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Approximation of surface urban heat island (SUHI) effect over four populated cities of Andhra Pradesh state of India using ground and satellite data

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Abstract

This work reports the probable effect of population ingress in generating urban heat islands over four cities of Andhra Pradesh state of India. We identified twenty-six UHIs and chose four UHIs based on the population data. The period from 1961 to 1990 was selected as the reference period, and 2003 to 2020 was selected as the study period to determine the deviations in mean temperatures. We framed a methodology to filter and select the UHIs to know the effect of SUHI using online resources for data and plots that are free of cost and user-friendly. One out of four UHIs exhibited a stronger deviation in night-time temperatures than in day-time temperatures. We observed that the rise in population equally contributes to the temperature deviations over the long term in the selected areas. We conclude that the population ingress may influence land surface temperatures and induce the SUHI effect.

1. Introduction

The land surface temperature (LST) variation between urban and non-urban areas can be called the surface urban heat island (SUHI) effect. Population growth and other variables can change the thermal characteristics of land, thereby generating surface urban heat islands (SUHI) [1]. Normalized Difference Vegetation Index (NDVI) and seasonal variations have influenced the SUHI effect over some of the regions in India [2]. Index-based built-up Index (IBI) and NDVI values were used to determine the land surface temperature (LST) variations that aided in explaining urban microclimate (SUHI effects) [3]. Urban agglomeration (reduction of natural resources) has a definite effect on varying LST, leading to urban heat islands that may lead to climate anomalies [4]. Increasing LST and urban population can induce a domino effect of irreversible environmental damage that may have long-term effects on the quality of life (QOL) [5–7]. The population ingress into urban areas in various unsustainable approaches led to reduced green cover (vegetation), leaving the inhabited terrain and UHIs [8–10]. Landsat 8 and Sentinel 2,3 data were used in various studies to explain the extent and effects of UHIs (SUHI effects) [11–13]. The surface urban heat islands can be characterized using simplified urban-extent algorithms (using Google Earth engine) with vegetation as a controlling factor [14]. The datasets and plots needed to investigate urban heat islands and the SUHI effect can be easily obtained online with no charges and limited effort and are user-friendly [15,16]. The United States Environmental Protection Agency (US EPA) describes the causes of UHIs. Some of the causes are diminished natural landscapes, characteristics of urban materials, urban geometry, heat from anthropogenic activities, geography, and weather. Reduced natural landscapes can lower moisture and shade in urban areas. The materials used in urban infrastructures absorb heat throughout the day but release it slowly during the night. The dimensions and spacing between the buildings can affect the wind flow, reducing the chances of natural urban cooling. Vehicles, air conditioners, and others can generate heat, contributing to UHI formation. Though mountains in the vicinity naturally block wind flow into the urban areas, clear and calm weather can also create UHIs. The present study is aligned with contemporary research [17–20] and aimed at filling the gaps in terms of filtering and selecting UHIs based on population and demonstrating the SUHI effect with reference period (1961 to 1990) and study period (2003 to 2020).

2. Material and Method

The datasets needed for this study were obtained from NASA (AQUA Land Surface Temperature (LST) and MODIS TERRA) [21] and https://open-meteo.com/en/docs/historical-weather-api [12]. The population data (2001/2011) was obtained from the Census of India website (https://censusindia.gov.in) [22]. The SUHI temperature deviations were obtained from a previous study on urban heat islands by Chakraborty and Lee, 2019 [14]. The plots for this study were prepared from the Python-based application provided by Jan Kühn, 2023 (https://github.com/yotkadata/meteo_hist) [23]. The population data collected was used to filter the areas with a high population. There are approximately 26 urban heat islands spread across the study area. We filtered out the urban heat islands with high populations and selected four out of 26 UHIs. The SUHI deviations were studied, the years in which there is a high deviation were selected, and the annual temperature deviation for the selected years was studied and plotted for reporting. The reference period considered in this study is from 1961 to 1990, as recommended by the World Meteorological Organization (WMO), and the study period is from 2003 to 2020. The study areas are given in Figure 1, and detailed methodology is given in Figure 2.

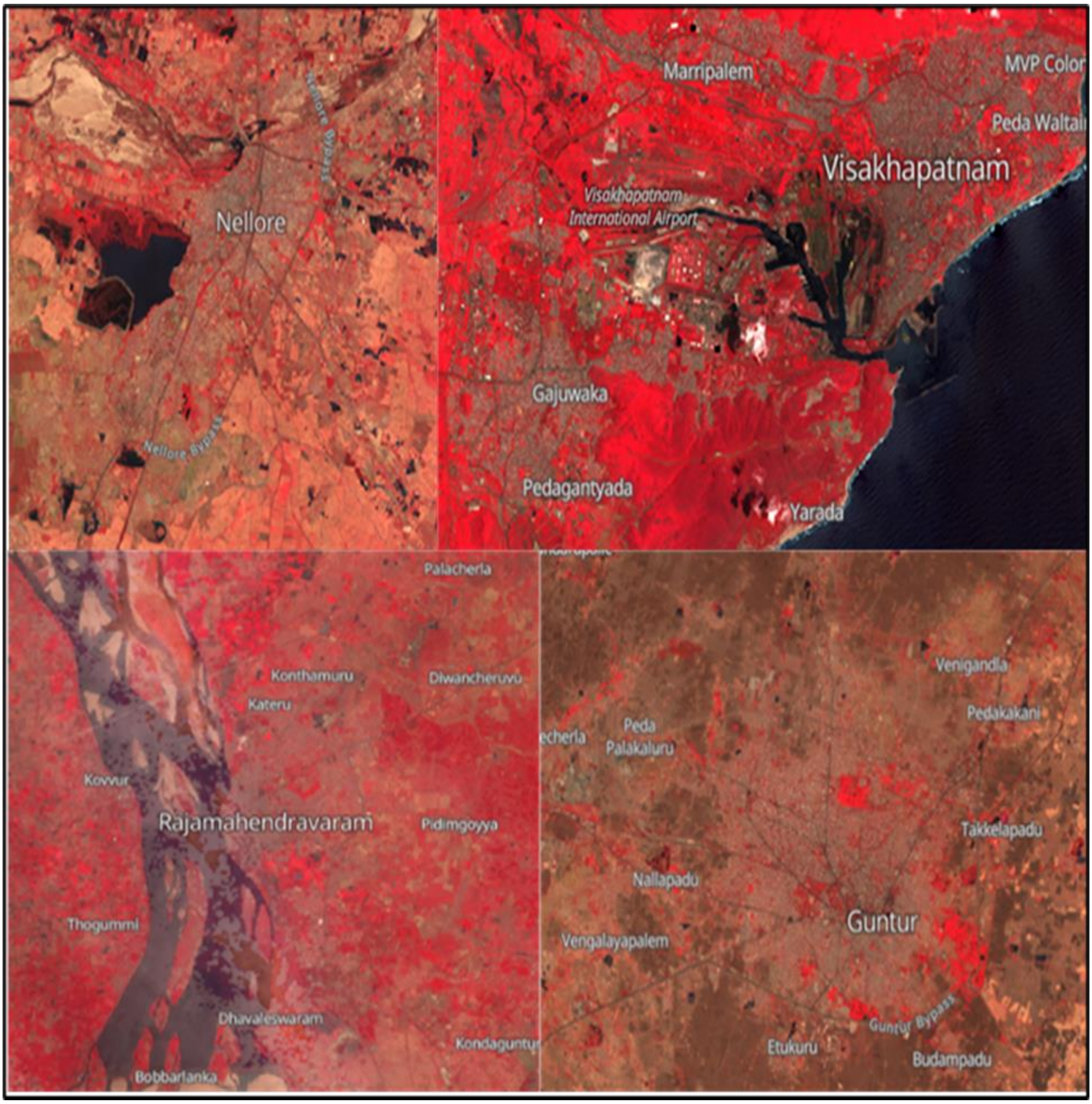

Figure 1. Harmonized Landsat and sentinel images of four urban heat islands.

NDVI can be calculated using Equation 1.

$$(NIR - R) / (NIR + R), \text{In Landsat 4-7, NDVI} = (\text{Band 4} - \text{Band 3}) / (\text{Band 4} + \text{Band 3}) \quad (1)$$

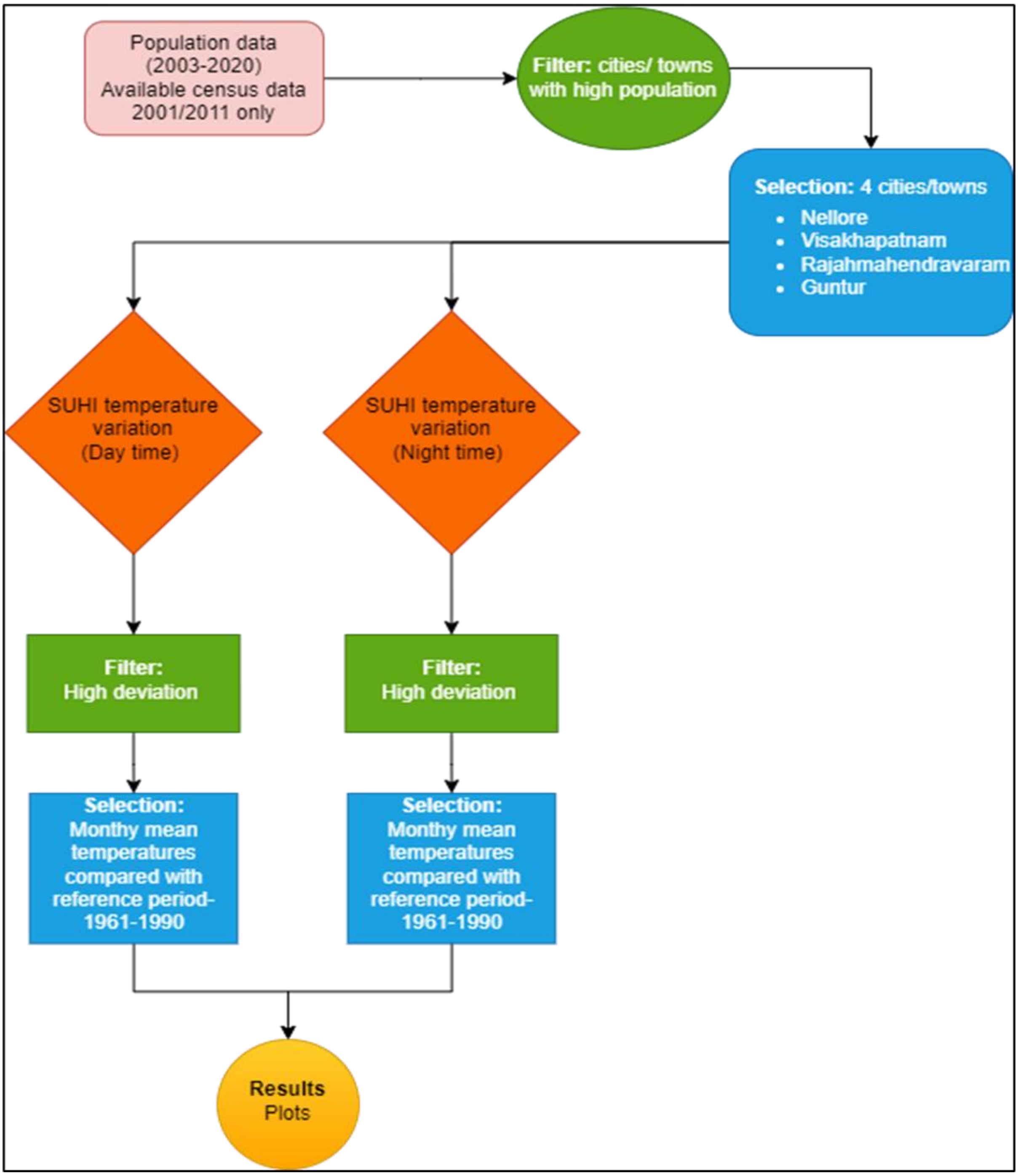

Figure 2. Method.

3. Results

The results are given in Figures 3 to 11. We obtained 4 UHIs out of 26 UHIs based on the population data. They are Nellore, Visakhapatnam, Rajamahendravaram, and Guntur. The change in population from 2001 to 2011 for these cities is 28% (Nellore), 22% (Visakhapatnam), 14% (Rajahmahendravaram), and 24% (Guntur). We observed an increase of 2.8 °C in Sep-Oct/2011 and a 2.6 °C increase in May/2020 compared to the reference period for Nellore UHI (Figures 3 & 4). We observed an increase of 2.2 °C in Dec/2016 and about 3.4 °C increase in May/2020 compared to the reference period for Visakhapatnam UHI (Figures 5 & 6). We observed an increase of 4.8 °C in Jun/2014 and about 2.8 °C in Nov/2020 compared to the reference period for Rajahmahendravaram UHI (Figures 7 & 8). We observed an increase of 4.6 °C in May/2013 and about 3.9 °C in April/2016 compared to the reference period for Guntur UHI ((Figures 9 & 10). NDVI images of all UHIs are also presented in Figure 11.

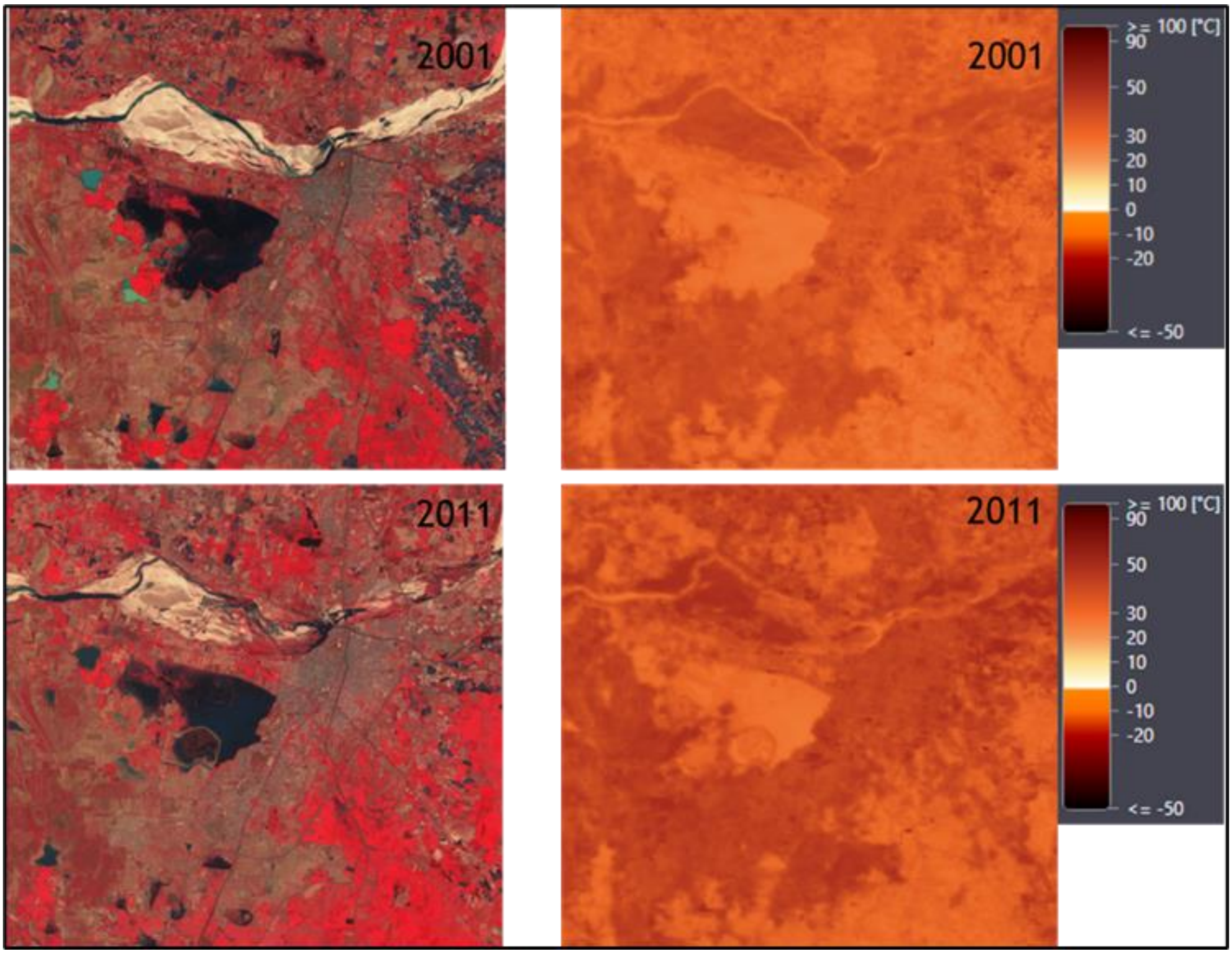

Figure 3. Nellore UHI FCC and Thermal band 6 (Landsat 4-5 TM L2).

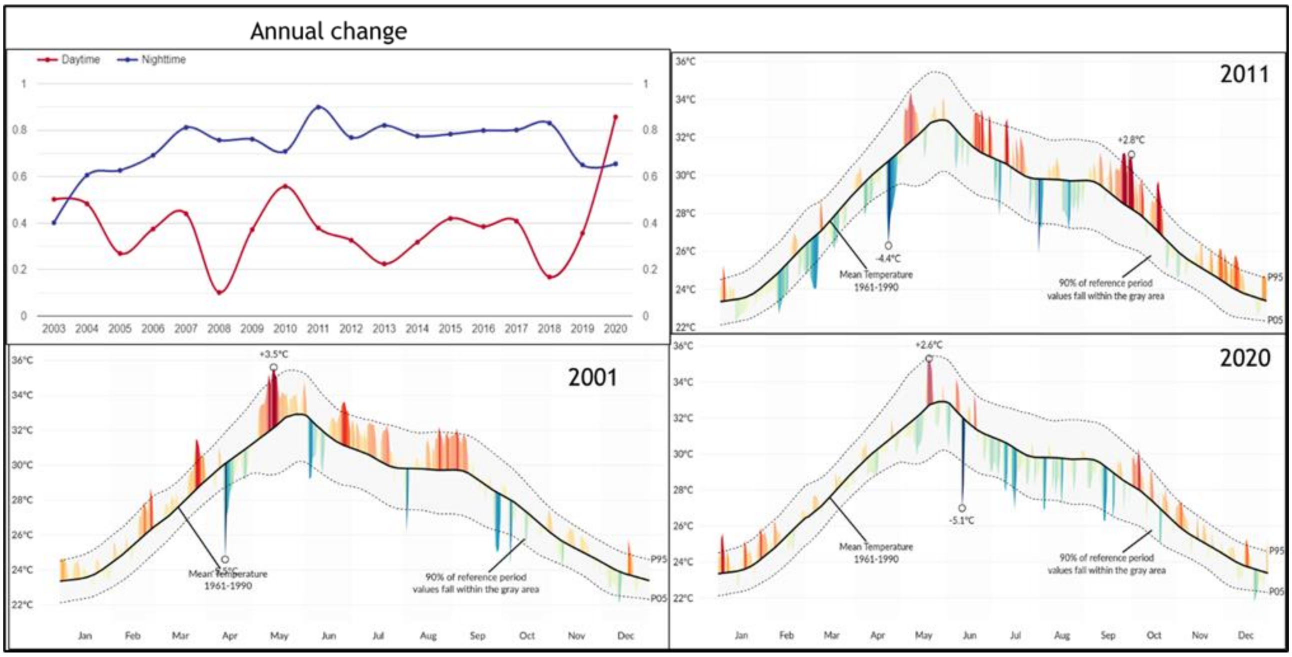

Figure 4. Nellore (UHI) Annual change (°C) & mean annual temperature variation in 2001, 2011, and 2020 (Reference period: 1961-1990).

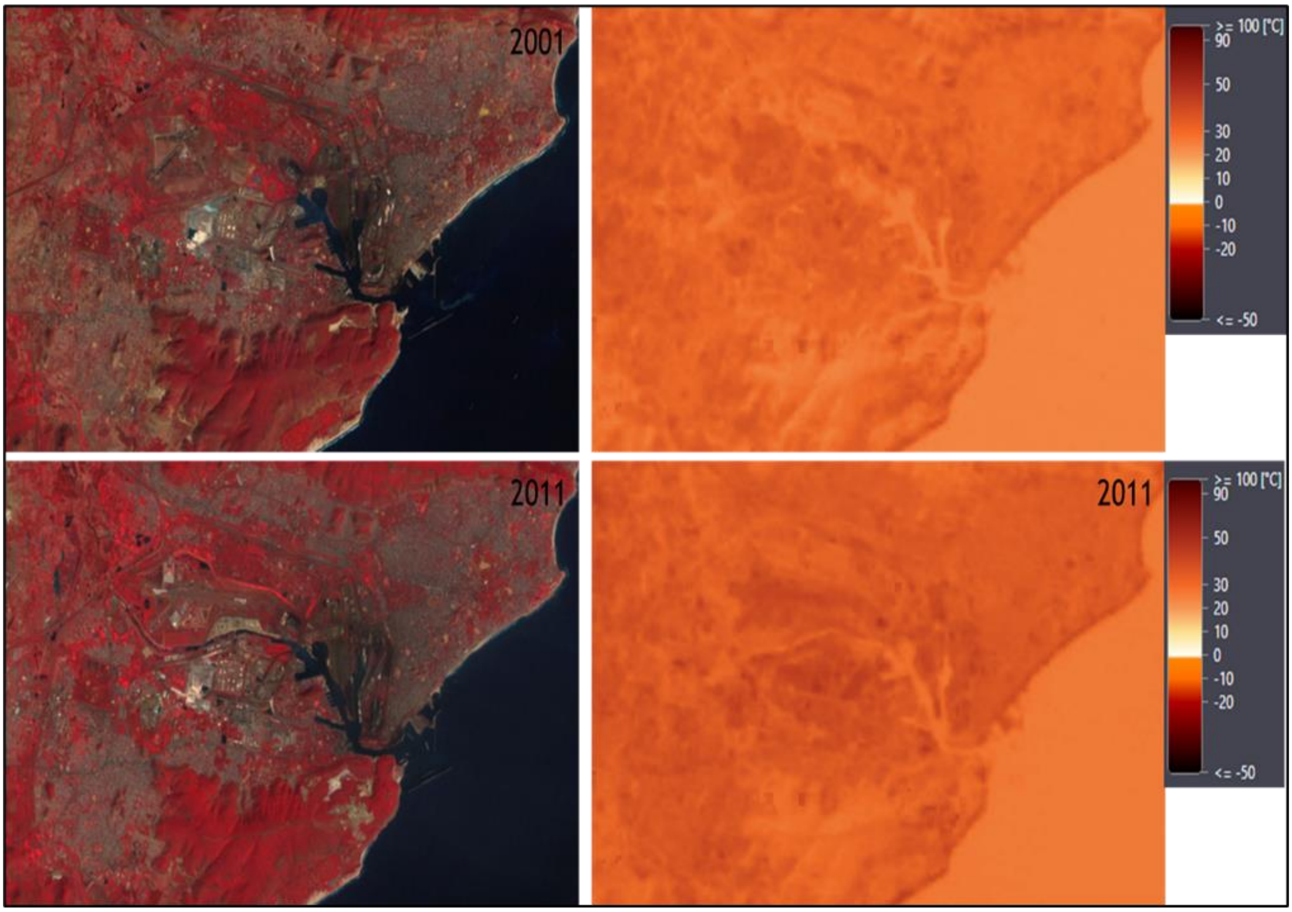

Figure 5. Visakhapatnam UHI FCC and Thermal band 6 (Landsat 4-5 TM L2).

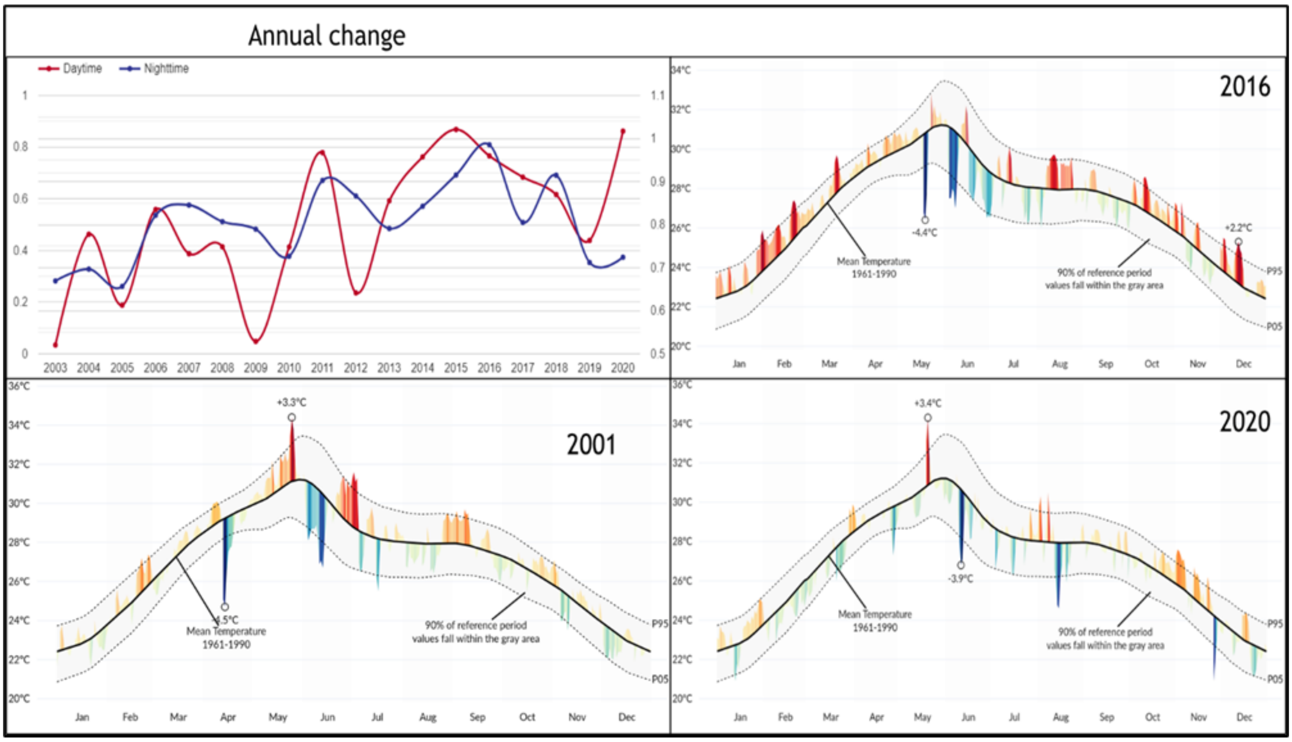

Figure 6. Visakhapatnam (UHI) Annual change (°C) & mean annual temperature variation in 2001, 2016, and 2020 (Reference period: 1961-1990).

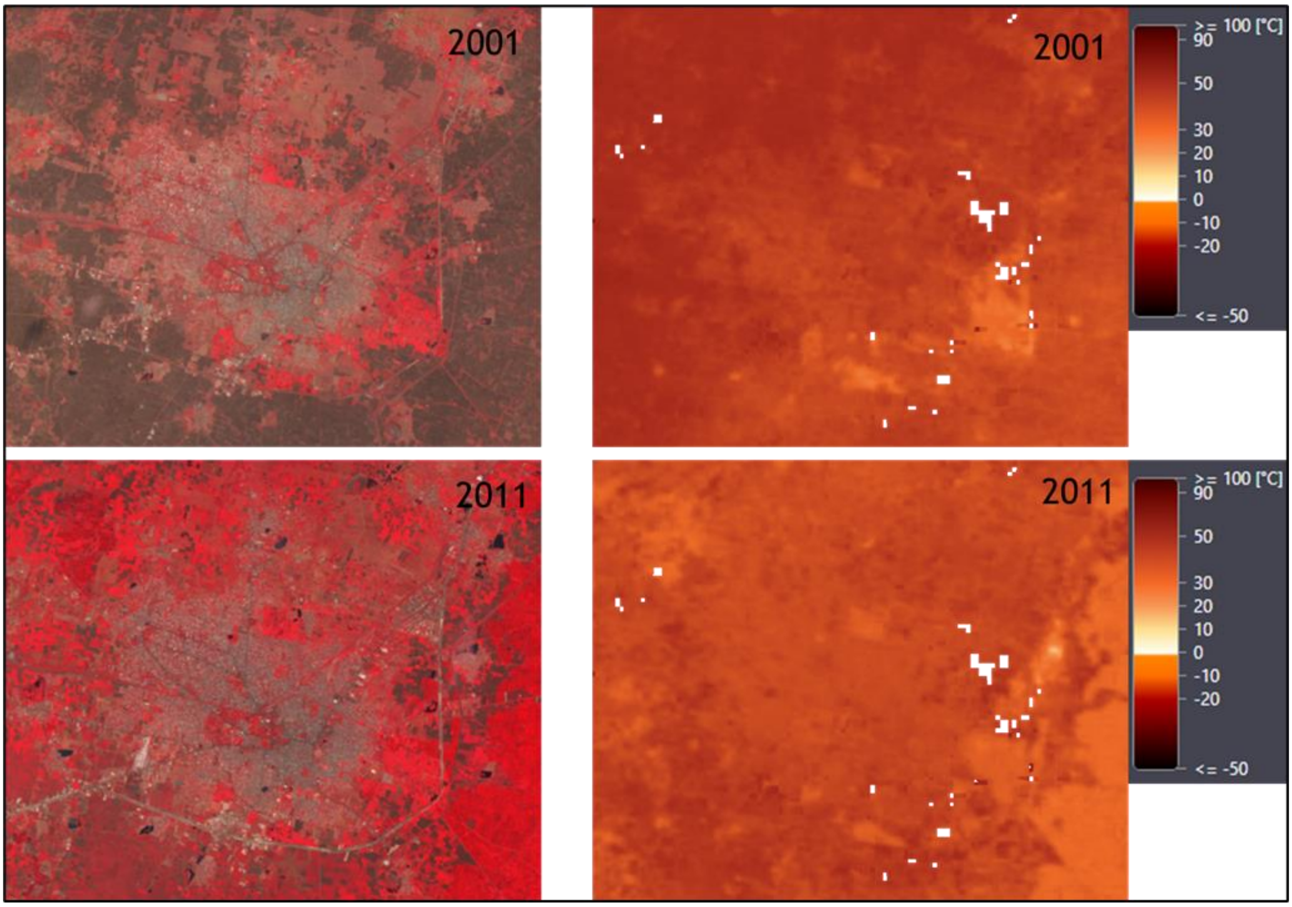

Figure 7. Guntur UHI FCC and Thermal band 6 (Landsat 4-5 TM L2).

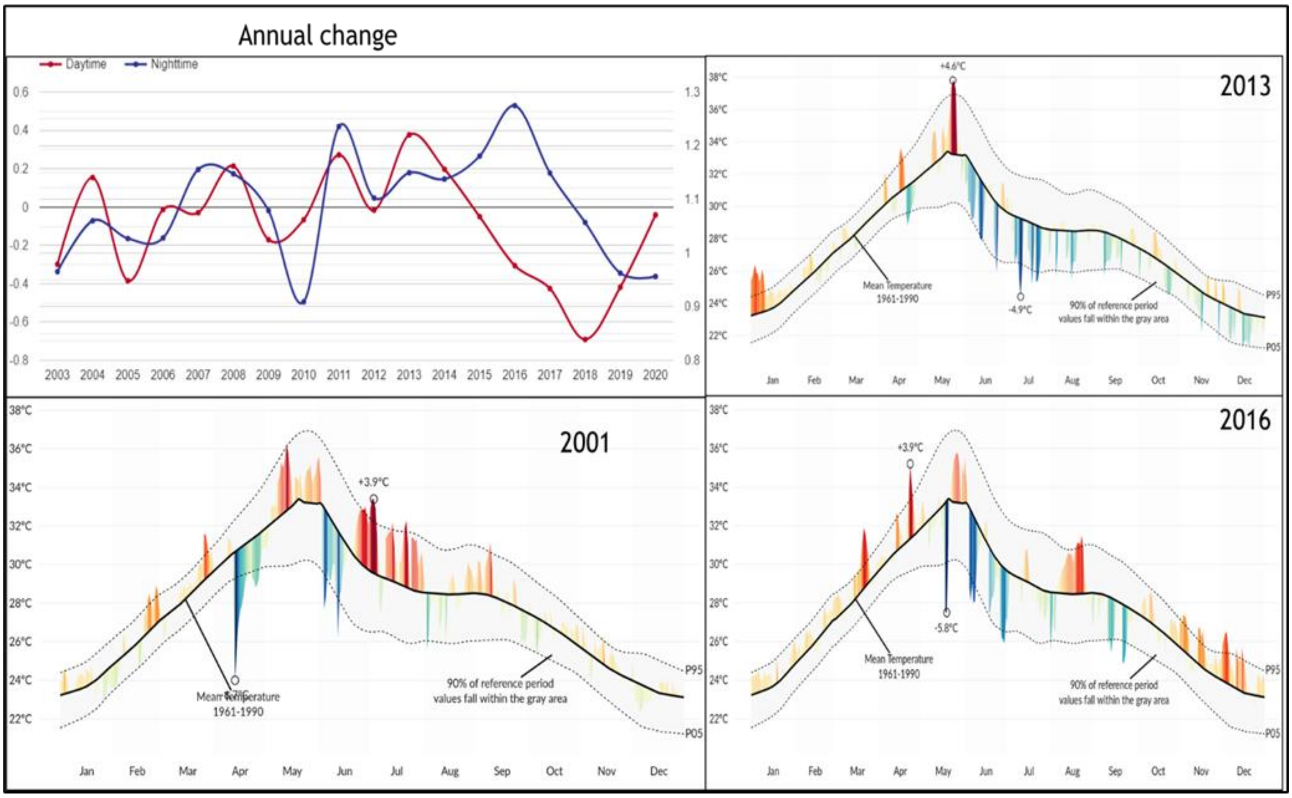

Figure 8. Guntur (UHI) Annual change (°C) & mean annual temperature variation in 2001, 2013, and 2016 (Reference period: 1961-1990).

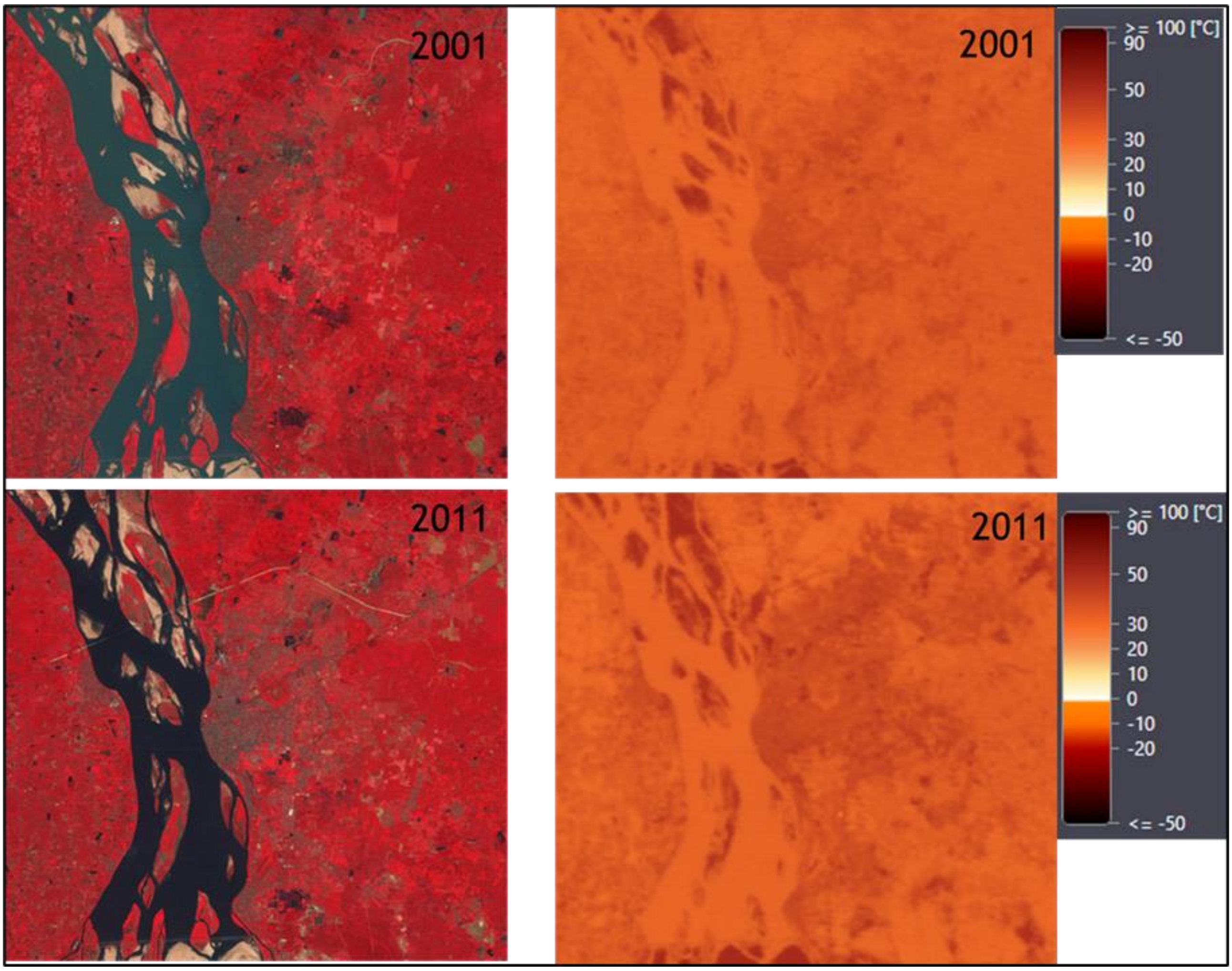

Figure 9. Rajahmahendravaram UHI FCC and Thermal band 6 (Landsat 4-5 TM L2).

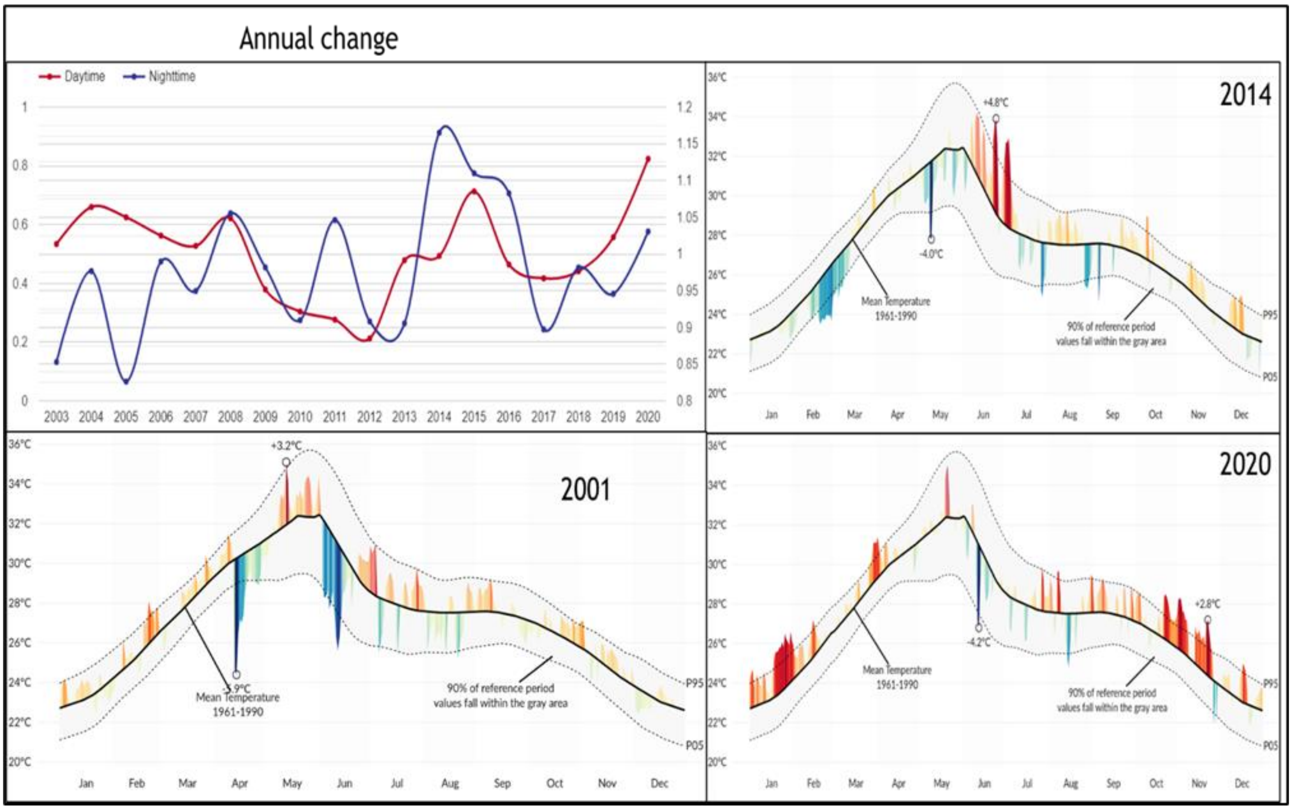

Figure 10. Rajahmahendravaram (UHI) Annual change (°C) & mean annual temperature variation in 2001, 2014, and 2020 (Reference period: 1961-1990).

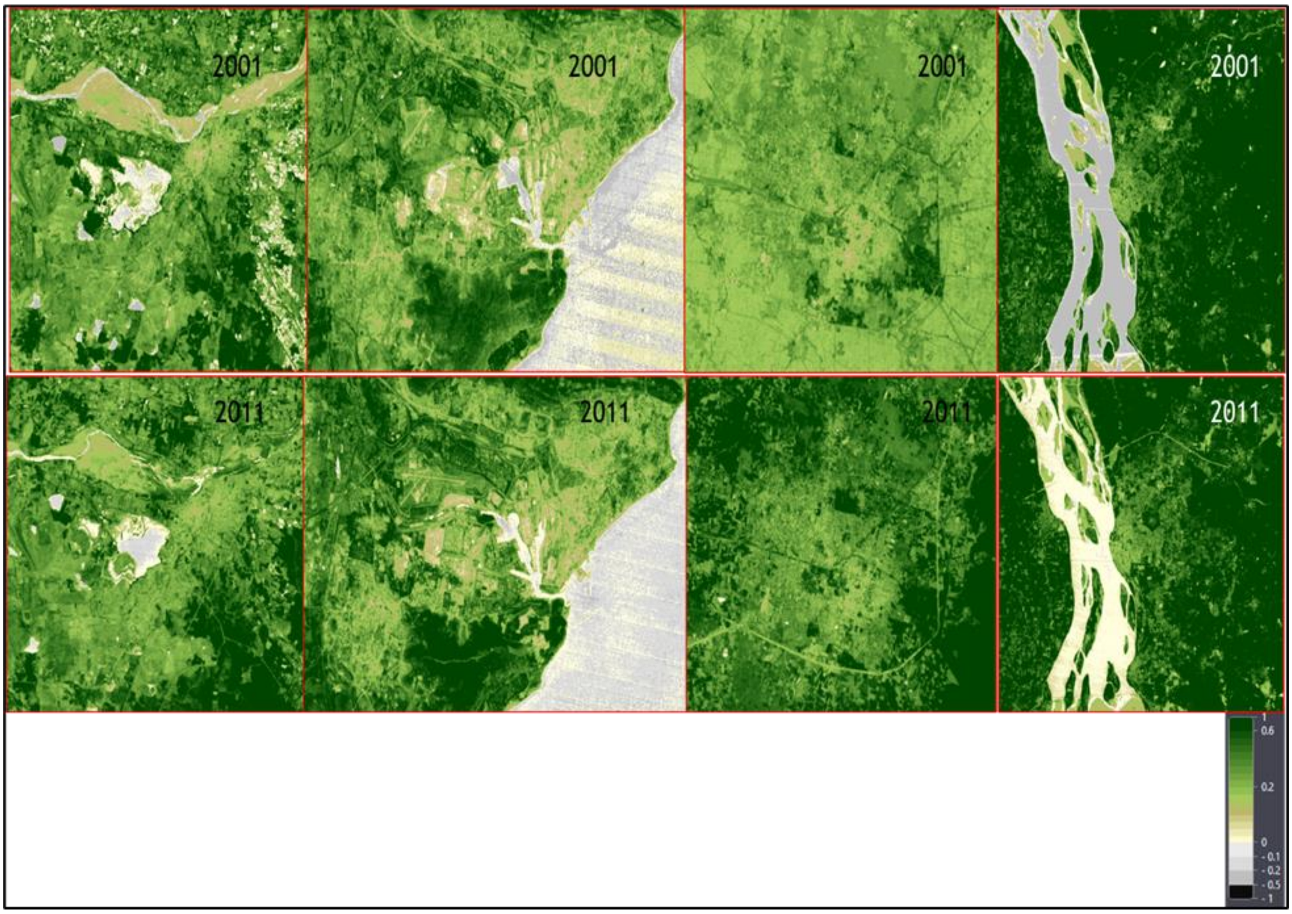

Figure 11. NDVI (2001 & 2011) of 4 UHIs.

4. Discussion

This work was initiated on the premise that there will be a clear indication of population growth and the SUHI effect. Considering our research premise, we observed the following that may be worth discussing. Nellore UHI: The population increase of 28% from 2001 to 2011 has affected the SUHI temperature deviations (discrete), supporting our view. The night-time temperatures were relatively less affected than day-time temperatures. Visakhapatnam UHI: The population increase of 22% from 2001 to 2011 has affected the SUHI temperature deviations (discrete), supporting our view. The night-time temperatures and day-time temperatures were affected. Rajahmahendravaram UHI: The population increase of 14% from 2001 to 2011 has affected the SUHI temperature deviations (discrete), supporting our view. The night-time temperatures were more deviated than day-time temperatures. Guntur UHI: The population increase of 24% from 2001 to 2011 has affected the SUHI temperature deviations (discrete), supporting our view. The night-time temperatures and day-time temperatures were affected. We also observed that certain regions in the study area showed changes in vegetation cover, supported by NDVI images (Landsat). We noticed that all the UHIs have exhibited a considerable variation in vegetation cover.

5. Conclusion

We conclude that population growth may have a role in inducing the SUHI effect over the highly populated urban heat islands. We also opine that sustainable population ingress methods can improve the quality of life in the future. Some of the vegetation renewal practices can improve the livability in the urban zones. The urban areas need to imbibe some sustainable methods to lower the SUHI effect without jeopardizing industrial development. There is no escape from natural radiation, and this can be the main reason behind the UHI formation. We can sense UHIs easily at night when they start exhaling heat, which helps us track the selective characteristics of the materials used in urban structures. Given the budgetary constraints in manufacturing an urban area and its maintenance, there is always a void of information/data that condenses us to limit our studies. At this juncture, we can include some vegetation renewal methods that can reduce heat to some extent, but that may not be sufficient. If we push to include measures to revamp urban layouts, keeping urban cooling in our minds completely, then it is hard to strike a balance between quality of life and employment opportunities. As the roots of the urban landscape lie in continuous development, space for commercial and non-commercial businesses is always needed. This will create a dilemma as to the balance we seek between environment and development. The governments of India and

Andhra Pradesh are making many efforts to reduce the SUHI effect in many areas, and many positive developments are ongoing, leading us to sustainable development.

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Conflicts of interest

The authors declare no conflicts of interest.

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