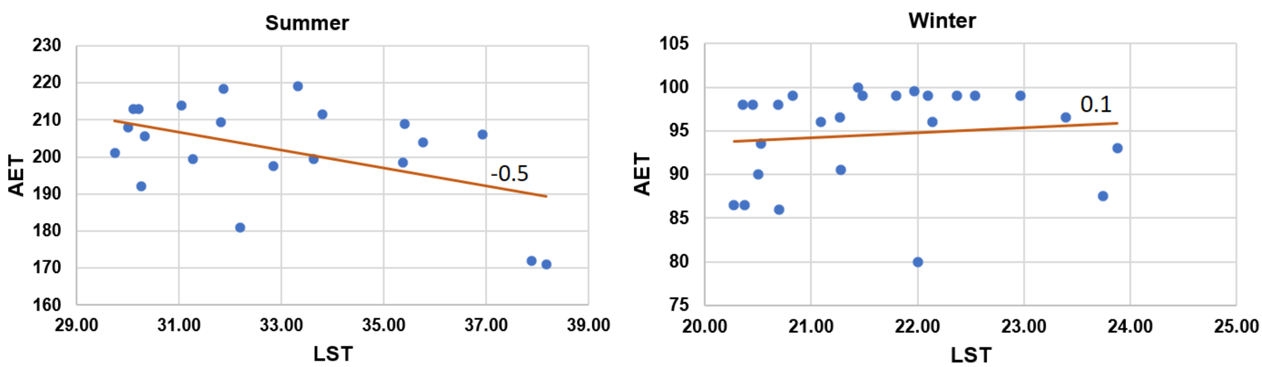
(a) Built-up class



(b) Vegetation



(c) Bare land



(d) Water bodies

Figure 6. Scatter Plots

Table 3 presents the average values of LST and AET for each land cover class. These values specifically pertain to a minimum class density of 60%. The table provides a comprehensive overview of the LST and AET averages, allowing for a comparative analysis of these variables across different land cover categories. During the summer season, the LST exhibits the highest values in bare land areas, while water bodies have the lowest LST values. This trend is also observed during the winter season. Similarly, the AET is highest for water bodies during summer, while bare land shows the lowest AET values.

In winter, water bodies have the highest AET values, while built-up land exhibits the lowest AET values.

Table 3. Seasonal average LST and ET by land cover class

Class	LST		AET	
	Summer	Winter	Summer	Winter
Water	33.91	21.98	188.05	92.82
Vegetation	41.48	25.67	74.01	61.26
Built-up	42.30	26.50	52.28	38.74
Bare land	45.37	27.58	36.43	40.81

Figure 6 depicts the scatter plots illustrating the relationship between LST and AET for both the summer and winter seasons. These scatter plots encompass all four land cover classes that were considered in the study.

The built-up land class exhibits a positive correlation between the LST and AET values. A high temperature in the built-up areas stimulates greater transpiration from available vegetation such as gardens, lawns, and trees. However, due to the limited availability of green spaces and a high percentage of impervious surfaces in this class, the correlation is relatively weak. Nonetheless, during the summer season, the correlation between LST and AET is stronger compared to the winter season, indicating a relatively higher influence of temperature on evapotranspiration in built-up areas during hotter months. Furthermore, Figure 3 illustrates that a significant portion of the built-up class is surrounded by vegetation. This presence of vegetation contributes to the observed positive correlation between LST and AET in built-up areas.

Vegetation exhibits a negative correlation between LST and AET. While higher temperature values would typically indicate increased AET, the presence of impervious surfaces or bare land occupying the remaining 40% of the grid can lead to elevated temperatures without a corresponding increase in AET. Consequently, grids with higher LST values tend to have lower AET values. This trend is particularly noticeable during the summer season.

Bare land demonstrates a negative correlation between LST and AET. Elevated temperature values indicate a scarcity of vegetation or water, which would contribute to cooling and evapotranspiration processes. In contrast, bare land is characterized by an abundance of soil and rocks, which tend to heat up quickly, leading to higher temperature readings.

Similarly, the water bodies class in the study demonstrates a negative correlation during the summer season. However, in contrast, it exhibits a slight positive correlation during the winter season. The reason behind this is that even when 60% of the grid is covered by water, the remaining 40% consists of built-up areas or bare land. During the summer season, the water level in the bodies decreases, leading to the emergence of more non-vegetated or bare land areas. Once the soil water evaporates, these areas become dry and do not contribute to transpiration. Consequently, this results in high temperatures but not necessarily high AET values. This can be attributed to the observed negative correlation in the summer season. On the other hand, during the winter season, which follows the monsoon period, some vegetation appears around the water bodies, contributing to evapotranspiration. This accounts for the slight positive trend observed during the winter season.

6. CONCLUSION

The green areas and lakes of the city showed a higher ET and lower LST, whereas the built environment behaved in just the opposite manner. The built-up land in the vicinity of the water bodies also showed a lower LST as compared to the other parts built-up land cover. When the land surface is hotter, more energy is available to drive the evaporation of water from the surface and the transpiration of plants. Thus, as LST increases, so does the potential for ET and cooling effect induced by it. This strongly implies that increasing ET in urban areas can reduce the impact of UHI. This study provides some references for urban planning and design, such as how to distribute urban greenery, including urban agriculture and water bodies, on aspects of cooling urban temperature and improving urban heat environment. These findings can assist planners in better incorporating environmental factors into the creation and maintenance of urban landscapes. It can be inferred from the current study that it is essential to comprehend the local context and consider a variety of variables to effectively determine the relationship between LST and ET in a particular scenario.

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