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Assessment of Outdoor Thermal Comfort during the last decade Using Landsat 8 Imageries with Machine Learning Tools over the Three Metropolitan Cities of India †

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Abstract: Due to rapid urban growth and population increase, accurately tracking land use and cover changes (LULC) is vital for predicting outdoor thermal comfort. We used high-res Landsat 8 imagery and on-site weather data, employing Support Vector Machine (SVM) with PCA to estimate thermal comfort. PCA addressed variable multicollinearity, and LULC was classified using decision trees. Notable LULC trends emerged. In Hyderabad, built-up areas rose from 37% to 48% (2009-2019), barren lands fell from 42% to 18%. In Bangalore, built-up areas surged from 25% to 80%, causing vegetation loss (25% to 2%) and reduced barren land (50% to 18%). Jaipur saw a 12% built-up area increase with slight vegetation uptick. Thermal comfort analysis highlighted Bangalore's intense urbanization and Jaipur's limited expansion. Discomfort ranked highest in barren lands, followed by urban, vegetation, and water areas.

Keywords: Thermal comfort; SVM; PCA; Landsat 8

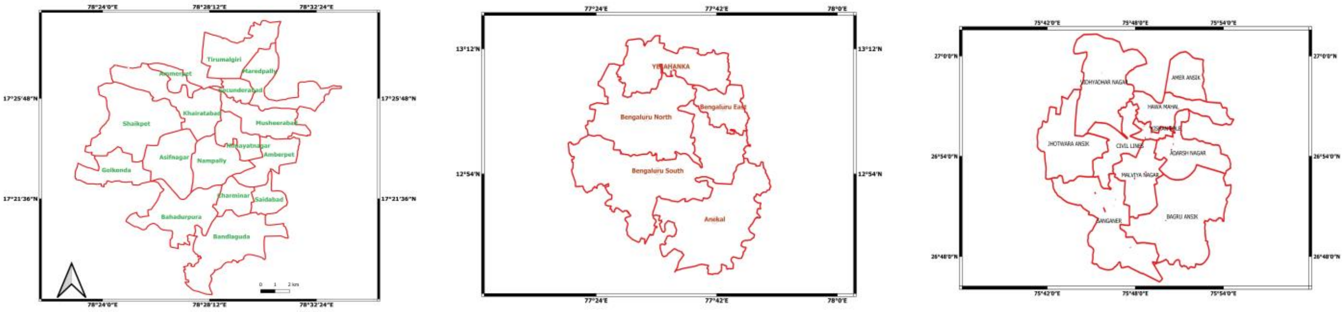
1. Introduction

Rapid urbanization increases Land Surface Temperature (LST), impacting outdoor thermal comfort, residents' health, and daily life. Thermal comfort depends on meteorological factors like air temperature, humidity, radiant temperature, and wind speed. Urban expansion alters these factors, affecting local weather conditions. With more people in urban areas (https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS?), outdoor thermal discomfort can lead to health problems, including dehydration, eye strain, dizziness, and respiratory/cardiovascular issues [1,2]. To address this, city planning should consider mitigation strategies to modify meteorological parameters like air temperature, humidity, local wind patterns, and albedo.. So, this paper aims to predict the thermal comfort levels by using Landsat imageries to provide necessary information to policymakers to plan a city. In early studies, people estimated thermal comfort by taking synoptic observations in a city such as [3–7], but these single-point studiedo not adequately represent spatial patterns over the region. So, people started considering LST as a proxy for thermal comfort and analysis the spatial patterns [8–13]. Again LST alone is insufficient to represent thermal comfort, thus, we adopted the regression-based methodologies to analyze thermal comfort. This kind of study was adopted in the city of Theran [14] and they utilized OLS (ordinary least square) regression to estimate thermal comfort. In the present study we used an advanced machine learning technique to estimate thermal comfort.

2. Material and Methods

2.1. Study Area and Data

The main aim of the study is to assess the thermal comfort in metropolitan cities of India. For this purpose, we chose three major cities across India are chosen, where the synoptic station observations exist. The study area includes different climatological areas according to Köppen climate classification. Since we are interested in micro-scale thermal comfort study we have chosen mandal/ sub-administrative boundaries within city as shown in **错误!未找到引用源。**.



(**a**) (**b**) (**c**)

Figure 1. Cities with sub-administrative boundaries.

2.2. Data

The observed synoptic station data for the period of 2009-2020 . The data contains daily level meteorological data at the airports comprised of wind speed, wind direction, temperature, and relative humidity taken from Kaggle (**https://doi.org/10.34740/KAGGLE/DSV/1129180).** The daily observed meteorological data consists of maximum and minimum values of temperature Ta (C), relative humidity RH (%), and wind speed V (ms-1) of 16 Mandals of Hyderabad city The meteorological data is collected from an open data source: **https://data.telangana.gov.in/**

2.3. Satellite Data

The Landsat multispectral bands are used for the period of 2009-2020 with resolution 30m×30m with cloud cover less than 20%. The above data sets are obtained from the USGS Earth Explorer user Interface (**https://earthexplorer.usgs.gov/)**

2.4. Methodology

- Acquiring the real time data of meteorological variables over different locations within a city. Estimating thermal comfort index using below THI formula at those locations.

$$THI = 37 - \frac{37 - T_a}{0.68 - 0.0014RH + 1/(1.76 + 1.4V^{.75})} - 0.29T_a\left(1 - \frac{RH}{100}\right) \quad (1)$$

- Estimating the environmental parameters at those locations that influence the Thermal comfort. The environmental parameters include NDVI, NDWI, LST etc. These can be estimated from the Satellite imagery data such as Landsat, MODIS, etc.
- Principal component analysis.
- Using Machine learning techniques, finding the Thermal comfort maps over fine resolution.

$$THI_{model} = a_0 + a_1PC_1 + PC_2 + a_3PC_3 \quad (2)$$

3. Results

3.1. Hyderabad

Hyderabad city, with 16 mandals, is considered for the assessment of thermal comfort. Before analyzing the thermal comfort, the LULC changes over Hyderabad are estimated. Hyderabad's built-up was increased from 37% to 48% in 2009 to 2019. Substantially there is a decrement in the barren lands 42% to 18% in 2009 to 2019. The water bodies percentages are almost same with an area of 3% occupied in the city. Interestingly there is an increment in the vegetation from 20% to 30%.

The built-up of Hyderabad city was substantially increased, but most of the greenery was almost the same. Most of the conversion of the built-up is from bare lands, which in turn may alters the thermal comfort. So, in order to analyse the spatial variation of the thermal comfort in detail, the mandal level thermal comforts are plotted and analysed.

Figure 2. Outdoor Thermal comfort changes of Hyderabad from 2009-2019.

From the above Figure 2, the results clearly portray a fact that there is a substantial increment in the built-up from 2009 to 2019 and associated with linear increment in the thermal discomfort. The mandals like Secunderabad has highest water bodies and achieving maximum thermal comfort. Again, the mandals like Nampally and Charminar has highest built-up and barren lands results in maximum discomfort. Similarly in winter most of the mandals turned to neutral conditions in 2019 from the moderately comfort conditions in 2009. Charminar, Himayat Nagar witnessed most urbanization and results in poor discomfort conditions.

3.2. Bangalore

Bangalore was subdivided into 5 major parts. The drastic urbanization was seen in the city and maximum vegetation loss was observed. The Bangalore built-up was increased from 25% to 80% in 2009 to 2019. The vegetation decreased from 25% to 2% and bare lands decreased from 50% to 18%. There is a huge vegetation loss was observed. There is a slight decrement in water bodies within during the study period and most of the bare lands and vegetative lands turned to the built-up.

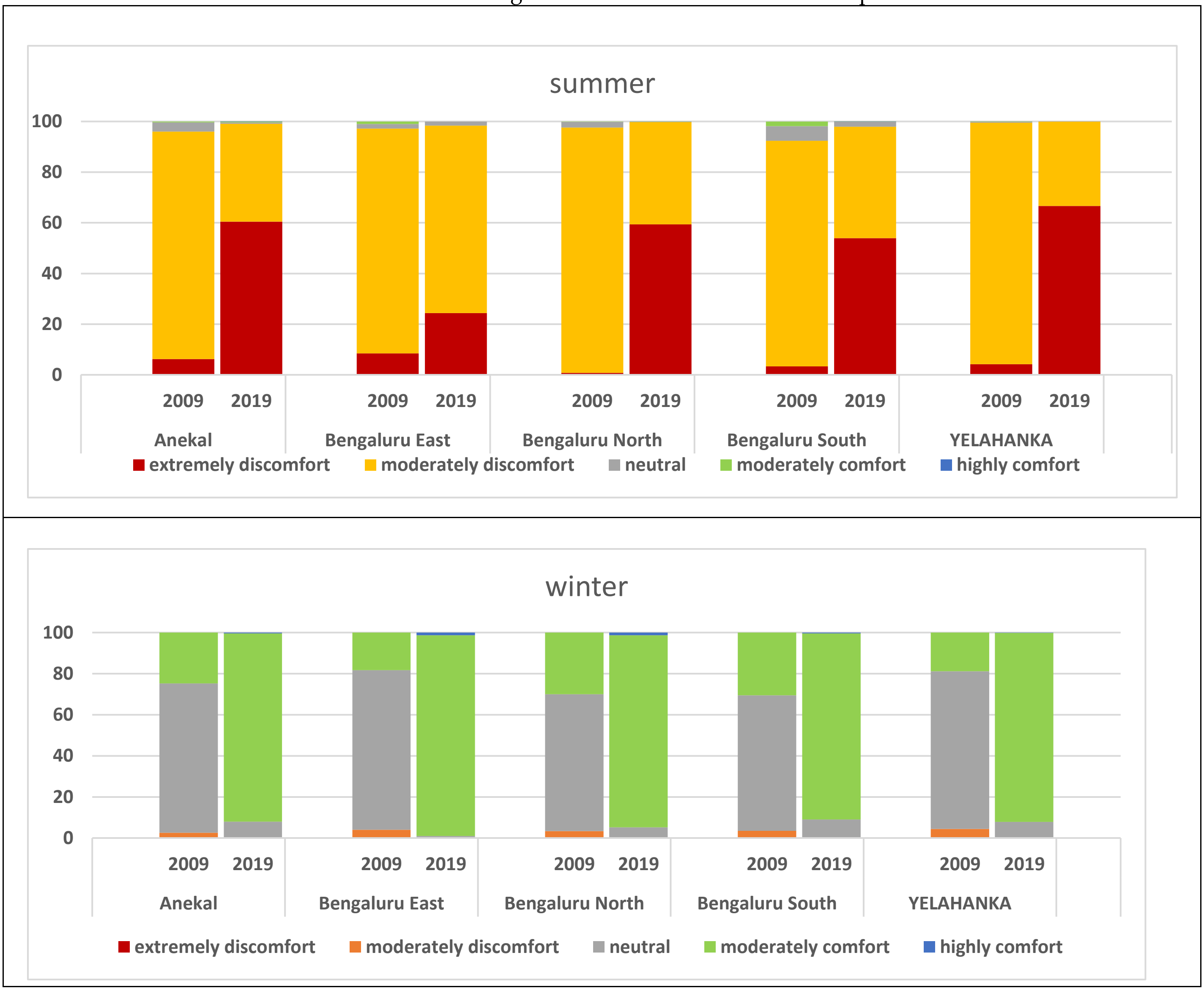


Figure 3. Outdoor Thermal Comfort changes of Bangalore from 2009-2019.

From Figure 3 every subdivision of Bangalore has shown moderate discomfort in 2009 and turned to high discomfort in 2019. Very few water bodies are observed over Bangalore resulting in very few comfort zones over the city. A contrasting situation is shown in winter, the maximum zones of Bangalore come under comfort conditions from 2009 to 2019

3.3. Jaipur

There is a slight increment in vegetation and mostly barren land loss is observed. The below Figure 4 shows the ward level thermal comfort assessment over the Jaipur city. In summer the Johtwara ansik and Kishan pole showed maximum discomfort conditions from 2009 to 2019. Almost all wads exhibited moderately discomfort in 2009 and turned to highly discomfort in 2019. Only Amer ansik has small portion of water body results in moderately comfort in 2009 and neutral

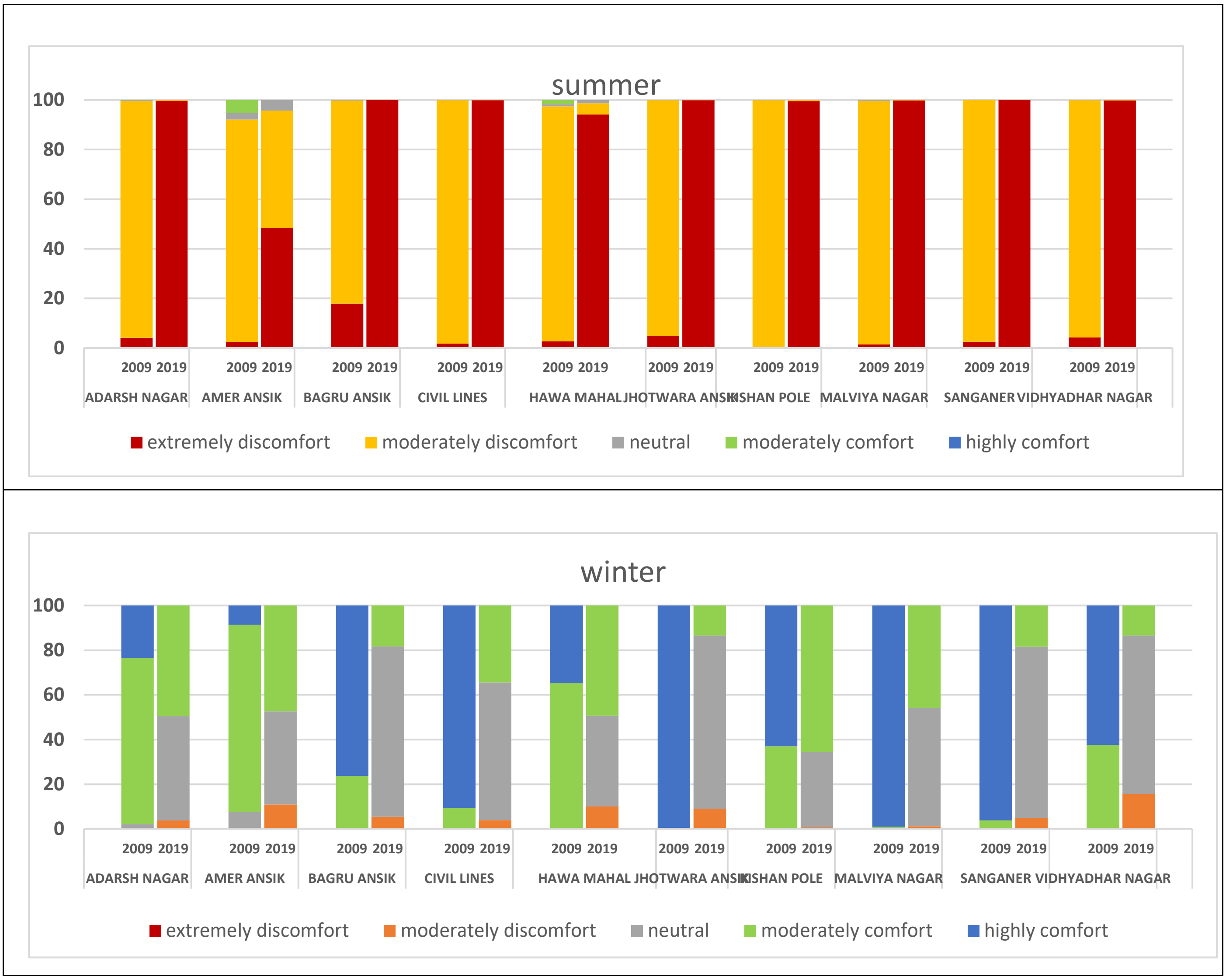


Figure 4. Outdoor Thermal Comfort changes of Jaipur from 2009-2019.

The over all discomfort was very poor compared to the remaining cities in summer. But the comfort conditions in winter is highly comfortable in all ward levels, portraying very low LST over the city during winter. Jhotwara ansik and Malviya nagar had maximum comfort in 2009 and turned to be neutral in 2019. Unlike other cities, some portion of moderate discomfort conditions prevailed over the city during the 2019 winter.

4. Discussion and Conclusion

The above method relies on environmental parameters that can be retrieved from satellite imageries to assess thermal comfort. This method is highly useful for analyzing thermal comfort with corresponding changes in LULC, especially where the in-suite data is absent. From the above analysis, there has been an increment in discomfort in the past decade in all three cities. This can be easily associated with the corresponding increment in Built-up, but this model's major limitation is that it relies primarily on LST and other surface parameters. But, T2m and humidity and wind will substantially change from the surface. So, this model is a preliminary vision for policymakers to plan mitigation strategies; however, more research is needed to get insights into thermal comfort.

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