Available online at http://www.journalcra.com

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

International Journal of Current Research
Vol. 17, Issue, 04, pp.32686-32695, April, 2025
DOI: https://doi.org/10.24941/ijcr.48839.04.2025

ISSN: 0975-833X

RESEARCH ARTICLE

EVALUATION AND OBSERVATION OF WIND SPEED AS A KEY FACTOR IN URBAN HEAT ISLAND AMPLIFICATION OF RAJKOT CITY - INDIA

Kavya P. Tanna and Rina P. Dave*

Department of Biology, Shri M. & N. Virani Science College (Autonomous), Rajkot, Gujarat, India

ARTICLE INFO

Article History:
Received 20th January, 2025
Received in revised form
19th February, 2025
Accepted 26th March, 2025
Published online 30th April, 2025

Key words:
Urban Heat Island (UHI), Wind speed, Urbanization, GIS mapping, Landsat satellite.

**Corresponding author: Rina P. Dave*

ABSTRACT

This research Urban Heat Island (UHI) is an urban climate phenomenon that can be defined as a condition in which the temperature inside urban boundaries is significantly higher than its rural surrounding. This leads to increase in energy consumption as a consequence of elevated cooling demands, green house emissions, alteration in local wind patterns, ventilation and pollutant dispersion, thereby impacting human health, air quality and hydrology. On the other hand wind speed acts as a critical meteorological parameter, that governs energy exchange, pollutant dispersion and urban microclimate dynamics. Higher wind speeds generally reduce the intensity of the Urban Heat Island (UHI) effect, as wind helps to disperse heat and cool urban areas. However, with the rise in urban areas, reduction in local wind speed is remarkably observed. This reduction in wind speed hinders natural ventilation, exacerbating pollutant accumulation and thermal stress. Such airflow leads to challenges for mitigating heat island effects. Urban heat island and wind speed shows a strong relation, but precise study on its correlation is not carried out in India so far. This article aims to investigate the statistical and spatial relationship between wind speed and UHI intensity of Rajkot city, Gujarat - India. The study uses meteorological data, GIS mapping of landsat images and statistical correlation method to analyze UHI - wind interaction. Result of the study reveals strong negative correlation between wind speed and UHI intensity, thereby promoting green corridors and optimized city planning to mitigate UHI effects.

Citation: Kavya P. Tanna, Rina P. Dav, 2025. *"Evaluation and observation of wind speed as a key factor in urban heat island amplification of rajkot city - India". International Journal of Current Research, 17, (04), 32686-32695.*

INTRODUCTION

India faces urban sustainability difficulties on two fronts: existent and upcoming. Existing urban issues include poverty, rising GHG emissions, pollution, and increased energy demand. The upcoming challenges includes mitigation of temperature rise in winters and frequency of extremely hot days and nights in summers (IPCC, 2013). Between 1990 and 2012, India's greenhouse gas (GHG) emissions doubled, with metropolitan areas accounting for more than 60% of the increase. Investigating the impact of anthropogenic activities and land-use change on urban climate can have significant implications for energy management, human health, productivity, ecology, air pollution reduction, and sustainable urban development (Kotharkar *et al*., 2018). The Urban Heat Island (UHI) effect refers to greater temperatures in cities compared to rural or suburban locations. UHIs are understood to arise as a result of the arrival of artificial surfaces, such as buildings and roadways built of dry and impervious construction materials, as well as human activities that significantly disrupt the energy balance in cities and the atmosphere. The UHI has a direct impact on human health due to rising temperature, but it also affects rainfall patterns, air pollution, flood danger, and water quality. Thus, a complete study of India's UHI research is needed to improve scientific understanding of the urban environment and improve city planning and policy-making. The UHI occurs when a city experiences warmer temperatures thansurrounding rural areas due to factors like increased heat absorption byurban surfaces and reduced vegetation. Wind plays a crucial role inmitigating this effect by facilitating heat transfer and ventilation. There are two types of elements that contribute to heat island incidence and intensity. The first category include meteorological parameters such as wind speed and direction, humidity, and cloud cover. The second group is influenced by city design elements like density, aspect ratio, sky view factor (SVF), and construction materials. Wind speed is an important element in metropolitan settings that influences health, outdoor/indoor comfort, air quality, and building energy consumption. Wind's cooling influence reduces the negative impact of heat islands on microclimate and thermal comfort. In tropical places like Singapore, a wind velocity of 1-1.5 m/s can reduce temperature by 2 degrees Celsius (Erell *et al*., 2011). According to Kato and Huang (2009), wind-induced airflow can help reduce air pollution in cities. Understanding the link between built-up and wind speed is crucial, especially in tropical regions where urban winds provide cooling benefits.

On the other hand, urbanization is very fast in India, and design issues related to urban climate are normally neglected. Unplanned and rapid urban development in Rajkot city of Gujarat, can alter the microclimate of this tropical town, thus changing the air temperature and wind pattern. Furthermore, wind speed has widely been reported to have lessened the intensity of heat island effect in urban areas (Morris *et al*., 2001; Kim and Baik, 2002; Memon *et al*., 2010). Therefore, this paper aims to identify the existence of urban heat island in Rajkot, as a consequence of reduced wind speed in one of the fast growing cities of Gujarat, India.

STUDY AREA

Fig.1. Google Earth Image of Rajkot city (Date: 09/03/2025)

Rajkot is located in Gujarat State's central plains, at the centre of the Saurashtra peninsula. Rajkot's elevation is 138 meters above mean sea level. The climate in Rajkot is hot and dry. Over the past 40 years, the average maximum temperature has been 43.5 °C, while the average lowest temperature has been 24.2 °C. Rajkot receives an average annual rainfall of 500 mm. Rainfall has been below normal over the last 20 years. Rajkot city covers 104.86 km^2 and has a population density of 12,735 people/km^2 with a total literacy rate of 82.20%.

METHODOLOGY

Step 1: Land Use Land Cover Classification:

With the help of Google Maps, a shapefile of Rajkot City was created in Google Earth Pro. Satellite images from the USGS Earth Explorer website covering the study area were obtained. In QGIS Desktop, the pictures were further processed by performing supervised land use and land cover classification. The city was categorized into five different classes: 1) Wild Vegetation, 2) Agriculture3) built-up (concrete constructions), 4) water bodies, and 5) open land. The classified images of the years 1991 and 2021 were compared with each other to observe the variation in the LULC pattern.

Step 2: Selection of Training Data Samples:

This method allowed the research area's distinct traits to be identified. A variety of band combinations were employed to determine a class's color tone. For vegetation, forest, crops, and wetlands investigation, the band combination 5–4–3 was employed. The built-up land was analyzed using the band combination 7–6–4. The tone of the pixel color was used to train data sets. Drawing polygons and placing them in an AOI (Area of Interest) layer were used to generate training sites in the imagery. Polygons were made and placed in the signature editor to train each class. These polygons were combined and given a unique class name. Finally, in the supervised image classification procedure, the trained data sets were utilized.

Step 3: Assessment of Urban Heat Island:
Semi-Automatic Classification Plugin (SCP) in QGIS provides a straightforward approach to derive urban heat island (UHI) metrics from Landsat satellite imagery. After installation of the SCP plugin, necessary inputs were loaded, including the thermal band (Band 6 for Landsat 5/7 or Band 10 for Landsat 8/9) as well as the corresponding MTL.txt file. Before executing the processing step, it becomes essential to enable the “brightness temperature” checkbox within the plugin settings. Upon running the tool, SCP plugin computes the land surface temperature (LST) for the entire satellite image. Our study area can then be delineated

by overlaying a vector layer with a boundary shapefile, thus isolating the region of interest for further analysis. Once the LST raster is generated, the UHI index is calculated by adopting the following formula:

UHI=(LST−LSTm)/SD

Where,
UHI = Urban heat island
LST= LST raster that is generated
LSTm = Mean temperature of LST (Found in properties of LST layer)
SD = Standard Deviation (Found in properties of LST layer)

Finally, by applying an appropriate color ramp authors could visually interpret UHI intensity across the study area, facilitating comparative urban heat assessments and thus enhancing the accuracy of microclimate investigations

Step 4: Correlation of LULC and Wind Speed:

Climate refers to a region's long-term weather trend, which is usually averaged over 30 years. NASA's POWER (Prediction of Worldwide Energy Resource) data, with a grid resolution of one-half arc degree longitude by one-half arc degree latitude, is freely available for download via a web interface. The data, funded by the NASA EarthScience Directorate Applied Science Program, provides daily global coverage for all weather parameters from 1983 to the present, with a several month delay from January 1997 to the present.Thus, area specific wind speed data of Rajkot city was downloaded from POWER data and was compared with our NDVI data to understand the statistical correlation between them.

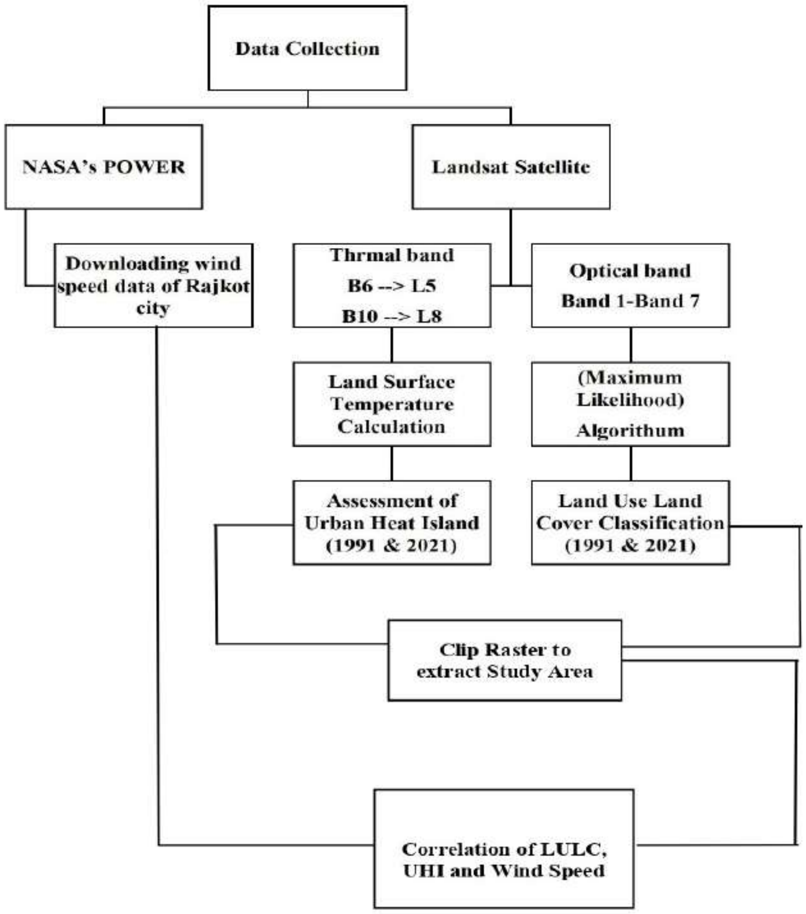


Fig 2. Flow chart of Methodology

In present study, clear satellite images were downloaded from USGS (United States geological survey) Earth Explorer, were combined and demographic data was generated to interpret the land use and land cover changes and Urban Heat Island in Rajkot city of Gujarat. The methodology which has been carried out in this research is is shown in the flowchart accordingly :

RESULTS

To carry out the study on Rajkot city of India, satellite imagery from USGS Earth Explorer website with is a free access to public. Landsat 5 satellite images were used to analyze LULC for the year 1991 whereas Landsat 8 satellite images were used to analyze LULC for the year 2021. Furthermore, UHI was assessed to understand the impact of urbanization on local climate for suggesting city-specific policy recommendation leading to sustainable urban management and planning. The urban wind can heats environment directly and affects the sustainable development of cities, with persistent high temperatures and increasing climate extremes, continue to pose a threat to human life and health.

Land use land cover classification of Rajkot city:

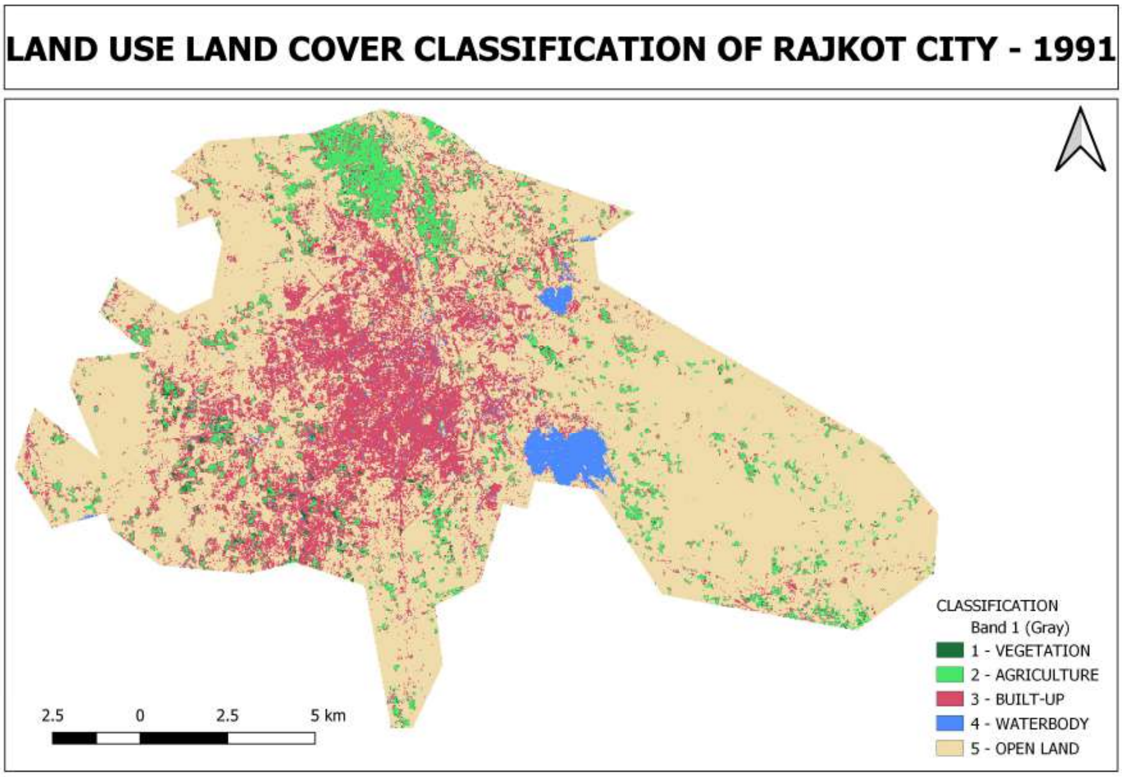
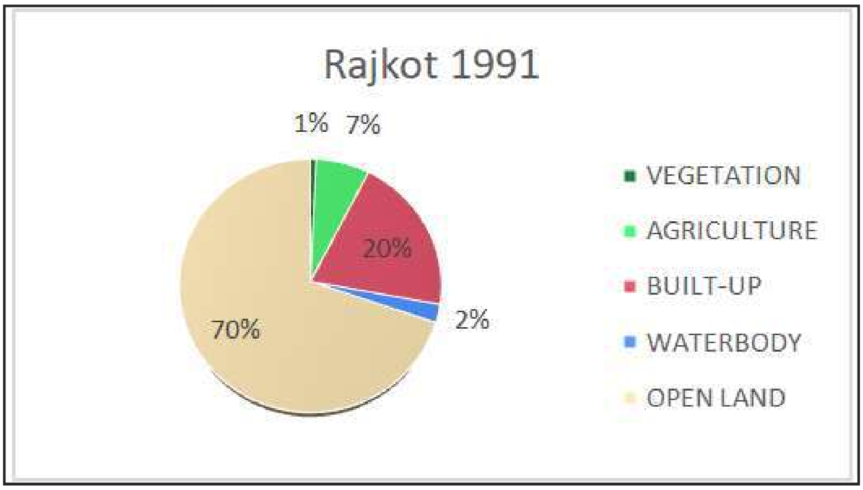


Fig.3. LULC Maps of Rajkot city – 1991



Pie Chart of LULC Rajkot 2021

Land use land cover map of Rajkot-1991 depicts early stage of urban growth. The central zone primarily shows compact residential and commercial sectors, while the outer area of the city largely hosts agricultural lands and scattered settlement clusters. Green patches predominate in suburban rings, indicating the presence of natural habitat for biodiversity of the region and farmlands. Infrastructure growth seems gradual with the roads linking to city neighborhoods. Overall the map of 1991-Rajkot illustrates balanced distribution of built-up and green spaces reflecting moderate population and modest industrial growth at this time. Urban expanion seems minimal and waterbodies remain undisturbed. On the other hand land use land cover map of Rajkot-2021reveals extensive urban transformation over three decades. Concrete materials have easily and significantly replaced agricultural lands and open spaces that were visible in 1991. Residential and commercial zones dominate the core of the city, forming a continuous belts of development towards suburban patches. Green cover is mostly designated parks and sparse peripheral tracts, although no major change is observed in waterbodies of the city. The map highlights the growing prevalence of impervious surfaces, indicating a dynamic increase in population density and infrastructure footprint.

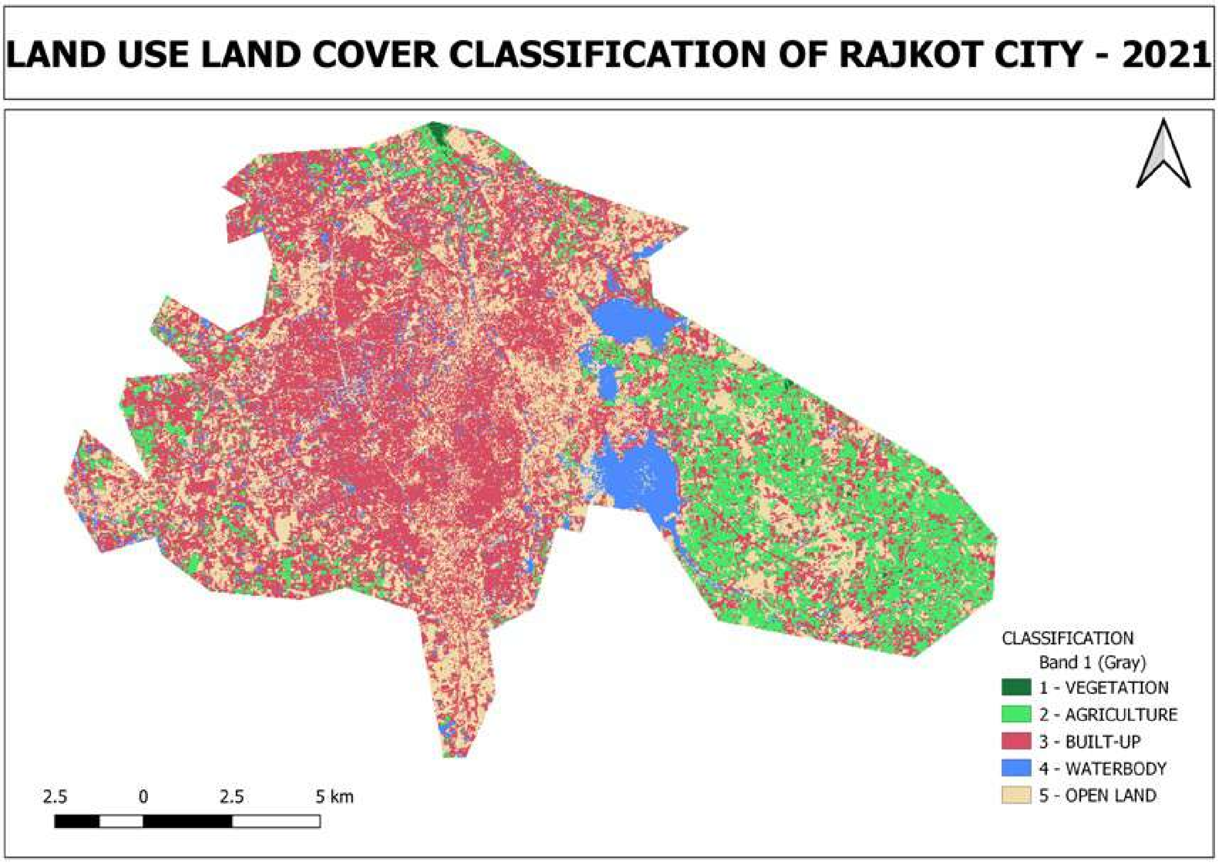
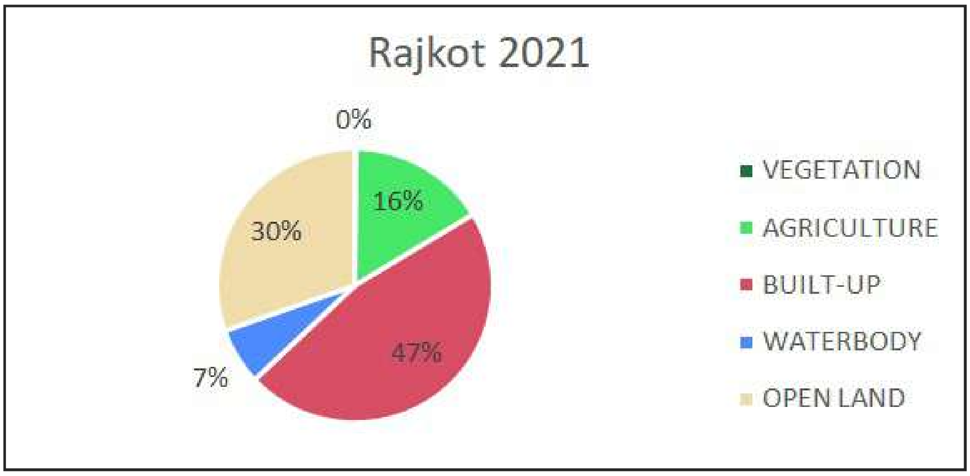


Fig.4. LULC Maps of Rajkot city - 2021



Pie Chart of LULC Rajkot 2021

Change Detection Analysis: The temporal land cover change in Rajkot city between 1991 and 2021 is presented in Table below. It depicts a sharp increase in built-up area from 46.86 sq km in 1991 to 107.44 sq km in 2021. This expansion is likely to have occurred largely at the expense of open lands, which reduced drastically from 160.90 sq km to 69.67 sq km. Agricultural area, on the other hand interestingly, showed an increase from 15.74 sq km to 37.37 sq km, likely due to changes in land use practices in peri-urban areas.

Table 1. LULC Area Statistics for Rajkot (1991–2021)

Year	Vegetation (sq km)	Agriculture (sq km)	Built-up (sq km)	Waterbody (sq km)	Open Land (sq km)
1991	1.70	15.74	46.86	5.39	160.90
2021	0.44	37.37	107.44	15.42	69.67

Accuracy Assessment: The accuracy assessment of the classified Rajkot LULC maps was conducted using ground control points and confusion matrices. The results shows high classification accuracy for all years, with Overall Accuracy being 92% to 96%, and Kappa Coefficient from 90% to 95%. Details for 1991 and 2021 are provided below.

Table 2. Accuracy Metrics for LULC Classification – Rajkot City 1991

	VEGETATION	AGRICULTURE	BUILT-UP	WATERBODY	OPEN LAND	TOTAL (USER)
VEGETATION	4	0	1	0	0	5
AGRICULTURE	0	5	0	0	0	5
BUILT-UP	0	0	5	0	0	5
WATERBODY	0	0	0	5	0	5
OPEN LAND	0	0	0	0	5	5
TOTAL (PRODUCER)	4	5	6	5	5	25

Overall Accuracy = (Total no. of correctly classifies pixels / Total no. of reference pixels) X 100

= (24/25) X 100
= 96%
User's Accuracy = [Number of correctly classified pixels in each category / Total number of classified pixels in that category (the row total)] X 100

- Vegetation = [4/5] X 100 = 80%
- Agriculture = [5/5] X 100 = 100%
- Built-Up = [5/5] X 100 = 100%
- Waterbody = [5/5] X 100 = 100%
- Open Land = [5/5] X 100 = 100%

Producer's Accuracy = [Number of correctly classified pixels in each category/ Total number of reference pixels in that category (the column total)] X 100

- Vegetation = [4/4] X 100 = 100%
- Agriculture= [5/5] X 100 = 100%
- Built-Up = [5/6] X 100 = 83.33%
- Waterbody = [5/5] X 100 = 100%
- Open Land = [5/5] X 100 = 100%

Kappa Coefficient = [(TS X TCS) – ∑ (Column Total X Row Total) / TS^2 - ∑ (Column Total - Row Total)] X 100
Where, TS = Total Sample

TCS = Total Correctly Classified Samples

Therefore,

Kappa Accuracy = (25x24) – ∑ [(4x5) + (5x5) + (6x5) + (5x5) + (5x5)] / 625 – ∑ [(4x5) + (5x5) + (6x5) + (5x5) + (5x5)]

= 475/500 × 100
= 95%

Overall Accuracy = (Total no. of correctly classifies pixels / Total no. of reference pixels) X 100

= (24/25) X 100
= 96%

User's Accuracy = [Number of correctly classified pixels in each category / Total number of classified pixels in that category (the row total)] X 100

- Vegetation = [5/5] X 100 = 100%
- Agriculture = [5/5] X 100 = 100%
- Built-Up = [4/5] X 100 = 80%
- Waterbody = [5/5] X 100 = 100%
- Open Land = [5/5] X 100 = 100%

Producer's Accuracy = [Number of correctly classified pixels in each category/ Total number of reference pixels in that category (the column total)] X 100

- Vegetation = [5/5] X 100 = 100%
- Agriculture= [5/5] X 100 = 100%
- Built-Up = [4/4] X 100 = 100%
- Waterbody = [5/5] X 100 = 100%

- Open Land = [5/6] X 100 = 83.33%

Kappa Coefficient = [(TS X TCS) – ∑ (Column Total X Row Total) / TS^2 - ∑ (Column Total - Row Total)] X 100
Where, TS = Total Sample

Table 3: Accuracy Metrics for LULC Classification – Rajkot City 2021

	VEGETATION	AGRICULTURE	BUILT-UP	WATERBODY	OPEN LAND	TOTAL (USER)
VEGETATION	5	0	0	0	0	5
AGRICULTURE	0	5	0	0	0	5
BUILT-UP	0	0	4	0	1	5
WATERBODY	0	0	0	5	0	5
OPEN LAND	0	0	0	0	5	5
TOTAL (PRODUCER)	5	5	4	5	6	25

TCS = Total Correctly Classified Samples

Therefore,

Kappa Accuracy = (25x24) – ∑ [(5x5) + (5x5) + (4x5) + (5x5) + (6x5)] / 625 – ∑ [(5x5) + (5x5) + (4x5) + (5x5) + (6x5)]
= 475/500 × 100
= 95%

Urban Heat Island of Rajkot city: Urban Heat Island of Rajkot city was estimated with help of Land Surface Temperature and was successfully processed in QGIS software using a formula:

UHI (Z-score) = LST – LSTm / SD

Where,

LST = Land Surface Temperature of each pixel
LSTm = Mean LST
SD = Standard Deviation of LST

This Z-score based classification enables us for identification of urban hotspots (positive UHI values) as well as cool islands (negative UHI values). UHI maps for Rajkot 1991 and Rajkot 2021 are shown below:

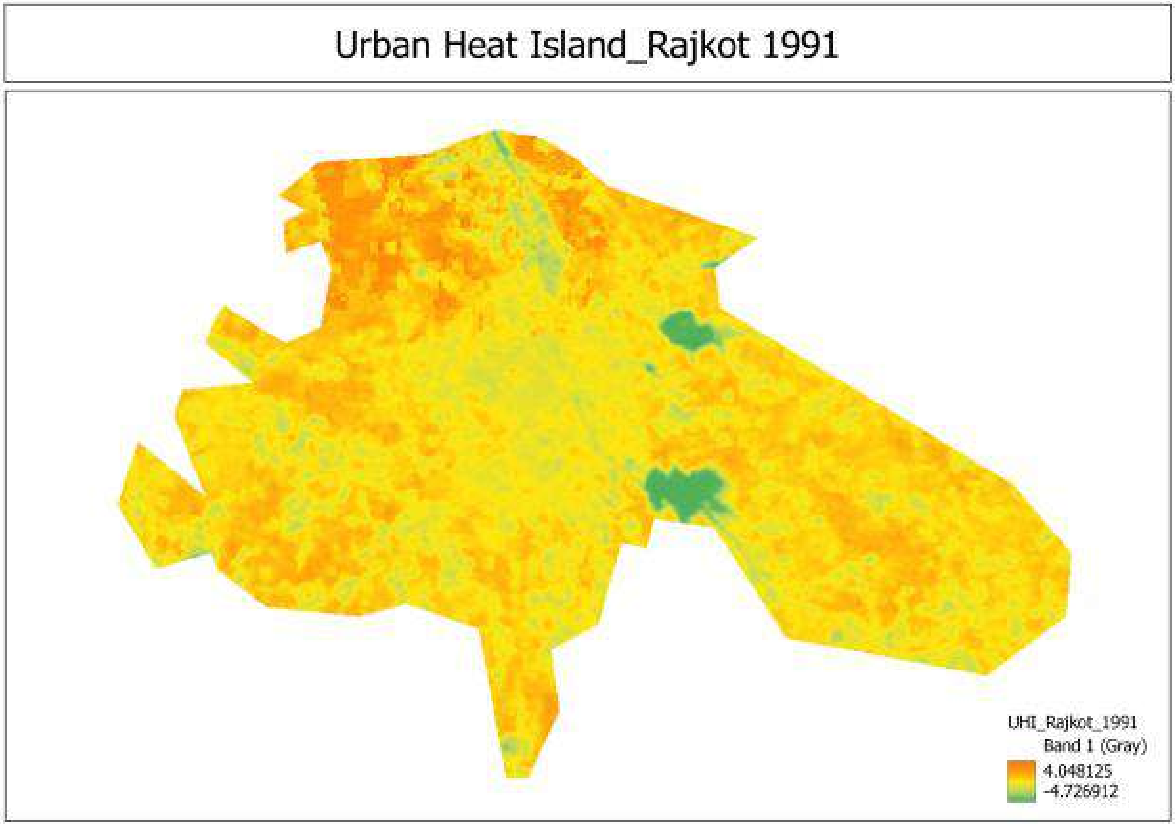


Fig. 5. UHI Maps of Rajkot city - 1991

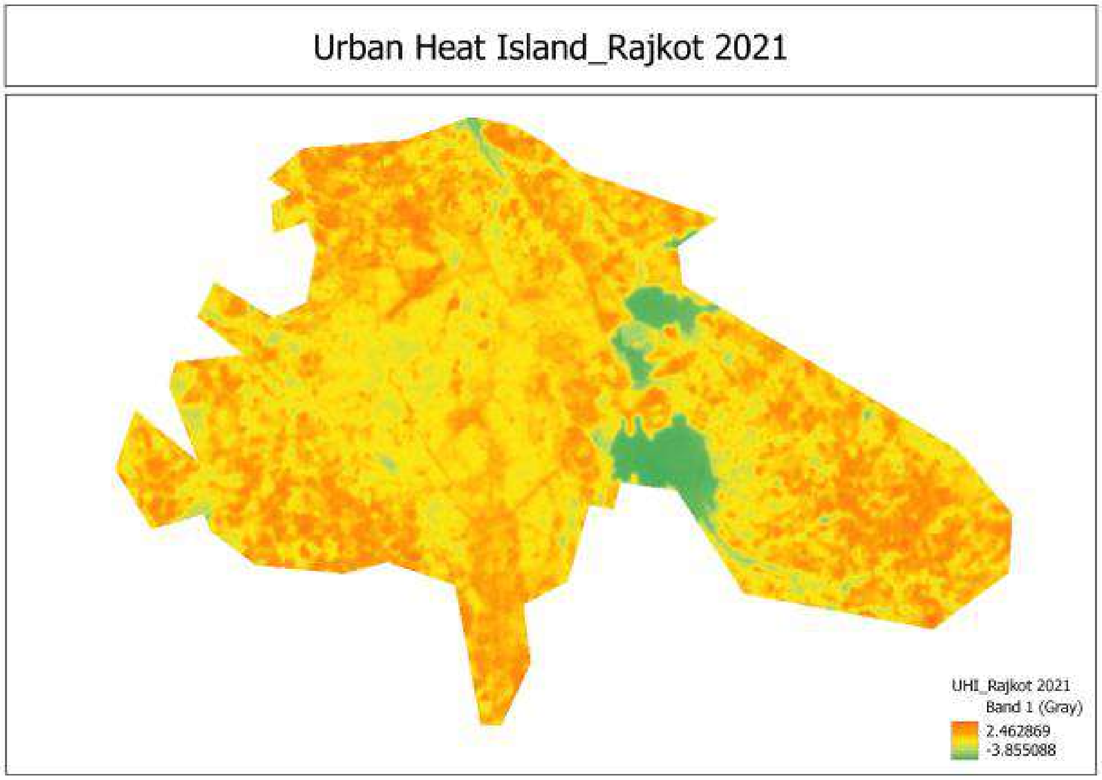


Fig. 6. UHI Maps of Rajkot city - 2021

The Urban Heat Island (UHI) map of Rajkot 1991 reveals the localized difference of surface temperature between urban and peripheral zones. Colors like orange and yellow signifies major heat island intensity often arising due to dense construction materials, less vegetation and more population density. Cool colors like green and blue highlights vegetation-rich or water-influenced landscapes, where evapotransipiration and shade of vegetation mitigates the access heat accumulation in the surrounding. In the year 2021 a clear picture of presence of heat pockets is evident when compared to the UHI map of Rajkot-1991, underscoring the cumulative effect of urban expansion and reduced vegetation patches. This result leads to a note of urban heat.

Table 4. UHI Z-score Classification

Z-Score Range	Thermal Zone Classification
> +1.0	Indicating High Heat Island (Hotspots)
+0.5 to +1.0	Indicating Moderate UHI
-0.5 to +0.5	Indicating Neutral Zone
< -0.5	Indicating Cool Island (Vegetation/Water)

Wind Speed of Rajkot city

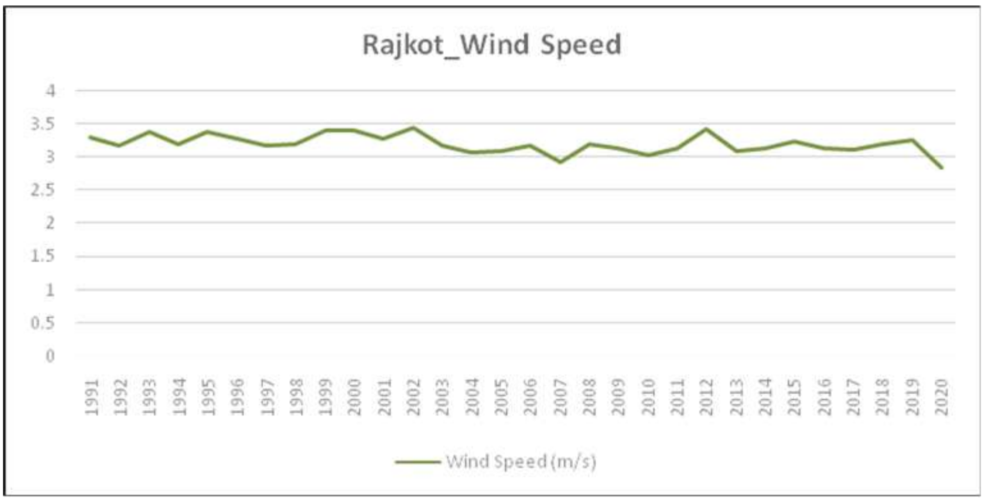


Fig. 7. Wind Speed of Rajkot city 1991- 2020

The graph represents the interannual variation in average wind speed (m/s) of Rajkot from the year 1991 to 2020. Wind speed values of Rajkot consistently oscillate between 3.0 and 3.5 m/s for most of the study period, indicating relative atmospheric stability. Minor peaks are observed around the years 1994, 2002, and 2012, while occasional troughs appear, particularly in the year 2007 and 2020—the latter marking the lowest average wind speed to be (~2.8 m/s). This overall marginal decline in wind velocity, especially post-2015, may be due to urban growth, increased surface roughness, or because of broader climatic transitions. Reduced wind activity can potentially exacerbate urban heat retention and humidity buildup. Stronger winds can carry away the heat trapped within urban areas, preventing it from accumulating and causing temperatures to rise.

It promotes convective heat exchange, allowing cooler air to replace the warmer air near the ground, thus lowering temperatures. Moreover wind speed improves ventilation in urban canyons, which can help reduce the concentration of heat-trapping pollutants and further mitigate the UHI effect. Low Wind Speeds (less than 2 m/s) can exacerbate the UHI effect as they limit heat dispersion and trap hot air within the urban environment. As wind speed increase, the UHI intensity tends to decrease, with a critical wind speed around 4-5 m/s, above which the UHI strength is significantly reduced. While higher wind speeds generally reduce UHI intensity, excessive wind can also have negative impacts, such as increased energy consumption for cooling buildings. The shape and density of urban areas can also influence how wind affects the UHI. For example, urban canyons, which are narrow streets flanked by tall buildings, can experience reduced wind speeds and increased UHI intensity compared to more open areas. Besides wind speed, other factors such as urban surface materials, vegetation cover, and building density also contribute to the UHI effect

Correlation of LULC and Wind Speed with UHI of Rajkot city:

The graph presents a statistical correlation between Built-up Area and Wind Speed in Rajkot city over the period of 1991 to 2021. It clearly illustrates a strong inverse relationship, with a Pearson correlation coefficient of -0.96 and indicating that as an extent of urbanization increase as well as average wind speed significantly declines. Built-up area shows expansion from approximately 29.24 to 107.44 square km over 30 years, while wind speed is decreased from 3.29 m/s to 2.84 m/s. This trend highlights that the intensification of urban land cover directly affects the local atmospheric dynamics.

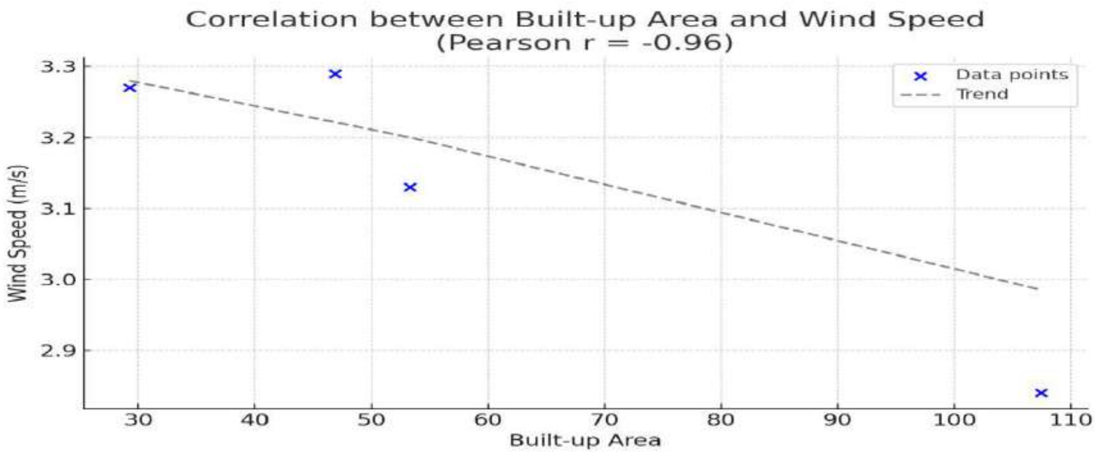


Fig 8. Correlation of Built-up and Wind speed

Urban expansion can often lead to the replacement of vegetated and permeable surfaces with impervious materials like cement concrete and asphalt. These materials not only retain heat but also increases surface roughness, which disrupts wind flow patterns resulting in reduces air movement. The reduction in wind speed acts as a huddle in convective cooling and facilitates heat accumulation, exacerbating the Urban Heat Island (UHI) effect. Consequently, urban areas have to experience elevated temperatures in comparison to surrounding rural zones. The plotted data supports existing literature asserting that urban morphology plays a critical role in modifying microclimatic variables. Although based on limited temporal data points, the near-linear negative trend underscores the significant climatic implications of rapid urbanization, providing empirical support for urban climate mitigation strategies. Visual correlation suggests that recent analyses of Rajkot's land surface temperature patterns and its corresponding wind speed data suggests a strong correlation between increasing urban growth and diminished wind flows, ultimately leading to urban heat island (UHI) effects (Voogt & Oke, 2003). As the city's built-up area has expanded, impervious surfaces such as concrete and asphalt have displaced vegetative or open lands, thus restricting wind flow and reducing the natural dissipation of heat (Rizwan, Dennis, & Liu, 2008). This UHI phenomenon is further intensified by the alteration of urban morphology i.e. taller buildings, denser clusters, and narrower streets, which together create barriers that slow or redirect winds and limiting convective heat transfer away from ground surfaces (Oke, 1973). Rajkot's data from 1991 to 2021 shows a marked increase in built-up growth, corresponding with a noticeable decline in mean wind speed from approximately 3.5 m/s to 3.0 m/s in three decades. Concurrently, UHI intensity, has risen, indicating that reduced wind speed has curtailed the mixing of warm and cool air layers by allowing localized heat pockets to persist (Zhou *et al*., 2019). The decline in wind speed is critical since even moderate breezes can remove accumulated thermal energy from urban surfaces and thereby mitigating UHI effects. In this case, decreasing wind speeds have led to amplified warming of the urban area, particularly in highly urbanized zones, resulting in heightened energy demands for cooling, increased emissions from air-conditioning systems, as well as degraded thermal comfort for residents (Arnfield, 2003). These findings underscore the importance of conserving open spaces and adopting climate-sensitive urban design approaches for mitigating the adverse consequences of reduced wind speed in the context of rapid urbanization.

CONCLUSION

The findings of the study underscore a clear relationship between Rajkot's expanding urban footprint to declining wind speed, and intensifying UHI effects. As built-up areas grow, natural ventilation corridors are obstructed, restricting airflow and preventing the movement of accumulated thermal energy. This localized warming not only raises local temperatures but also increases energy demands, adding to broader environmental challenges such as air pollution and greenhouse gas emissions.

To mitigate UHI effects and support Rajkot's sustainable development, urban planners and policymakers can prioritize expanding green infrastructure which includes parks and urban forests, for enhancing evaporative cooling and restoring wind pathways. The acceptance of high-albedo (light-colored) roofing materials and the promotion of green roofs can further help to reduce surface heat absorption, while strategic orientation of buildings can provide cooler microclimates by preserving wind corridors. Moreover, integrating permeable surfaces may help alleviate thermal stress at street level. For long-term policy measures, updating building codes to mandate energy-efficient designs and incorporate rainwater harvesting in public spaces can yield multiple co-benefits, including improved stormwater management and temperature management. A balanced land-use plan that limits unbridled sprawl and preserves open space is important for maintaining vital ventilation channels. By blending these strategies and suggestions with continuous monitoring of Land surface temperature and wind dynamics, Rajkot can effectively manage UHI impacts and ensure a healthier as well as more resilient urban environment.

It can be concluded that urban heat island (UHI) effect is likely possible in Rajkot city. Its location being in semi-arid zone, coupled with its increasing urban growth and climate patterns, contributes to this effect, leading to temperatures in the city being higher than surrounding area Sustainable Development Goal 13, which focuses on combating climate change is closely linked to increase in built-up areas and Urban Heat Island intensity. Urban expansion replaces natural land which has impervious surfaces, causing higher temperatures in cities. This intensifies energy usage for cooling, increasing greenhouse gas emissions and thus contributing to climate change. High temperatures also raises health risks during heatwaves. Sustainable urban planningsuch as green roofs, reflective materials, and more vegetationcan certainly help reduce UHI effects, support emission reduction, and grows climate resilience, directly aligning with the targets of SDG 13.

ACKNOWLEDGMENTS

Authors are thankful to Principal Shri Dr. Kartik Ladva of Shri Manibhai and Smt. Navalben Virani Science College (Autonomous) and management for providing the working facility to carry out this research work. Authors are also grateful to Dr. Chandra Prakash Singh SCI/ENGR.SF, AED/BPSG/EPSA, Space Application Centre, ISRO for vividly introducing in the field of remote sensing and GIS along with its application in vegetation analysis.

REFERENCES

IPCC, 2013. *Climate change 2013: the physical science basis. In: Stocker*, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (Eds.), Contribution of working group I to the Fifth Assessment Report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Kotharkar, R., Ramesh, A., & Bagade, A. (2018). *Urban Heat Island studies in South Asia: A critical review. Urban Climate, 24, 1011–1026.* doi:10.1016/j.uclim.2017.12.006

Erell, E., Pearlmutter, D., Williamson, T.T.J., 2011. *Urban microclimate: designing the spaces between buildings*. Routledge.

Kato, S., Huang, H., 2009. *Ventilation efficiency of void space surrounded by buildings with wind blowing over built-up urban area.* J. Wind Eng. Ind. Aerodyn. 97 (7), 358–367.

Morris, C., Simmonds, I., Plummer, N., 2001. *Quantification of the influences of wind and cloud on the nocturnal urban heat island of a large city.* J. Appl. Meteorol. 40 (2), 169–182.

Kim, Y.-H., Baik, J.-J., 2002. *Maximum urban heat island intensity in Seoul.* J. Appl. Meteorol. 41 (6), 651–659.

Memon, R.A., Leung, D.Y., 2010. *Impacts of environmental factors on urban heating.* J. Environ. Sci. 22 (12), 1903–1909.

Arnfield, A. J. (2003). *Two decades of urban climate research: A review of turbulence, exchanges of energy and water, and the urban heat island.* International Journal of Climatology, 23(1), 1–26.

Oke, T. R. (1973). *City size and the urban heat island*. Atmospheric Environment, 7(8), 769–779.

Rizwan, A. M., Dennis, L. Y., & Liu, C. (2008). *A review on the generation, determination and mitigation of Urban Heat Island.*Journal of Environmental Sciences, 20(1), 120–128.

Voogt, J. A., & Oke, T. R. (2003). *Thermal remote sensing of urban climates.* Remote Sensing of Environment, 86(3), 370–384.

Zhou, D., Xiao, J., Bonafoni, S., Berger, C., Ren, H., & Zhang, L. (2019). *Satellite remote sensing of surface urban heat islands: Progress, challenges, and perspectives.*Remote Sensing, 11(1), 48.

****