TEMPORAL VARIATION OF URBAN HEAT ISLAND USING LANDSAT DATA: A CASE STUDY OF AHMEDABAD, INDIA

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Abstract: Rapid urbanization and population increase have led to alterations in the surrounding environment of cities, thereby making it imperative to determine the relationship between climate and urbanization. Ahmedabad is the 7th largest city of India situated in the hot and dry climatic region. This research aims to map the Urban Heat Island of Ahmedabad City using Thermal Infrared Imagery of Landsat TM and ETM+. Land Surface Temperature has been calculated using emissivity values and brightness temperature from satellite images of Ahmedabad acquired at same time of the year.

The variations in intensity of Urban Heat Island in decade were studied. The UHI intensity varies from 0.4°C to 0.8°C approximately. The land cover types were determined by Supervised Classification using Maximum Likelihood Classifier. The effect of various land cover types on UHI Intensity was assessed. The average surface temperature was calculated for each land cover class. The highest temperature is contributed by the built up areas. Built up areas occupy 45% of the total area of Municipality Corporation in 2011 as compared to 38% in 1999, contributing to UHI Intensity. The spatial profiles of surface temperature from different years were compared. The changes in the spatial extent of land cover contributing to variations in spatial profile have been determined. The changes in UHI patterns were analyzed in association with land cover maps to determine the impact of surface properties on UHI intensity. The results show that the temperature is low in areas having high NDVI.

INTRODUCTION

Urbanization, while being necessary for advancement of humanity, has many irreversible negative impacts on the environment. These urban areas contribute a lot of anthropogenic heat and air pollution to the environment thus affecting the climate. This interrelation between urbanization and climate is manifested by two major phenomena observed in cities namely Urban Heat Island (UHI) and Urban Cool Valley (UCV) representing a higher and a lower temperature pool in a city (Memon, 2009). The higher temperature in urban areas compared to the surrounding rural areas confirms the existence of UHI in major cities across the world. The intensity and spatial extent of UHI varies with time, location, meteorological characteristics and construction patterns of a city (Shahmohamadi et al., 2010). Hence, UHI study needs to be attempted specifically for a particular city due to the difference in its local and synoptic factors (Velazquez-Lozada et al., 2006), to prepare the future development plan of the city and to determine the mitigation measures.

STUDY AREA

This study focuses on the assessing the UHI intensity for Ahmedabad city. Ahmedabad is the 7th largest city of India situated in the hot and dry climatic region. Ahmedabad spans between 72° 30' E to 72° 41' E longitude and 22° 56' N to 23° 07'N latitude (AMC, 2011). The major physiographic feature of Ahmedabad is the Sabarmati River which divides the city into two halves: the eastern walled city and the western Ahmedabad (Figure 1). There are three main seasons: summer, monsoon and winter. Summer season begins in March and continues till June. Winter extends from December to February.

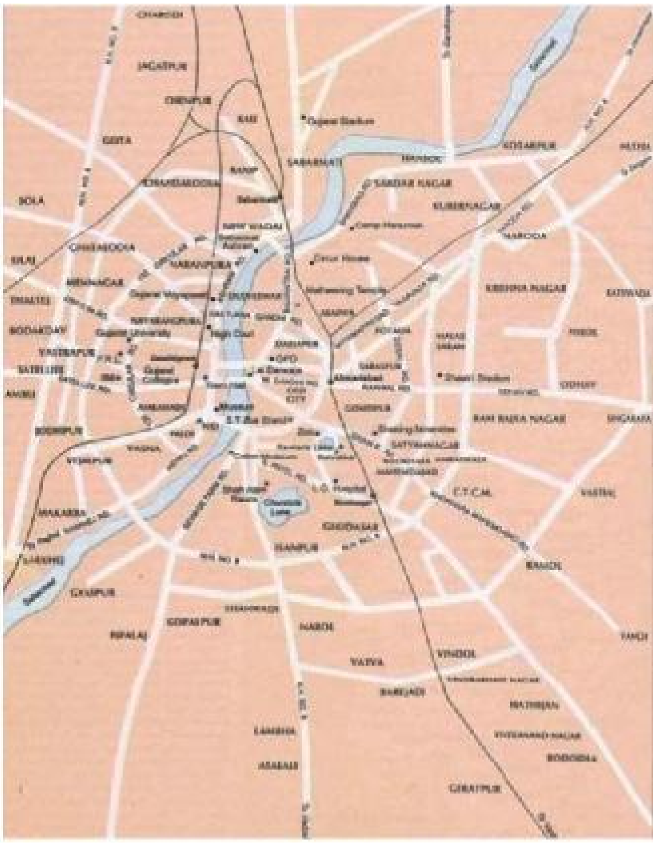

Figure 1: Map of Ahmedabad City
(Source: AMC, 2011)

METHODOLOGY

Data Selection

LandSat 5 TM datasets were used for this study. Level 1G data was used for the estimation of land surface temperature, NDVI and for land cover classification. Winter season was considered from mid December to February end. Two satellite images of 4th January, 1999 and 21st January, 2011 depicting peak winter season were used to assess the temporal variation in the Urban Heat Island intensity of Ahmedabad in 12 years.

Image Classification

The selected images were classified by supervised image classification technique using Maximum Likelihood Classifier method. The land cover was classified considering Level one NRSA Classification (NRSA, 2006) into Built-up Area, Water Body, Open or Fallow Land and Vegetation (agriculture and forests). This Land Cover Map was used to find the UHI statistics for each type of land cover by overlaying the LST Layer of Ahmedabad.

Stacked and subsetted images of LandSat were used for supervised image classification. The training sets were generated from field sampling and prior knowledge of the study area. The number of training pixels for each class was approximately kept similar to reduce and prevent any classification bias.

LST Estimation

The DN values were converted to Spectral Radiance using Equation 1 (NASA, 2008).

$$L_{\lambda} = G_{rescale} * Q_{cal} + B_{rescale} \qquad (1)$$

Where:

L_λ = Spectral Radiance at the sensor's aperture in W/ m^2.sr.μm
Grescale = Rescaled gain in W/ (m^2.sr.μm) /DN
Brescale = Rescaled bias in W/ m^2.sr.μm
Q_{cal} = the quantized calibrated pixel value in DN

The spectral radiance values obtained from Equation 1 were used to calculate the Brightness Temperature using the Equation 2 similar to the Planck's Equation with two pre-launch calibration constants (NASA, 2008). These temperatures were derived assuming unit emissivity.

$$T = \frac{K2}{\ln\left(\frac{K1}{L_\lambda}+1\right)} \quad (2)$$

Where:
T = Brightness Temperature in Degree Kelvin
K2 = Calibration constant 2 (607.76 W/ m^2.sr.μm)
K1 = Calibration constant (1260.56 W/ m^2.sr.μm)
L_λ = Spectral Radiance at the sensor's aperture in W/ m^2

Emissivity values were estimated using a combination of NDVI based emissivity calculation method by Van de Griend and Owe, 1993 (Sun et al., 2010) and classification based emissivity calculation technique. Van de Griend and Owe gave Equation 3 for calculation of emissivity values from NDVI when the NDVI values vary from 0.157 to 0.727 (Sun et al., 2010). For the remaining pixels, emissivity values were assigned based on land cover type.

$$\varepsilon = 1.0094 + 0.047 \ln(\text{NDVI}) \quad (3)$$

These emissivity values were combined with Brightness Temperature values obtained from Equation 2 to derive Land Surface Temperature using the Equation 4 (Artis and Carnahan, 1982).

$$T_S = \frac{T}{1+\left(\lambda * \frac{T}{\rho}\right) * \ln \varepsilon} \quad (4)$$

Where:
T_s = Land Surface temperature in Degree Kelvin
T = Brightness Temperature in Degree Kelvin
λ = Wavelength of emitted radiance = 11.5 μm
ρ = h *c / σ = (1.438×10^{-2} mK),
h = Planck's constant = 6.626×10^{-34} Jsec)
c = Velocity of light =2.998×10^{8} m/sec
σ = Boltzmann constant =1.38 × 10^{-23} J/K
ε = Surface Emissivity

LST values obtained were converted from Kelvin to Degree Celsius.

RESULTS AND DISCUSSION

The supervised image classification using Maximum Likelihood Classifier on the two LandSat Images of 1999 and 2011 gave the following results as shown in Figure 2. Built up areas occupied approximately 45% of the total area of Municipality Corporation in 2011 as compared to 38% in 1999. Thus, the total percentage increase in Built up area was 7% in the past 12 years. This increase in built-up area led to reduction in the vegetation cover and open land within the Municipality limits.

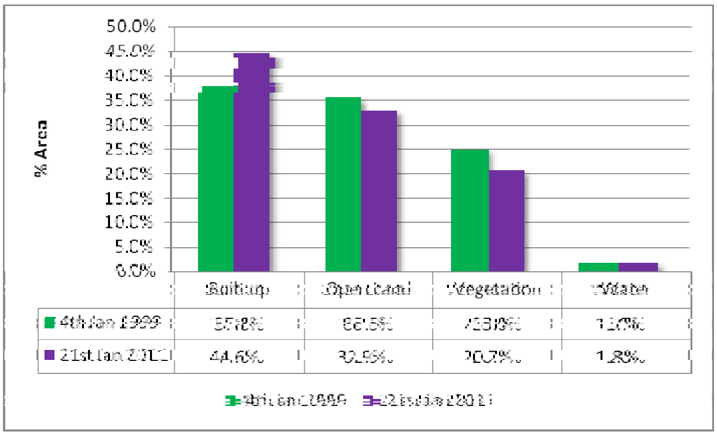

Figure 2: Land Cover Classification of Ahmedabad within AMC limits

Figure 3 shows the Land Surface Temperature Maps for the LandSat Images dated 4th January, 1999 and 21st January, 2011 along with the Land Cover and NDVI Map. It is clearly evident from the maps that a strong negative correlation exists between LST and NDVI, as the areas having lower temperatures correspond to the high NDVI zones. These high NDVI regions represent the densely vegetated pockets in the city. Thus, vegetated zones have lower temperatures compared to surroundings. Higher temperature is mostly seen in the eastern part of the city. These high temperature zones are densely populated walled city areas or the industrial areas of Ahmedabad.

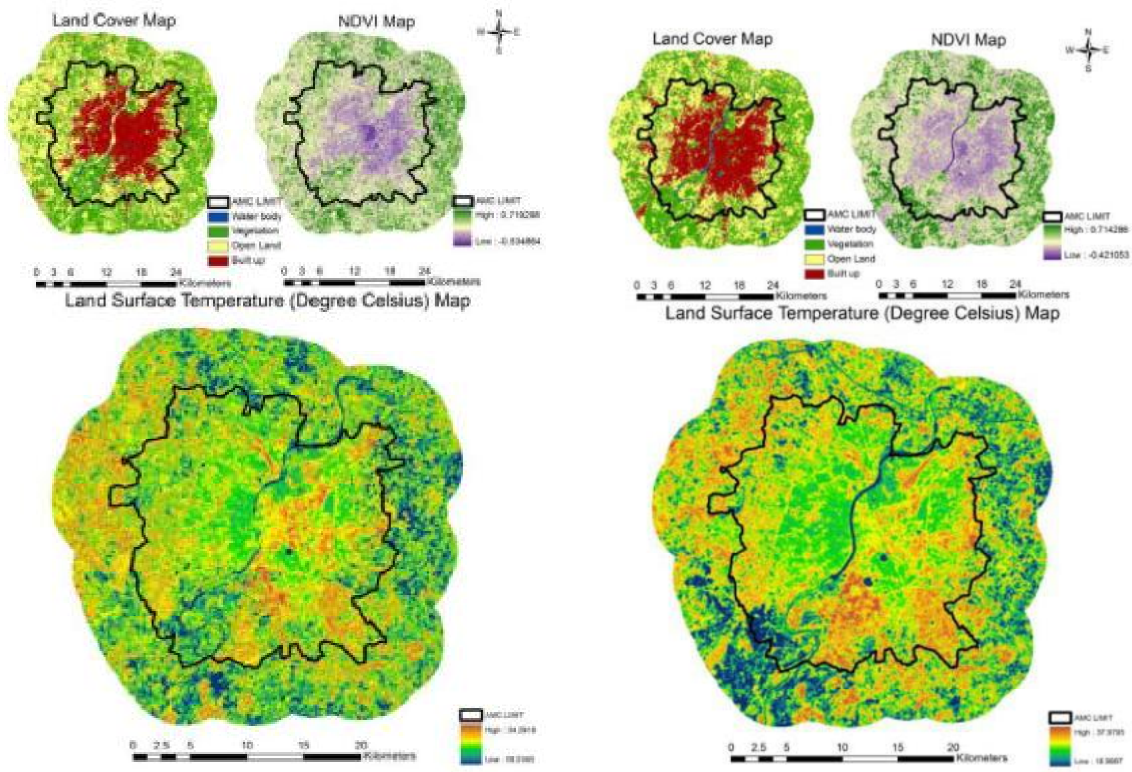

Figure 3: Land Surface Temperature Map, Land Cover Map and NDVI Map or 4th January, 1999 and 21st January, 2011

Figure 4 shows the variation in LST within Municipal Limits. As evident from the graph, the mean, maximum and minimum temperatures vary by almost 1.5 to 3 ºC. In all the scenarios, temperature in 2011 shows increase compared to 1999.

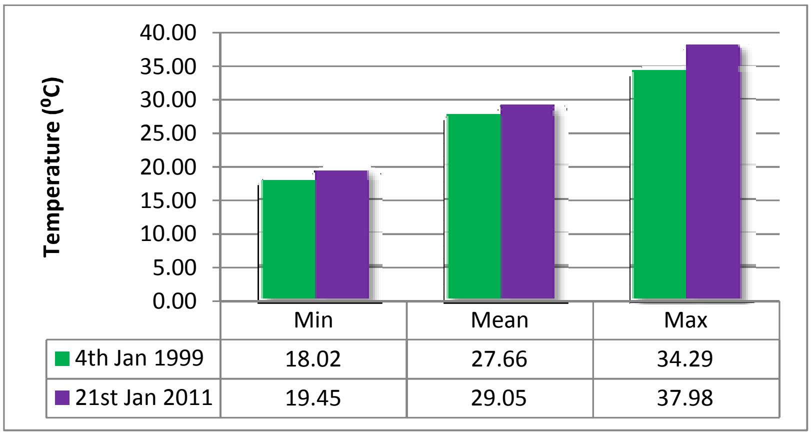

Figure 4: LST variation within AMC limits

The average LST for each Land cover class was obtained combining the outputs from Supervised Image Classification and LST Maps. The results are evident in Figure 5. The temperature of Built up and Open Land are almost equal for both the study years. This is due to the high heat retention capacity of the sandy loamy soil found in this region. Water bodies and Vegetation have the lowest LST.

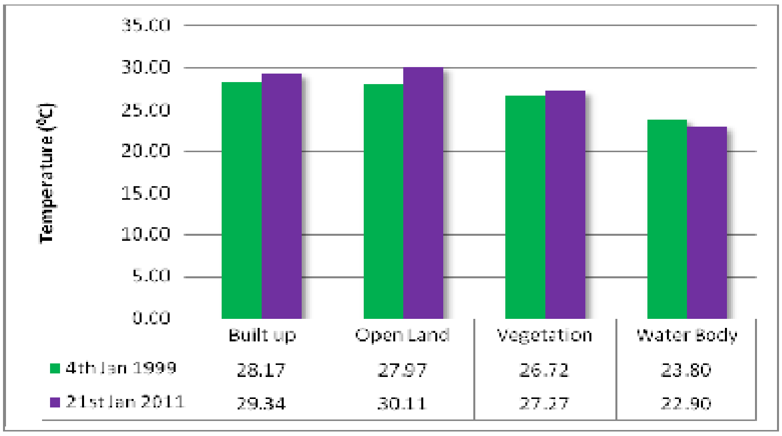

Figure 5: Land Cover Temperature

On comparing the mean LST within Ahmedabad Municipal Limits and the rural areas surrounding Ahmedabad, UHI intensity for 1999 was found to be 0.81ºC in 1999 and 0.41ºC in 2011. The reduction in the UHI intensity was due to the increase in the temperature of surrounding areas. This increase in temperature of rural area could be attributed to the reduction in vegetation cover and increase in built up and open land in the rural area and the rise in the mean LST of open land.

Two temperature transects were plotted across the city to determine the effect of land cover on temperature and find out the locations of major temperature variation over the years. Figure 6 shows the location of temperature transects plotted for Ahmedabad City. The influence of Land Cover on LST is also evident from the temperature profiles plotted in Figure 7 and 8. The valleys in profiles confirm the presence of vegetation cover or water in that area. The peaks illustrate the presence of large patches of built up areas or open land on surface. From Figure 7 and 8 it can be observed that the temperature is higher in 2011 for majority of locations in Ahmedabad City.

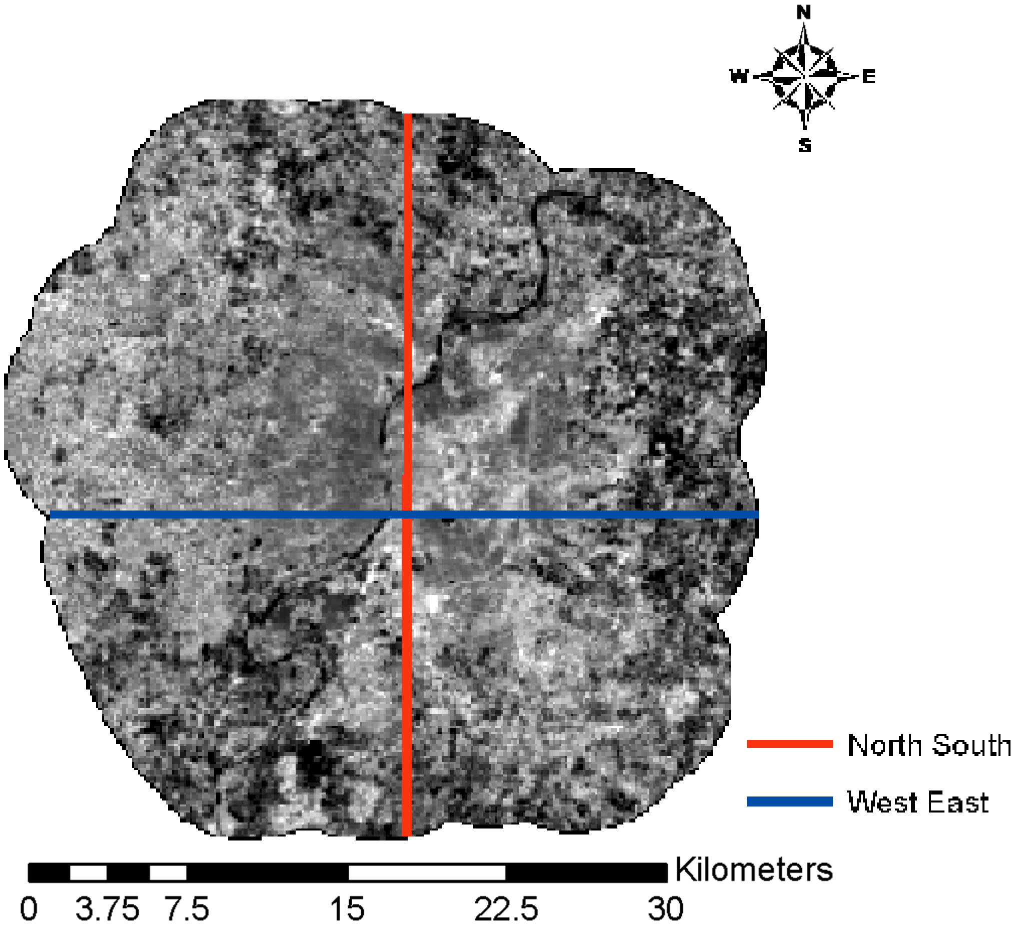

Figure 6: Temperature Profile

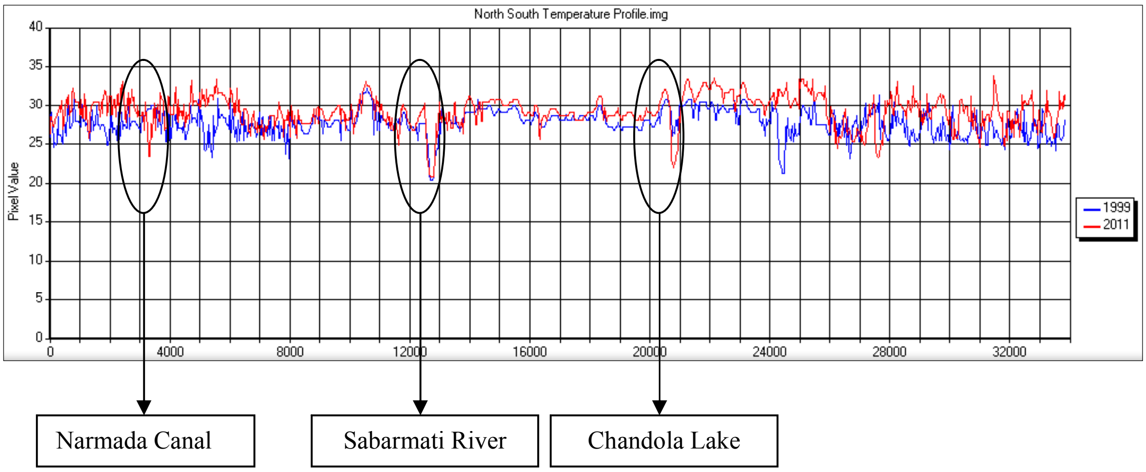

Figure 7: North South Temperature Profile

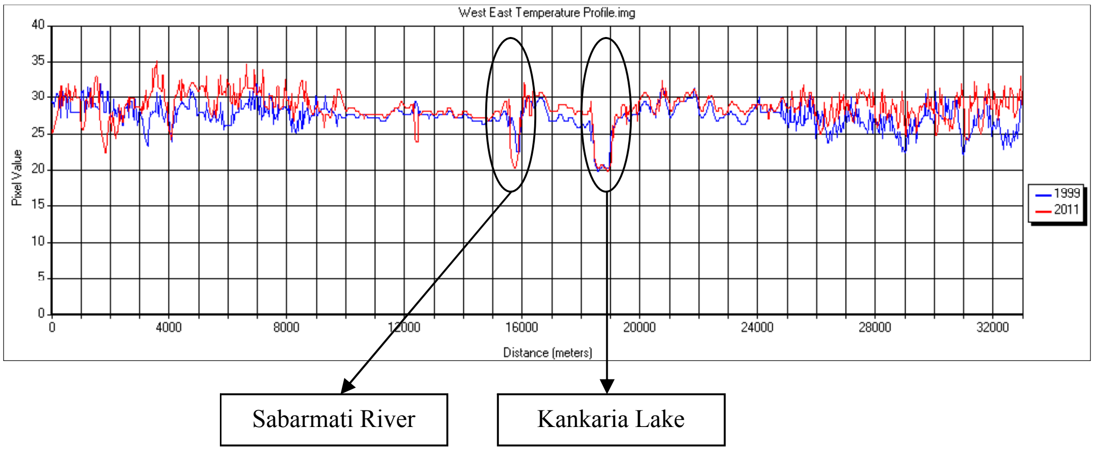

Figure 8: West East Temperature Profile

The temperature profiles show a sudden drop in temperature at location of water bodies. In case of North South Temperature Profile, Narmada Canal which became operational post 1999, shows a sudden temperature drop in 2011 profile. Same is the case with Chandola Lake which was a dry lake in 90s and has been reclaimed later. Kankaria Lake, which has been a major tourist spot for Ahmedabad shows considerably lower temperature than surrounding areas. These lower temperature zones or pockets also contribute to the reduction in temperature of surrounding areas. As evident from the figure, the location of Sabarmati River plays an important role in considerably lowering the temperature of surrounding areas compared to the areas at a distance. The eastern fringes show noticeably higher temperature in 2011. This is due to the reduction in Vegetation cover in this area due to the infrastructure development.

CONCLUSIONS & RECOMMENDATIONS

Built up areas depicted the highest surface temperature in 1999, but in 2011 open land depicted a slightly higher surface temperature than built up areas. Over the years, temperature for built up areas and open land is comparable. This is due presence of sandy loamy type of soil in Ahmedabad having a higher heat retention capacity.
The built-up areas within AMC limit increased from 171.29 sq. km in January 1999 to 201.94 sq. km in January 2011. This increase of built-up area by 7% contributed to an increase in the overall mean surface temperature due to reduction in the pervious surfaces.

The UHI intensity depicts temperature difference between urban and rural area. The UHI intensity has reduced from be 0.81°C in 1999 and 0.41°C in 2011. This is in spite of the increase in the overall mean LST. This explains the fact that the surrounding rural areas are also experiencing a temperature increase due to the alteration in land cover. The increase in open land in the surrounding area due to reduction in vegetation cover has also played a major role in the overall increase of rural temperature.

Thus, to control the temperature in a city like Ahmedabad, care should be taken to cover the bare soil with grass for future development. Also, the terraces of built up areas should be provided with heat reflective coatings. A mitigation strategy needs to be developed to control and monitor the temperature of surrounding areas along with the areas within Municipality Limits. . A detailed study at micro level, determining the impact of various types of built-up areas needs to be carried out.

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