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Assessment of Urban Heat Island Using Geospatial Technology: A Case of Titilagarh City, Odisha

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Abstract

A phenomenon known as an urban heat island (UHI) occurs when temperatures in an urban area are greater than those in a nearby rural area. The main causes of this temperature differential are urbanization, human activity, and the construction of artificial infrastructure like buildings and roads in place of natural landscapes. Titilagarh, a city in Odisha, is often referred to as one of the hottest places in the state, making it an example for studying the Urban Heat Island (UHI) effect. The UHI phenomenon in Titilagarh is likely influenced by factors such as rapid urbanization, less green cover, and the prevalence of heat-absorbing materials like concrete and asphalt in its infrastructure. For the analysis of different indices such as Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-Up Index (NDBI) and Land Surface Temperature (LST) data from the satellite for the period 2015 and 2025 have been used. The results suggest that the deforestation and urbanization are the main cause of rising LST in Titilagarh town. The urban heat island effect is exacerbated by an extension in built-up and declining plant cover.

Keywords: UHI, NDVI, NDBI, LST, satellite

INTRODUCTION

An urban region that suffers greater temperatures than its surrounding rural area is known as an urban heat island (UHI). Urbanization, human activity, and the replacement of natural landscapes with man-made constructions like buildings and highways are the main causes of this temperature differential. These materials absorb and retain heat more effectively than vegetation and natural surfaces, resulting in warming in urban space. UHIs not only impact local climate and weather patterns but also contribute to increased heat energy consumption, higher air pollution levels, and adverse health effects for urban populations [1]. Factors such as population density, urban design, and land use play critical roles in the intensity of UHIs. In the context of climate change mitigation and sustainable urban development, addressing UHIs has become crucial. Studying UHIs provides an opportunity to deal with the linkage of urban planning, environmental science, and public health. Out of various environmental problems and challenges, UHI effect is just one and is characterized by elevated temperatures in densely built urban areas compared to their rural surroundings, primarily due to the replacement of natural landscapes with heat-absorbing materials such as concrete and asphalt. Additionally, human activities, including transportation, industrial processes, and air conditioning, contribute to increased heat emissions [1–4].

The UHI effect has far-reaching consequences, including higher energy consumption, increased greenhouse gas emissions, adverse health impacts, and altered local weather patterns. Developing

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successful methods that improve urban sustainability requires an understanding of the dynamics and effects of UHI. The Urban Heat Island (UHI) effect has significant environmental challenges, not only climate change impacts, increasing heat, migration effect to urban area, and compromising public health. As urban areas continue to expand, the replacement of natural surfaces with heat-absorbing materials, along with human activities such as heat emissions from industry and other activities, intensifies temperature differentiation between cities and their rural surroundings. UHI intensity variation across different geographical contexts requires different solutions which are feasible or fit. This research seeks to address these gaps by analyzing spatial and temporal variations of UHI, assessing its impact on urban sustainability [5–7].

Titilagarh, a city in Odisha, is often referred to as one of the hottest places in the state, making it an example for studying the Urban Heat Island (UHI) effect. The UHI phenomenon in Titilagarh is likely influenced by factors such as rapid urbanization, less green cover, and the prevalence of heat-absorbing materials like concrete and asphalt in its infrastructure. These factors help explain why urban temperatures are higher than those in nearby rural areas. Remote sensing technology serves as a valuable tool for studying and analyzing different indices such as vegetation, built-up etc. with accurate information, time-and-cost effectively. Applications of satellite remote sensing in urban heat islands have several benefits and can result in improved planning, analysis, and management of sustainable urban solutions. Additionally, it aids in identifying built-up areas, human and industrial activity, vegetation acreage, vegetation health, and overall impacts. The use of remote sensing techniques is becoming more and more crucial for mapping and monitoring urban heat in real time. However, in recent years, remote sensing techniques, in combination with spatial modeling and Geographic Information Systems (GIS), have improved our ability to assess change rate, patterns, and directions of urban heat.

Study Area

Titilagarh is a city in Balangir district, Odisha, India, situated in the western part of the state. It lies at 20.28°N latitude and 83.14°E longitude. Titilagarh is located at the bank of Tel River. The town is regarded

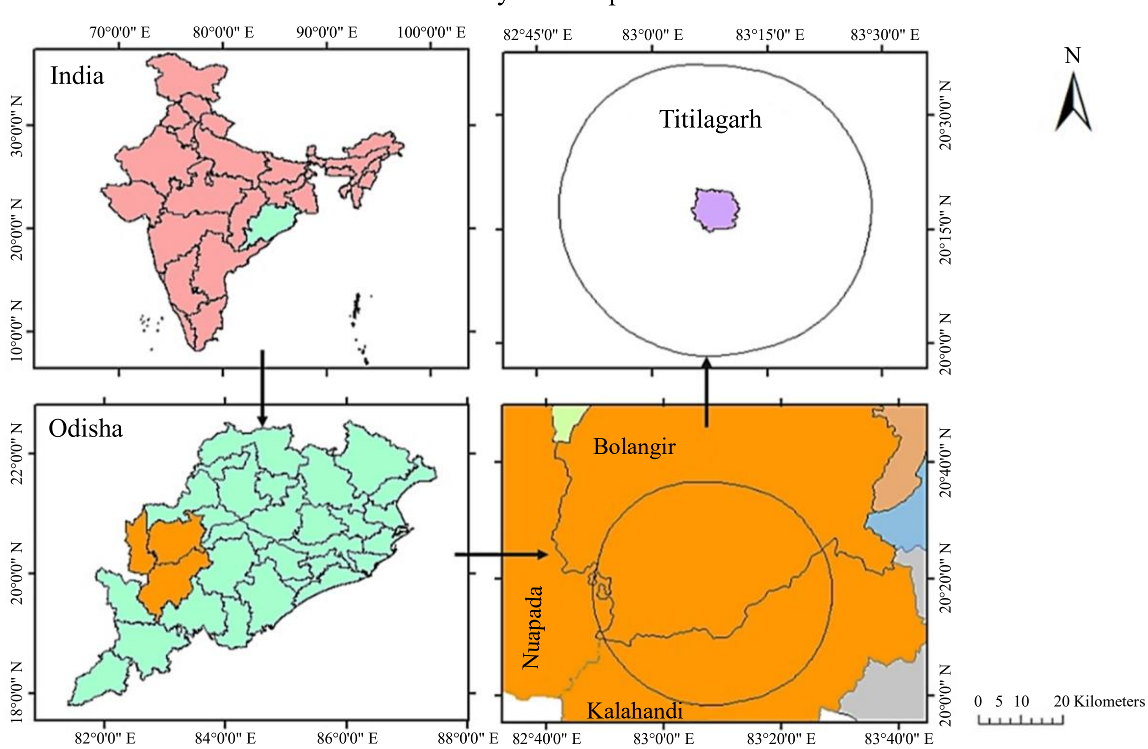

Figure 1. Location map of the Study Area.

as one of the hottest spots in India because of its very scorching summers. Titilagarh, often referred to as the "hottest place in Odisha", is a prime example of how urbanization and climatic conditions can amplify the UHI effect. The town's geographical location, combined with its rapid urban development, has led to significant temperature variations between urban and rural areas. This condition is caused by a few factors, including industrial activity, deforestation, and a lack of green places [8]. Additionally, Figure 1 shows the distinct study areas.

Goal

- To calculate and analyze the Land Surface Temperature in Titilagarh.

DATABASE AND APPROACH

Data from the satellite for the years 2015 and 2025 have been utilized to analyze various indices, including the Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-Up Index (NDBI), and Land Surface Temperature (LST). The NDVI, NDBI and LST, Landsat 8 and Landsat 9 (Level-2, Collection-2) data are used, which are originally derived from USGS Earth Explorer for the analysis of Urban Heat Island. LST was calculated for the month of March, the pre-arrival of summer, making the analysis suitable for Urban Heat Island [9, 10].

Landsat data of 30 m resolution has been taken of two time periods starting from 2015 to 2025, with a span of 10 years. The data set obtained for the two years were first geometrically corrected. All the datasets were brought into WGS 84 datum and UTM projection. By using different spectral indices, it found the status of different index. 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 different spectral indices comparisons are done through spatial analysis through classification method. Moreover, Figure 2 shows the flow chart of the methodology.

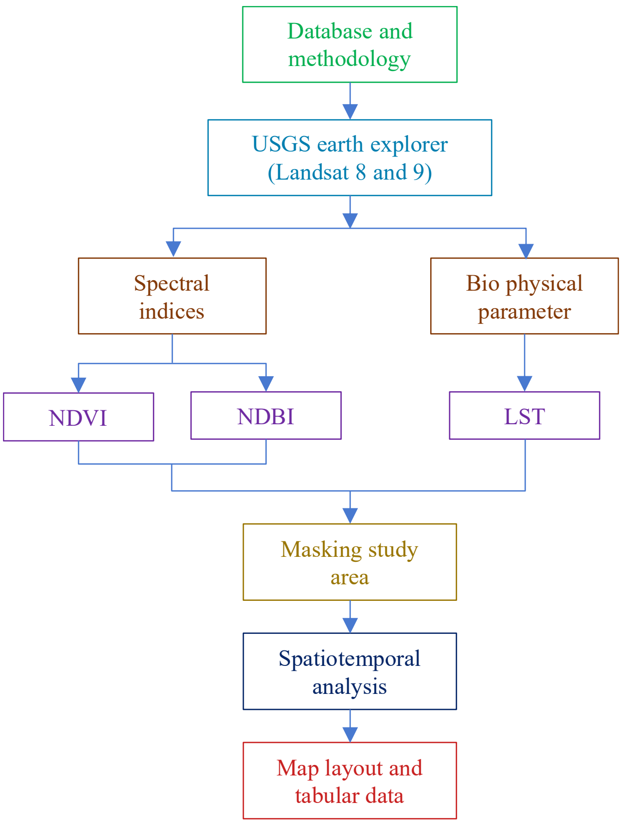

Figure 2. Flow chart of the methodology.

Normalized Difference Vegetation Index (NDVI)

Normalized Difference Vegetation Index is a valuable index for observing and analyzing vegetation related phenomena, such as forestation, deforestation, agriculture, crop health etc.

NDVI=(NIR−RED)/(NIR+RED)

Where,
NIR: DN values from the NIR band, and
RED: DN values from RED band.

Normalized Difference Vegetation Index (NDBI)

NDBI is used for observing and analyzing urban areas and built-up land. Higher NDBI value indicates areas with more built-up structures.

NDBI=(SWIR-NIR)/(SWIR=NIR)

Where,
SWIR= DN values from the Short-Wave Infrared Band, and
NIR= DN values from the Near Infra-Red Band.

Land Surface Temperature (LST)

The radiative skin temperature of the land, which is determined by solar radiation and measures the thermal radiation emitted from the land surface, is known as the land surface temperature (LST).

Spectral Radiance

The term “radiance spectrum” describes the measurement of electromagnetic radiation intensity at various frequencies or wavelengths throughout the electromagnetic spectrum. It provides information about the distribution of energy or power emitted or reflected by an object or a region of interest at each specific wavelength. Radiance spectral distribution can be written as:

$L\lambda = ML \times Qcal + Al$

Where,
$L\lambda$: Top of Atmosphere,
ML: Band specific multiplicative value from the MTL file,
Qcal: DN value, and
Al: Band-specific additive value from the MTL file.

Brightness Temperature (BT)

The BT is defined as the temperature of a hypothetical blackbody that would emit the equal amount of radiation at a particular wavelength as the observed object.

$BT = K2/In\{k1/L\lambda\}+1) - 273.15$

Where,
BT: TOA brightness temperature,
$L\lambda$: Top of Atmosphere),
K1: Constant band no. from the MTL file, and
K2: Constant band no. from the MTL file.

Normalized Difference Vegetation Index

The Normalized Difference Vegetation Index (NDVI), which measures the variation between the visible and near-infrared reflectance of plant cover, can be used to calculate the density of green over a given area of terrain. NDVI is measured by following formula,

NDVI=(NIR−RED)/(NIR+RED)

Proportion of Vegetations (PV)

The proportion of vegetations, refers to the extent or percentage of an area that is covered by vegetation. PV is measured by following formula:

PV={(NDVI–NDVI min)⁄(NDVI max+NDVI min)}

Where,
PV: Proportion of Vegetations,
NDVI: Digital number values from the NDVI image,
NDVI min-min DN number from the NDVI image, and
NDVI max-max DN number from the NDVI image.

Emissivity (E)

It refers to the proportion of radiant energy emitted to energy radiated by perfect black body at same temperature and same circumstances. Emissivity is given by:

E=0.004×PV+0.986

Where,
E: Emissivity, and
PV: Proportion of Vegetations.

LST

LST is given by the following formula:
LST=(BT/(1+(0.00115×BT/1.4388)×Ln (E)))

DISCUSSION

The spatial and temporal distribution of NDVI from the Landsat 8 and 9 in the Titilagarh urban area for 2015 and 2025 are shown in Figure 3. The minimum and maximum NDVI values of 2015 are in the range between –0.55 and 0.393 and the range between –0.079 and 0.349 in 2025. This shows an overall fall in vegetation pattern over the year. It can be noted that urban plantations are decreasing with rise with respect to urbanization in respective years. From the spatial analysis, there is decrease of vegetation cover in the area Gunchitara, Nanjhar, Badamal and Bandupala in the north eastern part and Darlo, Sanpatrapalli, Lenjha Belpahar and Ranibandh are some area in the western part inside the Titilagarh urban space. Moreover, in the Titilagarh Municipality Area, the vegetation cover has also decreased in some extent.

Spatiotemporal Analysis of NDBI

The NDBI is a common indicator used to extract built-up from the urban areas. The spatial pattern of NDBI is shown in the Figure 4. The minimum and maximum NDBI values of 2015 are ranged between –0.212 and 0.146 and the NDBI values of 2025 are ranged between –0.192 and 0.154. As we can see, the built up has increased in 2025 as compared to 2015. The areas with a value greater than zero represent red areas with increasing NDBI values, showing more reddish where the non-built-up features such as barren lands values lie near or below zero. From the analysis, an area Lenjha, in the western part to the Titilagarh urban area is exhibiting more built-up structure in 2025 as compared to 2015. Also, the Titilagarh railway junction with increasing ironic built setup contributes heat in that area.

Spatiotemporal Analysis of LST

The analysis shows Titilagarh's land surface temperature (LST) spatial dispersion. The thermal bands of band 10 of Landsat 8 and 9 are used to calculate the LST. Figure 5 displays the LST for the years 2015 and 2025. The LST spatial patterns of each Landsat data is observed and it is observed that the temperatures ranged from 27.47 to 38.90°C and from 27.18 to 39.62°C in the year 2015 and 2025 respectively. It can also be observed that there is an increase of approximately 0.7°C temperature that a decade generally acquires the temperature rise over an urban area. As Titilagarh city is fast growing in western part of Odisha, the rapid urbanization which replaces the natural surfaces by concrete buildings, road-highways, railways and other construction that lead to temperature rises, contributing urban heat island.

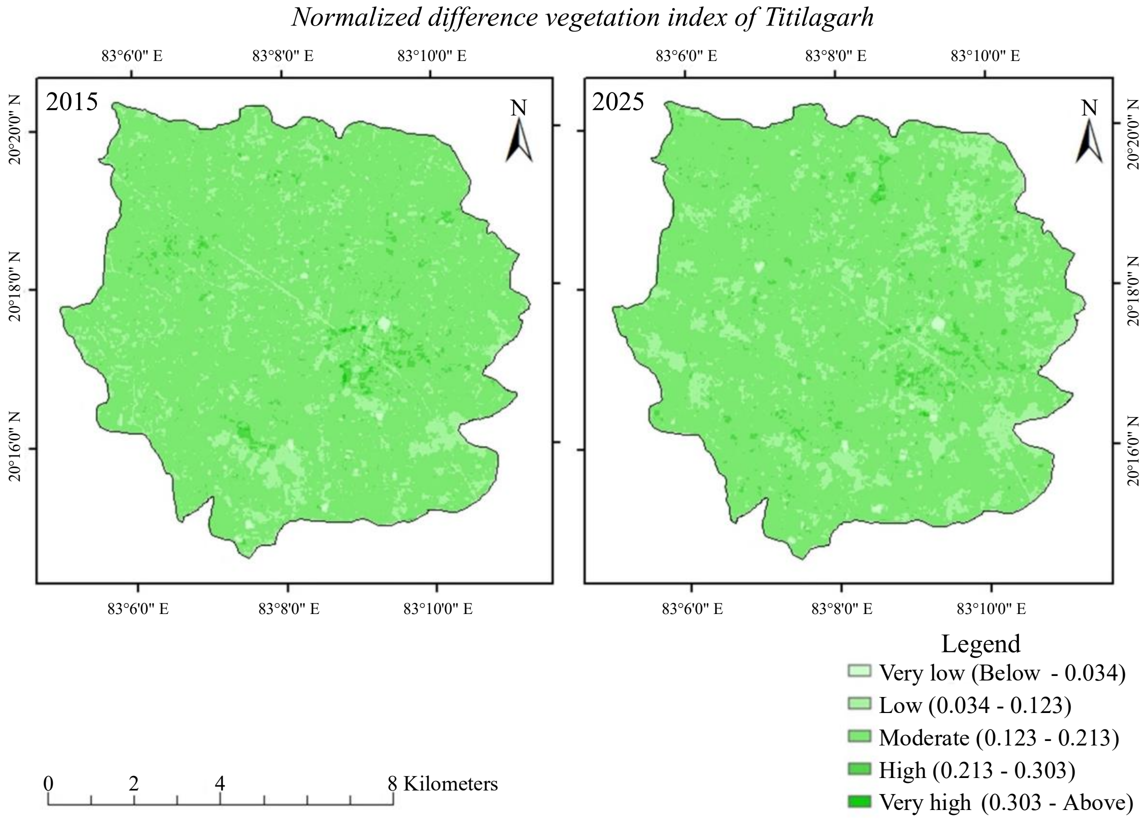

Figure 3. NDVI analysis of the study area.

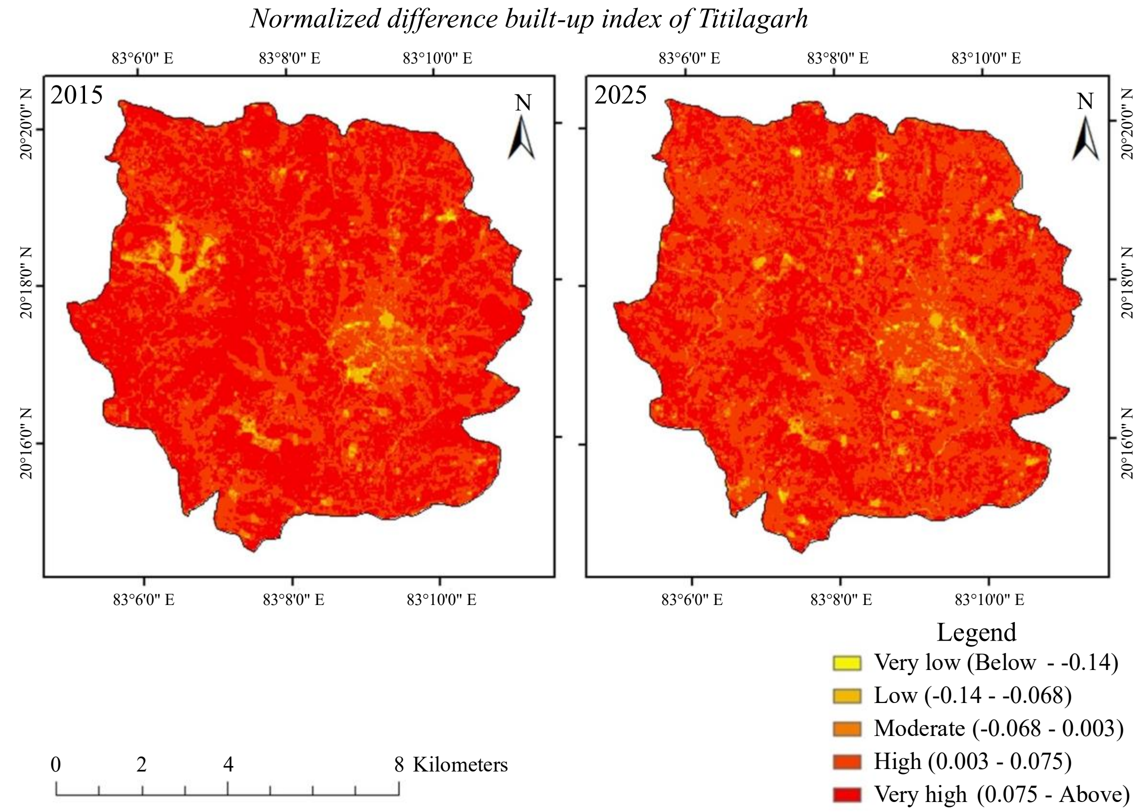

Figure 4. NDBI analysis of the study area.

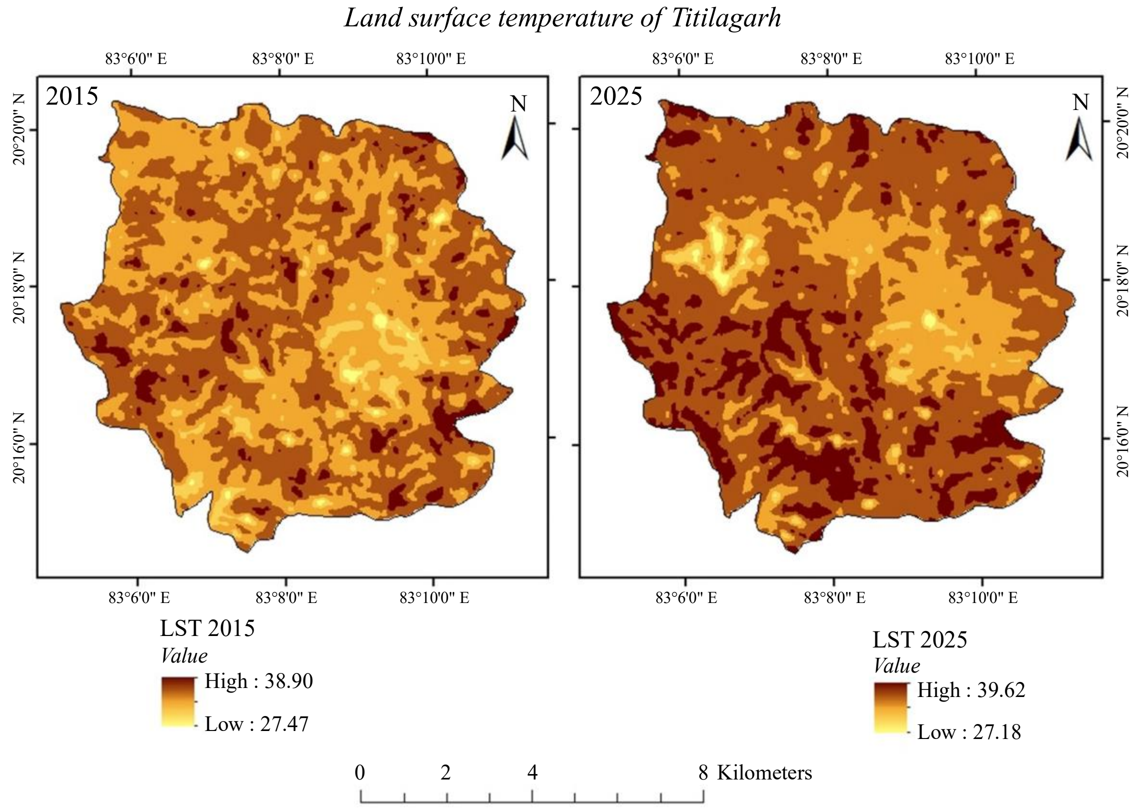

Figure 5. LST analysis of the study area.

Coming to vegetation, it has a high level of emissivity that lowers the LST. NDVI has a major role affecting LST. In present study, decreased NDVI in 2025 has led to LST rise in some extent. The water bodies exhibit minimum temperature level and open areas are considered to have high temperatures. The south-western part to the Titilagarh city, is exhibiting more land surface temperature. Bhatipara, Khaliapara and Darlo are some regions where temperature has significantly increased due to barren land and discrete vegetation.

CONCLUSION

This study offers information on the causes of rising temperature in Titilagarh town and the surrounding areas, as well as how quickly it is approaching the urban heat island effect. The key conclusions of the aforementioned works are as follows: Over the course of study period, the analysis showed a considerable increase in LST suggesting the possibility of urban heat island effect trend. The NDVI indicates deforestation trend by showing a decline in vegetation cover. Beyond research and analysis, it is possible to establish a connection between the urbanization phenomenon and the urban heat island phenomenon. A positive connection between NDBI and LST shows rise in built-up regions results in rise in LST, specifically the local temperature fluctuation, especially at peak. The results show that the deforestation and urbanization are the main cause of rising LST in Titilagarh town. An increase in built-up areas and a decrease in plant cover intensify the urban heat island effect. The method of assessable remote sensing and GIS technique in digital image processing, spatial comparison of different spectral indices like NDVI and NDBI and biophysical parameter LST in the study area validate urbanization stretch that has influence over the ecological possessions. Combining geospatial technology offers a creative way to visualize urban growth in relation to heat islands and assess how it affects surface temperature. The method associated with GIS has demonstrated its ability to incorporate environmental data. The central regions of Lenjha, Belpahar, Darlo, and Titilagarh municipality, particularly the Titilagarh railway junction, have been significantly affected by the UHI impact. The ordinance factory in Badamal, 25 km away from Titilagarh, the heat absorbing khondolite rock type present in the hilly area of Dumerbahal forest range also give some significant contribution to heat island in buffer area. The UHI effect over Titilagarh has tremendous impact on human health and ecosystem. The city has undertaken a number of recommendations and strategies to lessen the impact of UHI. This has to include increasing the plants and water in the city influencing as cooling material and to consider the related changes in urban climate to track UHI phenomenon. On the basis of result of analysis following recommendation can be suggested like urban planning strategies to consider sustainable land utilization and management practices, heat-resistant building design, afforestation and green corridor enhancement, plantation of vegetative layer in household rooftop etc.

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