# Spatio-Temporal Evolution Analysis of the Urban Heat Island: A Case Study of Butwal City, Nepal


## Abstract

During the progress of urbanization in Nepal, a large number of natural landscapes have been replaced by impervious surfaces. The strong interference from human activities has led to the intensification of urban heat island (UHI) effects and has had a negative influence on the health of residents. Butwal, as a new representative city of rapid urbanization, can be used as a case study for UHI.The study examines the urban heat island (UHI) effect in Butwal, Nepal, from 2014 to 2023, analyzing changes in land surface temperature (LST) over the years 2014, 2017, 2020, and 2023. The results show an increase in average LST, with the mean rising from 30.91°C in 2014 to 32.09°C in 2023. The trend is attributed to the expansion of built-up areas and the reduction of vegetative cover. The study also reveals that vegetation and construction have contrasting effects on LST, with urban areas showing the highest temperature increases. The research underscores the need for sustainable urban development strategies, including green spaces and heat-mitigation techniques, to reduce the UHI effect in fast-growing cities like Butwal. By understanding the driving forces behind LST changes, policymakers can implement targeted interventions to control urban heat and promote ecological balance.


## 1. Introduction

In 1818, Howard was the first to document the phenomenon of the urban heat island in his work, *The London Climate* [1]. This concept refers to the observation that temperatures in urban areas are typically higher than those in surrounding suburban or rural regions [2]. Over time, as urbanization and industrialization have expanded globally, the extent and intensity of the urban heat island (UHI) effect have grown. This has had a significant impact on local climate patterns, energy consumption, and public health. In larger cities, central areas often experience higher temperatures than nearby suburbs [3]. This rise in temperature results in lower air pressure and alterations in atmospheric behavior, such as the circulation of pollutants, which can greatly affect regional climates.The UHI effect also leads to increased air conditioning use during the summer, creating a feedback loop that escalates both temperatures and energy consumption. Due to the rising urban temperatures, residents are increasingly facing health challenges, including high-temperature diseases and epidemics. Understanding the mechanisms that influence the UHI effect is crucial in grasping the broader impact of human activities on urban climates [4]. This research seeks to further clarify how human actions contribute to the UHI effect and aims to promote sustainable urban ecological development.

In recent years, advancements in space information technology have led to the use of inversion algorithms based on Geographic Information Systems (GIS) and remote sensing (RS) technology to study thermal environments. In 1972, Rao[5] was the first to apply remote sensing images for retrieving land surface temperature (LST). Since then, satellite data from sources such as NOAA(National Oceanic and Atmospheric Administrate) /AVHRR (Advanced Very High Resolution Radiometer) [6, 7] , MODIS, Aster, HJ-1, and the Landsat series [8-10] have been extensively used to analyze LST. Among these, the Landsat series stands out for its high spatial resolution, abundant spectral information, archived data, and free accessibility, making it a popular tool for remote sensing studies of thermal environments.

Traditional methods of field observation often fall short in accurately capturing temperature variations over large areas or extended time periods. GIS and RS technologies help overcome this limitation by enabling the acquisition, processing, and analysis of critical data. These technologies have become essential in providing a detailed understanding of the temporal and spatial variations in the urban heat island (UHI) effect, becoming the primary tools for studying it.

Currently, many researchers have investigated the driving mechanisms of the UHI effect from various angles, such as land cover, landscape patterns, and socio-economic factors. Using 3S technology (remote sensing, GPS, and GIS) in conjunction with methods like correlation analysis, fractal mathematics, and gray system theory, scholars have explored the influence of surface cover on LST. Key factors include vegetation, urban construction, and bodies of water. Additionally, human activities play a significant role in driving the UHI effect[11, 12].

The rapid urbanization of Butwal, Nepal, can serve as an important case study for understanding the urban heat island (UHI) effect in developing regions. In recent years, Butwal has experienced significant growth, driven by several factors, including infrastructure development, transportation expansion, and the city's strategic location as a gateway between the plains and the hilly regions. The introduction of policies aimed at urban development, such as the establishment of industrial zones and improvements in road connectivity, has accelerated the city's transformation.Between 2014 and 2023, the proportion of constructed land and built-up areas in Butwal increased significantly. The urbanization process has drastically altered the surface characteristics and spatial function of the city.These changes have affected the surface's ability to reflect sunlight (albedo) and increased heat from human activities, both of which play a major role in the urban heat island (UHI) effectt[13-15]. As a result, Butwal offers a strong case for studying the factors driving the UHI effect in a rapidly urbanizing area.

This study utilizes high-resolution data from 2014, 2017, 2020, and 2023 to analyze surface temperature changes in Butwal. The data is derived from Landsat images and thermal infrared bands, which are used to build a temperature model that captures the inversion of surface temperatures during these years. By analyzing the surface temperature profiles over time, the spatio-temporal evolution of Butwal's heat field is visualized, showcasing the characteristics of the urban heat island's rise. Although studies have quantitatively explored the impact of land cover on the UHI, further research is needed on the socio-economic drivers, such as population growth and energy consumption, which are critical to understanding how human activities intensify the UHI effect. This study helps to better understand the processes and causes involved in the formation of the UHI effects in Butwal.

## 2. Materials and Methods

### 2.1 Study Area: Butwal, Nepal

Butwal, a significant city in Nepal, has experienced rapid urbanization from 2014 to 2023, making it an insightful case study for the urban heat island (UHI) effect. Located between 27°42'N to 27°44'N latitudes and 83°27'E to 83°30'E longitudes, Butwal covers 69.28 km² and has seen notable changes in its built-up areas. This period of intense growth includes infrastructure projects, residential expansions, and the development of new commercial centers. By 2023, Butwal's urban landscape had dramatically transformed, with substantial increases in constructed land and modifications to the city's surface coverage. This transformation has significantly impacted the UHI effect, evident in rising surface temperatures, particularly in the urban core compared to the surrounding rural area.

Butwal's climate, characterized by a humid subtropical pattern with an annual mean temperature of approximately 24°C and about 1500 mm of rainfall annually.The city enjoys a frost-free period of 209 days and approximately 2200 sunshine hours each year. These climatic conditions, combined with the increase in built-up areas and a reduction in green spaces, have exacerbated the UHI effect. The study utilizes Landsat satellite images and thermal infrared data from the years 2014, 2017, 2020, and 2023 to analyze trends in surface temperatures. The findings highlight a clear upward trend in urban temperatures, linked to increased energy consumption, notably from air conditioning, and rising public health issues related to heat. This research emphasizes the need for further exploration into socio-economic factors driving the UHI effect to develop effective strategies for sustainable urban development in Butwal.

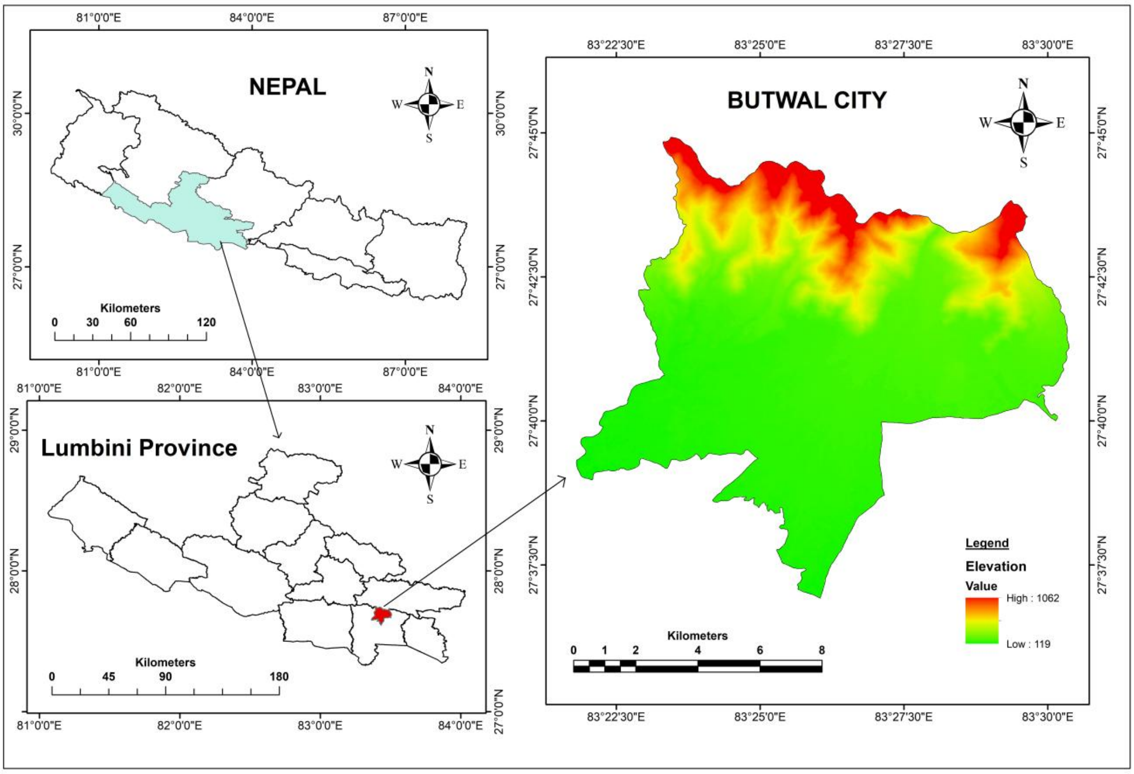


**Figure 1.** Location of the research area: Butwal,Nepal

## 2.2 Data

In this research, all images utilized were sourced from the Landsat program of NASA (National Aeronautics and Space Administration), specifically using Landsat-8 Level 1 data. This dataset was employed to retrieve land surface temperatures (LST), extract land use types, and calculate the land cover index for Butwal, Nepal. Images were downloaded from the USGS (United States Geological Survey) website[16]. To ensure consistency and minimize the influence of meteorological factors such as cloud cover and precipitation, the images were selected from early April, a transitional period between summer and winter in Butwal, where cloud cover was less than 5% and there was no precipitation on the day prior to imaging.

The study incorporates Landsat-8 images from the following dates: April 2, 2014, April 10, 2017, April 2, 2020, and April 29, 2024. These dates were chosen to provide a consistent basis for analyzing temporal changes in surface temperatures over the decade. By focusing on early April, the research minimizes the impact of seasonal variations and provides a reliable assessment of urban heat island effects and land cover changes in Butwal.

## 2.3 Normalized Difference Vegetation Index (NDVI) and Normalized Difference Building Index (NDBI)

The NDVI is the Normalized Difference Vegetation Index[17]. It has been widely used in the research of the UHI effect to detect the vegetation growth status and vegetation coverage. The range of NDVI is [–1, 1], and the negative value indicates that the land cover is cloud, water, snow and so on. It reflects the high reflection of visible light, and the 0 value indicates that the land cover is rock or bare soil, and the positive value indicates that the surface is covered by vegetation and increases with an increase in coverage. The formula for NDVI is as follows (Equation (1)):

$$\text{NDVI} = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}} \tag{1}$$

$\rho_{\text{NIR}}$ represents the reflectance of the near infrared band, where $\rho_{\text{NIR}}$ = Band 5 (for Landsat-8 OLI); $\rho_{\text{RED}}$ represents the reflectance of the red band, where $\rho_{\text{RED}}$ = Band 4(for Landsat OLI).

The NDBI is the Normalized Difference Building Index[18]. It is used to reflect the density of buildings in unit pixels. The range of NDBI is [−1, 1], and a negative value indicates that the land cover is water. A value of 0 means that the land cover is vegetation, and a positive value indicates the land cover is built-up area. The formula for NDBI is as follows (Equation (2)):

$$\mathrm{NDVI} = \frac{\rho_{SWIR} - \rho_{NIR}}{\rho_{SWIR} + \rho_{NIR}} \qquad (2)$$

$\rho_{SWIR}$ represents the reflectance of the middle-infrared band, where $\rho_{SWIR}$ = Band 6 (for Landsat OLI).

2.4 LST Retrieval

2.4.1 Thermal Radiation Intensity

The thermal radiation ($L_\lambda$) received by a satellite sensor includes the radiative energy produced by the surface body itself and generated by the surrounding environment [19]. The thermal radiation of Landsat OLI is recorded by the DN (digital number) value. DN is the gray value of pixels; it is an integer, with no units and a range from 0~255 — the greater the DN value of the pixel, the greater the corresponding thermal radiation value [$L_\lambda$] is expressed as follows (Equation (3)):

$$L_\lambda = Gain * DN + Offset \qquad (3)$$

The gain expresses the gain coefficient; its units are W/($m^2$ ·sr·µm)/DN and its values are as follows: gain=0.0003342 and offset =0.10000 (for Landset OLI)

2.4.2 Radiation Brightness Temperature

The radiation brightness temperature ($T_d$) is expressed as follows (Equation(4)):

$$T_d = \frac{K_2}{In(1 + \frac{K_1}{L_\lambda})} \qquad (4)$$

$K_1$ =1321.0789 and $K_2$ = 774.89 are the revision coefficients and has the unit as W/($m^2$ ·sr·µm).

2.4.3 Surface Emissivity

Surface emissivity( ε ) is a critical parameter in calculating land surface temperature (LST) from satellite data. It represents the efficiency of a surface in emitting thermal radiation compared to a perfect blackbody, which emits the maximum possible radiation at a given temperature. Emissivity values range from 0 to 1, with 1 indicating a perfect blackbody and lower values indicating less efficient emitters. The formula is expressed as in (Equation(5)):

$$\varepsilon = 0.004 * PV + 0.986 \quad (5)$$

Where, PV= Proportions of Vegetation calculated by using NDVI.

2.4.4 LST

Most of the objects in nature are not black bodies. It is necessary to use the surface emissivity to correct the radiation brightness temperature, so that it can be converted into the real surface temperature (Ts). The Ts is expressed as follows (Equation (6)):

$$T_s \frac{T_d}{1+\left(\frac{\lambda * T_d}{\rho}\right) ln(\varepsilon)} - 273.15 \quad (6)$$

In the above formula, λ is the wavelength of the emitted radiance: λ = 10.8 μm (for Landsat OLI) ; $\rho = 1.438 \times 10^{-2}$ mk[20-22].

2.5 Classification of Land Use Types

This study used the land-use monitoring classification system suggested by National Land Cover Monitoring System of Nepal[23]. Through the land classification standard, the support vector machine (SVM) in the supervised classification is used to set up the interpretation mark, and the land use in the study area is divided into five types. The classification results that result from using these five land use types are very accurate, with the average accuracy being 85%. The land use maps of Butwal for 4 periods (2014, 2017, 2020 and 2023) were obtained (**Figure 2**).

**(a) 2014** **(b) 2017**

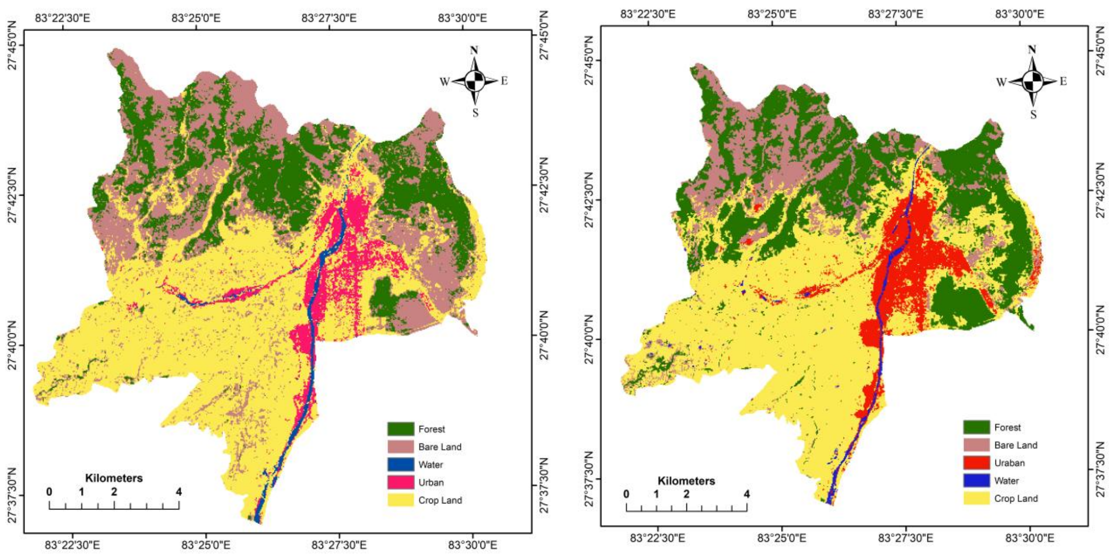


Figure 2. Conti

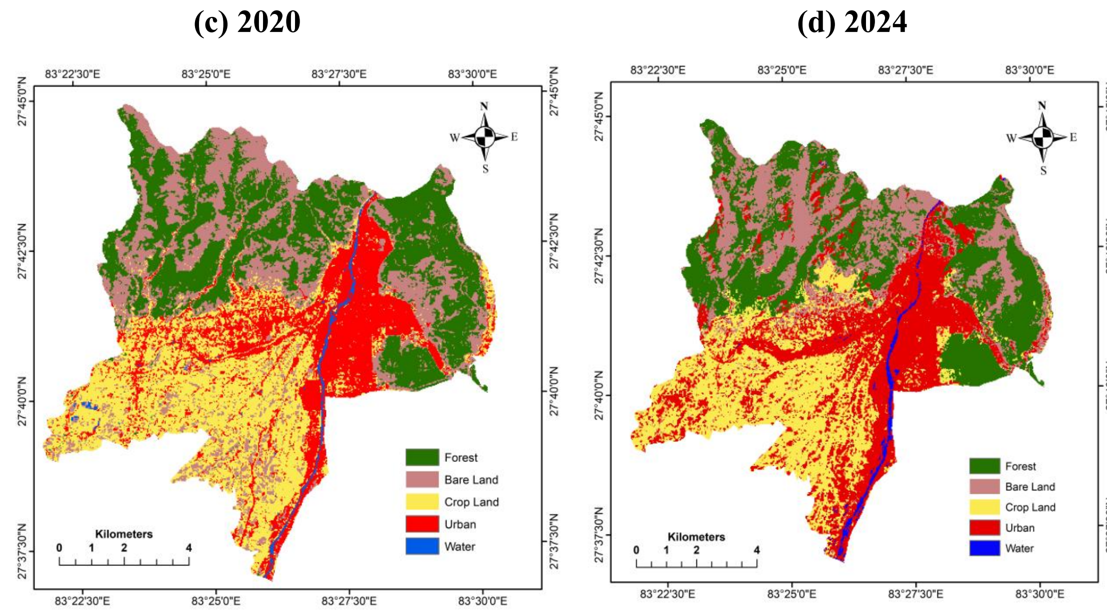


**Figure 2.** The land use maps in (a) 2014, (b) 2017, (c) 2029, and (d) 2023 in Butwal, Nepal

2.6 Precision Verification

All the results of the remote sensing retrieval need to be verified by precision, and the retrieval of LST is no exception. Precision verification is generally used to verify the temperature products using imagery with high spatial resolution, and the measured air temperature data that is consistent with the satellite transit time can also be used. The Landsat-8 OIL image used in this study had high spatial resolution, and it is difficult to obtain high precision temperature data. Therefore, the measured air temperature data were used for validation.

The precision was verified by comparing the mean value of the measure air temperature of the study area with the LST value obtain from the retrieval, to prove the effectiveness of the retrieval results. The retrieval results of Butwal for 03 April 2023, showed that the average LST value was 32.09°C. According to historical meteorological data [24], the average LST in Butwal on 03 April 2023 was 35°C. The difference between the measure value and retrieval value is 1.942°C. It can be considered that the retrieval of LST is effective [25].

# 3. Results

3.1 Temporal and Spatial Variation characteristics of LST

The results of the four-phase retrieval are shown in **Figure 3**. The thermal environment in Butwal showed a tendency to change from an uneven distribution of high and low temperatures to a uniform distribution of high temperatures.

The maximum, minimum, average and standard deviation values of the four-phase retrieval results are shown in Table 1. In 2014, 2017, 2020, and 2023, the maximum LST consistently reached around 40°C, while the average LST values were 30.916°C, 32.019°C, 29.162°C, and 32.093°C, respectively. Despite some fluctuations, the general trend shows a steady increase in average temperatures over the years, with a brief dip in 2020. This dip could be related to local or global environmental factors, such as reduced human activity during the COVID-19 pandemic, which temporarily influenced the urban heat profile.

However, the increase in temperature variability, reflected in the rising standard deviations (2.68 in 2014, 2.85 in 2017, 2.87 in 2020, and 2.91 in 2023), suggests that while the urban area's overall temperatures are becoming higher, they are also becoming more erratic. This growing variability, coupled with higher maximum and average LST values, signals a continuous intensification of the urban heat island effect in Butwal.

**(a) 2014** **(b) 2017**

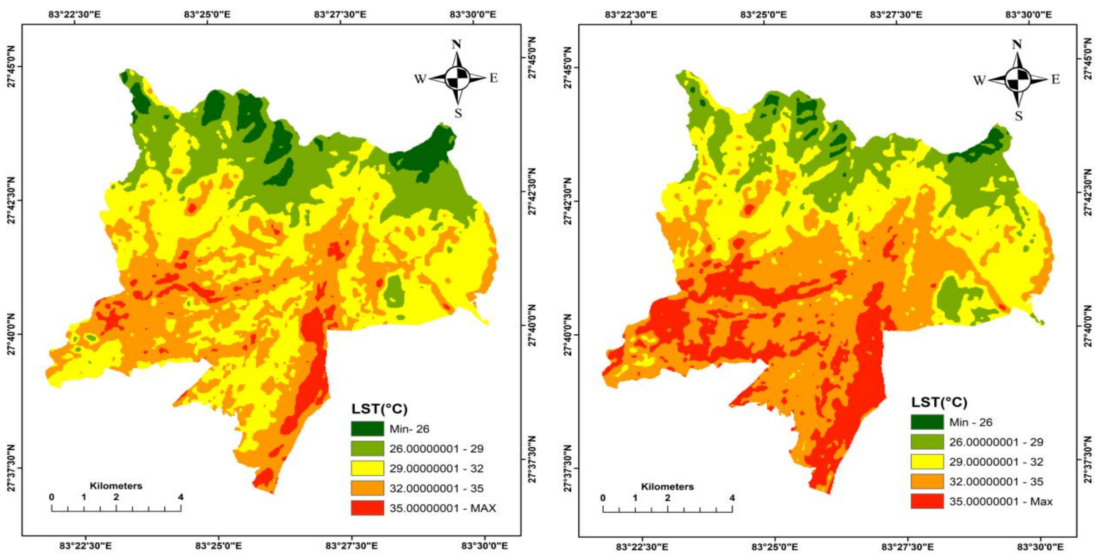


Figure 3. Conti

**(c) 2020** **(d) 2023**

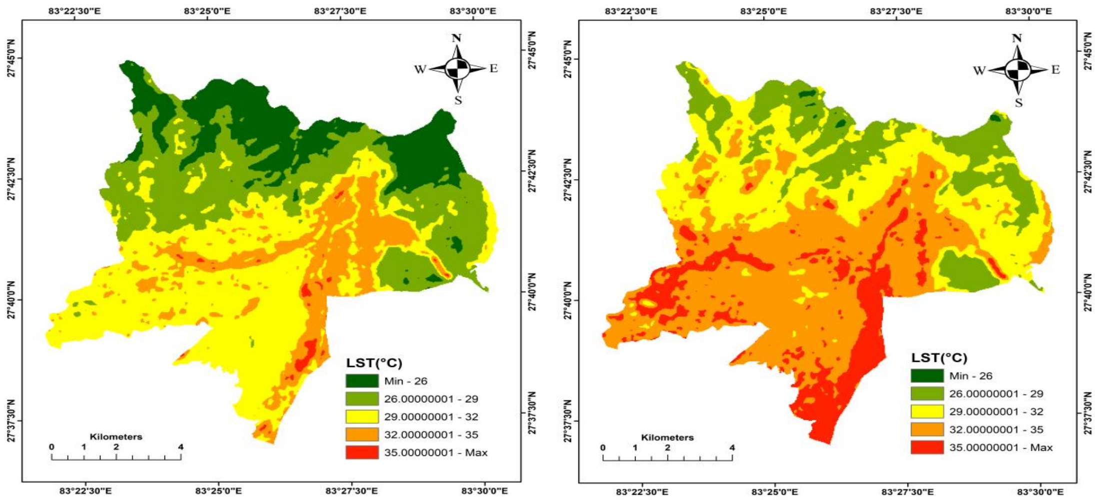


**Figure 3.**The land surface temperature (LST) maps of Butwal, Nepal in (a) 2014, (b) 2017, (c) 2020 and (d) 2023

**Table 1.** The LST in Butwal, Nepal

| Year | Maximum(°C) | Minimum(°C) | Amplitude(°C) | Average(°C) | Standard Deviation |
|---|---|---|---|---|---|
| 2014 | 38.53 | 23.2 | 15.33 | 30.91 | 2.68 |
| 2017 | 40.73 | 24.29 | 16.44 | 32.01 | 2.85 |
| 2020 | 38.92 | 21.46 | 17.46 | 29.62 | 2.87 |
| 2023 | 40.54 | 24.16 | 16.38 | 32.093 | 2.91 |

3.2 The relationship between Land Use and LST

The statistics of LST for the five land use types in 2014, 2017, 2020 and 2023 in Butwal are shown in Figure 4 .The average Land Surface Temperature (LST) values of the five land use types from high to low are: urban ≈ water > cropland > bareland > forest. The highest LSTs are observed in urban areas and water bodies, while the forests consistently have the lowest LSTs.The LST of vegetation-covered areas (forest and cropland) shows variation, with forest land having a slightly lower LST than cropland, likely due to the cooling effects of dense tree cover and evapotranspiration. On the other hand, bareland displays intermediate temperatures, reflecting its limited vegetation and heat-retaining surfaces.

The increase in temperatures across urban areas and water bodies suggests that these land use types have the most significant influence on the local Urban Heat Island (UHI) effect, with urban areas in particular contributing to higher temperatures due to infrastructure and built-up surfaces that trap heat.Even for the same land use types, the average LST shows a consistent increasing trend from 2014 to 2023, indicating that urbanization, changes in land cover, and climatic factors are contributing to higher surface temperatures across the region.

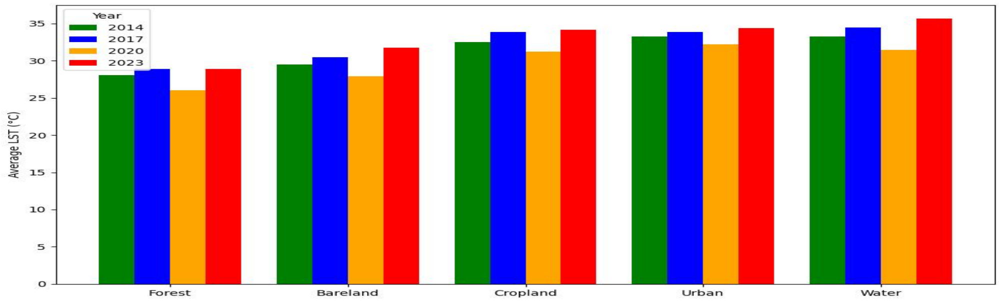


**Figure 4**. The LSTs for different land use types in 2014, 2017, 2020 and 2023 in Butwal, Nepal(◦C)

3.2.1 The Relationship Between NDVI and LST

The NDVIs of Butwal city in 2014, 2017, 2020 and 2023 are shown in Figure 5. Blue indicates areas covered with spare vegetation , and yellow indicates barran Area(rock,sand,snoe,urban). With the change over time NDVI changes changes and fluctuated as the conditions.

**( a) 2014** **(b) 2017**

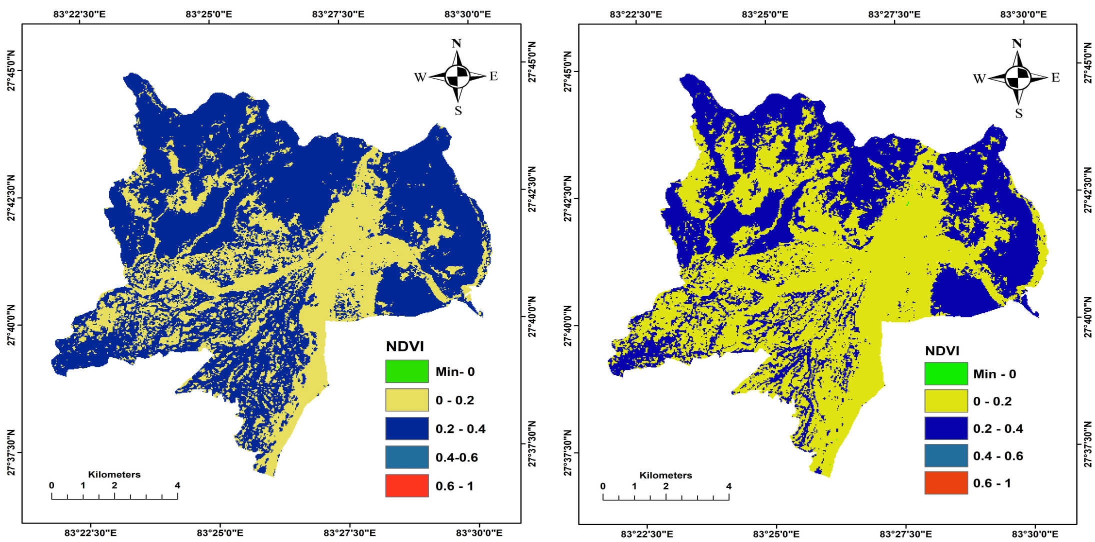


Figure 5. Conti

**(c) 2020** **(d) 2023**

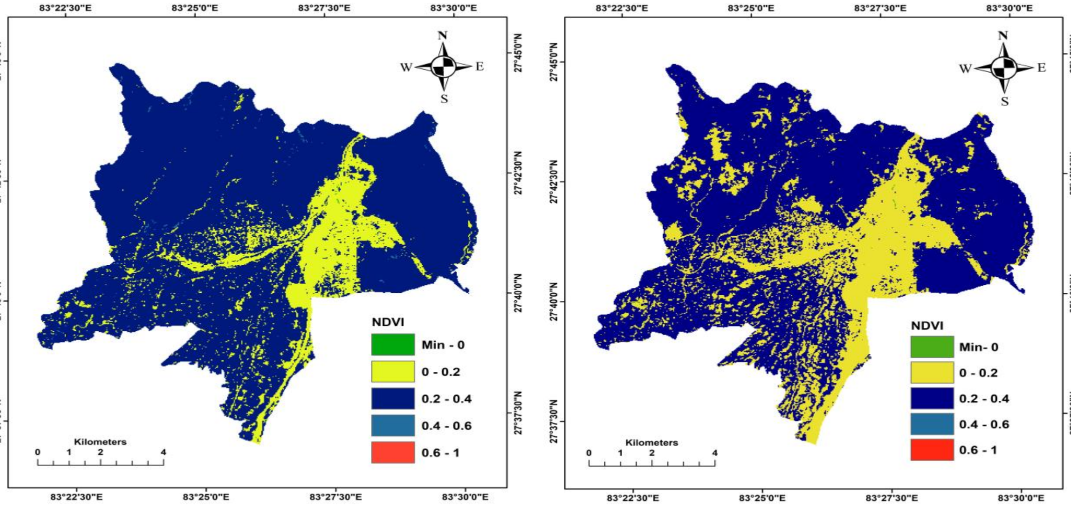


**Figure 5.** The Normalized Difference Vegetation Index (NDVI) maps in (a) 2014, (b) 2017, (c) 2020 and (d) 2023 in Butwal, Nepal

As shown in the Figure 6 the correlation between NDVI (Normalized Difference Vegetation Index) and LST (Land Surface Temperature) from 2014 to 2023 shows a stable negative relationship, ranging from -0.54 to -0.65. This indicates that as vegetation density increases, surface temperatures tend to decrease, consistent with the cooling effect of vegetation through shading and evapotranspiration. While the correlation is generally steady, the slightly stronger negative correlation in 2020 suggests that during this year, the cooling effect of vegetation was more pronounced, potentially due to specific environmental conditions or climatic anomalies. Overall, the data reflects a stable pattern where vegetation consistently contributes to lower surface temperatures over the years, with only minor variations.

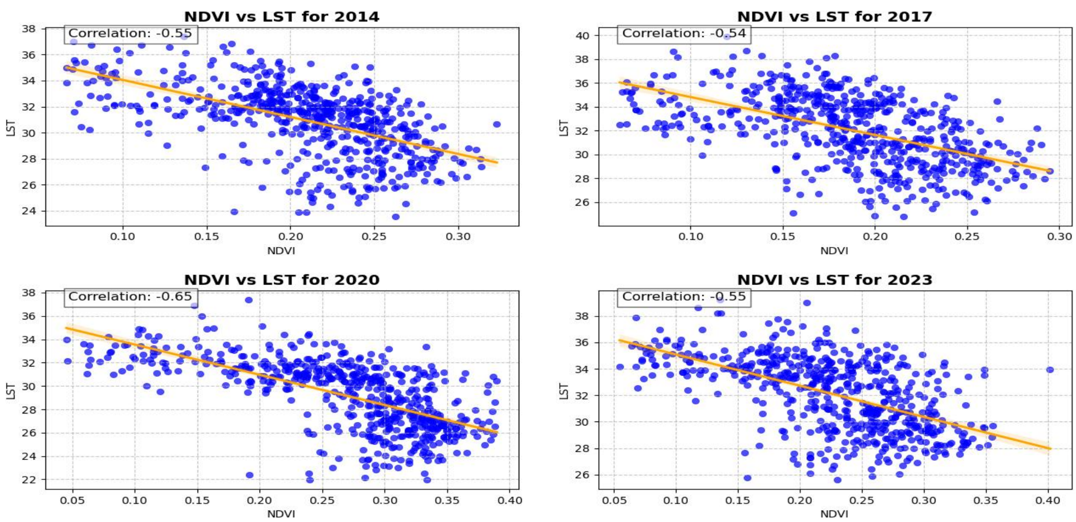


**Figure 6**. The NDVI vs LST Plot

### 3.2.2 The Relationship between NDBI and LST

The NDBIs of Butwal City in 2014, 2017, 2020 and 2023 are shown in Figure 7. Red indicates areas of high building density and blue indicates areas of low building density. As in Figure 7, the impervious layer symbolized by red expanded rapidly from 2014-2023.

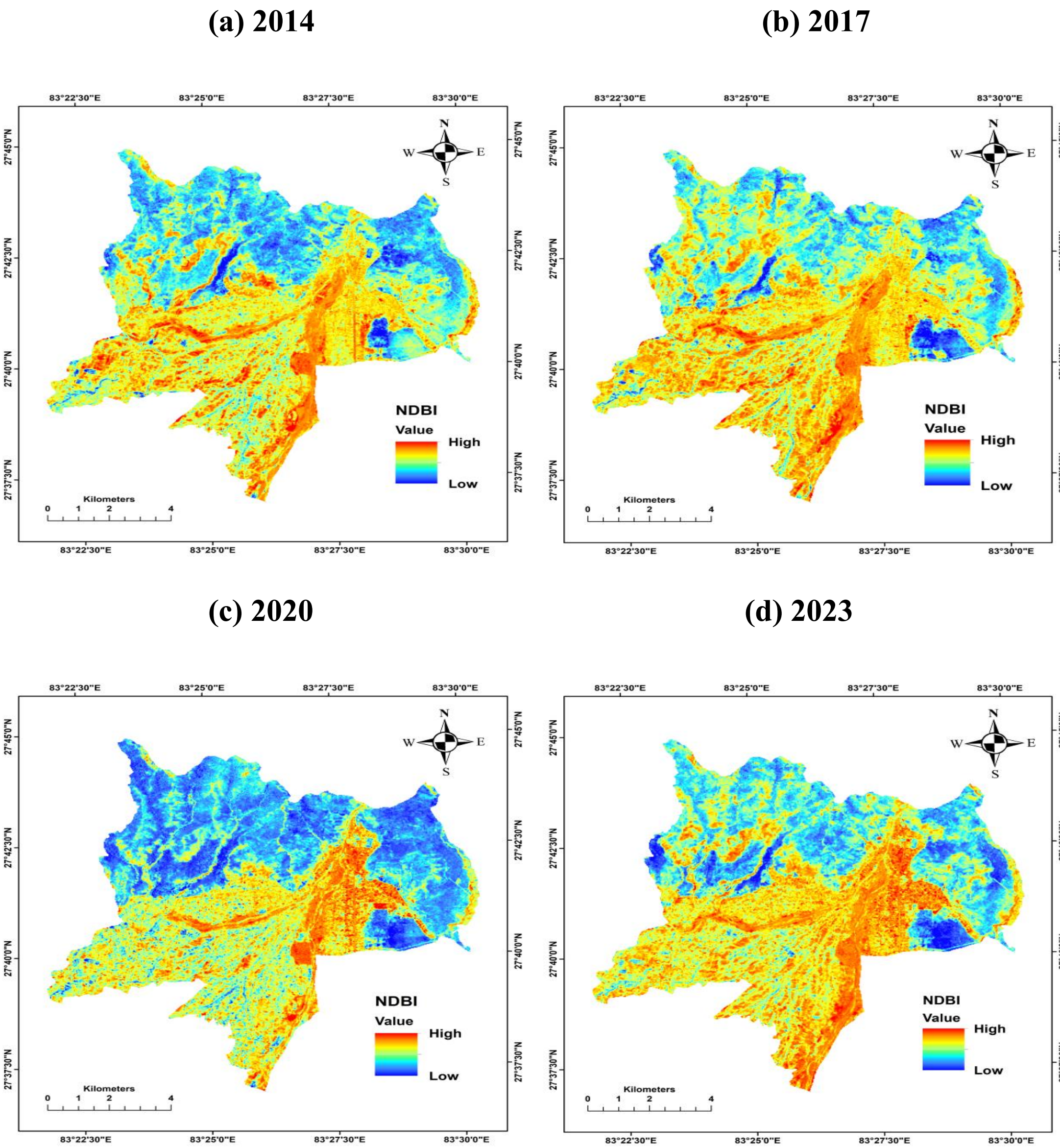


**Figure 7.** The Normalized Difference Building Index(NDBI) maps in (a) 2014 (b) 2017 (c)2020 and (d) 2023 in Butwal, Nepal

The relationship between the variation in NDBI and the varaiation in LST is shown in Figure 8.

The consistently high positive correlation between NDBI and LST from 2014 to 2023, ranging from 0.77 to 0.83, points to a robust relationship between urbanization and rising surface temperatures. This trend highlights the intensifying impact of built-up areas on the urban heat island effect, where impervious surfaces, such as concrete and asphalt, contribute significantly to higher land surface temperatures. The slight increase in correlation in 2020 (0.83) could indicate heightened urbanization or a period of extreme climate conditions, emphasizing the growing vulnerability of urban areas to heat stress.When viewed alongside the NDVI-LST correlation, which shows a stable inverse relationship, these findings suggest that vegetation acts as a natural cooling agent, while urbanization exacerbates warming trends. The contrast between these two indicators reflects the critical need for sustainable urban planning, particularly the importance of integrating green spaces into urban environments to mitigate heat.

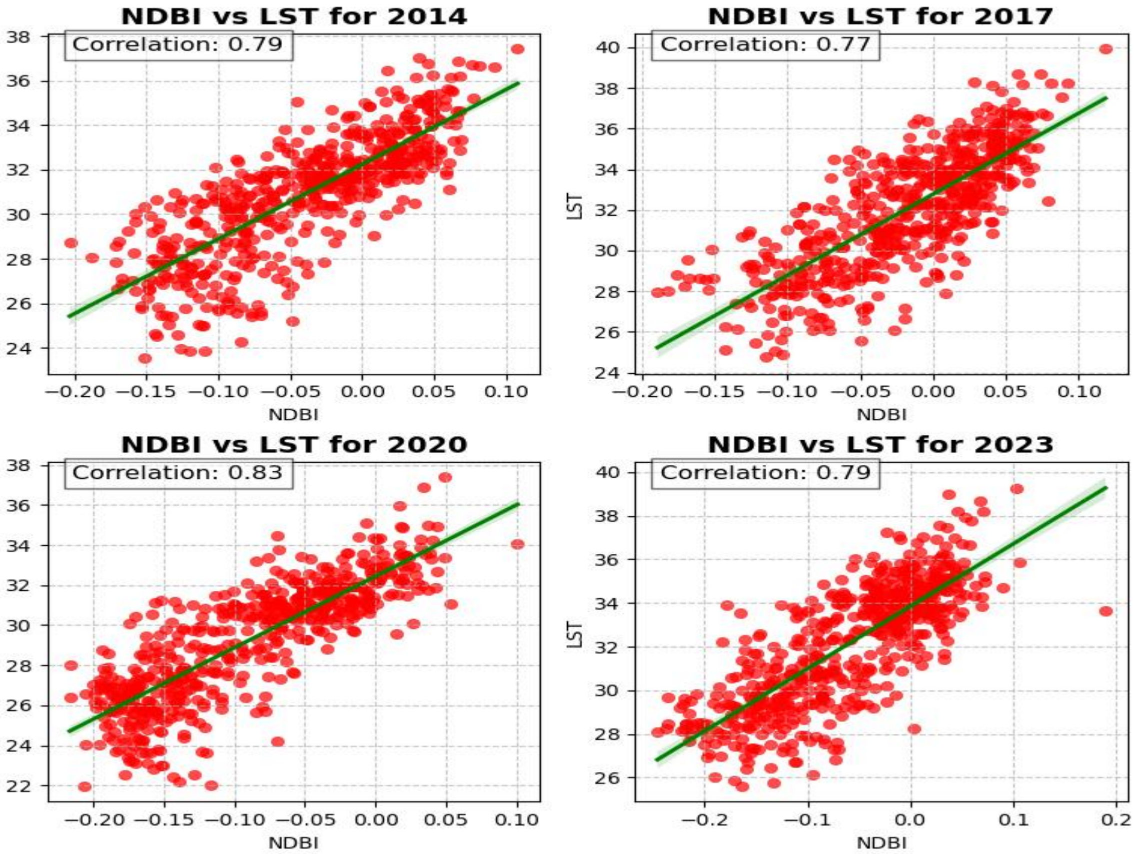


**Figure 8.** The NDBI vs LST Plot

Over time, the constant strength of the NDBI-LST correlation suggests that without intervention, urban areas will continue to experience increasing heat stress, with potential consequences for human health, energy demand, and overall urban livability. This data underscores the urgency for adaptive measures, such as expanding vegetation cover and implementing heat-reducing infrastructure, to offset the growing impacts of urbanization on local climates.

# 4. Discussion

4.1 Land Use/Land Cover (LULC) Has a Strong Driving Effect on LST

The rapid expansion of the city has led to dramatic changes in the underlying surface and spatial functional structure [26]. Changes in the surface albedo greatly impact the UHI effect.

According to Figure **3**,in 2014 the high LST area is concentrated in the central urban areas and River side.t. Due to the long wave radiation emitted by dense buildings, the temperature in the central city is higher than that in the suburbs. The imaging period used in this study was in 1$^{st}$ week of April. In the first week of April, Butwal typically experiences very warm weather, with daytime temperatures around 34°C and nighttime lows near 19°C. It is generally one of the hottest times of the year in this region. Rainfall is relatively low, with only a few days of rain, averaging around 39 mm throughout the month.

According to the hypsometric map (Figure **1**), the northern part of Butwal is more elevated, with altitudes reaching up to 1,062 meters, particularly in the Chure hill region. These higher elevations contribute to reduced soil water retention due to steeper slopes, causing increased runoff and faster evaporation of soil moisture, which in turn can lead to elevated LST (Land Surface Temperature). In contrast, the southern part of Butwal lies in the lowlands, especially near the Tinau River floodplain, where the soil is primarily composed of alluvial sandy deposits. This sandy soil tends to heat up rapidly under direct solar radiation, leading to increased surface temperatures. The combination of varied elevation and soil types creates distinct patterns of temperature and moisture retention across the region.

In 2017, the spatial distribution of high Land Surface Temperature (LST) areas closely mirrored that of 2014, indicating stable temperature patterns over this period. However, as urbanization progressed, particularly in central urban areas, there was a notable expansion of high-temperature zones towards the periphery, a trend consistent with the Urban Heat Island (UHI) effect. This effect occurs because built-up areas with extensive concrete and asphalt absorb and retain more heat compared to natural landscapes, leading to elevated LST.

By 2020, there was a temporary decrease in LST, which can be attributed to several factors. One significant factor was increased vegetation cover resulting from urban greening initiatives, such as planting trees and creating parks, which help mitigate the

UHI effect by providing shade and cooling the air. Additionally, improved urban planning practices, including the use of reflective materials for pavements and roofs, and the incorporation of sustainable building practices, may have contributed to this reduction. Natural climate variations, such as cooler temperatures or increased rainfall, could also have played a role. Another possibility is a temporary slowdown in urban expansion, which may have halted the spread of high-temperature zones.

However, by 2023, LST levels began to rise again, largely due to renewed construction and urban development, particularly in the south-east parts of Butwal. This region experienced significant growth, with new infrastructure and development zones being established. The replacement of natural landscapes with heat-absorbing surfaces such as new buildings, roads, and industrial areas intensified the UHI effect, leading to an increase in LST. Thus, while the decrease in LST in 2020 was likely due to targeted interventions and natural factors, the rise in temperatures by 2023 reflects the impact of ongoing urban expansion and development.

The negative correlation between NDVI and LST shows that vegetation has the effect of alleviating the heat island effect. Plants can evaporate water into the atmosphere through transpiration at the leaf surface, increasing the humidity of the air, and removing some of the heat, thus reducing the temperature. Large areas of green space especially help to improve the thermodynamic properties of the surface and promote the cooling and circulation of air, thus playing a significant role in easing the heat island effect and limiting the diffusion of the heat island effect.

It is worth noting that the relationship between NDVI and LST is segmented.In areas with smaller changes in NDVI, The LST is also susceptible to the external environment. This is similar to related research results. The climate, research scale, and soil moisture will interfere with the cooling rate of vegetation on the LST, especially in areas with smaller changes in NDVI, and this interference is significant [82,83]. At the same time, the vegetation types and landscape pattern of the vegetation area will also affect the cooling effect. It is shown in Figure **6** that the cooling potential of forests is the greatest. The vegetation heat dissipation showed a clear, consistent potentiality increase to a curved patch shape, with bigger dimensions that was smoothly connected to other patches, which facilitated surface heat loss to the surroundings [27].

The positive linear correlation between NDBI and LST shows that buildings change the exchange of latent heat and sensible heat on the surface directly and play a significant role in driving the UHI effect [28]. The urban system is an important ecological system and is most affected by human activities; transformation of a city radically changes the thermal properties of the underlying surface. Urban construction and expansion have resulted in a large amount of vegetation and fertile land being replaced by an impermeable layer. These materials have the characteristics of high thermal conductivity, a strong absorptive capacity, a large heat capacity, small thermal inertia and low evaporation energy consumption, and under the same solar radiation, the impermeable layer warms faster than the natural surface.

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### 4.2 The Driving Effect of Socio-Economic Factor on LST

From 2014 to 2023, Land Surface Temperature (LST) in Butwal, Nepal, has been significantly influenced by a range of socio-economic factors. In 2014, central Butwal had an average LST of approximately 35°C. By 2023, areas undergoing intensive development, particularly those with substantial new construction and infrastructure, recorded temperatures as high as 40°C. This notable increase in LST is primarily attributed to the Urban Heat Island (UHI) effect, where urban areas, with their extensive use of heat-absorbing materials like asphalt and concrete, experience higher temperatures compared to surrounding natural landscapes.

Economic growth in Butwal has further amplified this trend. The city has seen a substantial expansion of commercial and industrial activities, which has led to the proliferation of heat-retaining surfaces. Data from 2017 to 2023 shows that regions with significant economic development, such as new business and industrial zones, experienced a temperature rise of about 5°C. This increase aligns with patterns observed in other rapidly urbanizing cities, where economic activities correlate with elevated LST due to the extensive use of materials that absorb and retain heat.

The reduction in green spaces has also played a crucial role in the rising temperatures. In Butwal, green cover decreased from approximately 28% in 2014 to 18% in 2023. This decline is directly linked to the expansion of urban areas, which replaces natural vegetation with impervious surfaces. The loss of green spaces, which traditionally provide cooling through shade and evapotranspiration, has resulted in temperature increases of up to 6°C approx. in affected areas. This reduction in vegetation directly contributes to higher LST by eliminating natural cooling mechanisms.

Population growth has compounded these temperature trends. Butwal's population grew from around 100,000 in 2014 to over 150,000 by 2023. This rapid increase in population has driven higher demand for housing, infrastructure, and services, contributing to further urban sprawl and the expansion of heat-absorbing surfaces. As the city expands to accommodate a growing population, LST in newly urbanized areas has risen, reflecting the combined impacts of increased population density and development.

4.3 Implications

From the abovementioned analysis, this study has produced some implications for urbanists to consider to reduce the negative UHI effect of city development.

1. Enhance urban greening coverage by increasing public facilities like green parks and forest parks. Encourage residents to build green roofs.
2. Reverse the traditional expansion model of single-center cities and promote multi-center cities. Control the total scale of built-up areas.
3. Control energy consumption, urban economic development intensity, population, and distribution to curb the UHI effect.
4. Control the development of urban real estate and high-rise buildings to reduce atmospheric pollution and human energy emissions.

## 5. Conclusions

This study highlights the significant impact of urbanization on land surface temperature (LST) in Butwal, Nepal, from 2014 to 2023. Over this period, the LST showed a consistent upward trend, with temperatures increasing as natural vegetation was replaced by impervious surfaces such as buildings and roads. The analysis of specific years reveals that the average LST rose from 30.91°C in 2014 to 32.09°C in 2023, with 2017 recording 32.01°C and a temporary decline to 29.62°C in 2020. The brief decrease in 2020 may be attributed to urban greening efforts or climatic variations, but the general trend points to a steady intensification of the urban heat island (UHI) effect. The strong positive correlation between the Normalized Difference Building Index (NDBI) and LST emphasizes that areas with high building density experience higher temperatures. Conversely, the negative correlation between the Normalized Difference Vegetation Index (NDVI) and LST indicates that vegetation plays a crucial role in mitigating heat. The results suggest that socio-economic factors, including population growth and infrastructure development, have driven the increase in LST, further contributing to the UHI effect. Therefore, implementing sustainable urban planning practices is critical to managing rising temperatures and ensuring long-term livability in Butwal.

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