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Satellite-Based Trends Analysis of Land Surface Temperature, Vegetation Growth, and Precipitation: Evaluating Seasonal Variation and Correlation in Ahmedabad, India

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Abstract

Objectives: This study aims to analyze LST, NDVI, and precipitation patterns in Ahmedabad, India, from 2014 to 2023. The main research purpose is to study component relationships and assess the influence of vegetation and rainfall on urban heat management. **Methods:** The study used Landsat 8 satellite data at a high resolution together with CHIRPS rainfall data through Google Earth Engine (GEE) to extract LST, NDVI, and precipitation patterns. The analysis computed seasonal averages while Pearson correlation methods evaluated variable relationships between pre-monsoon, monsoon, and post-monsoon periods. The team used previous findings to validate the obtained temporal trends in their analysis. **Findings:** The data showed that when pre-monsoonal heat stress increased from 39.32 °C in 2014 to 41.29 °C in 2023 while all seasons demonstrated intensifying heat stress patterns. The NDVI levels showed a decreasing tendency during this period, as it went from 0.362 to 0.343, thus indicating both vegetation reduction and heat-related stress in the area. The positive connection between precipitation and NDVI reached its highest value of 0.43 during monsoon, while during post-monsoon it increased to approximately 0.52. During post-monsoon periods, the negative relationship between NDVI and LST reached -0.59. Surface temperatures show different patterns of influence depending on seasonal variations between rainfall and vegetative cover. **Novelty:** The research combines long-term high-definition seasonal evaluations of LST and NDVI and precipitation records from Landsat 8 and GEE for analyzing changes in a rapidly expanding Indian metropolis. This study stands apart from prior short-term and coarse-resolution research since it delivers both fine-scale and season-specific understanding regarding how climate and urbanization jointly affect surface thermal environments. The study delivers essential knowledge to develop urban planning approaches that combine vegetation control and heat wave protection systems under climate change.

Keywords: Land Surface Temperature; NDVI; precipitation; Seasonal variation; Pearson correlation; Satellite data

1 Introduction

Human activities produce most climate change effects, leading to noticeable changes in temperature conditions and rainfall patterns as well as modifications in environmental parameters. Tropical regions, especially India, illustrate the most prominent manifestation of these changes because monsoons determine their climate patterns. Distinct knowledge regarding climate elements and vegetation changes will improve the implementation of land-use strategies [(1)]. The increased rate of urban growth has further deteriorated environmental issues in megacities, causing the urban heat island (UHI) effect that makes urban areas hotter than surrounding rural areas [(2)]. The changes in thermal properties reshape land surface temperatures (LST), thus affecting vegetation growth. A heat balance for Earth's surface results from vegetation control of surface temperature by evapotranspiration, together with albedo modifications [(3)]. The connection between plant dynamics and LST and precipitation effects during environmental changes in fast-changing cities remains understudied, according to Hussain et al. (2020) [(4)]. NDVI functions as the primary vegetation index for detecting vegetation changes in extensive research applications. Short-term research on combined relationships between temperature, precipitation, and NDVI prevents understanding long-term multi-seasonal interactions between these elements, particularly in urban environments [(5)]. Major studies employ LST and NDVI data collected from the Moderate Resolution Imaging Spectroradiometer (MODIS) and Landsat based on their required study spatial-temporal scale [(6)]. MODIS data offer observations twice a day and contain high temporal resolution, and since 2001, have collected long-term spatial-temporal data. At a resolution of 1000 meters, the product fails to detect the temperature differences between urban regions. The Landsat data offers optimal conditions for examining detailed land surface temperatures (LST) in urban areas. Its thermal band contains a spatial resolution of 100 m and operates with day-specific observation timing at a 16-day temporal frequency [(7)]. When conducting long-term research on NDVI and LST patterns at high resolution, the Landsat dataset offers the most beneficial data analysis approach for regional studies. The study and impact of rainfall on NDVI and LST were previously researched in West Bengal and Ethiopia. Yet, these analyses presented certain restrictions through seasonal time limitations and short observational periods without considering the total environmental and urbanization effects on vegetation fluctuation [(8)], [(1)].

Researchers focus on resolving these inconsistencies through an extended period analysis of NDVI, LST, and precipitation patterns in Ahmedabad, India, by utilizing Landsat 8 and CHIRPS rainfall datasets. The cloud platform Google Earth Engine (GEE) permits large-scale geospatial processing to study how vegetation and surface temperature change throughout a season and year in urban and peri-urban areas. This research explores the combined influence of meteorological precipitation with city growth patterns on plant development, together with LST patterns. The research strives to create essential information that promotes the development of urban climate-resistant management strategies. The research establishes fundamental knowledge that will support future investigations about heat mitigation through vegetation-based urban development strategies during city expansion.

2 Methodology

Ahmedabad is the largest metropolitan city in western India, which is located in the State of Gujarat. According to geography, it is centralized at 23°09′54.68” N 72°33′40.02” E and 22°54′19.90 ”N 72°39′51.62” E along the Sabarmati River, as shown in (Figure 1) [(9)]. The eastern region is characterized by densely stacked buildings, narrow roads, and multiple manufacturing industries, all of which contribute to raising Land Surface Temperature (LST) values. The city has arid zones and high temperatures throughout the summer season, with a maximum of 45°C in April and May. The mean temperature during winter is between 30°C and 35°C, while the temperature during the monsoon season, between July and September, is quite comfortable [(10)].

Landsat 8 satellite data are used to estimate Land Surface Temperature (LST) and create vegetation indices. The Google Earth Engine (GEE) software processed and analyzed data from 2014 to 2023 [(11)]. The dataset utilized is from the Landsat 8 Collection-2 Tier-1 (LANDSAT/LC08/C02/T1_L2), which provides Brightness Temperature (BT) and Top-of-Atmosphere (TOA) reflectance data. It has two instruments, an Operational Land Imager (OLI) and a Thermal Infrared Sensor (TIRS). The OLI sensors have a resolution of 30 m and are used to collect non-thermal data such as land surface physical features, while TIRS has a resolution of 100 m and is used to collect LST data. For analyzing the temporal variation of rainfall, the daily product of Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) time series data is used (Table 1).

CHIRPS data is preferred over other satellite-based precipitation prediction products because it provides the most accurate correlation with rain gauge readings. It uses 0.05° resolution satellite images combined with in-situ station data to generate gridded rainfall time series for statistical analysis and seasonal monitoring. This information is received from the National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center (USGS, 2024) [(12)].

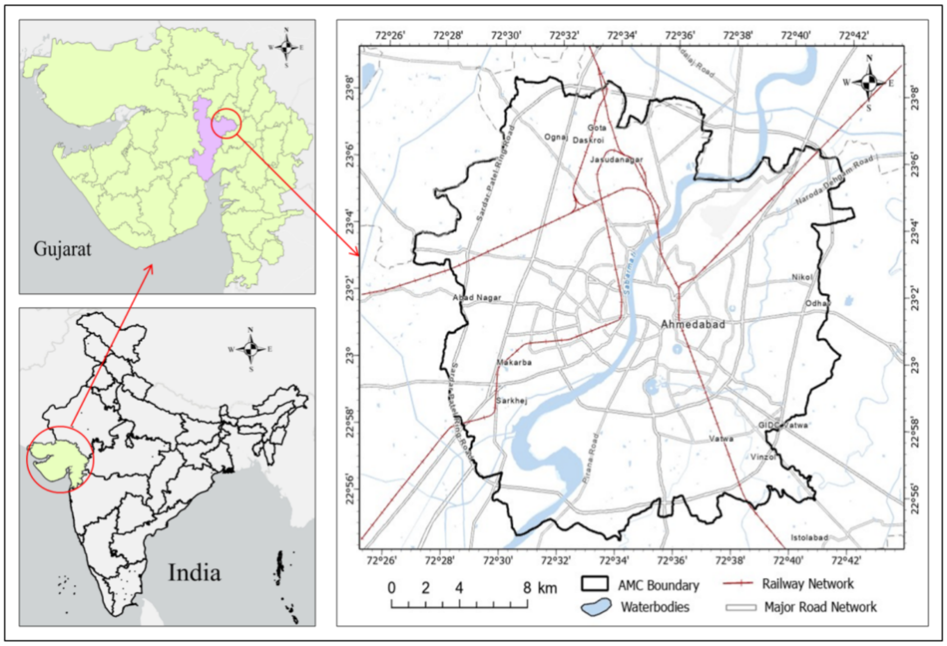

Fig 1. Study area

Table 1. Dataset used in this Study

Dataset	Data Collection from GEE	Resolution
Landsat-8 (OLI / TIR)	LANDSAT/LC08/C02/T1_L2	OLI: 30 m (Band 4, Band 5) TIR: 100 m (Band 10)
CHIRPS (Climate Hazards Group Infrared Precipitation with Stations)	UCSB CHG/CHIRPS/DAILY	0.05°

Figure 2 shows the methodology flowchart, which demonstrates the analysis of LST, NDVI, and precipitation raster data collected from the Google Earth Engine (GEE) platform for urban and peri-urban regions of Ahmedabad, covering the period from 2014 to 2023 [13]. The first process is to read the Landsat 8 image, and then the cloud mask, which involves the identification of clouds and cloud shadows that obscure the area of interest (Figure 2).

The land surface temperatures are calculated using Landsat-8 TOA corrected reflectance collection-2 satellite data product processed in GEE [14]. The TOA reflectance is selected for removing solar irradiance explanatory effects from the data. From the collection, satellite images with less than 1% cloud cover from 2014 to 2023 are used, and if cloud pixels exist, they are filtered off by masking.

The Brightness Temperature (B_T) is calculated using the thermal band of Landsat-8 as shown in **equation (1)** [15]

$$B_T = (K2/(\ln(K1/L)+1)) - 273.15 \tag{1}$$

Here, K1 and K2 are band-specific calibration constants in Kelvin, and B_T represents the effective satellite temperature, the $K1$ and $K2$ constants from the OLI/TIRS sensor [16].

The Normalized Difference Vegetation Index (NDVI) is derived using the Red (Band 4) and Near-Infrared (NIR, Band 5) bands with **equation (2)** [17].

$$\mathrm{NDVI} = (\mathrm{NIR} - \mathrm{Red})/(\mathrm{NIR} + \mathrm{Red}) \tag{2}$$

Land Surface Emissivity (LSE) is estimated using NDVI thresholds as per **equation (3)**

$$\mathrm{Emissivity}(E_m) = 0.004 * \mathrm{Pv} + 0.986 \tag{3}$$

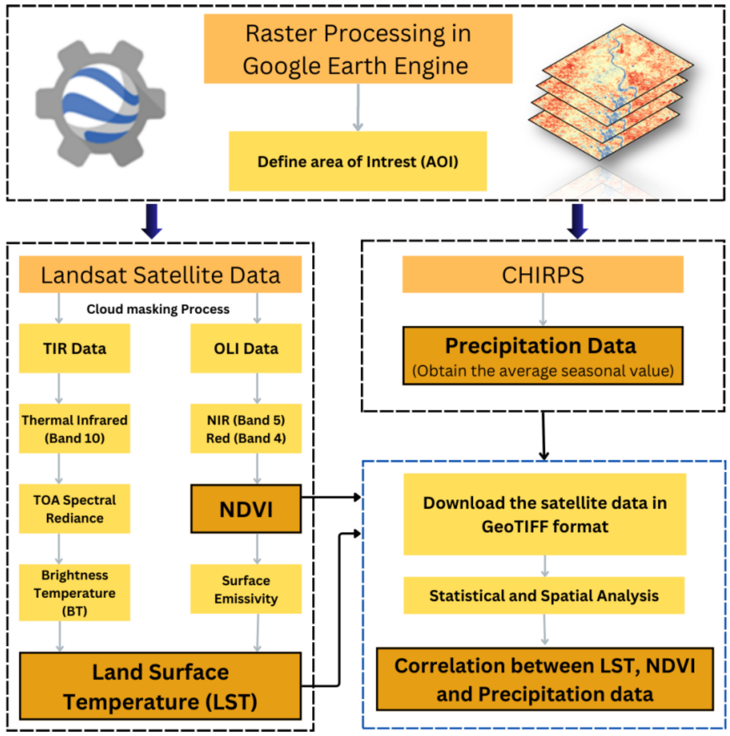

Fig 2. Flow chart of Methodology

The fraction of vegetation (Pv) is computed from NDVI values using **equation (3a)**.[18],[19]

$$Pv = [(NDVI - NDVImin)/(NDVImax - NDVImin)]^2 \tag{3a}$$

The Land Surface Temperature (LST) is calculated using B_T and Em values in **equation (4)**.[20],[21]

$$LST = (B_T/(1 + (0.00115) * (B_T/1.438)) * \log(E_m)) \tag{4}$$

Using **equations (2) and (4)**, seasonal mean values of NDVI and LST were calculated for the period from 2014 to 2023. Further, this set is used for geospatial and temporal analysis in the ArcGIS software.

For precipitation analysis, CHIRPS (Climate Hazards Group InfraRed Precipitation with Station) data were utilized for the Ahmedabad region over the period 2014-2023. Combining data from ground stations and satellite precipitation measurements, CHIRPS is a high-resolution worldwide gridded rainfall dataset that produces a reliable long-time-series resource[15],[8]. Moreover, it provides daily or monthly precipitation data calculated from the GEE (UCSB CHG/CHIRPS/DAILY) collection (Table 1). ArcGIS software was used to create yearly time series analysis maps[22].

3 Results

The analysis of LST and NDVI data calculated from Landsat 8 (OLI/TIR) and rainfall data obtained from CHIRPS using the cloud-based Google Earth Engine (GEE) platform from 2014 to 2023 shows significant regional climate variations in Ahmedabad.

3.1 Trends Analyses of LST, NDVI, and Precipitation

Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI), and precipitation data were thoroughly analyzed spatiotemporally in Ahmedabad for ten-year period beginning in 2014 and ending in 2023 (Figure 3). Since 2014, the average annual LST has developed considerably, reaching 41.29 degrees Celsius in 2023, indicating a 1.97-degree Celsius global warming. According to LST statistics, the pre-monsoon seasons noticed higher heat, with minimum LST dropping from 30.97°C to 30.05°C and highest LST dropping from 49.25°C to 48.88°C.

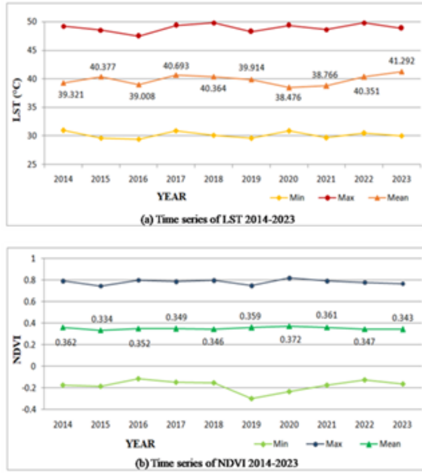

Fig 3. Time series analysis of (a) LST and (b) NDVI

From the research, NDVI displayed a modest negative pattern throughout time, with annual mean values decreasing from 0.362 in 2014 to 0.343 in 2023 (Figure 5). Due to desirable vegetation coverage, 2020 reached its greatest NDVI value of 0.372 while displaying a minimum LST reading of 38.5°C (Figure 4). According to previously reported findings (Guha and Govil, 2020) [14], the link between LST and NDVI is inverse; however, this investigation broadens their reach by mapping thermal urban functions over longer observation periods and with greater geographic accuracy.

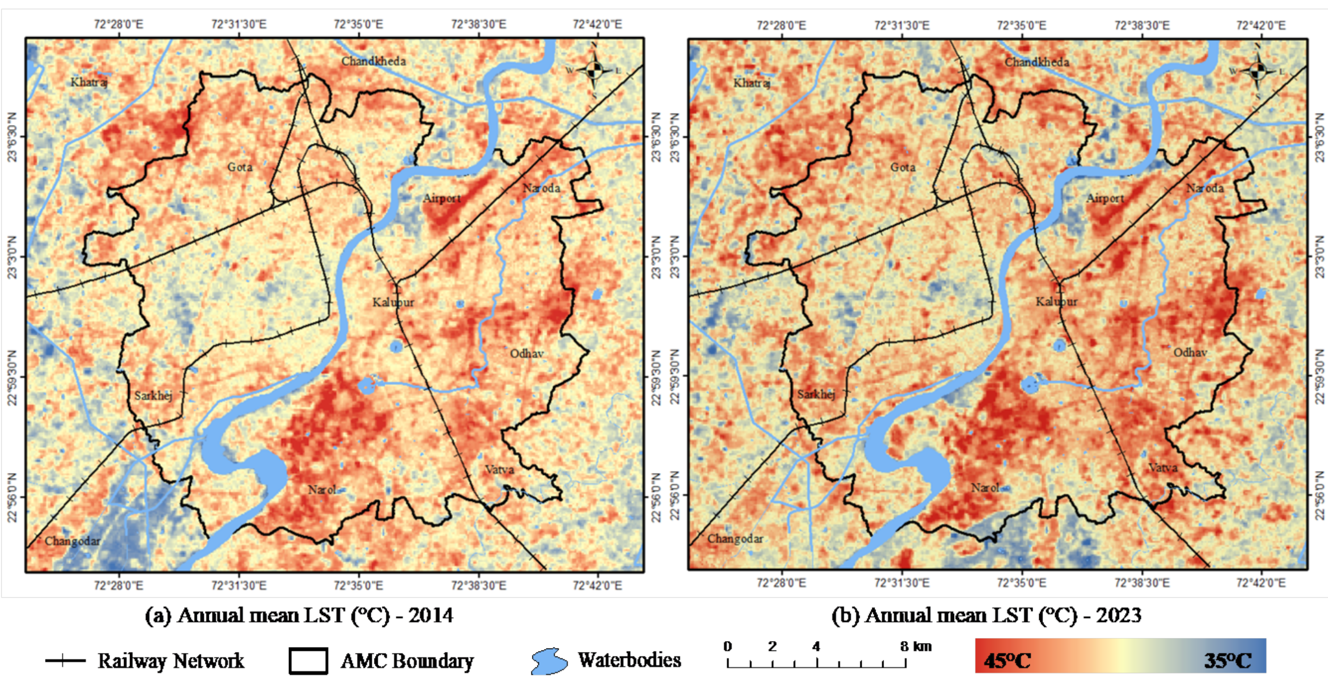

Fig 4. Annual Mean LST in (a) Year 2014 and (b) Year 2023 based on Landsat 8 data of Ahmedabad

According to the statistics, the precipitation pattern fluctuated significantly across the years. The maximum precipitation total of 15.21 mm was recorded in 2019, while the lowest was 9.35 mm in 2015 (Figure 6). The work varies from Garai et al. (2022) [1] and Meshesha et al. (2024) [8] in that it studies extended precipitation patterns in metropolitan areas, as well as dry-year rainfall deficiencies, to better understand how these factors influence vegetation stress and LST.

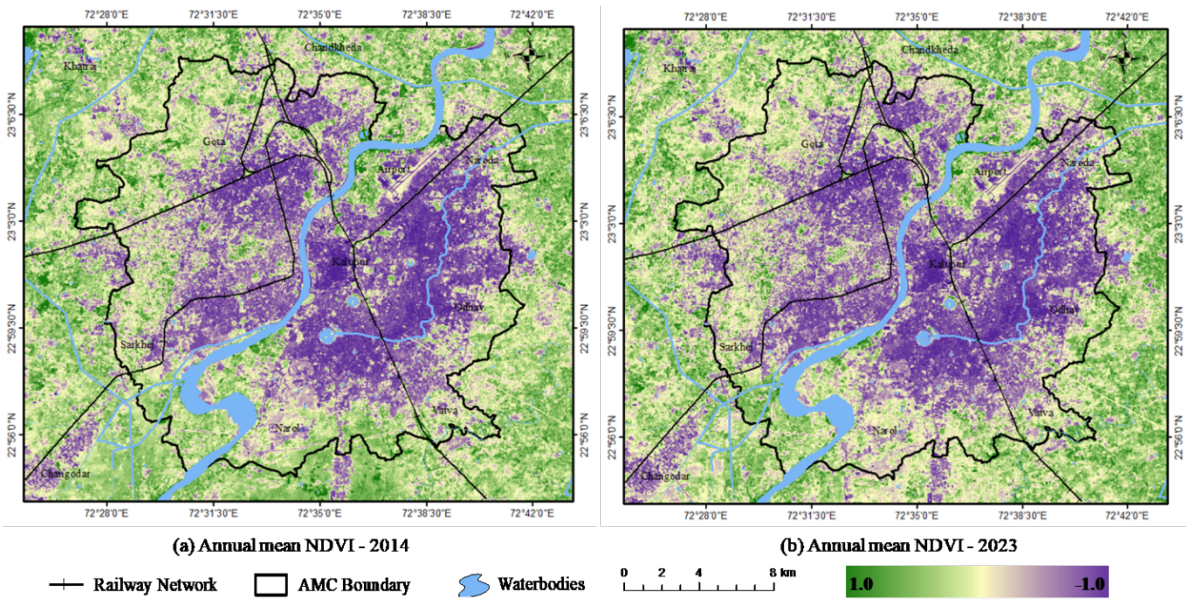

Fig 5. Annual Mean NDVI in (a) Year 2014 and (b) Year 2023 based on Landsat 8 data of Ahmedabad

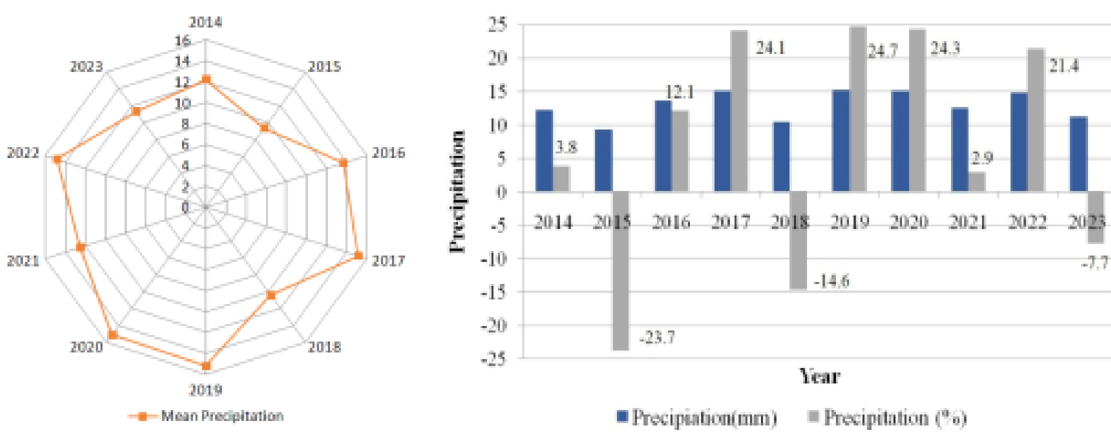

Fig 6. Time-series analysis of Precipitation (mm)

The research based on Landsat 8 data (100 m resolution) exceeds previous MODIS-based (1 km) research because its higher resolution exposes an important spatial correlation between NDVI and LST values. Accurate information gathered from this study becomes essential for developing climate resilience strategies that operate at the urban scale.

3.2 Seasonal variation of LST and NDVI distribution

Table 2 shows that seasonal variations of LST and NDVI data in Ahmedabad from 2014 to 2023 allow researchers to detect significant ecological and climatic phenomena. During pre-monsoon, the LST reached its maximum levels, yet the post-monsoon season brought the most extreme low temperatures. The mean LST 2014 reached a high temperature of 45.64°C during pre-monsoon but dropped to 32.74°C when the season became post-monsoon, thus leading to a 12.9°C difference (Table 2). The LST difference between the 2023 pre-monsoon and post-monsoon seasons reached 17.2°C, while LST values increased from 49.34°C to 32.13°C.

Table 2. Temporal and seasonal variation of LST and NDVI (2014–2023)

YEAR	LST (°C)			NDVI		
	Pre-Monsoon	Monsoon	Post-Monsoon	Pre-Monsoon	Monsoon	Post-Monsoon
2014	45.643	35.598	32.739	0.307	0.459	0.356
2015	48.885	39.201	33.579	0.284	0.452	0.336
2016	46.645	38.189	32.104	0.289	0.483	0.346
2017	50.052	40.196	31.948	0.315	0.441	0.345
2018	48.937	40.693	32.955	0.292	0.494	0.345
2019	49.221	38.418	32.352	0.292	0.494	0.345
2020	47.552	39.261	30.347	0.314	0.478	0.353
2021	45.316	38.619	30.691	0.322	0.496	0.354
2022	51.581	39.438	33.273	0.297	0.468	0.335
2023	49.335	40.586	32.133	0.274	0.477	0.362

The NDVI changed in opposite ways between different annual seasons. The monsoon season maintains the highest NDVI records, measuring 0.459 in 2014 and 0.477 in 2023, due to its strong ability to foster vegetation growth. The pre-monsoon season shows a decrease in NDVI values from 0.307 in 2014 to 0.274 in 2023 because drought conditions combined with heat stressed the vegetation (Figure 7). NDVI values displayed limited changes in the post-monsoon period because the vegetation benefited from the monsoon rainfall impact, which increased from 0.356 in 2014 to 0.362 in 2023.

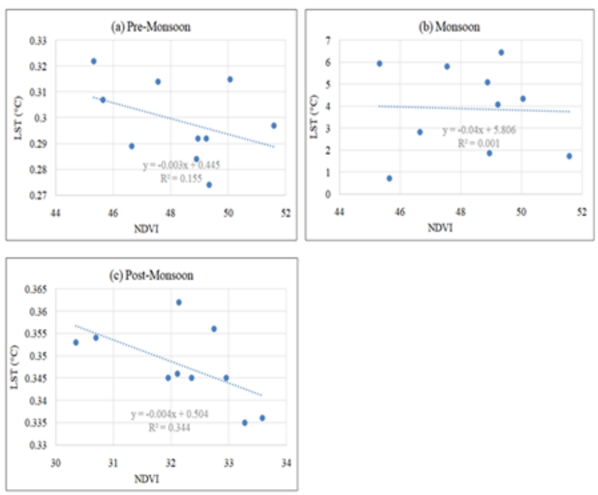

Fig 7. Seasonal variation of LST-NDVI relationship

The findings in this research support Pandey et al. (2024) [3] by showing that vegetation reduces surface temperatures more during wet periods than dry periods. This research contributes decadal, detailed findings about LST and NDVI dynamics, which reveal that seasonal LST variations have strengthened by 4.3°C throughout the past decade in Ahmedabad. The research findings show that the cooling strength of vegetation exhibits variation based on seasonal conditions. The monsoon season maintains elevated LST levels through latent heat flux combined with cloud cover effects, and the post-monsoon season shows a stronger NDVI-LST inverse relationship because stable vegetation reduced atmospheric moisture, as shown by the seasonal R^2 values discussed in Section 4.

4 Discussion

The Pearson correlation matrix (Figure 8) reveals notable seasonal variations between Land Surface Temperature (LST), NDVI, and precipitation over Ahmedabad from 2014 to 2023. LST maintains a weak connection with NDVI (-0.39) and precipitation (-0.04) during the pre-monsoon season because rising surface temperatures detrimentally affect vegetation health, and precipitation makes little difference to vegetation quantities. The positive connection between NDVI and precipitation is 0.01, indicating that dispersed precipitation has an influence on vegetation growth.

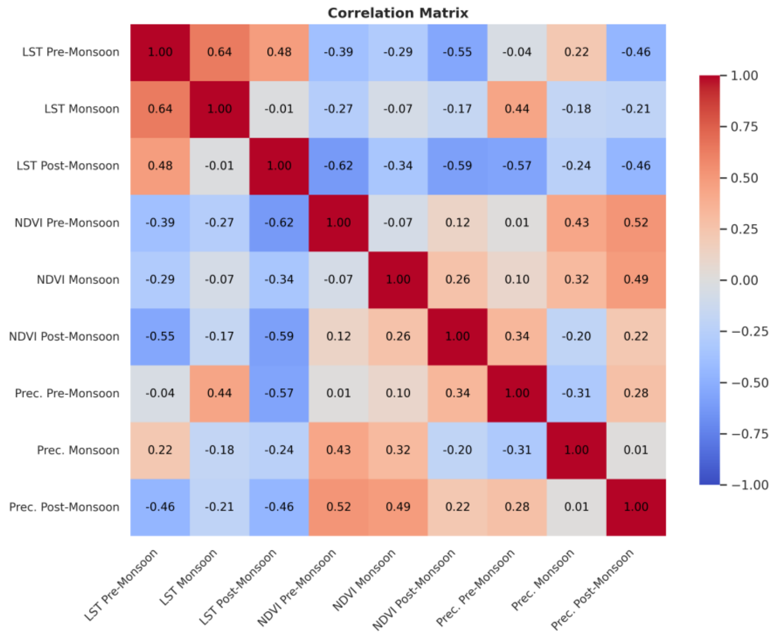

Fig 8. The Pearson correlation matrix of LST, NDVI, and Precipitation across different seasons (2014-2023)

Vegetation growth in the monsoon season becomes more linked to precipitation measurements through an observed correlation value of 0.43. During the wet season, the relationship between LST and precipitation is weakly negative (-0.18), and the relationship with NDVI stays near zero (-0.07) because clouds and wet season evapotranspiration likely influence these variables. The relationship between surface temperature and vegetation index during post-monsoon becomes the strongest negative link (-0.59) compared to other seasons, revealing vegetation as a primary factor in lowering surface temperatures. A positive correlation between precipitation effects and NDVI measurement strength at 0.52, as well as a stronger negative correlation (-0.46) between precipitation and local surface temperature, demonstrates the advanced conditions for vegetation growth and temperature control in urban regions.

This study demonstrates through its results that vegetation and precipitation play a vital role in temperature reduction for urban surfaces each season in Ahmedabad. The analysis shows monsoon rainfall immediately benefits vegetation health, which causes instant cooling before vegetation becomes the lead factor for extending surface temperature reduction during the post-monsoon season. This study provides long-term decadal insight through Google Earth Engine processing of Landsat data, whereas Guha and Govil (2020)[14] and Meshesha et al. (2024)[8] focused on seasonal short-term changes. Advanced microclimatic urban tracking is possible through this method. Previous research did not demonstrate this significant connection between the vegetation cover NDVI variable and surface temperature during the post-monsoon period, which our study revealed. According to research findings, sustained precipitation patterns demonstrate a negative relation with LST data. This research shows a compelling case for protecting and growing urban green infrastructure and developing improved strategies to manage precipitation and reduce the impacts of the urban heat island.

5 Conclusion

The research analyzed land surface temperature (LST) variations together with vegetation condition (NDVI) and precipitation patterns throughout the years 2014 to 2023 in Ahmedabad. The research conducted through Landsat 8 and CHIRPS datasets on the Google Earth Engine platform shows that urban temperatures dramatically increased from 39.32°C in 2014 to 41.29°C in 2023. Green cover degradation and vegetation health decline are indicated by decreasing NDVI values from 0.362 to 0.343. The surface temperatures reach their peaks during pre-monsoonal months because these months have the warmest climate, but monsoon and post-monsoonal seasons bring cooling effects to urban temperatures. The data revealed a robust negative relationship (-0.59) between LST and NDVI, which became evident during the post-monsoon season because vegetation serves as a critical factor for regulating surface temperature. During monsoon and post-monsoon periods, vegetation maintained a positive relation with precipitation, with corresponding correlation values of r = 0.43 and r = 0.52. This research provides an extensive small-scale evaluation of an expanding metropolitan area through which we discover the critical understanding of temperature patterns related to seasonal rainfall and vegetation patterns. The research outcomes demonstrate the necessity for comprehensive urban planning, which supports green infrastructure development, especially during times when vegetation demonstrates its most effective cooling capability. Ecological balance improvement and a decrease in urban heat stress can be achieved by boosting vegetation coverage preserving nature and applying water-retention methods to cities. Future investigations should expand this research by validating findings on location and implementing this approach for cities dealing with comparable climatic problems.

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