# Land-surface temperature dynamics in the fringes of north Bhubaneswar, India: an empirical analysis

**Priyanka Mishra[1], Damodar Jena[2,*], Nimay Chandra Giri[3], R. R. Thakur[4] and Debendra Nath Dash[5]**

[1]KIIT School of Architecture and Planning, KIIT Deemed to be University, Bhubaneswar 751 024, India
[2]KIIT School of Rural Management, KIIT Deemed to be University, Bhubaneswar 751 024, India
[3]Department of Electronics and Communication Engineering, Centurion University of Technology and Management, Khordha 752 050, India
[4]Odisha State Disaster Management Authority, Bhubaneswar 752 001, India
[5]Mahatma Gandhi National Council of Rural Education, Department of Education, Government of India, Hyderabad 500 004, India

**The urban fringes are experiencing a significant surge in surface temperature during the transition from rural to urban, inducing imperceptible disturbances. The present study analyses the temperature modulations from 2000 to 2022 in Kalarahanga and Raghunathpurjali fringes in North Bhubaneswar to understand the relationship between spatiotemporal changes and land-surface temperature in the fringes. The investigations reveal a consistent decrease in the area under water bodies and crops, with an increase in the built-up area. Besides, there exists an inverse correlation between the area under high and medium temperature with the area under cropland (–0.820) and the area under water bodies (–0.799), and a positive correlation coefficient (0.813) with the built-up area/impervious surfaces. This insists on eco-sensitive planning of the urban fringes with consistent monitoring of land use and thermal dynamics for apt control of the changes in the urban microclimate.**

**Keywords:** Geo-spatial technology, land-surface temperature, remote sensing, urban fringe, urban heat islands.

URBAN sprawl extends urban areas into neighbouring fringe areas, reshaping their biophysical features such as green spaces, forests and water bodies[1]. The expansion of urban areas significantly impacts demographic changes, energy consumption and economic growth, resulting in environmental quality alterations through land use conversion and decline in vegetation[2,3]. Anthropogenic modifications due to urbanization affect various environmental parameters, including the degree of absorption of solar radiation, surface temperature, transmission and storage of heat, and reduction and modulation of wind speed in relation to surface roughness[4,5]. This process alters the urban local climate by modifying land surfaces and interaction processes with the atmosphere, leading to phenomena like heat islands[6,7]. This process further influences the flow of material and energy in the urban ecological systems, which changes soil properties, urban hydrologic systems, and biological habitats, leading to unpredictable climate changes[8].

Remote sensing and geographic information systems (GIS) facilitate land use mapping, monitoring and analysing the extent and pattern of urban sprawl[9]. This makes them effective tools for studying the formation of urban heat islands (UHI) and their relationship with land-use land-cover (LULC) indices, thereby advancing the understanding of the intricate relationship between their patterns over both space and time[10,11]. However, most studies have primarily focused on larger cities, urban core areas, or rural regions, overlooking the mapping of these changes in the peripheries[11–13].

Urban sprawl in Delhi was studied from 1972 to 2014, and it was observed that there is an increase in the spatially average ambient temperature by 1.02°C, which has resulted in a rise in thermally discomforting hours from an average of 10 h to 13 h a day[14]. Dutta *et al.*[9] further found a high correlation between impervious land cover and vegetation surface fraction, normalized difference vegetation index (NDVI) and land-surface temperature (LST), indicating a significant expansion of impervious surfaces in the outskirts of the city, causing the surge in LST. In Kolkata municipality and its fringe areas, Halder *et al.*[13] reported an annual temperature increase of 0.157°C along with a negative correlation between LST and NDVI, and a positive correlation with normalized difference built-up index (NDBI). Meanwhile, studies conducted in the peripheries of Durgapur by Dutta *et al.*[15] and in Bilaspur by Halder and Bandyopadhyay[16] highlighted strong correlations between LST and LULC patterns, attributing the unexpected rise in LST to thermal variations, population density, industrial development and climate change. In Dodballapur Taluk, Bengaluru Rural District, Santhosh and Shilpa[11] observed a mean LST increase of 2.09°C with a variance of 2.75°C. Similarly, Ajmer and its vicinity have experienced the

*For correspondence. (e-mail: damodarjena@gmail.com)

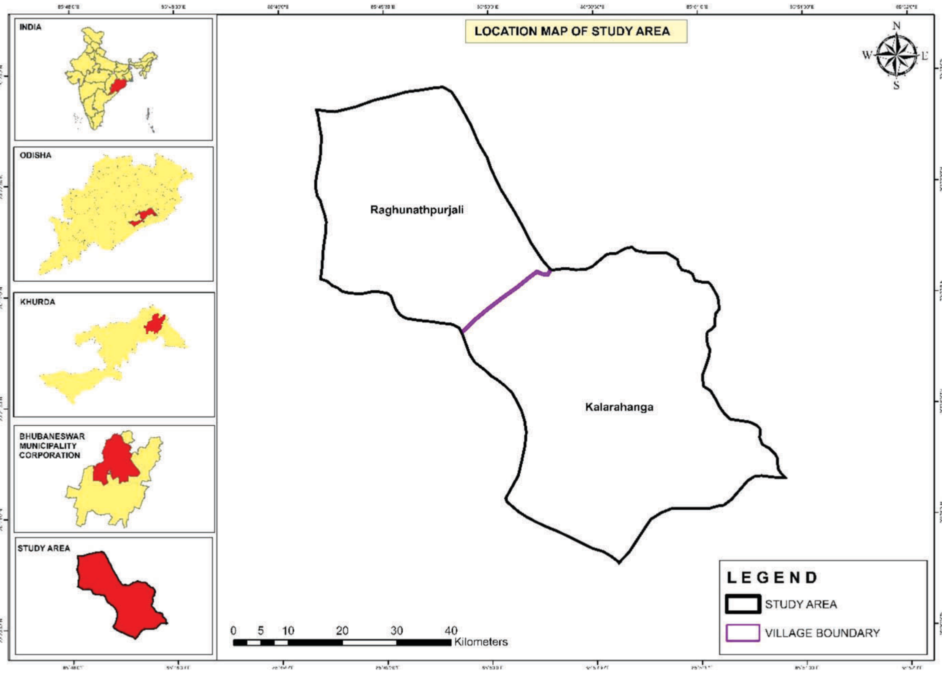


**Figure 1.** Location map of the study area, Raghunathpurjali and Kalarahanga in Bhubaneswar.

development of heat islands as a result of dense built-up areas and scanty vegetation[17]. Similarly, Bhubaneswar has rapidly urbanized in the last two decades, witnessing a 12% expansion in urban areas and over 70% increase in built-up areas[18], accompanied by uncontrolled urban sprawl that has irreversibly changed land use patterns[19]. This has contributed to an increase in urban LST.

UHI is emerging as a serious factor contributing to the soaring intensity and frequency of heat waves and global warming, posing risks to human health[20]. Extensive global research is focused on understanding the relationship between urbanization, urban sprawl, land use patterns, and their impact repercussions on modifications in urban fabric and water bodies, temporal urban changes, environmental changes and urban life quality[21–23]. While research in developing countries is progressing, studies often overlook the changes in LULC and thermal phenomena in the urban fringes and the interactions among various factors that influence these alterations[24,25]. These relatively small areas have the potential to substantially alter microclimates, with potential implications for the broader macro-climate on a global level[14]. This emphasizes the need for more thorough investigations and consistent monitoring of LULC changes and LST in the fringes essential for integrating effective urban planning initiatives.

This study addresses the research gap by utilizing remote sensing to analyse the dynamics of LULC, NDVI, NDBI and LST changes in the two burgeoning urban fringes of North Bhubaneswar from 2000 to 2022. The research also explores the correlation between LST and LULC to validate the impact of the changes in LULC on LST. It emphasizes the importance of conducting micro-level analyses for each fringe area due to their distinct characteristics. These analyses will provide essential insights for urban planners, researchers, and local communities to formulate sustainable land use strategies and comprehensive urban expansion plans. Such strategies are tailored to the unique attributes of these fringes and play a pivotal role in mitigating microclimate changes and minimizing impacts on health, infrastructure, energy and ecosystems.

## Methodology

### *Study area*

Bhubaneswar, the capital of Odisha, is located in the Eastern Coastal Plains of India and lies between 20°5′N to 20°26′N and from 85°30′E to 85°59′E with an average elevation of 45 m amsl. The eastern and southern parts of the city are gently sloping, consisting of fertile alluvial soil owing to Rivers Daya and Kuakhai, which are tributaries of River Mahanadi. The north and western parts have hard red lateritic soil with dispersed hillocks made up of Upper Gondwana shale–sandstone sequences in the west. The city experiences a humid tropical climate with an average annual rainfall of 1498 mm, characterized by hot, humid summers reaching 46°C from late March to mid-June and dry, cool winters.

With 67 wards, 46 revenue villages, and covering 186 sq. km, Bhubaneswar has seen a population surge from 16,512 in 1951 to 1,131,000 in 2019. Situated near

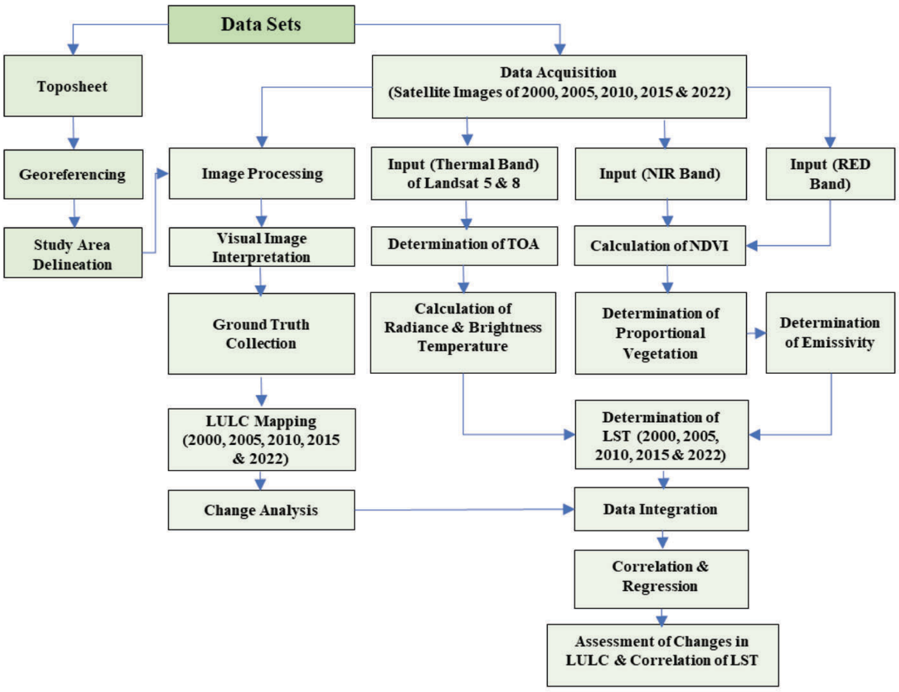


**Figure 2.** Schematic representation of the methodology for assessment of the influence of changes in land-use land-cover (LULC) on land-surface temperature (LST) in study area.

**Table 1.** Imageries used in the study

| Year | Date | Landsat sensor | Resolution (spatial; m) |
|---|---|---|---|
| 2000 | 6 May 2000 | Landsat-5 | 30 |
| 2005 | 13 May 2005 | Landsat-5 | 30 |
| 2010 | 13 May 2010 | Landsat-5 | 30 |
| 2015 | 21 May 2015 | Landsat-8 | 30 |
| 2022 | 20 May 2022 | Landsat-8 | 30 |

Source: USGS, USA website.

the Kuakhai and Daya Rivers in the Eastern coastal plains, the city faces natural hazards such as cyclones, earthquakes and urban flooding, alongside the growing magnitude and extent of UHIs.

Figure 1 shows Raghunathpurjali and Kalarahanga, neighbouring fringe areas in North Bhubaneswar, with distinct growth trajectories despite their proximity. Until the 1990s, they were primarily agricultural but underwent rapid urbanization post-2000, marked as the study's baseline year. Raghunathpurjali, known as the 'rice bowl of Bhubaneswar', has undergone transformations in land use, characterized by the filling and encroachment of marshlands and once-thriving paddy fields. This region has now transitioned into linear development along Nandankanan Road linking Cuttack and Bhubaneswar. This development has been marked by the emergence of high-rise structures and commercial zones on either side. On the other hand, the growth of Kalarahanga is clustered along Patia Station Road and the railway line, encroaching on agricultural lands with limited infrastructure, narrow streets, and low-rise apartments and buildings needing more planned open spaces.

## *Data and methodology*

The study aims to examine changes in LULC and its implications on LST on the fringes of Bhubaneswar using geospatial technologies. The methodology is outlined in Figure 2.

The LANDSAT 5 and 8 satellite imageries of the study area during the summer season in 2000, 2005, 2010, 2015 and 2022 were acquired from the United States Geological Survey (USGS), USA website and served as the primary data source for driving the whole research work. The delineation of the study area was accomplished using the Arc Map 10.5 version, software and the Survey of India (SOI) toposheet of 1 : 50,000 scale was utilized based on the availability as a reference. The downloaded imageries with 30 m spatial resolution were processed using the image processing software ERDAS Imagine 14 version. The thermal band was resampled with the pixel size of 30 m to match the optical bands, followed by atmospheric correction of the satellite imageries. Some of the images were geo-rectified in a GIS environment, and some specific image processing analyses such as layer stacking, mosaicking and enhancement were carried out. Comprehensive analyses for LULC mapping were conducted for different periods, and change analysis for each year was conducted to discern and quantify alterations over time. Details of

**Table 2.** Statistical measures

| Statistical measure | Equation | Description |
|---|---|---|
| ToA | $0.0003342 \times \text{band } 10 + 0.1$ | Top of atmosphere |
| BT | $(1321.0789/\ln(774.8853/\text{ToA}) + 1) - 273.15$ | Brightness temperature |
| NDVI | NDVI = Float (band 5 – band 4)/float (band 5 + band 4) | Normalized vegetation index |
| NDBI | NDBI = Float (band 6 – band 5)/float (band 6 + band 5) | Normalized difference built-up index |
| PV | PV = Square $(\text{NDVI} - \text{NDVI}_{min})/(\text{NDVI}_{max} - \text{NDVI}_{min})$ | Proportion of vegetation index (PV), $\varepsilon = 0.004 \times \text{PV} + 0.986$ |
| LST | $\text{LST} = \text{BT}/(1 + (0.00115 \times \text{BT}/1.4388) \times \ln(\varepsilon))$ | Land-surface temperature |
| UHI | $\text{UHI} = \mu + \sigma/2$ | Urban heat island, $\mu$ is the mean LST of the study area, $\sigma$ is the standard deviation of LST |

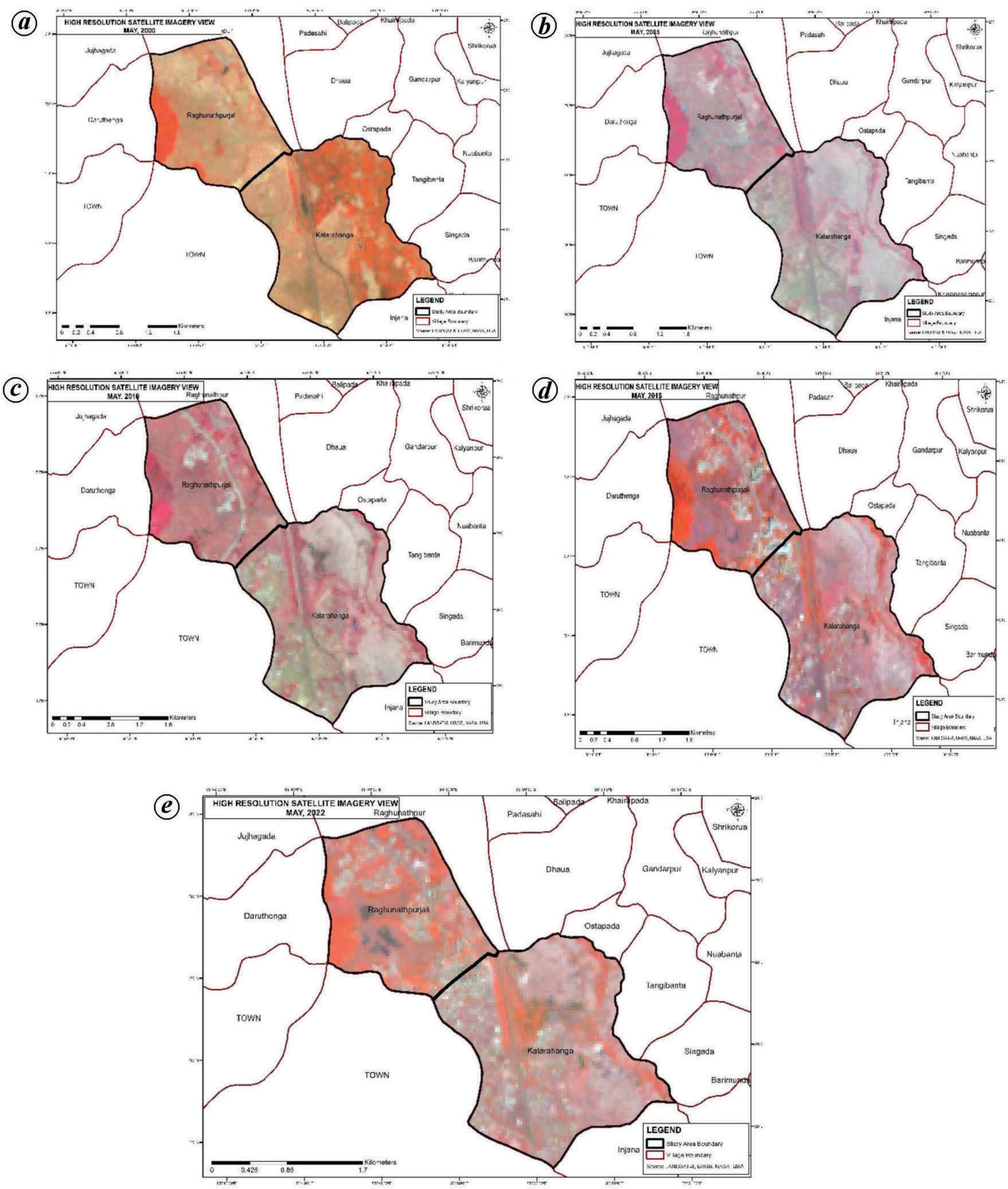


**Figure 3.** Landsat images of study area for the years (***a***) 2000, (***b***) 2005, (***c***) 2010, (***d***) 2015 and (***e***) 2022.

**Table 3.** Land use land cover changes from 2000 to 2022

| Class | Absolute area cover (%) | | | | | LULC changes (%) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2005 | 2010 | 2015 | 2022 | 2000–05 | 2005–10 | 2010–15 | 2015–22 | 2000–22 |
| Built-up area | 21.59 | 27.17 | 40.24 | 41.77 | 54.59 | 25.9 | 48.07 | 3.82 | 30.68 | 152.89 |
| Water bodies | 9.81 | 9.13 | 8.05 | 7.49 | 6.27 | –6.92 | –11.84 | –6.94 | –16.23 | –36.04 |
| Cropland | 60.73 | 56.12 | 44.68 | 44.49 | 33.75 | –7.6 | –20.38 | –0.42 | –24.15 | –44.43 |
| Vegetation | 2.75 | 2.53 | 2.42 | 2.67 | 2.55 | –8.02 | –4.47 | 10.62 | –4.49 | –7.16 |
| Wastelands | 5.12 | 5.05 | 4.62 | 3.57 | 2.84 | –1.48 | –8.57 | –22.7 | –20.54 | –44.67 |

the imageries used in the study for the study period are provided in Table 1.

The quality of the LST data was evaluated, and pixels affected by cloud cover, sensor aircraft, or other anomalies were discarded or flagged. The Landsat images for the study periods were employed, and the near-infrared (NIR) and infrared (IR) bands were used to compute the NDVI and NDBI. Several image processing steps were executed, including determining the top of atmosphere (TOA), calculating radiance and brightness temperature, proportional vegetation determination, and determining emissivity to obtain LST, as represented in Table 2. The data from the LULC change analysis were integrated with the LST output.

Subsequently, a correlation analysis was conducted among key variables, namely LULC, NDVI, NDBI and LST, and also for the area under cropland, water bodies and built-up areas with the area under high and medium temperature to assess the extent of association between land use patterns and temperature distribution.

## Results and discussion

### *Land use land cover classification*

The study area has been categorized into five major LULC classes using the Level-4 NRSC classification standard comprising built-up areas, water bodies, vegetation, agricultural land/cropland and wastelands. Figure 3 represents the satellite imageries of Kalarahanga and Raghunathpurjali for the years 2000, 2005, 2010, 2015 and 2022 and Table 3 provides a comprehensive overview of the LULC changes observed in the study area. These are crucial references for analysing the dynamic transformations in LULC patterns and understanding the evolving landscape characteristics in the two fringes.

The analysis shows that the area under cropland experienced the greatest decline of 44.43%, which reduced from 418.46 ha in 2000 to 232.55 ha in 2022. Similarly, the area under water bodies/marshy areas has reduced by 36.04% from 67.6 ha in 2000 to 43.24 ha in 2022. On the other hand, the built-up areas, which covered 21.59% (148.73 ha) of the total area in 2000, have shown substantial growth of 41.77% (376.13 ha) in 2022, which is an increase of around 153%. Statistical analysis of these images reveals a substantial growth of the impervious areas in both fringes as a consequence of the conversion of croplands, other vegetated areas, barren lands, wastelands, water bodies and marshy areas into built-up surfaces. These notable transformations, attributed to the rapid urban growth and associated anthropogenic activities, highlight the complex consequences of urban expansion on the ecological and environmental framework of the region.

### *LULC patterns and LST trends*

Figure 4 represents the changes in LULC patterns and classification results of the thermal band for the period of 2000–2022. The LST trends and the corresponding percentage changes in the study area are summarized in Table 4. This facilitates a comprehensive understanding of the environmental transformations in Kalarahanga and Raghunathpurjali over the study period.

The analysis reveals significant trends in LST within the study area from 2000 to 2022. The area under the high-temperature range has expanded from 170.68 ha to 207.18 ha, which indicates a growth of 21.39%. Similarly, the area under the medium temperature range has increased from 154.79 to 385.39 ha, which is an increase of around 149%. However, the area under the low-temperature range is reduced drastically from 363.59 ha to 96.49 ha, which is approximately 73.46%.

### *Correlation analyses between LULC, NDVI, NDBI and LST*

The study of land cover change relies heavily on LST, NDVI, and NDBI, as highlighted by Alademomi *et al.*[26] Despite their importance, few studies have explored the interconnectedness of LST, NDVI, NDBI and land cover dynamics. The NDVI is a widely utilized metric for monitoring vegetation changes, while the NDBI provides valuable insights into urbanization levels and land cover alterations within a given area. Figure 5 and Table 5 illustrate the distribution of LULC, NDVI, NDBI and LST for the study areas in the year 2022. Notably, the spatial distribution of LST closely aligns with built-up regions, affirming the well-known association between urban development and elevated LST levels. This correlation has been supported

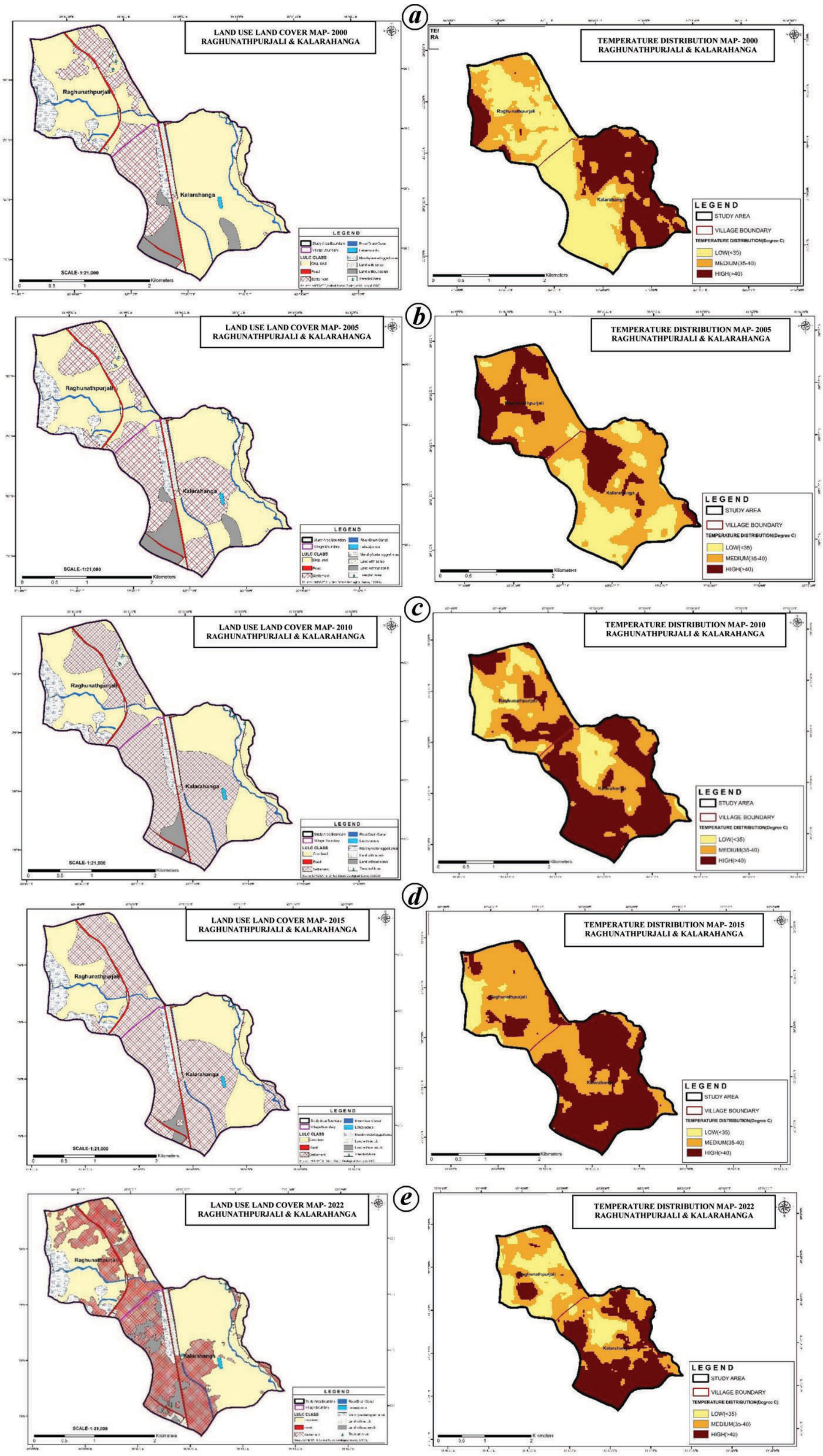


**Figure 4.** LULC changes and classification results of thermal bands and LST for (***a***) 2000, (***b***) 2005, (***c***) 2010, (***d***) 2015 and (***e***) 2022 (source: Interpreted from TM and ETM Landsat imagery).

**Table 4.** Temperature range modulations in the study area from 2000 to 2022

| | Area (ha) | | | | | Change (%) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Temperature range | 2000 | 2005 | 2010 | 2015 | 2022 | 2000–05 | 2005–10 | 2010–15 | 2015–22 | 2000–22 |
| High (above 40°C) | 170.68 | 45.41 | 241.73 | 316.12 | 207.18 | –73.39 | 432.33 | –30.77 | –34.46 | 21.39 |
| Medium (35°–40°C) | 154.79 | 404 | 403.13 | 339.29 | 385.39 | 161.02 | –0.23 | –15.84 | 13.59 | 148.98 |
| Low (<35°C) | 363.59 | 239.6 | 44.2 | 33.65 | 96.49 | –34.1 | –81.55 | –23.87 | 186.75 | –73.46 |

Source: Interpreted from Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM) Imagery.

**Table 5.** LULC, NDVI, NDBI, LST in 2022

| LULC | Area (Ha) | NDVI | Area (Ha) | NDBI | Area (Ha) | Temperature range | Area (Ha) |
|---|---|---|---|---|---|---|---|
| Crop land | 232.55 | Vegetation | 71.83 | Built-up-dense | 258.11 | High | 207.18 |
| Waterbody and marshy land | 43.24 | Waterbodies | 13.31 | Built-up-medium | 41.56 | Medium | 385.39 |
| Built-up area | 376.13 | Others | 603.93 | Others | 389.39 | Low | 96.49 |
| Others | 37.14 | | | | | | |

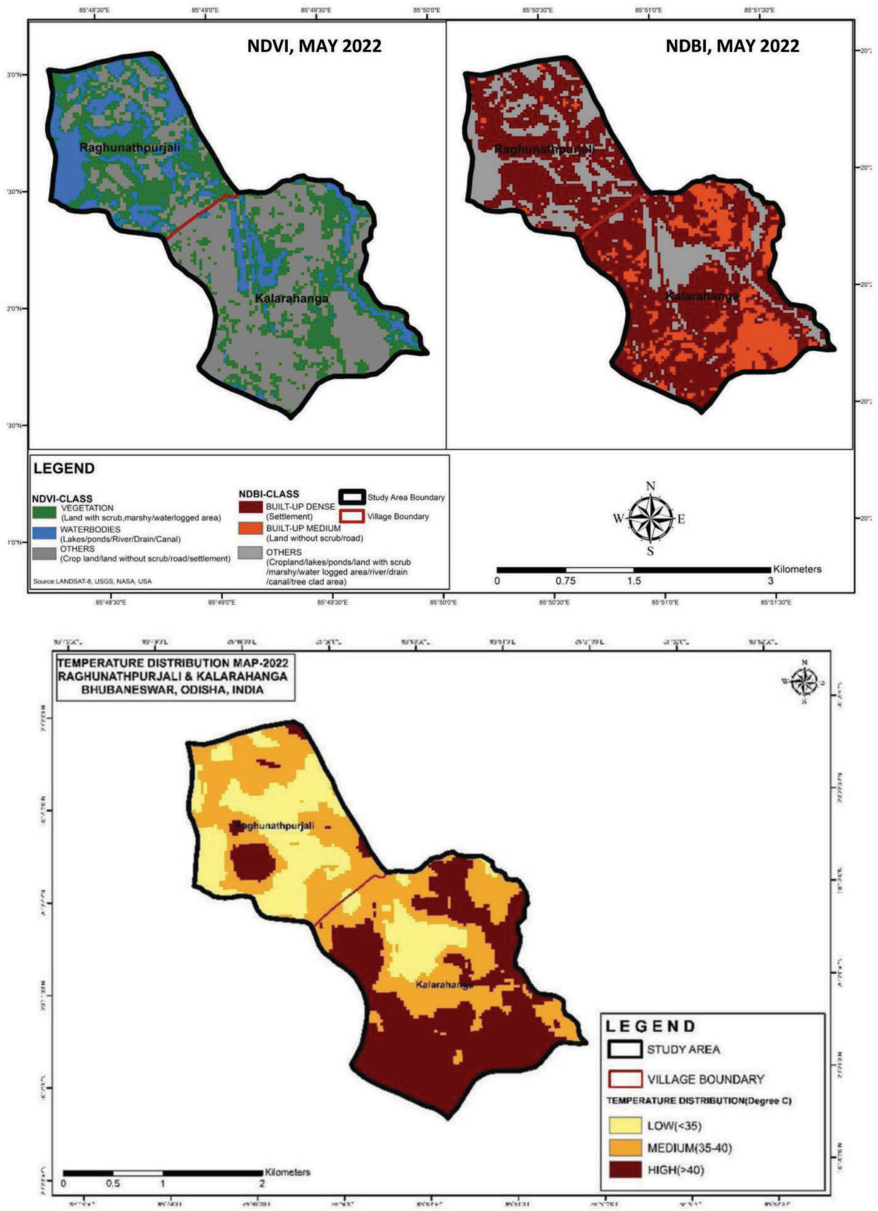


**Figure 5.** Maps showing distribution of normalized difference vegetation index, normalized difference built-up index and land-surface temperature in 2022.

**Table 6.** LULC changes in the study area

| Class | Area (Ha) | | | | | Change in area (%) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2005 | 2010 | 2015 | 2022 | 2000–05 | 2005–10 | 2010–15 | 2015–22 | 2000–22 |
| Crop land | 418.46 | 386.67 | 307.87 | 306.59 | 232.55 | –7.60 | –20.38 | –0.42 | –24.15 | –44.43 |
| Waterbody and marshy land | 67.60 | 62.92 | 55.47 | 51.62 | 43.24 | –6.92 | –11.84 | –6.94 | –16.23 | –36.04 |
| Built-up area | 148.73 | 187.24 | 277.25 | 287.83 | 376.13 | 25.89 | 48.07 | 3.82 | 30.68 | 152.89 |

Source: Data extracted and calculated data from Landsat images for the study period.

**Table 7.** Change in LULC and area under high and medium temperature in the study years

| Year | Crop land | Waterbody and marshy Land | Built-up area | Area under high and medium temperature |
|---|---|---|---|---|
| 2000 | 418.46 | 67.60 | 148.73 | 325.47 |
| 2005 | 386.67 | 62.92 | 187.24 | 449.45 |
| 2010 | 307.87 | 55.47 | 277.25 | 644.86 |
| 2015 | 306.59 | 51.62 | 287.83 | 655.41 |
| 2022 | 232.55 | 43.24 | 376.13 | 592.57 |

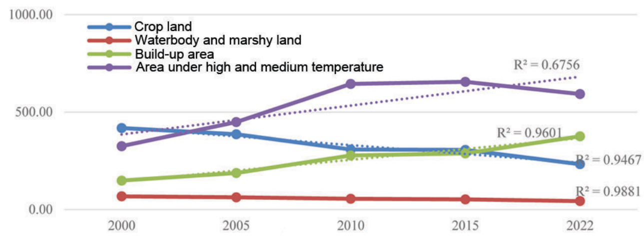


**Figure 6.** Land use changes in the study area from 2000 to 2022 (source: Interpreted from landsat sensor).

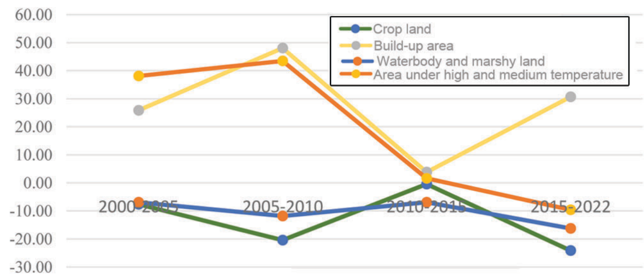


**Figure 7.** Land use and temperature changes (%) in the study area from 2000 to 2022 (source: Interpreted from landsat sensor).

by various researchers, including Das and Angadi[27] and Guha *et al.*[12].

The spatial distribution of NDVI shows an inverse pattern compared to LST and NDBI. In Kalarahanga, higher LST is observed, particularly evident in built-up areas and barren croplands during May, showcasing prominent heat islands. The croplands in Kalarahanga are dry and barren during this period due to soil preparation for farming beginning in June, which results in reduced evapotranspiration, and consequently, higher LST. Conversely, Raghunathpurjali, characterized by marshy areas and water bodies, experiences lower temperatures than Kalarahanga. This temperature difference is attributed to a higher rate of evapotranspiration in Raghunathpurjali, facilitating latent heat exchange between the surface and atmosphere[21]. However, the rapid conversion of these marshy areas into built-up zones is anticipated to elevate LST in the forthcoming years significantly.

## *Correlation analyses between LULC and LST*

The alterations in LULC and the areas experiencing high and medium temperatures during the study period are depicted in Tables 6 and 7. The analysis of Figures 6 and 7 reveals a consistent decline in the area covered by water bodies and crops, with a high correlation coefficient ($R^2$) of 0.9881 and 0.9467 respectively. Conversely, the built-up area, including settlements and roads, consistently increased with the $R^2$ value of 0.9601. Consequently, the area under medium and high temperatures has been increasing.

Further, to analyse the above variables, it is found from Table 8 that there is an inverse correlation between the area under cropland and the area under high and medium temperature (–0.820). A similar relationship was found between the area under water bodies and the area under high and medium temperatures (–0.799). The analysis also revealed a positive correlation coefficient (0.813) between built-up areas (settlements and roads) and the area under high and medium temperatures.

In light of the aforementioned changes, adopting a strategic and environmentally conscious approach to urban development is crucial. This approach needs to integrate conservation measures, sustainable land and water management practices, and initiatives such as urban farming and waterfront development to address weaknesses and threats while maximizing the potential for socio-economic growth and environmental resilience in Kalarahanga and Raghunathpurjali fringes, as displayed in Table 9.

**Table 8.** Correlation matrix

| | | Crop land | Waterbody and amp; marshy land | Built-up area | Area under high and amp; medium temperature |
|---|---|---|---|---|---|
| Crop land | Pearson correlation | 1 | 0.990* | –0.999* | –0.820 |
| | Sig. (2-tailed) | | 0.001 | 0.000 | 0.089 |
| | N | 5 | 5 | 5 | 5 |
| Waterbody and amp; marshy land | Pearson correlation | 0.990* | 1 | –0.994* | –0.799 |
| | Sig. (2-tailed) | 0.001 | | 0.001 | 0.104 |
| | N | 5 | 5 | 5 | 5 |
| Built-up area | Pearson correlation | –0.999* | –0.994* | 1 | 0.813 |
| | Sig. (2-tailed) | 0.000 | 0.001 | | 0.094 |
| | N | 5 | 5 | 5 | 5 |
| Area under high and amp; medium temperature | Pearson correlation | –0.820 | –0.799 | 0.813 | 1 |
| | Sig. (2-tailed) | 0.089 | 0.104 | 0.094 | |
| | N | 5 | 5 | 5 | 5 |

*Correlation is significant at the 0.01 level (2-tailed). Source: Data extracted and calculated data from Landsat images for the study period.

**Table 9.** Potential, threat and opportunities of the study area

| Potential | Threat |
|---|---|
| Socio-economic potential of Transit Oriented Development (TOD) along Nandankanan Road, Patia Station Road and Patia Station | Anthropogenic activities have been intensifying the conversion of the fertile agricultural land, wetlands and water bodies into built-up areas. |
| Environment or locational sensitivity: storm water reservoir collecting water from Patia, Shikharchandi and other neighbouring areas. | Increase in magnitude and intensity of LST due to land cover changes |
| Fertile agricultural land in Kalarahanga | UHIs are likely to escalate and would worsen on extremely warm days with further urban expansion |
| Natural resources: Budhi Nallah (natural drain) flows through Raghunathpurjali and Gangua Nallah through Kalarahanga | Urban flooding due to encroachment and filling of the ‘Jali’ or wetlands. |
| Opportunity | Changes in ecosystem; reduced groundwater recharge zones |
| Conservation of marshy area as planned waterfront development | Changes in the local micro climate that would affect the consumption of resources resulting in an adverse effect on the ecosystem as well as on the health of all living beings. |
| Develop as water reservoir and groundwater recharge zone of North Bhubaneswar | |
| Urban farming initiatives for protection of fertile land | |

## Conclusions and recommendations

The study investigates the emerging issues of expansion of urban land on the surrounding fringes through the lens of LULC changes and the variation in LST. The sprawl has sporadically taken place, compromising the croplands (reduced by 44.43%) and water bodies (reduced by 36.04%), which are vital zones for groundwater recharge and highly productive ecosystems. The changes in LULC patterns reveal an inverse correlation between areas experiencing high and medium temperatures with cropland (–0.820) and water bodies (–0.799) and a positive correlation of 0.813 with built-up areas. Additionally, marshy areas in Raghunathpurjali, agricultural lands in Kalarahanga, and natural drains are identified as vulnerable areas. These areas face the imminent threat of encroachment and land use conversion, contributing to the observed changes in LST patterns.

Urban fringes, in the process of transformation due to urbanization, present opportunities for planning for an integrated development of urbanizable land with ecological networks. Introducing legal and political frameworks for socio-economic-ecological resilience planning for the areas undergoing rural–urban transition would lead to sustainable development. Systematic and holistic planning is imperative for the judicious expansion of the cities, fostering a positive correlation between both urban and thermal dynamics.

*Declaration of competing interest:* The authors declare that there is no conflict of interest regarding the publication of this paper.

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