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RESEARCH ARTICLE

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Assessment of Annual and Seasonal Variation of Thermal Comfort Conditions in Pune

Ms. Dhanashree D. Karale

Research student, Dept. of Geography Sangameshwar College, (Autonomous) Solapur

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Abstract

Thermal comfort refers to the interactive effect of humidity and the air temperature on the thermal perception of humans. For instance, studies of the components that define climate sensitivity are critical for identifying and understanding the variations of climate and the impact on the comfort level of humans. This study aims to understand these components for the city of Pune. The study uses Thom's Discomfort Index (DI) for the years 1991-2019 to study long-term changes of thermal discomfort in Pune. For this study, the air temperature and relative humidity of the India Meteorological Department (IMD) Pune are used to calculate seasonal and annual DI. The study found that the annual DI values in the period of the study have progressively risen from 22.04 in 1991 to 24.07 in 2019. From the seasonal analysis, it can be observed that discomfort levels are the highest in the pre-monsoon season, and the winter season has the lowest levels of discomfort. The growing importance of bioclimatic indicators is evident in the recent studies undertaken in Pune about the human-comfort studies, as well as increased thermal stress conditions over the last 30 years in the region.

Author's e-mail: dhanashreekarale123@gmail.com

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1. Introduction

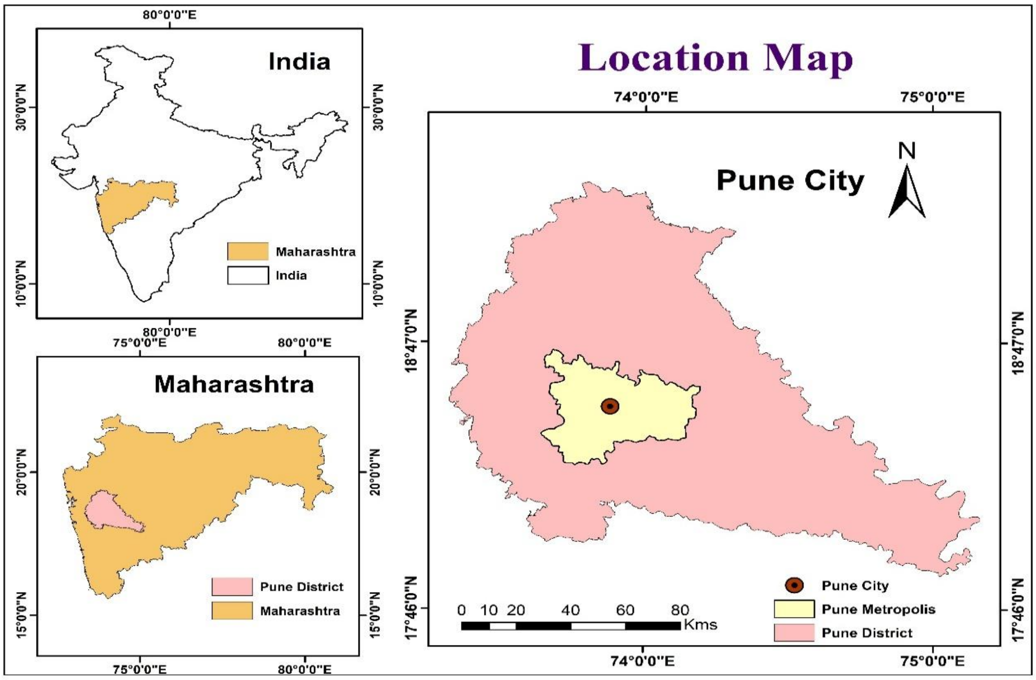
Thermal comfort plays an important role in how people experience climate conditions in their daily lives. There is an intricate balance in the interplay of heat and humidity, and how the varying combinations of these two elements interact determines the level of thermal stress and discomfort. The discomfort or stress a person feels because of hot or cold weather is influenced by the humidity and temperature, and the combination of the two. To determine and quantify the discomfort and stress level associated with the weather conditions, climatologists utilise various thermal indices. Thom's Discomfort Index (DI) is one of the most widely applied heat indices. The DI combines humidity and temperature and assesses the heat stress perceived.

Pune has varying seasonal weather patterns which include cool winters, hot pre-monsoon months, humid monsoon times, and moderate post-monsoon weather. These seasons in turn play a role in what we feel in terms of temperature at any point in the year. By looking at trends in the Discomfort Index we are able to see how climate has changed over time. This research looks into the annual and seasonal changes in the Discomfort Index in Pune from 1991 to 2019 which we have analyzed from weather reports.

2. Study Area

Pune is situated in the western part of India, in the state of Maharashtra. The city is placed on the leeward side of the Western Ghats, at an elevation of about 560 meters above sea level. Its geographical coordinates are 18.52° N latitude and 73.85° E longitude. Pune has a tropical wet and dry climate, with clear seasonal changes. The year is divided into four main seasons:

- Winter (December to February) – relatively cool and dry
- Pre-monsoon (March to May) – hot and dry weather with rising temperatures
- Monsoon (June to September) – high humidity and heavy rainfall
- Post-monsoon (October to November) – gradual transition to cooler conditions



Changes in temperature and humidity significantly affect the thermal comfort levels.To understanding long-term climate changes that impact human comfort recognizing these variations is crucial.

3. Objectives of the Study

The present study was based on the following objectives:

1. To calculate the annual Discomfort Index for Pune for the period 1991–2019.
2. To examine seasonal variations in thermal discomfort using Thom's Discomfort Index.
3. To analyse long-term changes in annual and seasonal DI values over the study period.

4. Data Source and Methodology

4.1 Data Source

The meteorological data for this study were collected from the India Meteorological Department (IMD) of India. The IMD provides the consistence and reliable long-term climate datasets from its network of meteorological stations. This study focused on two key climatic variables: the monthly mean air temperature (°C) and the monthly mean relative humidity (%). These parameters are very important in biometeorological research because they significantly influence human thermal comfort. Air temperature impacts the thermal energy in the atmosphere, while relative humidity affects how quickly sweat evaporates from the human body. Together, these factors determine the level of heat stress individuals experience in different climatic conditions.

The meteorological data includesthe monthly mean air temperature (°C) and the monthly mean relative humidity (%)from 1991 to 2019. To analyse annual and seasonal differences in thermal conditions, the monthly data were categorized into four climatic seasons commonly recognized in the region: Winter (December–February), Pre-monsoon (March–May), Monsoon (June–September), and Post-monsoon (October–November).

For each year seasonal mean values of temperature and relative humidity were calculated. These values were used to calculate the seasonal Discomfort Index (DI).In addition to the seasonal analysis, annual mean DI values were also calculated for each year within the study period. These annual values assist in identifying long-term changes in overall thermal comfort conditions.

4.2 Thom's Discomfort Index

The Discomfort Index (DI) was introduced by E. C. Thom in 1959for assessing the degree of heat stress experienced by humans. Thom formulated this index using air temperature and relative humidity. In environments where humidity significantly affects the body's cooling mechanismsonly temperature is an inadequate factor to determine human thermal comfort.

The mathematical expression of the Discomfort Index is given as:

$$DI = T - (0.55 - 0.0055RH)(T - 14.5)$$

Where:

- DI = Discomfort Index
- T = Air temperature in degrees Celsius (°C)
- RH = Relative humidity in percentage (%)

This formula has a humidity correction factor.The temperature is influenced by the amount of moisture in the atmosphere.A higher discomfort index (DI) value is observed when the correction term changes in response to rising relative humidity. This indicates increased heat stress experienced by people in humid environments. Lower DI values indicate more comfortable conditions, whereas higher values indicate greater heat stress and discomfort.

The Discomfort Index serves not only to describe air temperature conditions but also to offer a valuable assessment of perceived heat stress. To interpret the calculated Discomfort Index values in terms of human comfort levels, Thom suggested classification ranges that categorise the population's experience of thermal stress.

DI Value	Thermal Perception
<21	Comfortable conditions
21-24	Slight discomfort
24-27	Moderate discomfort
27-29	Strong discomfort
29-32	Severe heat stress
>32	Extremely dangerous heat conditions

5. Annual Variation of Discomfort Index (1991-2019)

The annual mean Discomfort Index (DI) values for Pune indicate a moderate increasing trend.Across the study period from 1991 to 2019,the annual mean Discomfort Index (DI) showed a progressive rise in thermal discomfort.

The lowest annual DI value recorded is 22.04 in 1991, which suggests very moderate heat conditions at the beginning of the study period.The index shows a general upward trend reaching its highest value of 24.07 in 2019.The long-term pattern of the annual mean Discomfort Index clearly shows a steady increase in heat discomfort. The annual DI series shows some variations from year to year.

Over the long term, the data indicates that heat discomfort increases consistently. There are consistent fluctuations, though they do show inter-annual variations, suggesting that the discomfort index (DI) does fluctuate annually. For example, the DI values for the 1990's are confined to values of 23 or less - compared to the value of 23.0 which suggests less severe heat discomfort. Beginning in the early 2000's, though, values were recorded above that threshold, suggesting a warm temperature perception shift.

This increasing trend becomes more apparent later in the study period, particularly after 2015. In recent years, especially from 2017 to 2019, the annual DI readings have been steadily high. These higher numbers imply that the combined impact of air temperature and humidity has increased in recent decades, leading to more thermal discomfort than in previous years.

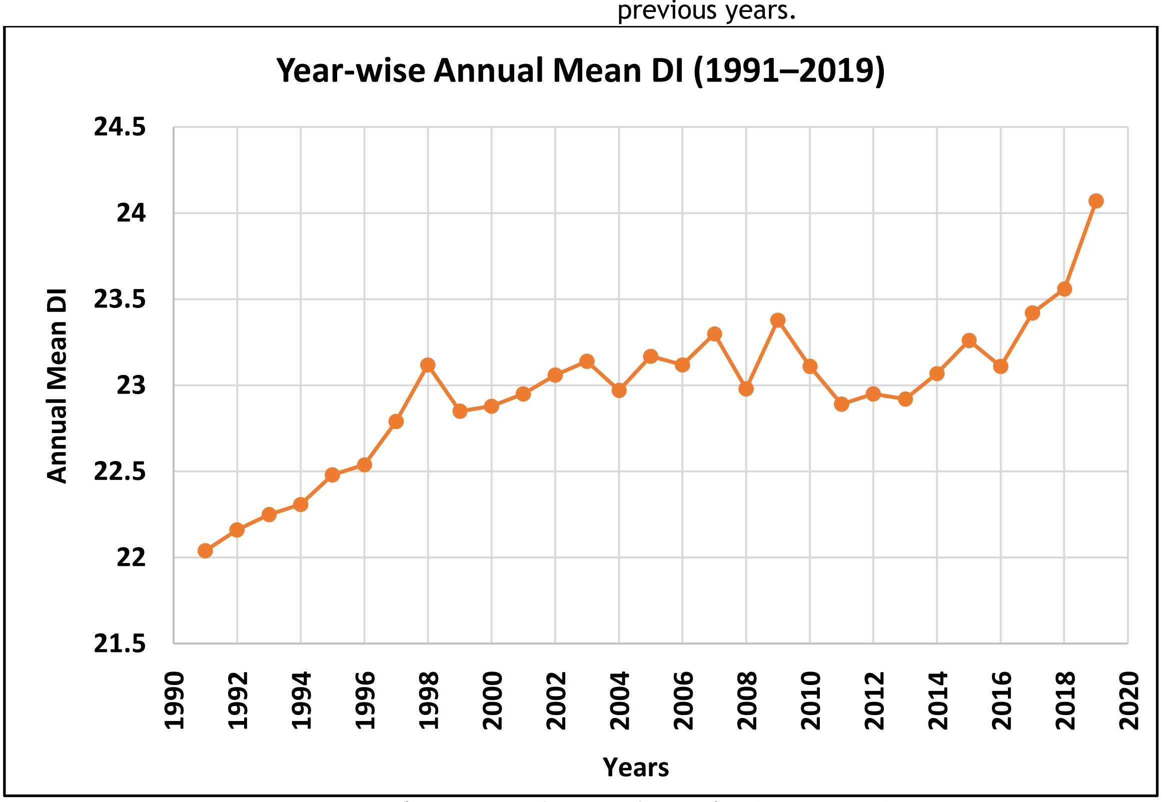


Fig.1 Annual Variation of Discomfort Index (1991-2019)

Overall, increasing annual DI values indicate that Pune's climate is progressively warmer. This emphasizes how crucial it is to keep an eye on bioclimatic parameters. This aids in comprehending how human thermal comfort varies over time.

6. Seasonal Variation of Discomfort Index

Understanding how thermal comfort conditions vary throughout the year is made easier by seasonal analysis of the Discomfort Index (DI). DI shows seasonal temperature fluctuations as well as the combined impacts of relative humidity and air temperature. Pune's seasonal DI values varied noticeably during the course of the four meteorological seasons between 1991 and 2019. Temperature and humidity changes during these seasons have a significant impact on the degree of thermal discomfort.

6.1 Winter Season

The DI measurements are regularly lowest during the winter, which suggests that the weather is generally pleasant. Seasonal DI values vary from 19.20 in 1992 to 21.17 in 2019. During the first several years of the study, winter DI values were generally below 20, indicating low thermal stress. However, DI values gradually increase in the years that follow, with several values approaching or slightly above 21. This pattern suggests that winter temperatures are gradually increasing over time. Winter is still Pune's most comfortable season despite this rise, with DI values significantly lower than those observed in other seasons.

6.2 Pre-Monsoon Season

Throughout the study period, the pre-monsoon season has the highest DI values, which indicate the highest degree of thermal discomfort. Between 1997 and 2019, seasonal DI values ranged from 24.07 to 25.85. Before the monsoon arrives, this season is marked by high temperatures and rising humidity, which raises DI levels. readings above 24 are recorded in the majority of years, and in recent years, a number of readings have above 25, indicating increased heat stress.The pre-monsoon period is the most thermally demanding season in Pune, as confirmed by the constantly high DI readings.

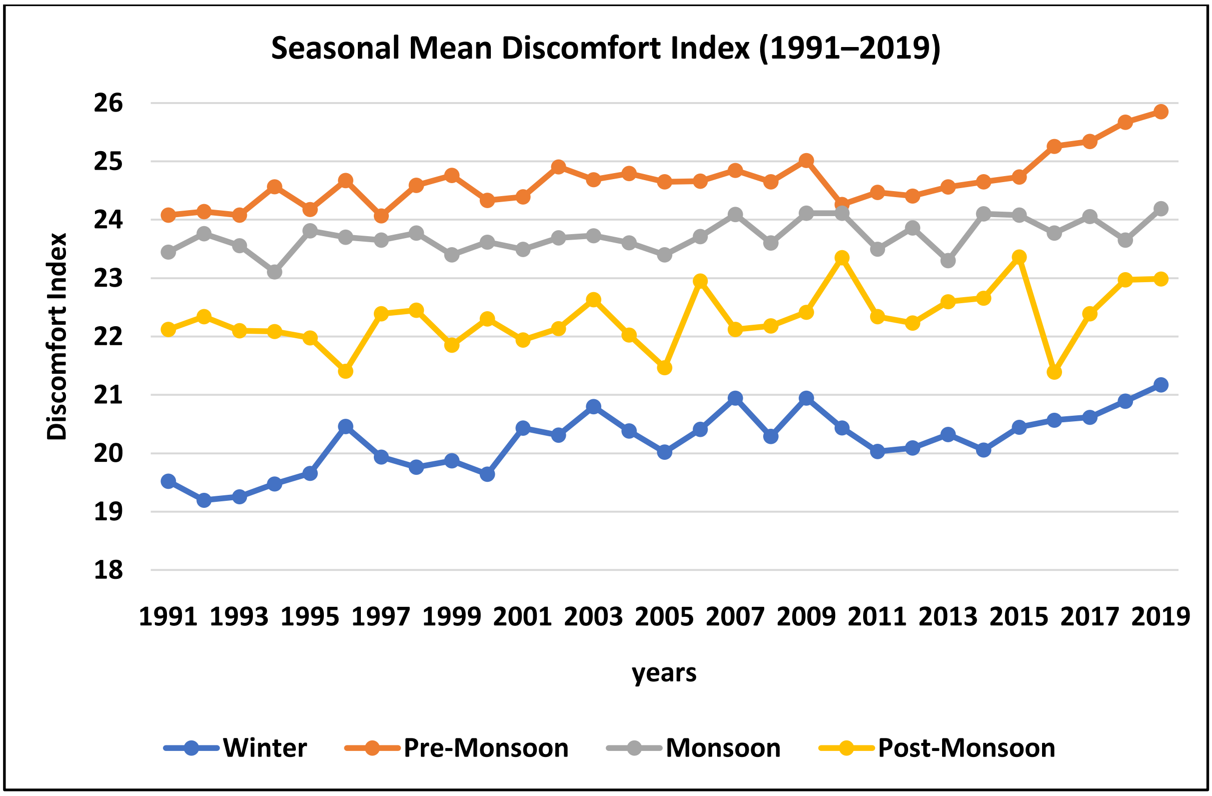


Fig. 2 Seasonal Variation of Discomfort Index

6.3 Monsoon Season

DI readings show moderate temperature discomfort throughout the monsoon season, ranging from 23.11 in 1994 to 24.19 in 2019. Humidity levels rise significantly while air temperatures are somewhat lowered by rainfall and cloud cover. The human body's evaporative cooling process is less effective amid high atmospheric moisture, which keeps DI values comparatively high. As a result, the majority of monsoon DI readings stay in the range of 23 to 24, indicating warm, humid weather.

6.4 Post-Monsoon Season

The warm monsoon months and the chilly winter season are separated by the post-monsoon season. During this period, DI values ranged from 21.39 in 2016 to 23.36 in 2015.

Thermal discomfort is comparatively less during this period than it is throughout the pre-monsoon and monsoon seasons.

Improved thermal comfort is a result of steadily dropping temperatures and decreased humidity after the monsoon retreats.DI observations, which indicate relatively warm temperatures with minimal variability, generally remain higher than 21.

7. Conclusion

The current study investigated the seasonal and annual fluctuation of the Discomfort Index (DI) in Pune from 1991 to 2019. The purpose of the investigation was to determine how temperature and humidity together affect thermal comfort levels over time.

The findings show that annual DI levels increased gradually during the course of the study. From 22.04 in 1991 to 24.07 in 2019, the annual mean DI rose, indicating a discernible increase in perceived heat discomfort. The overall trend shows a progressive increase of warm weather, despite small variations between particular years.

DI values are moderate during the monsoon season. Rainfall and cloud cover cause temperatures to slightly drop, but high humidity levels keep the uncomfortable conditions slightly elevated. On the other hand, when humidity progressively decreases and temperatures begin to decline, the post-monsoon season has relatively lower DI values.
The lowest DI levels are recorded during the winter, reflecting rather pleasant weather. Even in the colder months, a progressive warming tendency is suggested by a minor increase in winter DI values over time.
Overall, the study shows that Pune's thermal discomfort has steadily increased over the past three decades, mostly due to rising humidity and temperatures during the pre-monsoon and monsoon seasons. These results emphasize how crucial it is to keep an eye on thermal comfort levels in urban areas with unpredictable weather.

8. Recommendations

The following actions could lessen heat discomfort and enhance Pune's urban climate, according to the study's conclusions.

i. Expanding Urban Greenery
By providing shade and evapotranspiration, the expansion of green areas along the Mula-Mutha rivers, such as parks, roadside plantations, and green belts, can assist lower surface temperatures and enhance microclimatic conditions.
ii. Climate-Aware Urban Design
In order to prevent heat buildup in highly populated regions, Pune's urban development should include climate-responsive planning, which includes sufficient open spaces, appropriate building orientation, and enhanced ventilation.
iii. Utilizing Cool Roofing Materials
Building heat absorption can be decreased and indoor thermal comfort increased by promoting the use of cool roofs, reflective materials, and heat-resistant construction methods.
iv. Thermal Comfort Condition Monitoring
Effective urban climate planning in Pune can be supported by routine monitoring of temperature, humidity, and thermal indicators like the Discomfort Index.

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