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Study of the Land Surface Temperature (LST) of Gaya district of Bihar between the Year 2001 and 2021

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Abstract

An understanding of climate variability, trends, and prediction is important for better planning and management of natural resource. Thus, the current research focuses on the trend of temperature variability in response to climatic factors over Gaya district of Bihar, India from 2001 to 2021 that occurred due to land use land cover (LULC). The drivers of local climate zone (LCZ) *i.e.*, land surface temperature (LST) has been analyzed for its trend and magnitude. Gaya district is centrally situated in the southern Gangetic plain and has been geographically suited for the agricultural practices along with the center of attraction for tourism and various commercial and industrial activities. It results in urban sprawl attributable to high population growth with enormous human migration in the last decade with significant risks of environmental degradation. A significant increase in the mean temperature has been observed over the experimental period. The major causes found responsible include policies for rapid urbanization and economic growth, reduction in agricultural land, increased investment in real estate and infrastructure, augmented pollution emission from industrial hubs, construction sites etc. The study using Landsat satellite data displays that severely adverse climatic events have impacted the LCZ in Gaya district with growing vulnerability of environment and biodiversity. It demands an adaptative plan to be implemented to increase the resilience of adaptation and reduce the ecological degradation with relevant policies and inclusion of suitable programs.

Introduction

Land cover is the physical measurable at the surface of the earth such as vegetation area, water bodies, barren land, built-up area, bare soil etc.On the other hand, land use is the description of how people utilise the land for socio-economic activities such as commercial land, agricultural land, forested area, industrial area etc. (Jain, 2024).Climateis the overallregional or global weather during a long periodof time of about20 years or more(National Academy of Sciences, 2020). Climate varies on all scales of time and space for a variety of reasons(Defining Climate Normals in New Ways, 2022). Different geographical and climatic conditions *i.e.* temperature, rainfall, soil, latitude, longitude, height from sea level etc. need to be studied to plan suitable strategies (Kumar et al.,2018).The impact of climate change produces in direct and indirect ways. The direct impact ofclimatic change reflects as physical reduce of agricultural production, increases forest fires,decrease in the reservoir and river water levels and damage the biodiversity. Indirect impacts are the multiple effects of direct impacts as reducingthe income of farmers due to less crop production, increases prices of food and timberand reduction in rural employment (Dai et al., 2011a & 2011b).

Satellite remote sensing data, climatic data and earth observations have been used in monitoring the variability in vegetation of any climatic zone. Remote sensing can provide continuous datasets which are used to monitor climatic variables including as the main parameter in such studies (Kumar et al., 2018).Satellite remote sensing data is widely used in climatological studies from more than 20years(Le et al., 2023). In this study, Landsat series data are used for monitoring indices like Land Surface Temperature (LST), which gives the near values to monitor the climatic condition.

Gaya district is one of the thirty-eight districts of the Indian state of Bihar, formally established on 3rd October, 1865. Gaya district centrally situated in the southern Gangetic plain and has been geographically suited for the agricultural practices for a variety of food grain, pulses, vegetables commercial crops etc. This has led ahigh population growth resulting in dense population. This region is highly susceptible to climate-driven phenological changes. These change and associated uncertainties have serious direct and indirect consequences. Due to uncontrolled urbanization in Gaya, environmental degradation has been occurring very rapidly and causing many problems like degraded water quality, excessive air pollution, noise pollution, issues with the disposal of wastes, etc., which causes serious health problems. With these backgrounds, endeavours to analyse the temperature variability on the climatic condition of the Gaya district to identify the climate risks and/or opportunities, using weather data of 20 years (2001–2021) as a baseline.

Methodology

There is no previous research that maps Local Climate Zone (LCZ) in Gaya district of Bihar, using climate data of 20 years (2001–2021) as a baseline. A decadal analysis of changes in LCZ using Resourcesat-2A LISS III and IV satellite data through remote sensing techniques have been performed to understand the climate risks for Gaya district of Bihar.

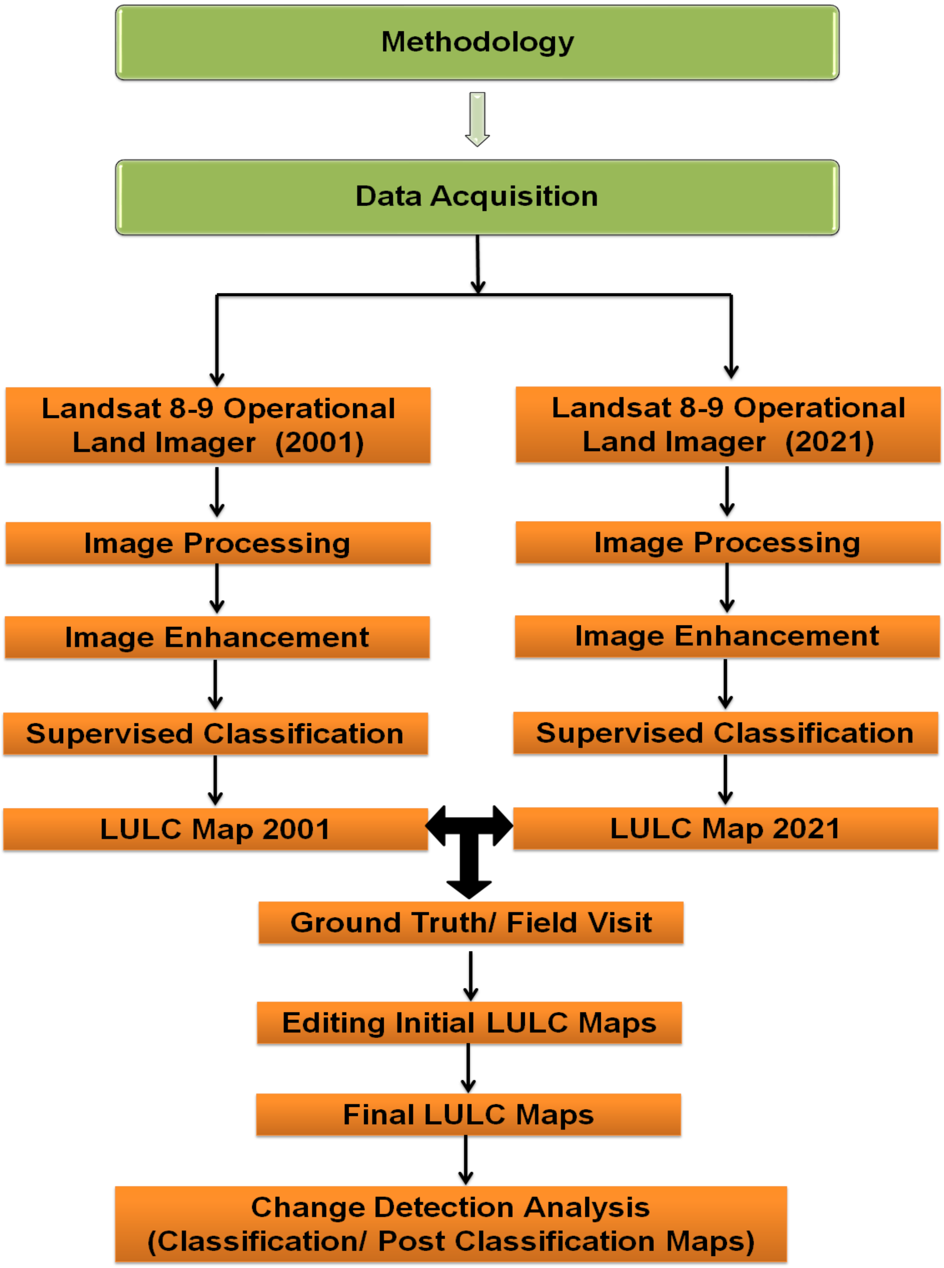

Fig. 1 Flow diagram showing an overview of proposed research work

The Linear Imaging Self-Scanning Sensor (LISS-IV) data provides a multi-spectral high ground resolution (5.8 m per pixels) satellite images, with three spectral bands (B2/ 0.52-0.59, B3/ 0.62-0.68, B4/ 0.77-0.86) has been used for LULC mapping. Resourcesat-2A LISS III (IRS R2A LISS-III) data of 2001 (path 102 row 053), acquired during April. Resourcesat-1 LISS IV (RS2 LIS3) data of 2021 (path 102 row 55/56), acquired during November(Table 1). The spatial resolution of 5.8 m was used to address temporal variability.

The pre-processing has been done to remove undesirable sources. The process is then rectified to transform the data with the use of pixel/grid system after one image correlated to the same pixel/grid system with another or second image and then pixels have been resampled.

Table 1: Technical Specification of LISS IV Data (Product Id: R2324NOV2021055001010300054PSANSTUC00GTDF)

SCENE DETAILS		**COVERAGE DETAILS**	
Satellite:	RS2	Top Left Lat:	25.846277
Sensor:	LIS3	Top Left Lon:	82.9295
Date of Pass:	24-Nov-2021	Top Right Lat:	25.810555
Imaging Orbit No:	055001	Top Right Lon:	84.7543
Ground Orbit No:	055001	Bottom Right Lat:	24.223244
Sensor Specification:	RS2_LIS3_-_F_L2	Bottom Right Lon:	84.7063
Sensor Specification Scheme:	Satellite_Sensor_ImagingMode_Subscene_Product	Bottom Left Lat:	24.256482
Scene Specification:	055001_103_54	Bottom Left Lon:	82.9048
Scene Specification Scheme:	GroundOrbit_Path_Row	Center Latitude:	25.036948
Roll:	0.000000	Center Longitude:	83.8238

The interpretation of images includes its tone, texture, slope, size, pattern and site. These imagery associations have been applied so that the satellite data have been visually analyzed and the LST map has been developed. The satellite imageries have been selected for three bands (Band 234) in the region of Green, Red and Near-Infrared respectively. The image used were of False Color Composite (FCC) type (Kiefer and Lillesand, 2004). The maximum likelihood Classifier technique has been used with the following equation (JARS, 2020): $\boldsymbol{L_k(X)} = \frac{1}{(2\pi)^{\frac{n}{2}}|\sum k|^{\frac{1}{2}}} \boldsymbol{exp} \left| -\frac{1}{2}(\boldsymbol{X} - \boldsymbol{\mu_k}) \sum_k^{-1} (\boldsymbol{X} - \boldsymbol{\mu_k})^t \right|$, where, ***n:*** number of bands; ***X:*** image data of n bands; ***L_k(X):*** likelihood of X belonging to class ***k***;***μ_k:*** mean vector of class ***k***; $^{\Sigma}$***k:*** variance-covariance matrix of class ***k*** and |$^{\Sigma}$***k***|***:*** determinant of $^{\Sigma}$***k***.The various activities have been studied to classify two multi-temporal images *viz.*, LISS III and IV data of 2001 and 2021 respectively.The accuracy and effectiveness of the classified images has been evaluated by confusion matrix approach. The land surface temperature (LST) has been calculated using the radiative transfer equation and a single channel (SC) technique by determining the radiance-at-the-sensor in a single band by the equation:$\boldsymbol{B(LST)} = \frac{\boldsymbol{Lsen - Lup - \tau * (1-\varepsilon) * Ldown/\pi}}{\boldsymbol{\tau * \varepsilon}}$, where, ε is the surface emissivity, τ is the atmospheric transmissivity, ***B***is the Planck function, ***Lsen*** is the radiance-at-the-sensor, ***Ldown***is the down

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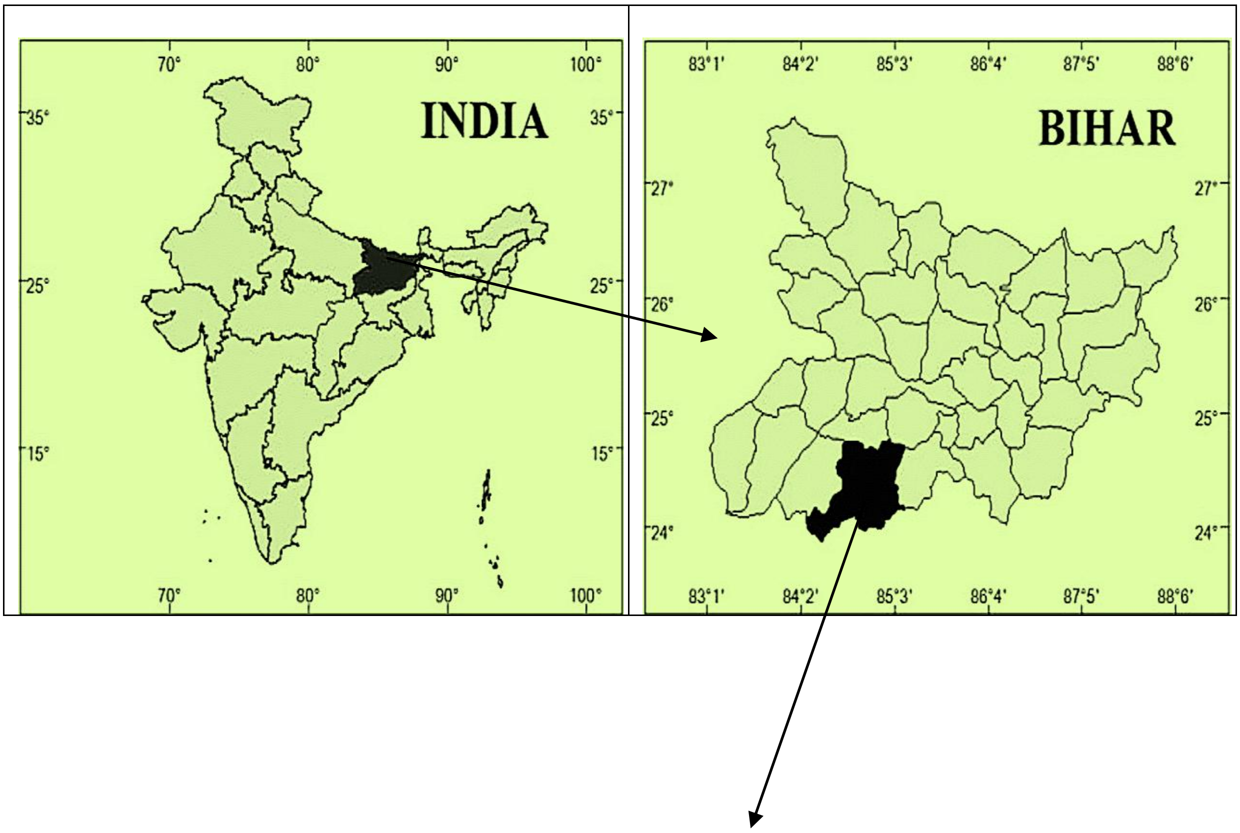
welling irradiance, and ***Lup***is the thermal path radiance (Dash et al., 2002).The brightness temperature data were used to extract information about clouds, cloud shadows, and water surfaces (Zhu and Woodcock, 2012).The Landsat surface reflectance, a high-level product developed by the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) provides surface reflectance data for six bands covering a wavelength range of 0.22-2.35m and with a spatial resolution of 30m × 30m (Schmidt et al., 2013). The fraction of vegetation cover (FVC) can be calculated with the following formulae: $FVC = \left[\frac{NDVI - NDVInonveg}{NDVIveg - NDVInonveg}\right]^2$ and $\varepsilon = \varepsilon_{nonveg} \times (1 - FVC) + \varepsilon_{veg} \times FVC$.All the statistical analyses were performed using PC based software, Sigma Stat® version 3.5 for Windows and SPSS® version 10.1 (Dwivedi and Shukla, 2020).

RESULTS

Gaya district of Bihar has an area of 4,976 square kilometres, with rural area of 4890.74 square kilometer and urban area of 85.26 square kilometer (Fig. 2). The district is situated between 24°5' to 25°10' north latitude and 84°4' to 84°5' east longitude having average elevation above sea level is 229.77 feet (111 m).The climate is extreme *i.e.*, very hot in summer and very cold in winter. Summer starts from the end of March with intense heat in June(Fig. 3 andFig. 4). The Köppen Climate Classification subtype for this climate is ***"Cfa"*** *i.e.,Humid Subtropical Climate***.**



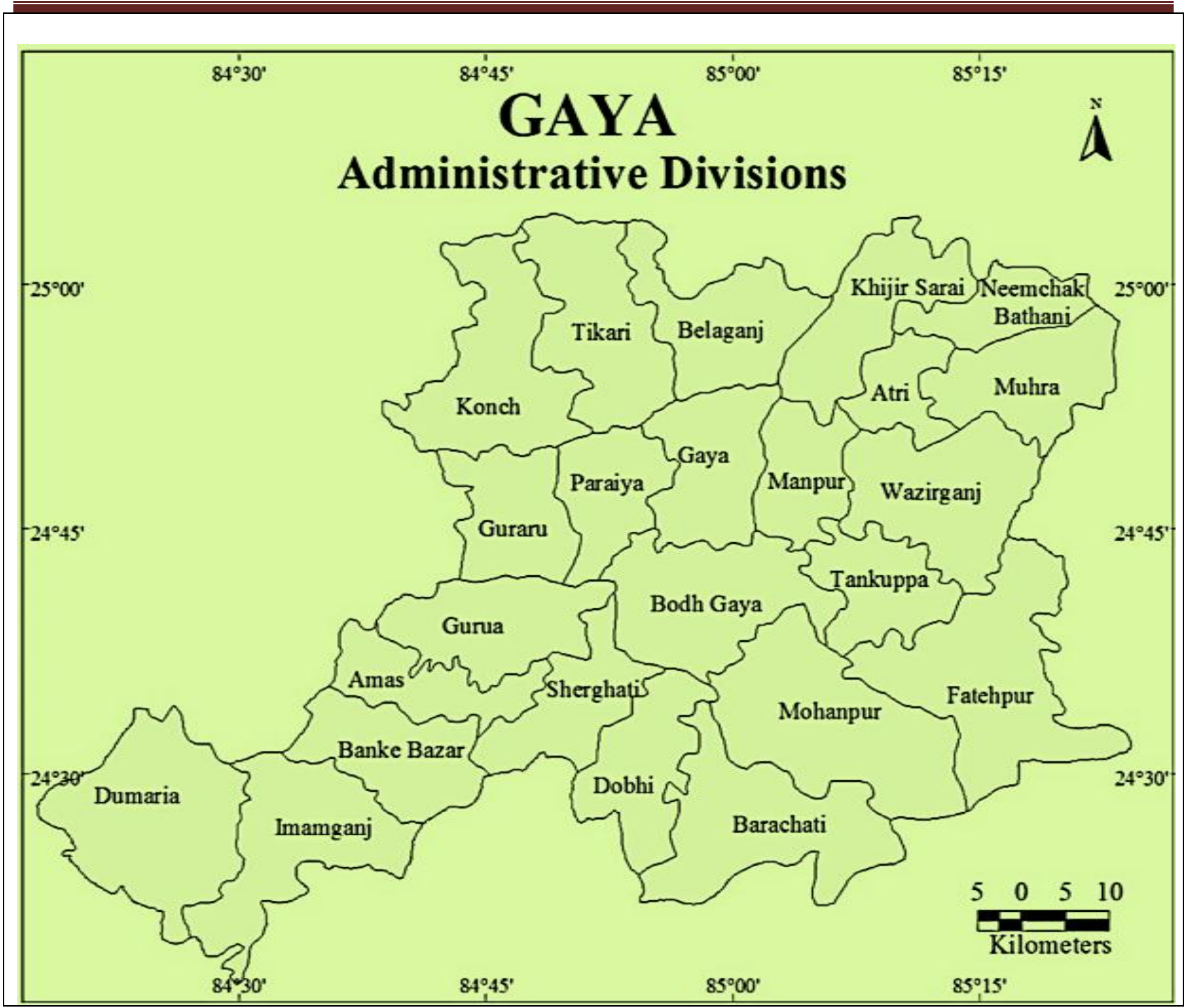


Fig. 2: District map of Gay

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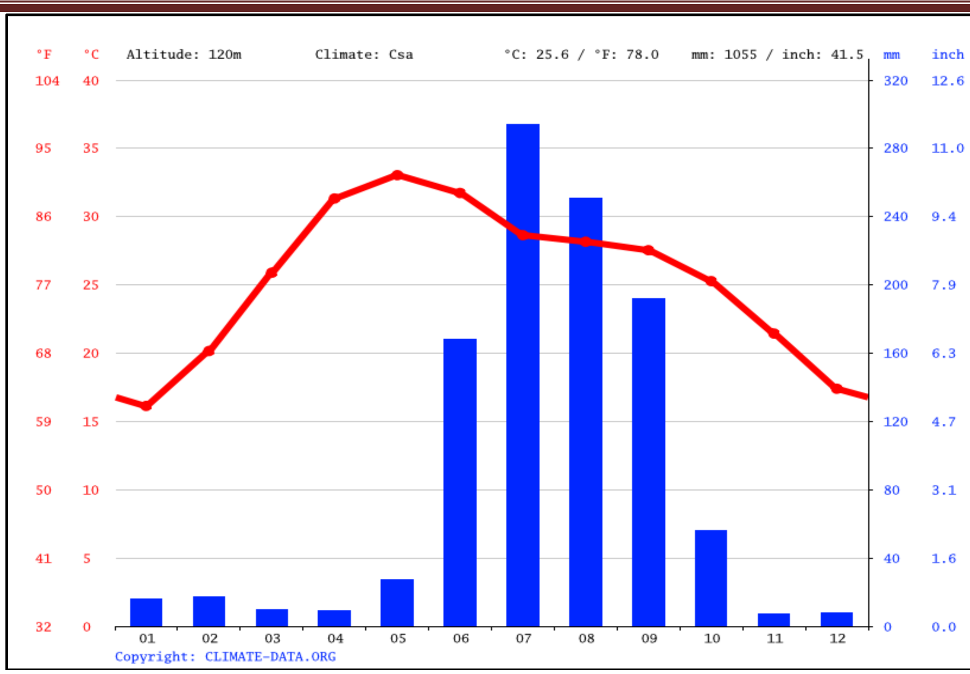

Fig. 3: The NDVI data for the average weather by month in the Gaya district of Bihar
(from https://en.climate-data.org/asia/india/bihar/gaya-2840/).

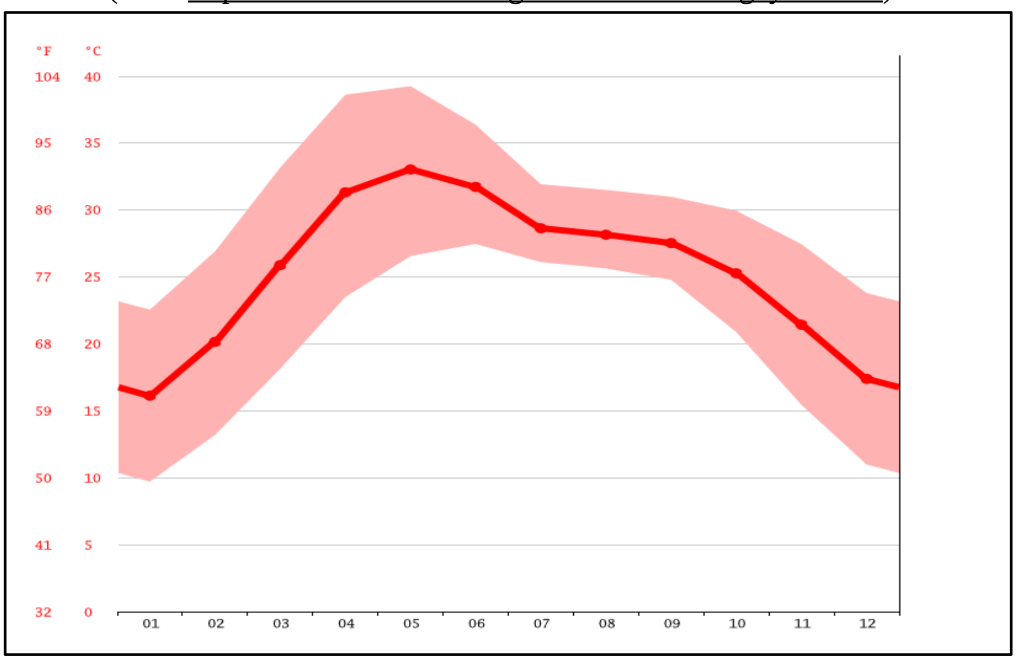

Fig. 4: The NDVI data for average temperature by month in the Gaya district of Bihar
(from https://en.climate-data.org/asia/india/bihar/gaya-2840/).

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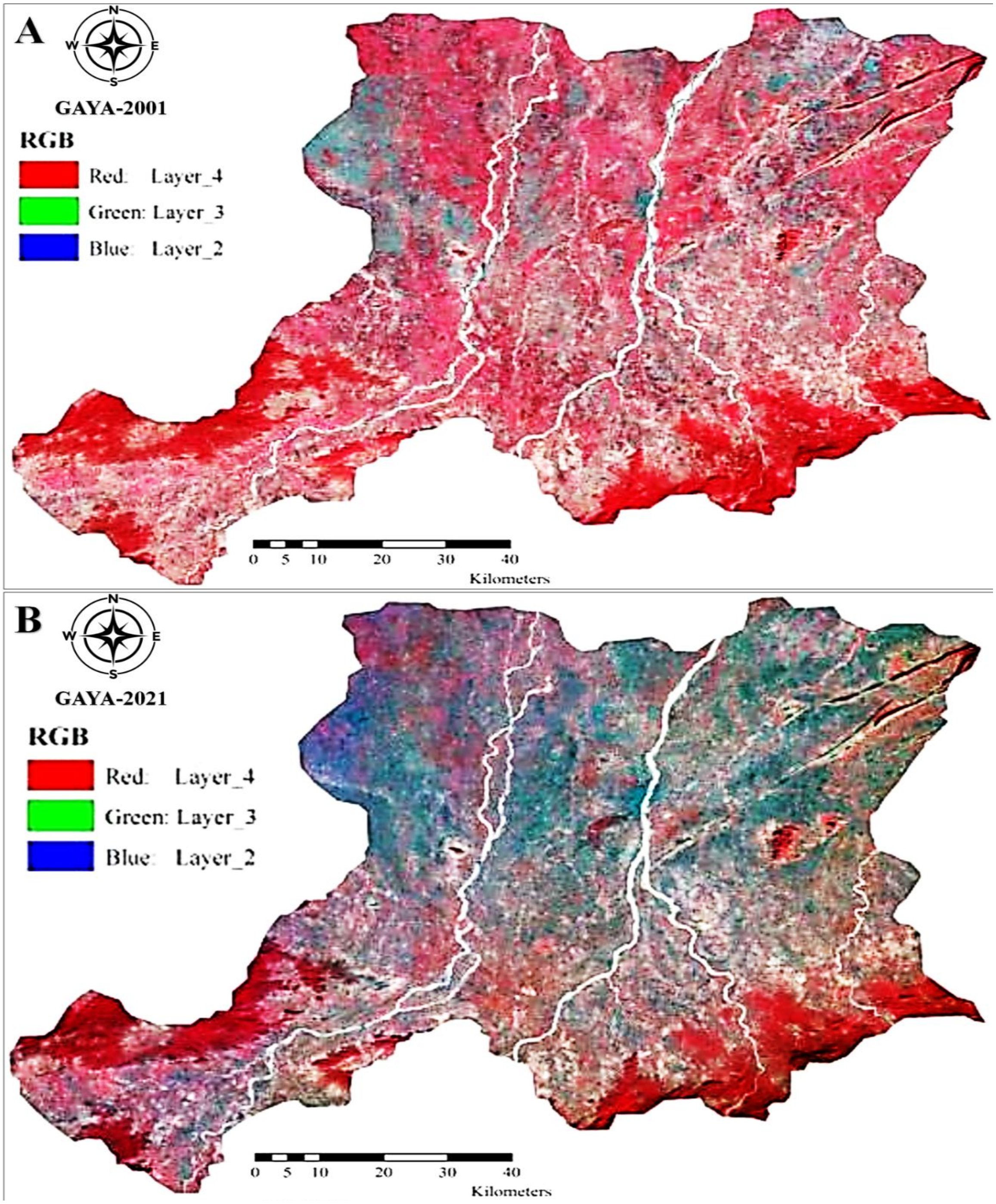

Fig. 5: Satellite Imagery of Gaya district of Bihar in 2001 (A) and 2021 (B)

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Brightness Temperature Map of studied area:

Brightness temperature is the surface air temperature of the study area of the Gaya district of Bihar, India has been presented in Fig. 6.

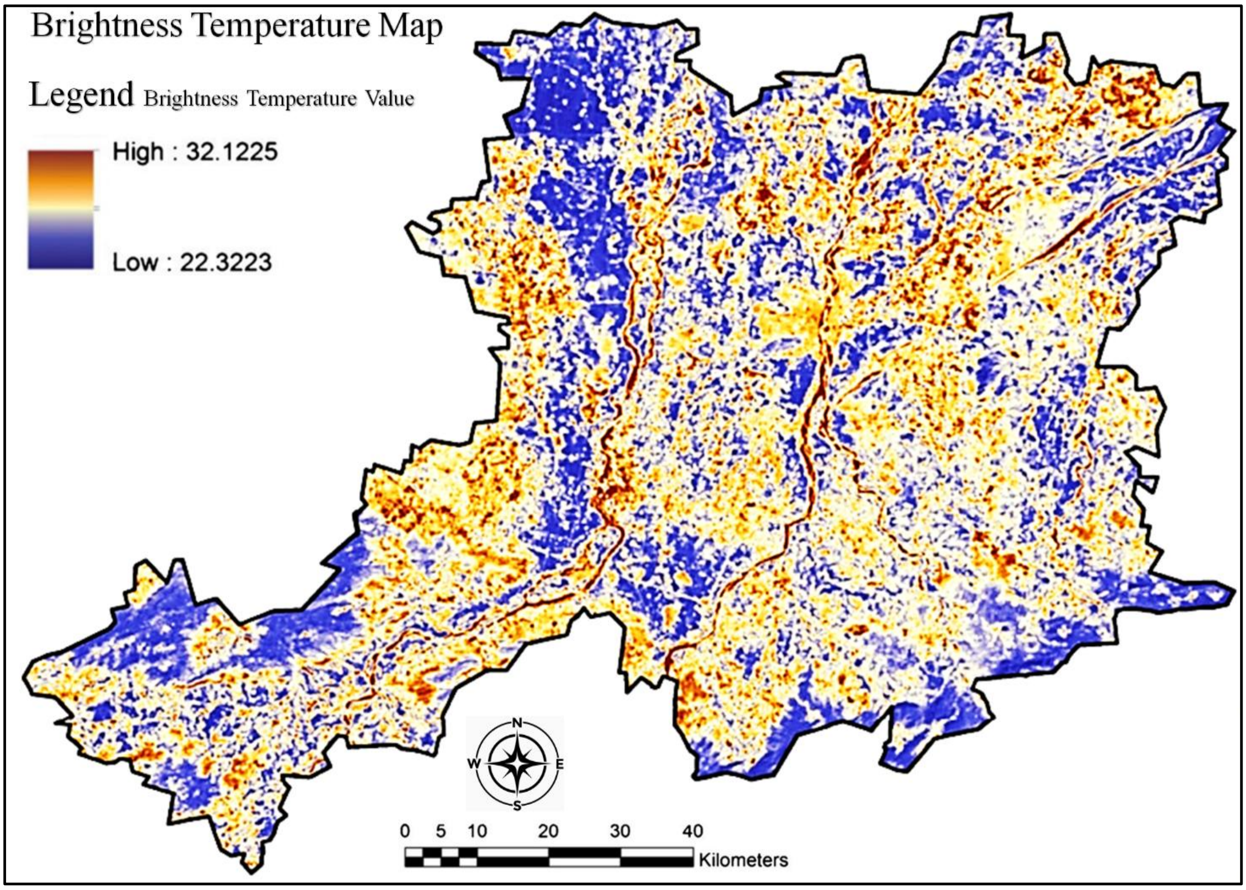

Fig.6: Satellite classified imagery of brightness temp. map of Gaya district of Bihar

Surface Emissivity Map of studied area:

The surface emissivity map of the studied area of the Gaya district of Bihar, India has been presented in Fig. 7.

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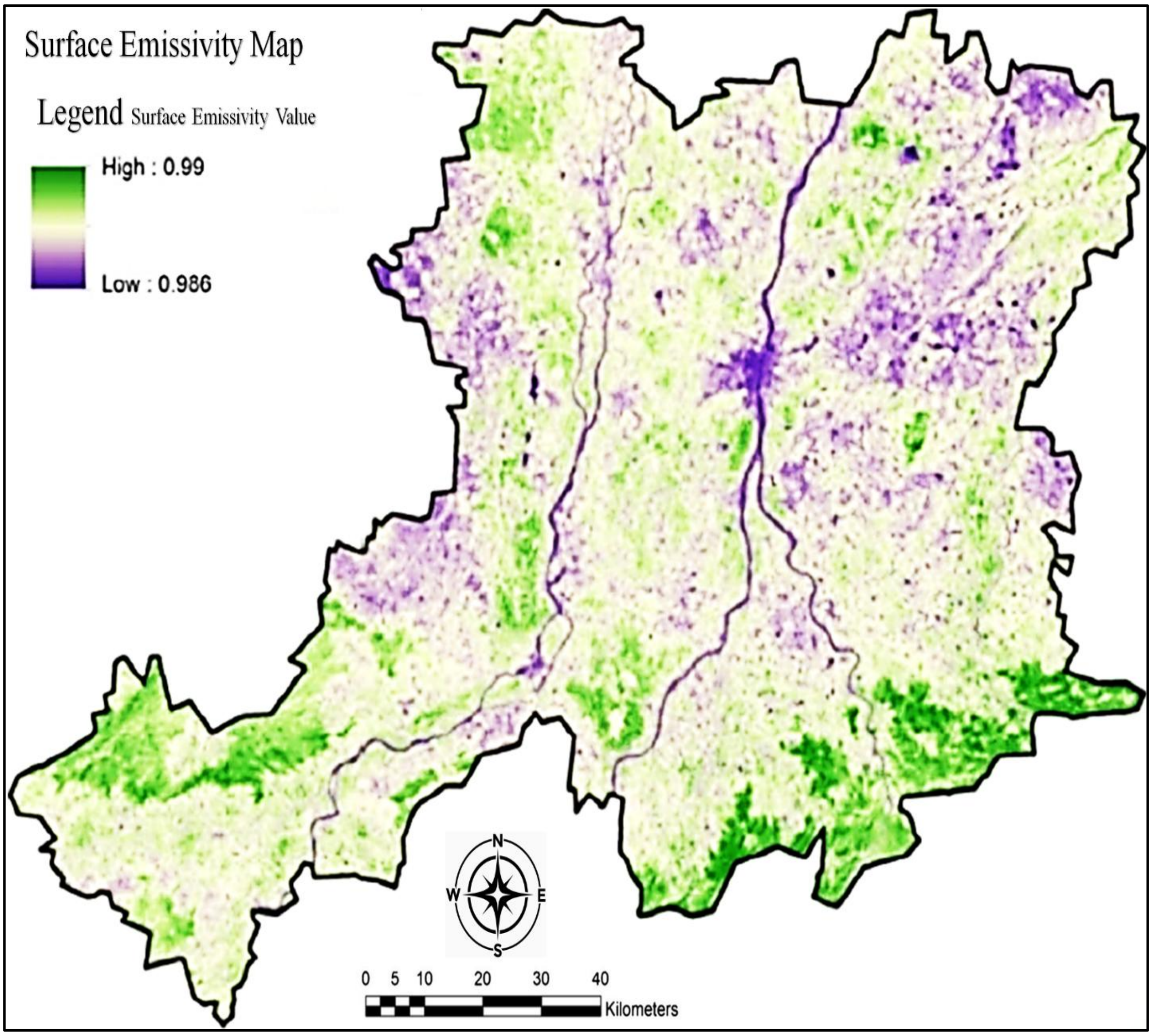

Fig. 7: Satellite classified imagery of surface emissivity map of Gaya district of Bihar

Land surface temperature map of the studied area

The land surface temperature map of the studied area of the Gaya district of Bihar, India has been presented in Fig. 8.

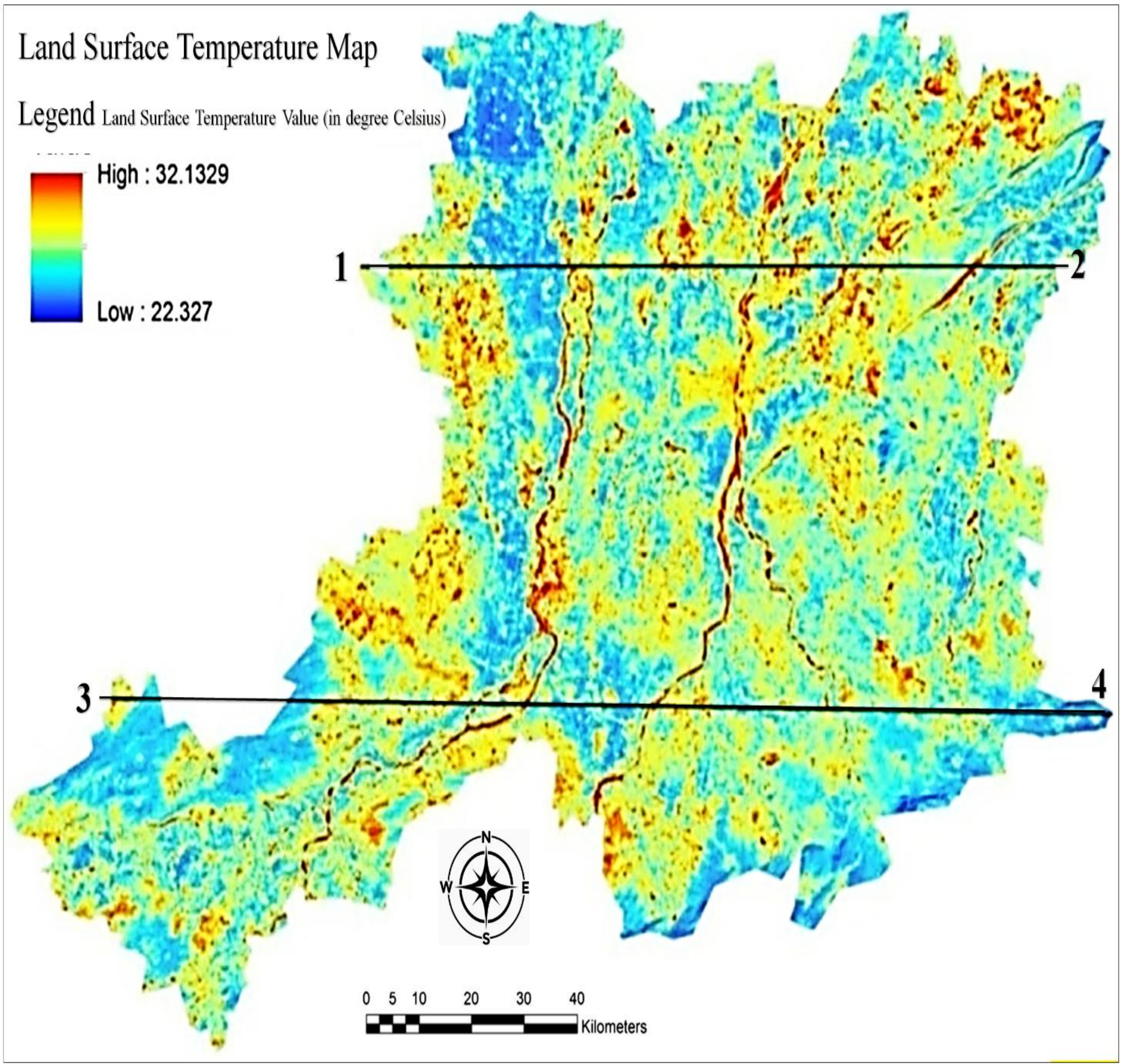

Fig. 8: Land surface temperature map for the study area, showing two cross sections 1-2 and 3-4

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LST profile of the two cross sections

The land surface temperature profile of the two cross sections namely 1-2 and 3-4 of studied area of the Gaya district of Bihar, India has been presented in Fig. 9A and Fig. 9B.

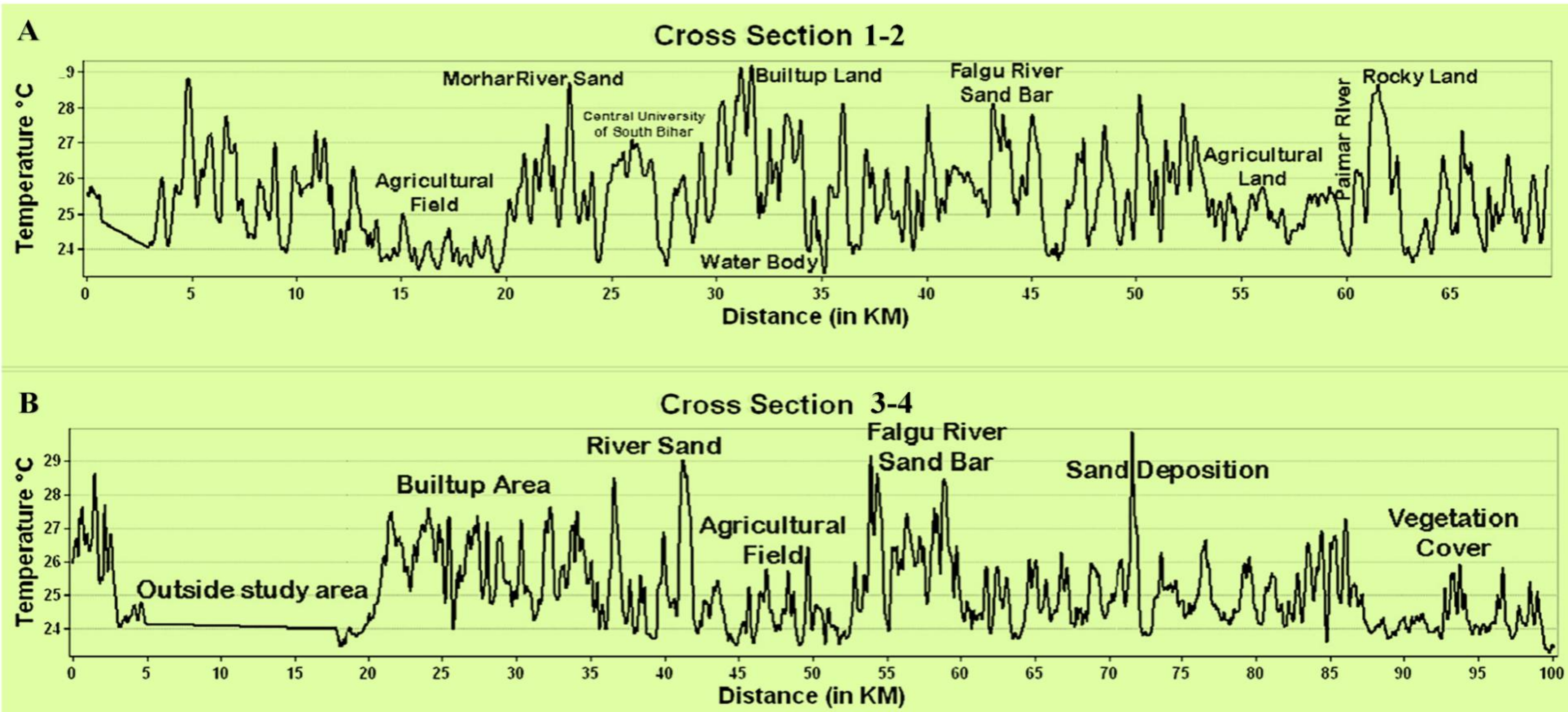

Fig. 9: Land surface temperature profile of the two cross-sections [1-2 (Fig. 9A) and 3-4 (Fig. 9B)] of the studied area

DISCUSSIONS

Environmental and climate changes have affected vegetation negatively. One of the reasons have been documented as the variations in land surface temperature (LST) (Mokhtar et al., 2022; Rendana et al., 2023; Jain, 2024). Other reasons documented are severe temperature stress and relocation of the people from rural to urban areas (Ali et al., 2018). Therefore, monitoring of the temperature variability of any climatic zone is a major aspect of planning, mitigation and policymaking. There is no previous research that maps the LST of LCZ in Gaya district of Bihar, using climate data of 20 years (2001–2021) as a baseline. The study has been based on satellite data through various remote sensing techniques that focus on variability in temperature and vegetation in the LCZ from 2001 to 2021.

Gaya district in the state of Bihar is centrally situated in the southern plain of the country of India. The district has an area of 4,976 square kilometres situated between 24°5' to 25°10' north latitude and 84°4' to 84°5' east longitude having average elevation above sea level of 111 m(Weatherbase, 2023).The district is acknowledged geographically appropriate for the agricultural practices for the cultivation of varieties of commercial crops (Baqa et al., 2022; Jain, 2024). Warmer temperatures have been reported to alter plant growth and moisture availability and are often followed by drier conditions (Afzal et al., 2023).

This study provides evidences about the drastic changes to the LST of the Gaya district of Bihar, India, over the period of 2001 to 2021. The study has been construed by means of the available data as well as other sets of data relying on earlier studies done by various researchers like Dibaba et al., 2020 and Mohajane et al., 2018. The spatial distribution of LST as thermal images, acquired in November, 2021, with an average temperature of 25.34°C ± S.D. of 1.209 (with T_{max}= 32.219°C and a T_{min}= 22.41°C). The temperature has been found to gradually decreases from the centre of the urban area towards the rural or suburban areas. The results of the LST exposed that the central urban region contain most of the urban built-up area and the higher LST value is also associated with the central urban setup ofGaya city with higher populationdensity. Therefore, this study safely submit that the spatial distribution of the urban heat islands is mainly located in the central part of Gaya. Densely populated urban areas experience an average LST of 31.1°C, while an area with scattered built-up lands gives an average LST of 29.7°C. This result suggests that the areas with high population density, impervious surfaces, and low vegetation cover experience high LST.The assessment also justified that the major locations which represent high temperature, e.g., river sandbars, are mainly associated with the low vegetation cover.

CONCLUSIONS

It can be concluded that the urbanization and thermal environment of the city are mainly associated with the urban built-up and barren land and decreased with vegetation cover. The aim of this study was to advance our understanding in identifying the climate risks and/or opportunities for Gaya district of Bihar, using weather data of 20 years. The study will help in developing specific adaptation and mitigation options that minimize the negative effects of climate change while maximizing the opportunities. This study helps in monitoring and mitigating the urban climate and the effect of vegetation on the urban heat island. The LST along with different indices can be used to predict the spatial characteristics of the urban heat island and could be applied further to the establishment of environmentally friendly urban planning. Additionally, the presence of healthy vegetation in the form of green spaces made important and significant contributions to the regulation of city climate, as healthy vegetation increased humidity in the air which may lead to a decrease in the temperature of the surrounding.

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