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ARTICLE

Impact of Urbanization on Temperature Regime in Indian Subcontinent—A Case Study of Patna City

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ABSTRACT

Land use change ranks as the second most significant human-made factor affecting climate, following greenhouse gas emissions. Patna is rapidly expanding cities in Bihar state. Urbanization caused substantial alterations in land use patterns in Patna, driven by its rapid urban growth and increasing population. Urbanization and population growth caused a rapid increase in built structures to cater the demand, which caused reduction in vegetation, water body, and wasteland cover, due to which land cover changed. Land cover change detection plays a vital role in identifying its impact on diurnal temperature range (DTR). To study the impact, land use/land cover change map for the city is produced from Landsat images for the study area Patna during 1995 to 2023. The supervised classification method is used to identify substantial changes in vegetation cover during 1995 and 2023 as a result of changes in land use and land cover. Landsat image supervised classification shows a growth of 47.80 percent in built-up areas in the last 28 years in the city of Patna. The classified image also shows a consistent decline of 31.74 percent in vegetation cover over the period of 28 years. Urbanization-driven changes in land use and land cover have led to a significant decrease of 20.24 percent in the near-surface DTR, average decrease of 12.54 percent in maximum temperature and an increase of 75.68 percent in minimum temperature of the city. The study offers scientific insights into how urbanization and human activities are impacting the eco-environment of the city.

Keywords: Land Cover; DTR; Urbanization; Remote Sensing (RS); GIS; Climate Change; Patna

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1. Introduction

In India, land use and land cover (LULC) has experienced rapid changes in recent decades, owing to a high rate of urban expansion [1], and it is expected to continue in the near future. The city of Patna (Patna Municipal Corporation, PMC), the state capital of Bihar, is a rapidly developing city that has emerged as a commerce and business center in recent decades. It has seen a surge of migration from the immediate hinterland and other parts of the state. The city's population is expanding by the day as per Bihar government, the population of Patna city was 11.27 lacs in 1990 and 25.80 lacs in 2023. Significant migration from various parts of Bihar has resulted from rapid urbanization. This rapid growth has led to unplanned construction in Patna in the absence of planning interventions since 1981. Haphazard development has resulted in the degradation of open space and forest areas, as well as uncontrolled and unregulated construction operations within the core and periphery of the city. The impacts of urbanization on local weather and climate are well-known and well-documented.

Recent studies have investigated the impact of urbanization on mesoscale weather patterns in various regions across the globe. From January 2000 to May 2016, [2] conducted a systematic review of scholarly papers. In the northeastern United States, urbanization has a significant impact on local temperature, up to 5 degrees Celsius, according to this study. Modeling and observational research were used to examine and document the consequences of urban-induced LULC alterations in various parts of the world [3–13].

The most recent Intergovernmental Panel on Climate Change (IPCC) report noted that the primary conclusion from the near-term DTR analysis focused mainly on the period prior to 2004 due to limitations in data availability. Consequently, it is essential to evaluate global DTR trends using the latest datasets.

The Patna Urban Agglomeration (PUA) has been rapidly growing at a rate of 48.13 percent (1991–2021). This issue has been fueled by both migration from the hinterlands and internal population increase in Patna. Therefore, it is essential to study changes in LULC in Patna to comprehend their impact on local weather and climate. Remote Sensing (RS) and Geographical Information System (GIS) techniques were employed to map different LULC types in the PMC study area. LULC changes were analyzed using False Color Composite (FCC) Satellite Images from Landsat data spanning from 1995 to 2023. The transformation of land use is a common occurrence in urban areas and significantly influences the local climate.

The LULC analysis revealed that in 2023, the largest portion of the PMC area, totaling 65.53 square kilometers, was covered under built-up areas due to rapid population growth. Agricultural land, fallow land, vegetation, and water bodies occupied an area of 38.03 square kilometers, while wasteland constituted approximately 8.47 square kilometers. The accuracy of the study was validated through field verification and analysis of Landsat satellite images.

Patna is the 17th most populous city in India, with a total urban agglomeration population of

The study highlights potential risks associated with a decline of DTR in PMC regions. To conduct the study for DTR and its impact in the city of Patna, the following data and procedure were adopted.

2. Study Area, Climate Dataset and Procedure

The study area , as shown in **Figure 1**, the city of Patna which is dominated by the PUA and is the state capital of Bihar. It is situated in south of river Ganga. The study area spreads over the municipal boundary of Patna. The study area is defined by latitude 25°33′0″ N to 25°39′0″ N and longitude 85°3′0″ E to 85°16′0″ E. Meteorological data for this area have been collected and organized in tabular form. Observations indicate that temperatures range from 1.40 °C to 46.10 °C, relative humidity spans from 5% to 100%, rainfall varies between 0.0 mm to 205.40 mm, and wind velocities range from 1 km hr^{-1} to 42 km hr^{-1}.

The cadastral map of Patna obtained from the Urban Department and Housing Department of Bihar has been geo-referenced and integrated into a GIS environment. GIS requires data to be geo-referenced in order to combine geographical and meteorological data effectively. Georeferencing ensures that each dataset is aligned spatially.

The digitization of the geo-referenced cadastral survey map facilitates the calculation of plot areas. Landsat satellite data used is mentioned in spanning from 1995, 2000, 2005, 2010, 2015, 2020, to 2023, and has been utilized for the study. The satellite data properties mentioned in **Tables 1** and **2**, processed using ERDAS software (as shown in **Figure 2**), enable the computation of land cover maps.

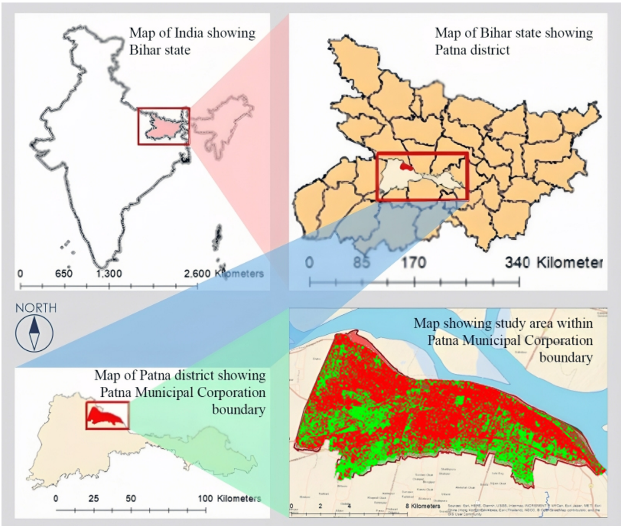

Figure 1. Location map of the State Capital of Bihar, Patna (PMC).

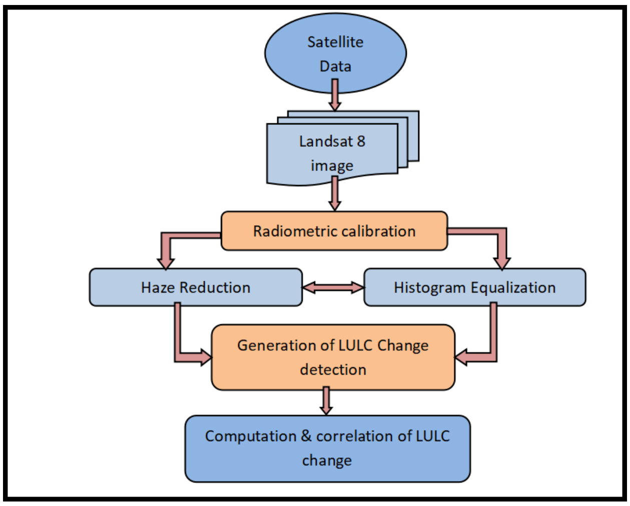

Figure 2. Image enhancement for the computation of climate change due to land use change.

Climatic data from the weather station in Patna, provided by the Indian Meteorological Department (IMD), have been utilized to assess the prevailing atmospheric conditions in the region such as daily maximum and minimum temperature. IMD data is used for the computation of DTR which is the difference between maximum and minimum temperature. The annual average of daily DTR values is used for the study area. This data helps in understanding how climate patterns and variables influence the environment.

Land cover maps derived from Landsat satellite date provide information on land cover types across different time periods. By doing so, changes in land use, vegetation, and other land cover features can be analyzed over time. Combining these two sources of information allows for a comprehensive evaluation of how climatic conditions interact with and impact land cover changes, providing valuable insights into environmental and ecological dynamics. The methodology used for the study is depicted in a flow chart in **Figure 3**.

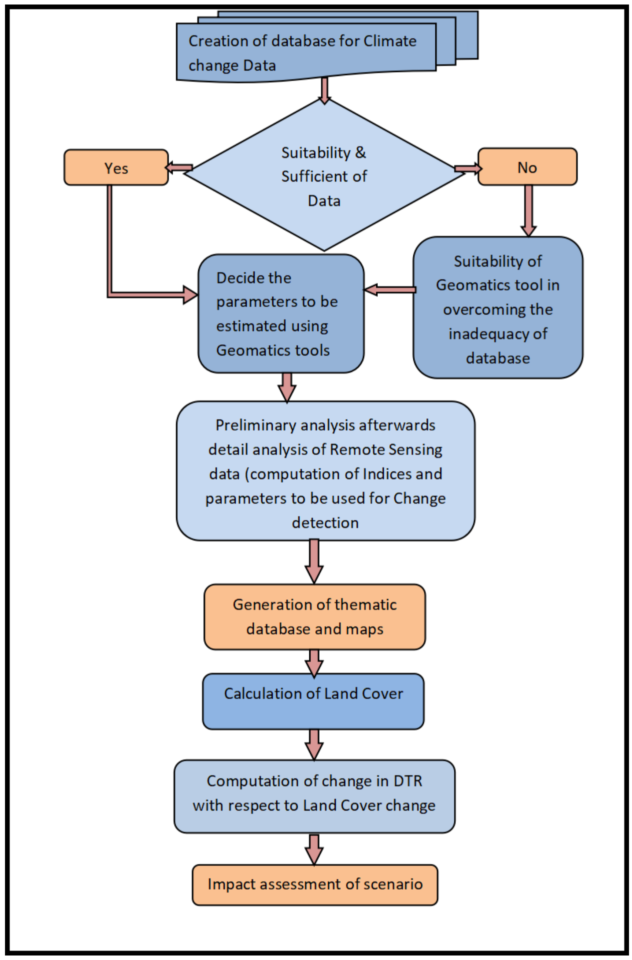

Figure 3. Concise flow chart of methodology.

3. Results and Discussion

The land use/cover maps generated by supervised classification for the periods between 1995 and 2023 (**Figure 4**) achieved an overall map accuracy of 89% for all images in the study area, as determined by error/confusion matrix analysis. This method, frequently used for per-pixel classification [14] provided reliable results. Each classified map was evaluated using Kappa statistics/index, all of which exceeded 0.89, indicating a high level of accuracy [15]. This accuracy was deemed sufficient for subsequent analysis and change detection.

Table 1. Landsat Mission details.

Mission	Year (Data Used)	Instruments	Equatorial Crossing	Repeat Cycle
Landsat 4	1995, 2000	Thematic Mapper (TM), Multispectral Scanner System (MSS)	9:45 a.m. ± 15 min	16 days
Landsat 5	1995, 2000	TM, MSS	9:45 a.m. ± 15 min	16 days
Landsat 7	2005, 2010, 2015	Enhanced Thematic Mapper Plus (ETM+)	10:00 a.m. ± 15 min	16 days
LDCM (Landsat 8)	2020, 2023	Operational Land Imager (OLI), Thermal Infrared Sensor (TIRS)	10:00 a.m. ± 15 min	16 days

Table 2. Landsat payloads.

Instrument	Mission	Spectral Bands	Ground Sampling
TM	Landsat 4 and 5	Visible blue (0.45–0.52 µm) Visible green (0.52–0.60 µm) Visible red (0.63–0.69 µm) Near-infrared (0.76–0.90 µm) Mid-infrared (1.55–1.75 µm) Thermal (10.40–12.50 µm) Mid-infrared (2.08–2.35 µm)	30 m for VIS, NIR, MIR 120 m for Thermal
(ETM+	Landsat 7	Visible blue (0.45–0.52 µm) Visible green (0.52–0.60 µm) Visible red (0.63–0.69 µm) Near-infrared (0.77–0.90 µm) Mid-infrared (1.55–1.75 µm) Thermal (10.40–12.50 µm) Mid-infrared (2.08–2.35 µm) Panchromatic (0.52–0.90 µm)	30 m for VIS, NIR, MIR 60 m for Thermal 15 m for Panchromatic
OLI	LDCM (Landsat 8)	Visible "ultra" blue (0.43–0.45 µm) Visible blue (0.45–0.52 µm) Visible green (0.53–0.60 µm) Visible red (0.63–0.68 µm) Near-infrared (0.85–0.89 µm) Mid-infrared (1.56–1.66 µm) Mid-infrared (2.10–2.30 µm) Mid-infrared "cirrus" (1.36–1.39 µm) Panchromatic (0.50–0.68 µm)	30 m for VIS, NIR, MIR 15 m for Panchromatic
TIRS	LDCM (Landsat 8)	Thermal (10.3–11.3 µm) Thermal (11.5–12.5 µm)	100 m nominal

Based on the image classification results, the total land area of PMC was determined to be 108.87 square kilometers. The distribution of individual land cover classes is illustrated in **Figure 5** and change statistics for 1995 to 2023 are summarized in tabular form **Table 3**.

In 1995, vegetation and water body areas comprised the largest share of the total LULC categories assigned, accounting for 51.18% (55.72 square kilometers). By 2023, this percentage decreased significantly to 34.93% (38.03 square kilometers).

Conversely, the built-up area class showed an increase over the study period. In 1995, it covered 40.72% (44.34 square kilometers) of the total area, which rose to 60.19% (65.53 square kilometers) by 2023. The wasteland class experienced a minor decline from 8.10% (8.82 square kilometers) in 1995 to 4.87% (5.30 square kilometers) in 2023, indicating a less significant shift compared to the other classes.

According to the study, built-up area increased by more than 47.80 percent between 1995 and 2023 (**Table 3**). This shift underscored the significant land cover transformation in the built-up surface category, exerting considerable pressure on non-built-up surfaces, especially vegetation and water body areas. The rapid construction of residential units, commercial and industrial facilities, road networks, pavements, leisure facilities, and other impervious surfaces across various parts of the city contributed to the continuous expansion of built-up areas. Several similar studies of LULC change have been done in different parts of the world such as the study[16], which focused on the investigation of land use and cover changes in the Aba Urban Area, Nigeria, using medium satellite imageries to detect changes. According to the findings, the built-up area expanded from 21.7 to 36.5 percent. Another study of[17] on LULC in Mekelle city, Ethiopia revealed a significant change of 200 percent in urban area.

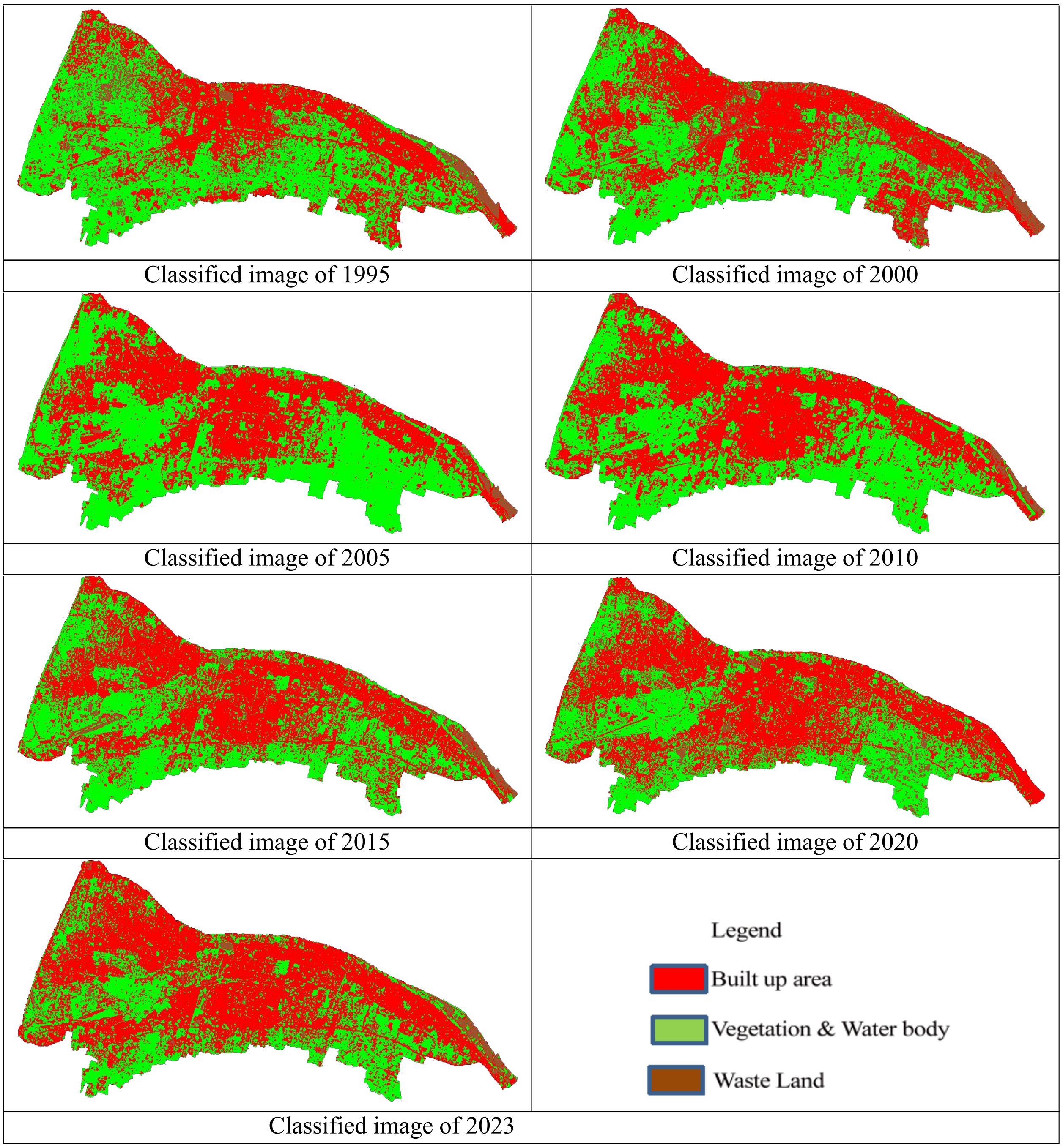

Figure 4. Classified image of study area Patna.

The latest report from the IPCC highlights an increase in the average global surface temperature of around 0.6 °C since the late 19th century, with an accelerated rate of temperature rise observed in recent decades[18]. Scientists have observed that this warming has not been uniform throughout the day, with less warming noted in maximum temperatures and significant warming observed in minimum temperatures, e.g.,[19], Easterling et al.[20], Aiguo, Anthony and Inez[21], and Braganza, Karoly and Arblaster[22]. As a result, the near-surface DTR has been falling over huge land areas around the planet; [23] revealed that this drop in DTR is also seen in AVHRR observations of the earth's skin temperature. Many scientists have postulated many causal theories for the differential diurnal temperature trends, based on the observed general drop in DTR. Increased quantities of greenhouse gases and sulfate aerosols appear to be the proposed factors for the drop in DTR[24–28]. According to various literatures, declining trends in DTR are eventually linked to rising cloud cover[19, 29–31]. While DTR has decreased in most of the regions studied, there have been some exceptions, including parts of India, where DTR has increased in recent decades[32]. Analysis of maximum and minimum temperatures at the regional level has revealed a notable increase in maximum temperatures, while minimum temperatures have remained relatively constant. This trend has led to an expanding DTR across extensive areas of India[33]. The western Himalaya was studied, and researchers discovered a significant fall in minimum temperatures in the latter half of the twentieth century, resulting in an increase in DTR. Regional deforestation and land degradation were responsible for such tendencies. Updated investigations of[20] and Houghton et al.[18] show that DTR is growing over India. In the current study, the plot of maximum, and minimum temperature and built-up area in **Figure 6**, for the duration of 1995 to 2023, is drawn. IMD data analysis of Patna city shows a decreasing trend in maximum temperature in **Figure 7** and an increasing trend in minimum temperature in **Figure 8**; the scatter plot of annual maximum and annual minimum is shown in **Figure 9** and the decreasing DTR trend is shown in **Figure 10**. Analysis indicates a linear relationship and strong correlation. The study's major goal is to determine the impact of land cover change, if any, on DTR variations throughout PMC. Our research should disclose the extent to which land cover is responsible for DTR changes and trends, as well as provide insights on spatial patterns in any unusual decline in DTR.

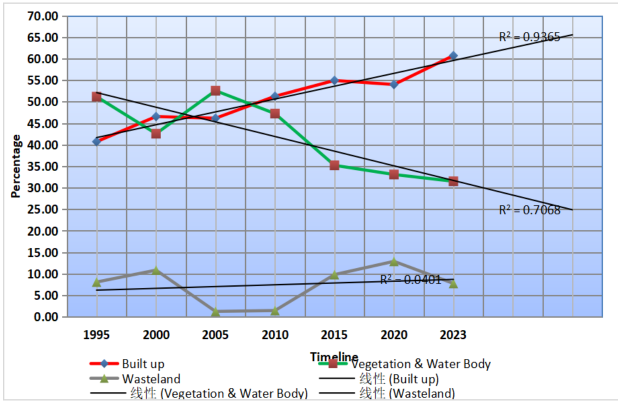

Figure 5. Land cover of Patna municipal corporation area in percentage from 1995 to 2023.

Table 3. Land cover of Patna in sqkm from 1995 to 2023.

	1995	2000	2005	2010	2015	2020	2023
Built up (in sqkm)	44.34	50.69	50.26	55.82	55.02	59.45	65.53
Veg & Water body (in sqkm)	55.72	46.35	57.23	51.44	47.01	44.07	38.03
Wasteland (in sqkm)	8.82	11.83	1.38	1.61	6.84	5.35	5.30
% change	**1995–2000**	**2000–2005**	**2005–2010**	**2010–2015**	**2015–2020**	**2020–2023**	**1995–2023**
Built up area	14.32	–0.85	11.07	–1.44	8.05	10.23	**47.80**
Veg & Water body area	–16.81	23.47	–10.12	–8.61	–6.25	–13.70	**–31.74**
Wasteland area	34.18	–88.31	16.49	324.65	–21.85	–0.79	**–39.84**

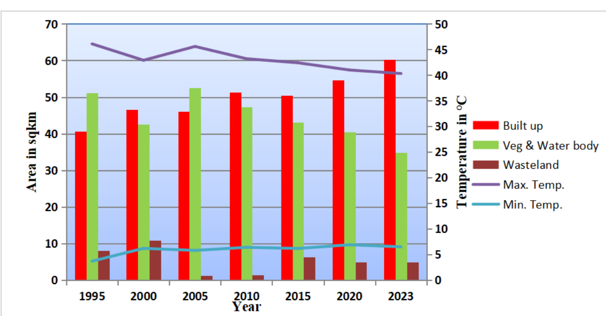

Figure 6. Plot of built-up area vs annual maximum & minimum temperature.

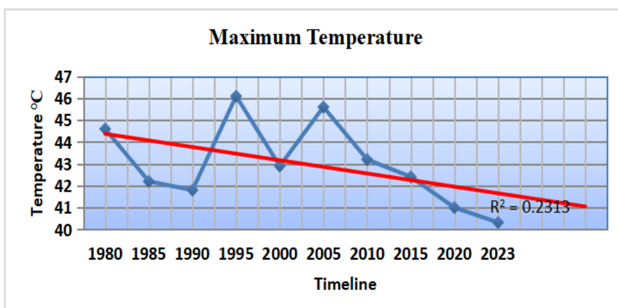

Figure 7. Annual maximum temperature graph during 1980 to 2023.

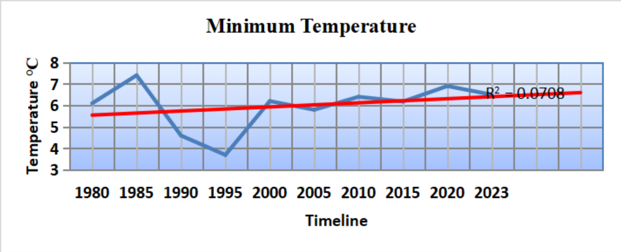

Figure 8. Annual minimum temperature graph during 1980 to 2023.

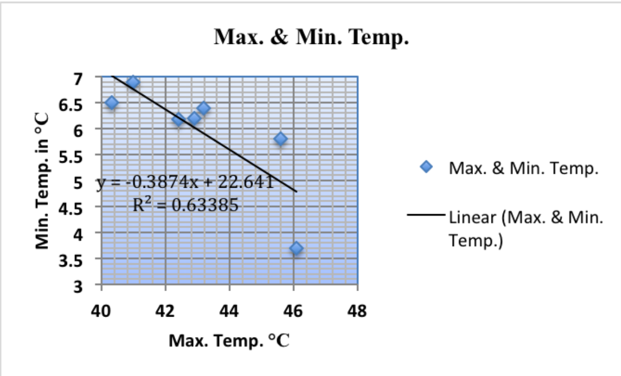

Figure 9. Plot of annual maximum temperature vs annual minimum temperature.

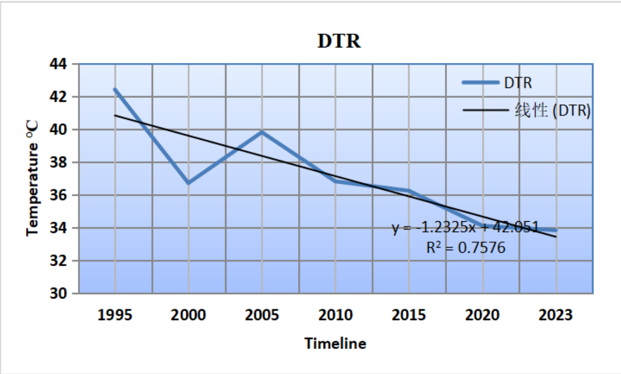

Figure 10. Annual average DTR of Patna during 1995 to 2023.

4. Summary and Conclusions

Since 1995 till 2023 the built up area has increased significantly. In the meantime, the yearly maximum temperature decline is due to the increasing proximity of the river Ganges (the course of the river is shifted towards the city), and the minimum temperature is increasing, for which the increase in infrastructure such as roads and buildings to cater to the growing population is responsible, leading to a decrease in DTR. The study reveals that the increase in land cover and the decrease in vegetation and water bodies play a vital role in the decline of the DTR trend. This issue is not addressed by the authorities concerned due to the lack of a city master plan and its implementation. If the issues are not addressed by the concerned authority in the near future, then it will cause severe implications for the climate of the city. This would lead to extreme weather or irregular seasons. We need to address the issue immediately and stop the decline of vegetation cover and water body cover, and try to increase the vegetation cover; only then can the implications of these issues be addressed. Strict policy and planning are required to tackle the issue. If the trend of increasing built-up areas and decreasing in vegetation and water bodies continues, it will lead to adverse impacts on climate, seasons and the lives of people. Warmer nights and enhanced diurnal cycles could be expected as a result of extreme LULC shifts and anthropogenic changes in the future. Because of the strong effect of urbanisation on minimum temperatures, winters may get warmer. Agriculture, pasture deforestation/reforestation, irrigation, and climatic influences all have an impact on surface temperature and hydrological cycles over cities, although they are not explicitly addressed in this study. However, further studies are needed to determine this hypothesis.

Author Contributions

The paper is equally prepared by all the authors. A.K.S. contributes under the guidance and supervision of M.K. and S.K.M.

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Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

Landsat data used in the study is downloaded from USGS website free of cost and Meteorological data is obtained from Indian Meteorological center associated with charges and privacy or ethical restrictions.

Conflicts of Interest

The authors declare no conflict of interest.

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