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REVIEW ARTICLE

SPATIO-TEMPORAL LAND SURFACE TEMPERATURE ANALYSIS – A CASE OF BARIPADA CITY, ODISHA

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ABSTRACT

Urbanization and industrialization are simultaneously responsible for the abnormal changes in temperature patterns to a global extent. Extreme weather events are impacted by climate change, which is a major concern, mainly global warming. The heat produced when urban buildings and other heat sources absorb and reradiate solar radiation is one of the main causes of UHIs. Anthropogenic activities, population explosions, increased emissions, air pollution, thermal power plants, greenhouse gas emissions, energy consumption, and so forth are the causes of these. The goal of this research is to investigate the land surface temperature (LST) in Baripada town using remote sensing (RS) and Geographic Information System (GIS) techniques. The three time series satellite images have been used for analysis of the years 2005, 2015, and 2024. To access and analyse the spatio-temporal variations in land surface temperature surrounding the area of Similipal Reserve Forest and Baripada Town. To identify and understand the key factors influencing LST patterns in the study area. The NDVI, NDBI, and LST techniques have been used for finding the output. The amount of vegetation has decreased during the last 20 years, from 35.03% to 30.5%.It is clear that the temperature of the research area is gradually rising while the amount of vegetation cover and water bodies are both steadily decreasing. Deforestation or damage from forest fires could be the reason for the vegetation cover. The results indicate that urbanization and deforestation are the main causes of the rising LST in Baripada town. The rise in LST is also attributed to changes in land use patterns, such as an increase in urban and agricultural regions. The summertime LST increase can also be attributed to periodic forest fires.

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INTRODUCTION

In recent years, extreme weather events tied to climate change have been the most urgent challenge facing society. Extreme weather events are impacted by climate change, which is a major concern, mainly the Global warming (Diaz & Murnane, 2008). Additionally, the rapid expansion of the population is driving urbanization into rural areas. According to the UN reports that 50% of the current population lives in urban areas, with this expected to rise to 70% by 2050 (Wu, 2008). Urbanization increases transportation and industry, but it also changes the local urban environment by raising the Land Surface Temperature (LST). In short, urbanization and industrialisation are simultaneously responsible for the abnormal changes in temperature pattern in global extent (Lee *et al*., 2018). Analysing LST is essential to comprehending how land surfaces behave thermally and how that affects different environmental aspects. The term "land surface temperature" describes the overall temperature of the Earth's surface, taking into account both natural and man-made factors. It is a significant factor influencing climate change, weather patterns, and the general thermal environment of cities. In recent years, Baripada town, which is located in the Mayurbhanj district of Odisha, has seen a significant increase in development and urbanisation. With urban expansion and changes in land use, there is a growing concern regarding the impact of these transformations on LST and the local climate (Singh *et al*., 2016) (Ambagudia, 2017). The urban heat island (UHI), ecological processes and human comfort and health are all significantly impacted by LST. UHI is a scientific term we used for uncontrolled environmental heat pollution. When the atmosphere and surfaces in urbanised areas are warmer than those in their non-urbanized surroundings, this is an inadvertent change of the climate. The heat produced when urban buildings and other heat sources absorb and reradiate solar radiation is one of the main causes of UHIs. Anthropogenic activities, population explosions, increased emissions, air pollution, thermal power plants, greenhouse gas emissions, energy consumption, and so forth are the causes of these (Rowland, 2001). UHI can cause major problems such as declining living standards, increased energy prices, elevated ground-level ozone, an increase in illness and mortality, and negative impacts on the ecosystem and climate change (Shahmohamadi *et al*., 2011). For efficient urban planning and environmental management, it is therefore crucial to comprehend the spatial and temporal variation in LST. At 43.50 degrees Celsius, Baripada city is the third hottest place on Earth, according to a Times of India report dated 14th April, 2023. A few days ago, reports also leaked out regarding the temperature in Baripada town, which is the hottest spot in Odisha, the second hottest in India, and the third warmest in all of Asia. In this sense, the goal of this research is to thoroughly investigate LST in Baripada town using Remote Sensing data and Geographic Information System (GIS) techniques. We also investigate the factors - vegetation cover, urban heat sources, and impermeable surfaces - that influence variations in LST. The Geo-spatial Technology is a useful instrument for researching changes in the land cover with timely, cost-effective, and accurate information (Nath *et al*., 2018).

OBJECTIVE

To analyse the spatio-temporal variations in land surface temperature in the surrounding area of Similipal R.F and Baripada Town.

STUDY AREA

Known historically as the "country of the Maharajas," Mayurbhanj is a district in northern Odisha that is well-known for its large population of tribal people, lively culture, the well-known Similipal forests, Chhau dance, exquisite temples, and works of stone, dhokra, and tassar. Located on the northern edge of the state, Mayurbhanj is a landlocked district with a total size of 10, 418 sq.km. Its district headquarters are located in Baripada. The district is located between 21^o and 22^oN latitudes and 85^o and 87^oE longitudes. The district is surrounded by the districts of Balasore on the east, Keonjhar on the west, and West Bengal and Jharkhand on the north. A significant town in the Mayurbhanj district, Baripada is a magnificent city situated beside the Budhabalanga River. It stretches from 86^o42'30" E to 86^o53'40" E and from 21^o45'0" N to 22^o0'15" N. Since our research area is a 75-kilometer buffer zone surrounding Baripada City, it also includes the Similipal Reserve Forest, which is located between 21°28′ and 22°15′ N latitude and 86°03′ to 86°37′ E longitude. The Figure 1 represents the study area (Saha, 1975)(Jana *et al*., 2014).

MATERIAL AND METHODS

Materials: The table 1 provides the details of the satellite data used in this study. Three sets of 30 m. resolution Landsat data have been collected, during the year 2005 to 2024. Experienced meteorological information and Landsat 5 (TM) and Landsat 8 (OLI & TIRS) satellite imagery were accessed via the USGS Earth Explorer website's free web-based platforms (Anderson *et al*., 2012). Several techniques were used to extract the LST from the infrared band once the satellite photos had been geometrically adjusted using the WGS 1984 datum and UTM projection. It was necessary to convert DN (Digital Number) values to TOA (Top of Atmospheric Reflectance). The information obtained in terms of correlation has demonstrated a relationship between the variables through the use of statistical computing and the data panel approach (Fu & Weng, 2015).

Methods

The basic methods include the accurate calculation of LST and NDBI. The methodology for calculating LST using Landsat data involves several key steps, starting with the conversion of raw digital numbers (DN) to Top of Atmosphere (TOA) radiance (Eq 1). This is followed by the calculation of Brightness Temperature (BT) in Eq.2, the derivation of the Normalized Difference Vegetation Index (NDVI) in Eq.3, estimation of the proportion of vegetation (PV) in Eq.4, followed by calculating the Emissivity in Eq.5 and finally, the application of these parameters to calculate LST in Eq.6 (Na *et al*., 2011)(Jung *et al*., 2013). The Eq.7 provides the appropriate formula to calculate the Normalized difference built-up index (NDBI).

Method

1. $L5 = ML * Qcal + Al$ **(1)**

Where,

- $L\lambda$ is Top of Atmosphere
- ML is Band specific multiplicative value from the MTL file
- Qcalis DN value
- Al is Band-specific additive value from the MTL file

2. $BT = K2 \, In\,(k1\, L\lambda + 1) - 273.15$ **(2)**

Where,

- BT is Brightness temperature
- $L\lambda$ is Top of Atmosphere
- K1 is constant band no. from the MTL file
- K2 is constant band no. from the MTL file

3. $NDVI = (NIR - RED)/(NIR + RED)$ **(3)**

Where,

- NIR is DN values from the NIR band
- RED is DN values from RED band

For Landsat 5 data, NDVI = (Band 4 –Band 3) / (Band 4 + Band 3)
For Landsat 8 data, NDVI = (Band 5 –Band 4) / (Band 5 + Band 4)

4. $PV = [(NDVI - NDVI\ min) / (NDVI\ max + NDVI\ min)]$ **(4)**

Where,

- PV is proportion of vegetations
- NDVI is Digital number values from the NDVI image
- NDVI minimum DN number from the NDVI image
- NDVI maximum DN number from the NDVI image

5. $E = 0.004 * PV + 0.986$ **(5)**

Where,

- Eis Emissivity
- PV is Proportion of vegetations

6. $LST = [BT / (1 + (\lambda * BT / c2) * Ln\ (E)]$ **(6)**

Where,

- BT is TOA brightness temperature
- λ is Specific wavelength
- E is Emissivity
- c2 is14388 μMk

7. $NDBI = (SWIR - NIR)/(SWIR + NIR)$ **(7)**

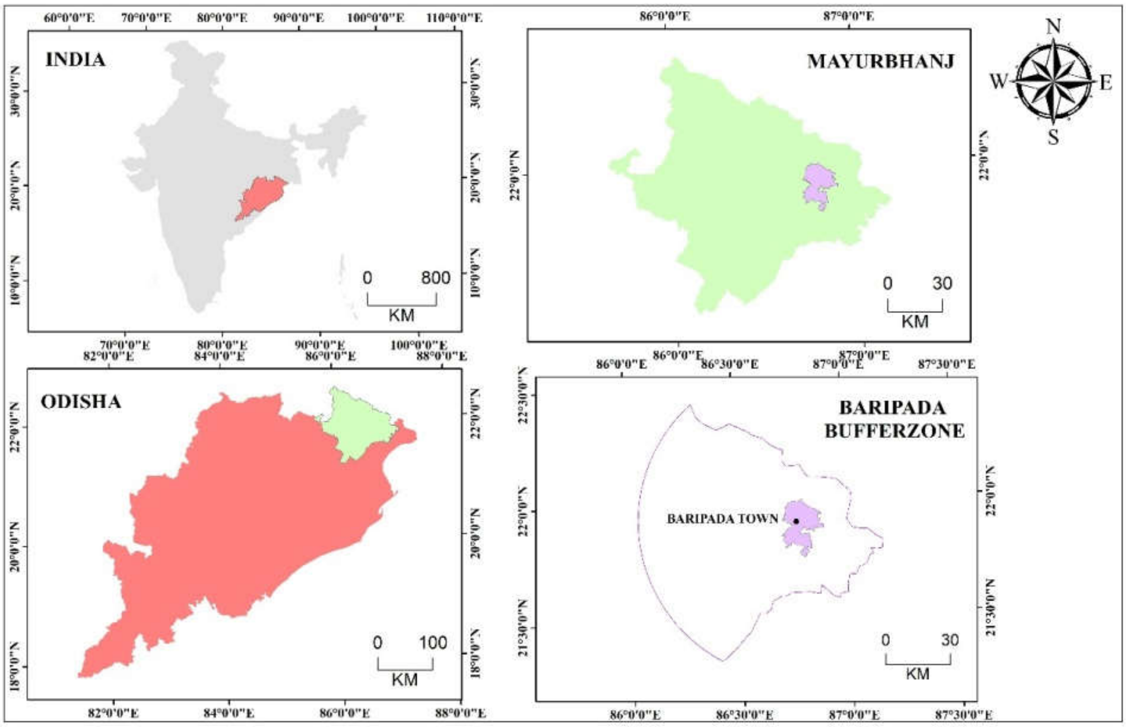

Figure 1. Location map of the Study area

Table 1. The dataset used for the research work

Datasets	Year	Data Acquisition Date	Satellite Sensor	Path/ Row	Used Bands	Wave Lengths	Spatial Resolution	Cloud Cover
Landsat 5	2005	19March 1993	Multi Spectral Scanner (MSS) & Thematic Mapper (TM)	139/045	All bands	0.63-0.69(3) 0.5-0.6(4) 1.55-1.75 (5) 10.40-12.50(6)	30	7%
Landsat 8	2015	15March 2023	OLI (Operational LandImager) & TIRS (Thermal Infrared Sensor)	139/045	4,5,6,10 (Red, NIR, SWIR & Thermal Infrared)	0.636-0.673 (4) 0.851-0.879 (5) 1.57-1.65 (6) 10.6- 11.19 (10)	30	0%
Landsat 8	2024	15 Mach 2024	OLI (Operational Land Imager) & TIRS (Thermal Infrared Sensor)	139/045	4,5,6,10 (Red, NIR, SWIR & Thermal Infrared)	0.636-0.673 (4) 0.851-0.879 (5) 1.57-1.65 (6) 10.6- 11.19 (10)	30	2%
Landsat 8	2024	22 March 2024	OLI (Operational Land Imager) & TIRS (Thermal Infrared Sensor)	140/045	4,5,6,10 (Red, NIR, SWIR & Thermal Infrared)	0.636-0.673 (4) 0.851-0.879 (5) 1.57-1.65 (6) 10.6- 11.19 (10)	30	0%

Table 2. Landuse/Landcover classification of the study area

LU/LC Classes	Area (%) 2005	Area (%) 2015	Area (%) 2024
Water Bodies	1.21	0.91	0.8
Vegetation	54.61	51.76	48.94
Agricultural Land	29.26	34.35	33.3
Built-up	2.09	2.9	4.22
Barren Land	12.83	9.8	12.65

For Landsat 5 data, NDBI = (Band 5 –Band 4) / (Band 5 + Band 4)

For Landsat 8 data, NDBI = (Band 6 –Band 5) / (Band 6 + Band 5)

RESULTS AND DISCUSSION

A research is carried out on the study area to identify the dynamic changes which have occurred during 20 years. The NDVI, NDBI, and LST mapping of the research area are conducted. The analysis has been done of 3 nos. of time series data of the year 2005, 2015 and 2024.

The range of NDVI minimum and maximum values has determined to be -0.97 to 0.76, -0.27 to 0.53, and -0.12 to 0.74, respectively. The amount of vegetation has decreased during the last 20 years, from 35.03 % to 30.5%.It is clear that the temperature of the study area is gradually increasing while the amount of vegetation cover and water bodies are both steadily decreasing. Deforestation or damage from forest fires could be the reason for the vegetation cover. The Fig.2 represents the spatio-temporal distribution of NDVI over the study area. The figure 3 represent the three nos. of time series NDBI index maps with values ranging from -1 to +1, where positive values indicates that the existence of populated areas and negative values indicates that the lack of populated areas or water bodies. The NDBI value of the vegetation is low.

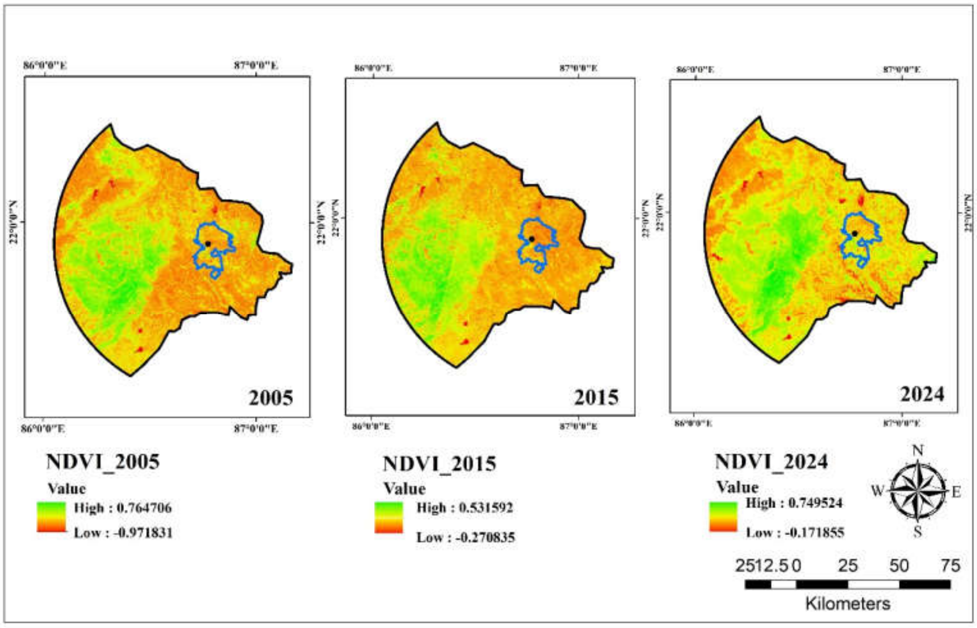

Figure 2. The NDVI Map of the Study area

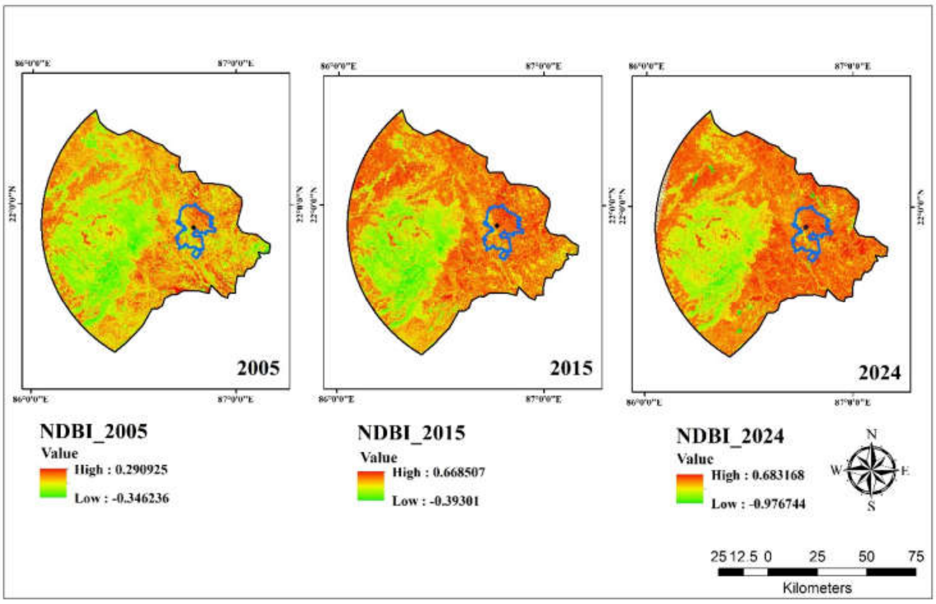

Figure 3. NDBI map of the Study area

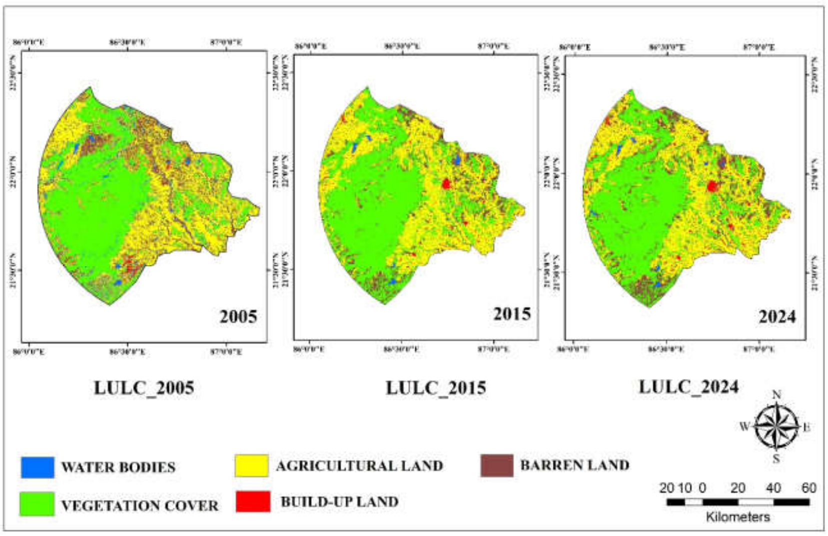

Figure 4. Land use/Land cover map of the study Area

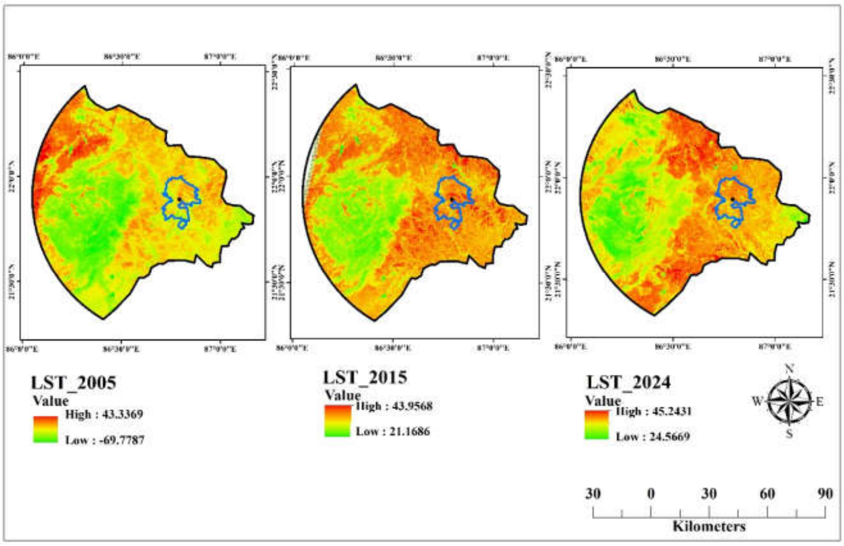

Figure 5. The LST map of the study area

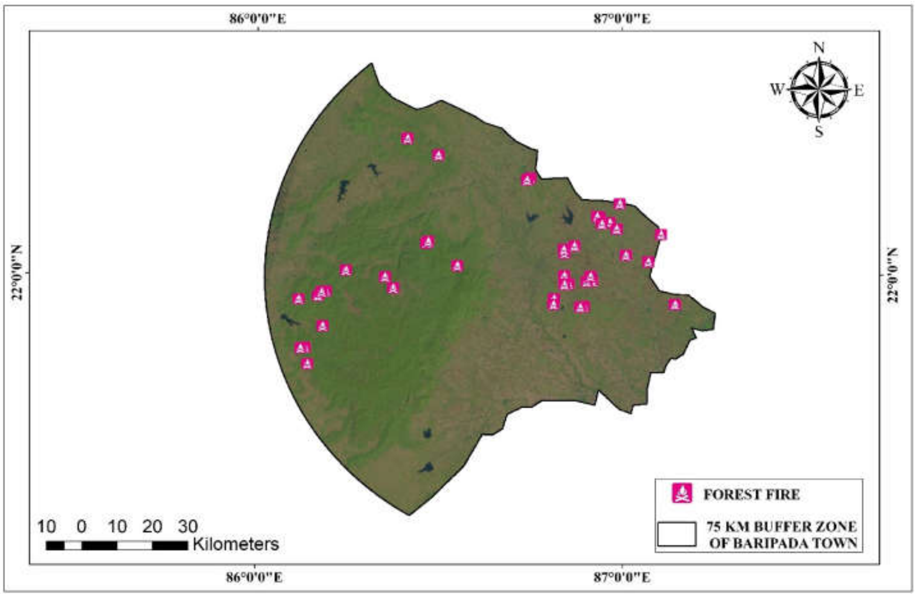

Figure 6. The forest fire location of the study area during the year 2004-05

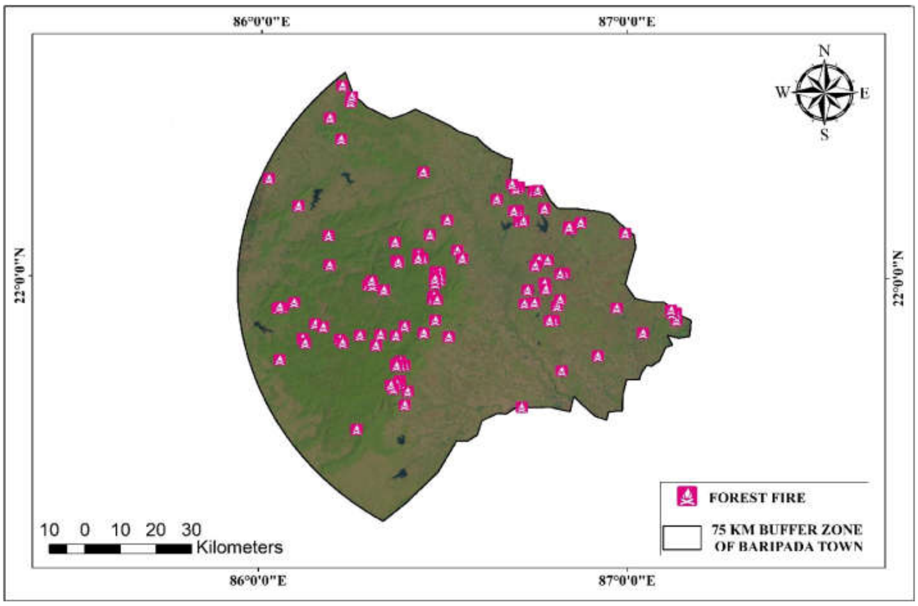

Figure 7. The forest fire location of the study area during the year 2021-22

The NDBI maps demonstrate the lands surrounding Baripada Town have gradually expanded during the year 2005 and 2024. The percentage of urban built-up area has increased from 18.03% to 32.8%.It is clear that the study area's NDBI value is trending upward, pointing to a process known as build-up area expansion, which is a contributing component to the urban heat island effect.

The changes in land use land cover (LULC) are an essential part of the searching environmental change on a regional, local, and global scale. Changes in land cover are the result of human modifications to Earth's surface. These changes have a major impact on crucial aspects of the functioning of the Earth system, including the equilibrium of energy, water, and soil. Following the classification as mentioned in table 2, it is found that the settlement region represents the maximum LU/LC dynamic. The combined 75 km. buffer zone and Baripada city habitation area was 2.09% of the total area. During the year 2005 to 2024, the settlement area had expanded to 4.22%. Next, the vegetation cover has reduced to 48.94% from 54.61%. But a lot of the greenery has been burned by forest fires and cleared for roads and towns. Comparably, the area covered by water bodies decreased from 1.21% in the year 2005 to only 0.08% in the year 2024. The amount of agricultural land varies significantly 29.26% in the year 2005 to 33.3% in 2015in the year 2024. The land classified as barren in the year 2005 was 12.83%and 12.83% in the year 2024 which shows the reduction of the land. The figure 4 represents the distribution of different LU/LC classes over the three temporal dimensions.

LST is a method or technique that is obtained by combining land surface energy and radiation balance. The Figure 5 indicates a noticeable increase in LST during the year 2005-2024. The maximum LST temperature rises by 1.90^{o}C during the above mentioned period. In the year 2005, the total land surface temperature was 43.33°C, it gradually grows to 43.95°C, finally it was 45.24°C in the year 2024. With a 1.5% GDP contribution, forestry ranks as the country's second-largest land use after agriculture. Forest fires directly affect the 65 million or more people who reside in tribal groups, whose survival depends on gathering non-wood forest resources. The analysis on forest fires during the year 2004 and 2005 and the year 2021-22.The analysis's concluded that it is really alarming. Between 2004 and 2005, there were about 38 nos. of forest fires in the study region overall. However, during the year 2021 and 2022, there was an unusual rise, with a total of about 125 nos. of forest fires as found from the satellite imageries. The forest fire and the high temperatures in the surrounding areas are mutually reinforcing in a catastrophic cycle of combustion and heat, just observe the cause-and-effect link. The intense flames of the forest fire raise temperature, and the high temperature in the region facilitate the ignition of fires and their rapid spread through the parched vegetation, producing a devastating and concerning environment crisis. The figure 6 and 7 represent the forest fire distribution during the year 2004-05 and 2021-22 respectively.

CONCLUSION

The current study offers information on the causes of the rising temperatures in Baripada town and the surrounding areas, as well as how quickly the town is approaching the urban heat island effect. The key conclusions of the aforementioned works are as follows:

Over the course of the study period, the analysis showed a considerable increase in LST, suggesting the possibility of an urban heat island effect trend. The NDVI indicates urbanization and deforestation by showing a decline in vegetation cover. A positive connection between the NDBI and LST indicates a rise in build-up regions. Changes in urban and agricultural regions were shown by the LULC map. The map of forest fires revealed a notable rise in these events, which may have contributed to the rise in LST. Specifically, the local temperature fluctuations, especially at peak.

The results indicate that the urbanization and deforestation are the main causes of the rising LST in Baripada town. The urban heat island effect is exacerbated by an increase in built-up areas and a decrease in plant cover. The rise in LST is also a result of changes in land use land cover patterns. The LST increases due to the frequency of forest fires has increased during the study period. In order to reduce the urban heat island effect and encourage sustainable urban growth, the study advises politicians and planners to take these aspects into account. This may entail lowering the urban heat island effect and adding green areas. Deforestation should be stopped and reforestation encouraged in order to preserve vegetation cover and lessen the impact of the urban heat island effect (Westendorff, 2020) (Mac Lachlan *et al*., 2021). Planning for land use should take into account how shifting patterns of land use may affect LST. Urban sprawl reduction and the promotion of sustainable agriculture are two examples of this. In order to lessen the frequency and intensity of forest fires, which can contribute to an increase in LST, techniques for managing forest fires should be established. Inform the public, corporate leaders, and lawmakers about the benefits of sustainable land management practices and the ways that shifting land use can affect the local climate. Promote community participation in environmental conservation initiatives, such as trash reduction programs, habitat restoration projects, and tree planting campaigns, in order to foster collective action toward climate resilience (Berke & Stevens, 2016) (Banba & Shaw, 2017).

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