Trans. Inst. Indian Geographers
ISSN 0970-9851
Indexed in Scopus

Evaluation of effective temperature over selected south Indian cities: Implications for human thermal comfort

Tanmay S. Jadhav, and Amit G. Dhorde*, Pune

Abstract

The present study evaluates effective temperature (ET) over selected 25 south Indian cities. Effective temperature (ET) is a direct human comfort index. Considering India's vast population size that is rapidly urbanizing in recent years, it is essential to assess the thermal comfort of the people residing in cities. South Indian cities constitute the focus of the study due to the fact that these cities are located in tropical region which is more prone to thermal discomfort. In this research, data for relative humidity, wind speed, minimum and maximum temperature for the period 1969 to 2015 (46 years) was used for the evaluation of ET. The trends in ET were verified by Student's t-test and Mann-Kendall Rank Test. The results indicated significantly increasing trends in ET over all the selected stations. The magnitude of increase in ET was calculated with Sen's slope and it was found to have increased by 0.04°C/year. Relative humidity was observed to be influencing effective temperature to the greatest extent. The results revealed that most of the cities lie in a thermal sensation criterion (17°C to 21°C ET). Nights were found more comfortable than the days and monsoon season was the most comfortable season of the year.

Keywords: *Human comfort index, effective temperature, increasing trends, south India, tropical region, seasonal variation*

Introduction

India is a country with unique physical characteristics which makes it a distinct physical and geographical entity characterised by a tropical climate. Tropical regions are prone to thermal discomfort. More than 50 percent of India's population is engaged in agricultural activities which have to be carried out in open field. Moreover, many workers in other activities also have to work outside exposing them to stressful thermal conditions. It is therefore imperative to investigate the changing pattern of thermal comfort/discomfort levels during different periods of the year along with the seasonal variations. India is the largest populated country in the world with close to 1.4 billion population. It is important therefore to identify and map comfort indices that give an account of the relationship between the efficiency of an individual and atmospheric phenomena. Researchers have concluded that there is a significant relationship between human health and changing climate, based on several factors that affect the human working style, house structures, clothing pattern, behaviour of a person, etc. It has been observed, whenever the comfort conditions prevail, the mind stays alert and the body operates at maximum efficiency. maximum productivity, as well as creativity, comes out from those who experience thermal comfort (Choudhury *et al.*, 2011).

Several indices are derived to examine human comfort which include Thermo-Hygrometric Index (THI), Heat Index (HI), Physiologically Equivalent Temperature (PET), Wet Bulb Globe Temperature (WBGT), Thom's Discomfort Index (TDI), Effective Temperature (ET) etc. A study conducted by Desai and Dhorde (2017) over a few selected cities in India analyzed the temperature data from 1969 to 2014 by using TDI, and reported a significant increase in thermal discomfort in these urban centers situated along the western coast of India. Ali and Patnaik (2017) used PET index in three different locations in Bhopal and found that the people residing in those areas tagged the locations either comfortable or uncomfortable, but all the three locations come under hot thermal conditions revealing the importance of physiological adaptation and acclimatization of the people residing in those areas. A study pursued using PET on the campus of Satyabhama University (Chennai, India) found nights as more comfortable compared to day (Amirtham *et al.* 2014).

According to Alwetaishi (2016), 8 major factors influence human comfort or discomfort. They are air temperature, radiant temperature, humidity, air velocity, metabolic rate, clothing insulation, skin temperature, and gender.

Effective temperature

Out of the numerous comfort indices, the present study focuses on effective temperature (ET). which is a thermal comfort index that attempts to measure the comfort or discomfort due to temperature. It relates to the sensation of warmth or cold experienced by a human body as being dependent on the temperature, humidity, movement of air, and the amount of clothing worn (Smith, 2001). Among empirical, rational, and direct indices, effective temperature is a direct index to demonstrate thermal comfort or discomfort with the requirement of climatic data for parameters such as relative humidity (RH), wind speed (WS) and mean temperature (MT). Though the empirical and rational indices are sophisticated, they are difficult to measure and calculate. Unlike these, the effective temperature being a direct index is easy to measure and can be calculated with a simple mathematical formula.

ET as an index of thermal comfort was first proposed by Houghton and his co-researcher Yaglo in 1923 (Houghton and Yaglo, 1923) to evaluate human thermal perception which was based on laboratory experiments. Later, Missenard (1933) developed a mathematical formula for ET as:

$$ET = T - 0.4 * (T - 10) * \left(1 - \frac{RH}{100}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where T is daily mean temperature (°C) and RH is relative humidity (%).

Later, Missenard's formula was modified by Gregorczuk (1968), also known as Net Effective Temperature (NET); with the addition of wind effect which was accepted and adopted by Landsberg (1972), Hentschel (1987), Li and Chan (2000) for their respective studies (Wu *et al.* 2017). The effective temperature is a multiple parameter-based index that is obtained from a combination of three parameters (Fantozzi and Rocca, 2020) as follows:

$$ET = 37 - \frac{37-T}{0.68-0.0014RH+\frac{1}{1.76+1.4V^{0.75}}} - 0.29T * (1-0.01RH) \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where T is the daily mean temperature (°C), RH is relative humidity (%) and V is average wind speed. Flach (1981) explained the usage of both formulae (1 & 2). According to him if the wind speed is less than 0.2 m/s i.e. calm condition, equation 1 can be used. On the other hand, if the wind speed exceeds 0.2m/s, equation 2 has to be used.

The weather data procured from IMD was on a daily basis. The monthly and annual average of daily mean temperature, relative humidity, and wind speed was derived. All the stations recorded wind speeds more than 0.2m/s. Thus equation (2) was used for the computation of ET. There are several scales of assessments of ET. Amongst those the one which was used in the present study for the analysis is as shown in table 1. This scale was given by Blazejczyk *et al.* in 2012 and accepted by Wu *et al.* in 2017 for the evaluation of ET in several regions of China.

Study area

Tropical regions are densely populated. This population is exposed to higher temperatures which makes it crucial to study the comfort and discomfort conditions of people residing in these regions. The tropic of Cancer passes approximately through the centre of the country and therefore cities located south of the tropic of cancer were selected for the present study which are generally hotter than those located to its north. As many as 12 coastal cities and 13 landlocked cities were selected to analyze Effective Temperature. The average annual wind speed over all the stations was 2.5 m/s with some variation. The relative humidity in the entire region varied from 39 to 75 percent depending on the location of the city. Relative humidity was maximum at locations nearer to the sea or major water bodies. The annual mean temperature over the southern Indian cities was 27°C ranging from a low of 23° to a high of 30°C.

The Cities selected for the study are widely dispersed over South India, which are Ambikapur, Aurangabad, Bhopal, Chennai, Cochin, Cuddalore, Hyderabad, Jabalpur, Jagdalpur, Kakinada, Kolkata, Kozhikode, Kurnool, Machilipatnam, Madurai, Mangalore, Mumbai, Nagpur, Panjim, Pune, Salem, Solapur, Thiruvananthapuram, Surat and Trichy (Figure 1).

As per Köppen's climatic classification, India mainly experiences four types of climates viz. Tropical Savanna, Tropical Rain

Table 1: Assessment scale of ET

ET (°C)	Thermal sensation
<1	Very Cold
1-9	Cold
9-17	Cool
17-21	Comfortable
21-23	Warm
23-27	Hot
>27	Very Hot

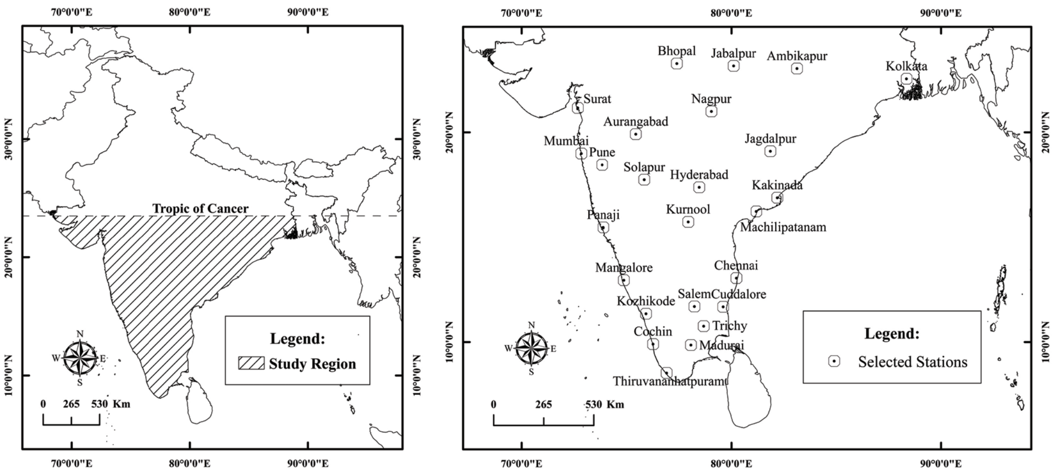

Fig. 1: Study area and selected stations

forest (Tropical Monsoon), Warm with dry winds (Mid-latitude Summer Mediterranean) and Dry steppe (Mid-latitude steppe and dessert) (Oliver and Wilson 1987; Dash *et al.* 2007). Among the selected 25 stations, 14 fall under the Tropical savanna type of climate with dry winter characteristics. A set of 4 stations fall under tropical monsoon, 4 under mid-latitude steppe and desert climate, and the remaining 3 under hot summer mediterranean type of climate.

Data and methodology

India Meteorological Department (IMD) is the main distributor of climatic data in India. The data which was required for this research was obtained from the National Data Center (NDC) of IMD. The vital parameters to calculate ET are Relative humidity (RH), Wind Speed (WS), maximum and minimum temperatures for the calculation of mean temperature (MT), etc. Daily data for the above-mentioned parameters was obtained for a period of 46 years- from 1969 to 2015 for all the twenty-five stations. RH, WS, MT were used to compute ET on a monthly, annual, decadal, and seasonal basis by considering summer (March, April, May), monsoon (June, July, August, September), post-monsoon (October, November), and winter (December, January, February) seasons as per accepted criteria by the IMD.

Linear multiple regression with stepwise method

Linear Multiple Regression with stepwise method is a statistical procedure to analyze the most influencing predictor among all the variables. To calculate the most influencing factor in the evaluation of ET, a linear multiple regression method was used. Consequently, from the results, preventive measures can be predicted to lower the thermal discomfort perceived by a person. According to Lam and Cheng (1998) and Cheng et. al (2007) stepwise regression is widely used for the prediction of the potential variable in synoptic climatology. Kim et. al (2010) had also used linear multiple stepwise regression for the selection of a set of predictors that resemble the prediction of summer-time tropical cyclone activities in climatology. In the present study, ET is the dependent variable while relative humidity, Mean Temperature, and Wind Speed are the independent variables.

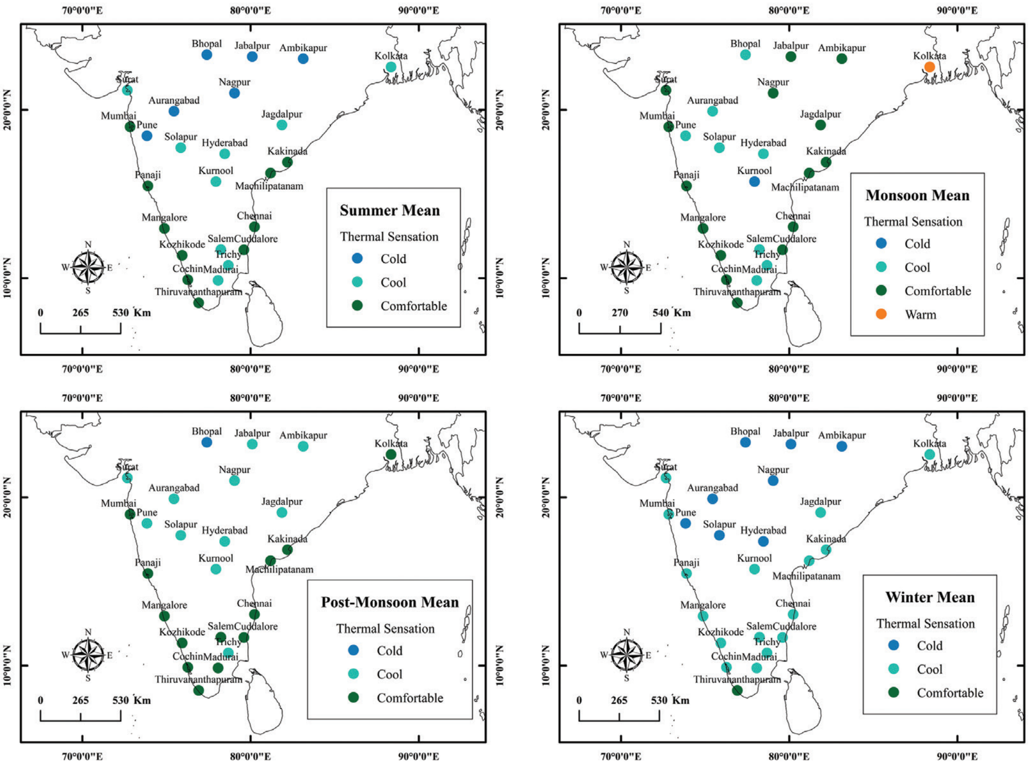

Fig. 2: Seasonal mean thermal sensation

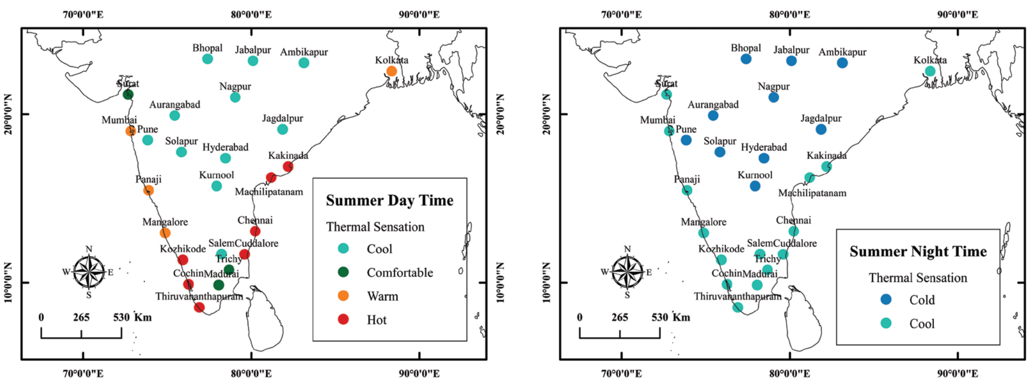

Fig. 3: Summer day-night thermal sensations

Temporal trend analysis

Linear regression was used to analyze the trend in RH, WS, mean temperature, and ET. This test is widely used by climatologists to assess long-term climatic data and it shows good results (Jaiswal *et al.* 2015; Dash *et al.* 2007). A series of xi, i=1,2,3….n, a straight line in the form of equation y=a+bx is the fit line for the data, where 'a' is the intercept, 'b' is the slope, and 'y' is the dependent variable that has to be predicted. R2 is a statistical measure that defines the variance for a dependent variable which is explained by an independent variable. This R2 from the trendline is used to check statistical significance in the trend by using Student's t-test. Besides this, Mann Kendall Rank test is applied for the evaluation and verification of the trend with non-parametric analysis (Gadgil and Dhorde 2005; Dhanya and Ramchandran 2015). Sen's slope estimator is used to measure the magnitude of slope for the time series of 1969-2015.

Pearson's correlation

Pearson's correlation describes the relationship between the variables where -1 is a strong negative correlation, while +1 is a strong positive correlation. Pearson's correlation is widely used to determine the relationship between climate data and topography. (Bretherton *et al.* 1992; Feidas *et al.* 2013). Hence, it was used to determine the relationship between elevation and effective temperature. It helped to find out the variation in effective temperature with the change in geographical and topographical patterns.

Results and discussion

Seasonal thermal sensation

Effective temperature is calculated by considering relative humidity, wind speed, and mean temperature as the major parameters whereas other factors such as skin colour, radiant temperature, metabolic rate, clothing insulation, and gender are assumed to be constant. In this study, ET was calculated on monthly basis. Monthly averages of the considered parameters were calculated first. From the calculated ET, a seasonal and monthly analysis of thermal sensation was done by using the thermal scale given by Blazejczyk *et al.* (see Table 1).

The cities lying in the tropical region experienced large variations in the thermal comfort sensation limit. These cities witnessed thermal sensation from warm to the cold regime ranging from 1°C to 23°C of ET (Figure 2). Monsoon season is found to be the most comfortable season of the year. In the summer season, only 2 of the 12 coastal cities namely Surat and Kolkata underwent a cool regime. A set of 10 cities namely Mumbai, Panaji, Mangalore, Kozhikode, Cochin, Thiruvananthapuram, Cuddalore, Chennai, Machilipattanam and Kakinada experienced comfortable thermal sensation during summer. In the monsoon season, 11 coastal cities among the 12 selected coastal cities i.e. Surat, Mumbai, Panaji, Mangalore, Kozhikode, Cochin, Thiruvananthapuram, Cuddalore, Chennai, Machilipattanam and Kakinada underwent the comfortable thermal sensation, whereas Kolkata falls under warm regime during monsoon season. Four landlocked cities namely Nagpur, Jabalpur, Ambikapur and Jagdalpur experienced comfortable thermal sensation. Overall, it was observed that the coastal cities are more comfortable to reside than the landlocked ones excluding the winter season. Bhopal observed cool to cold thermal comfort level throughout the year. Landlocked stations mostly observed a cool regime throughout the year. Thiruvanantpuram, a city located close to the sea in Kerala always showed comfortable thermal sensation that ranges from 17°C to 21°C of ET.

Summer

In the summer season, the coastal stations shifted from cool (9°C-17°C ET) towards hot (23°-27°C ET) thermal comfort sensation regime. During the day, the coastal cities experienced warm and hot thermal sensation except at Surat which perceived comfortable thermal sensation whereas the landlocked cities in general had a cool thermal sensation except for Trichy and Madurai. In contrast to this, nights were cold (1°C-9°C) to cool (9°C-17°C ET) for all the coastal and landlocked cities. Among the 25 stations, all the 12 coastal stations namely Surat, Mumbai, Panaji, Mangalore, Kozhikode, Cochin, Thiruvananthapuram, Cuddalore, Chennai, Machilipattanam, Kakinada and Kolkata experienced cool thermal sensation at night whereas 10 landlocked stations which are Pune, Solapur, Hyderabad, Aurangabad, Nagpur, Bhopal, Jabalpur, Ambikapur were cold; while Salem, Trichy, Madurai showed cool thermal sensation as shown in Figure 3. The results of stepwise regression revealed that around 61.38 percent of the variation in ET is explained by relative humidity, 25 percent by temperature, and 12.85 percent by wind speed. Together, these three parameters explain about 99.25 percent of the variation in ET. It was observed that the coastal stations record higher temperatures and relative humidity than landlocked stations resulting in having higher ET.

Monsoon

The monsoon season in India includes June, July, August, and September months of the year. Like the summer season, relative humidity affects the effective temperature the most, explaining almost 42 percent variation, while wind speed is the second influencing factor explaining 30.76 percent variation and temperature with 24.76 percent. The average wind speed is relatively less in the monsoon season compared to what it is in summer. In contrast, a hike in relative humidity was observed during the monsoon season. There was a slight difference in temperature during both the seasons. RH being the most influencing factor, ET increases with increasing RH. The selected stations experienced cool (9°C-17°C ET) to hot (23°C-27°C ET) regime. Figure 4 reveals that the days in the monsoon season were slightly more uncomfortable in cities located on the coasts. Most of the evaluated cities, especially the coastal stations fall under warm (21°-23°C ET) and hot (23°-27°C ET) regime. It was also observed that some of the evaluated cities located between 75°E and 79°E longitudes enjoy a more comfortable regime. Nights are found to be cooler at all the selected stations which recorded comfortable thermal sensations at night in contrast to other selected stations except Mumbai, Kolkata, and Cochin (Figure 4).

Post-monsoon

In the post-monsoon season, during October and November months, the temperature rises slightly compared to the monsoon season. The relative humidity is more compared to summer months. During this period, relative humidity influences effective temperature by 58.36 percent, while wind speed contributes 12.16 percent of the variation and temperature contributes to 7.7 percent variation in ET. Thermal sensation experienced at selected stations lies between cold (1°C-9°C ET) to hot (23°C-27°C ET) regimes. When the ET was calculated by considering the minimum temperature, it showed that the central part of India viz. Pune, Aurangabad, Solapur, Nagpur, Hyderabad, Bhopal, Jabalpur, and Ambikapur cities witnessed cold discomfort while all other stations lay between cool discomfort regimes as shown in Figure 5. During day time with consideration of

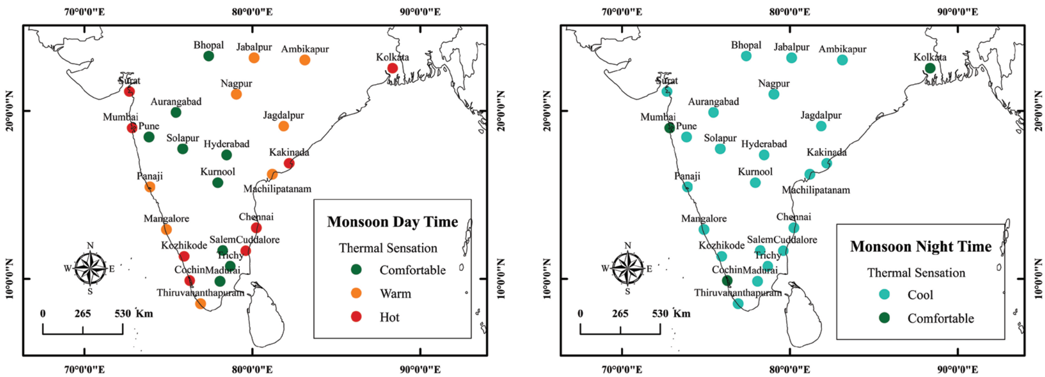

Fig. 4: Monsoon day-night thermal sensations

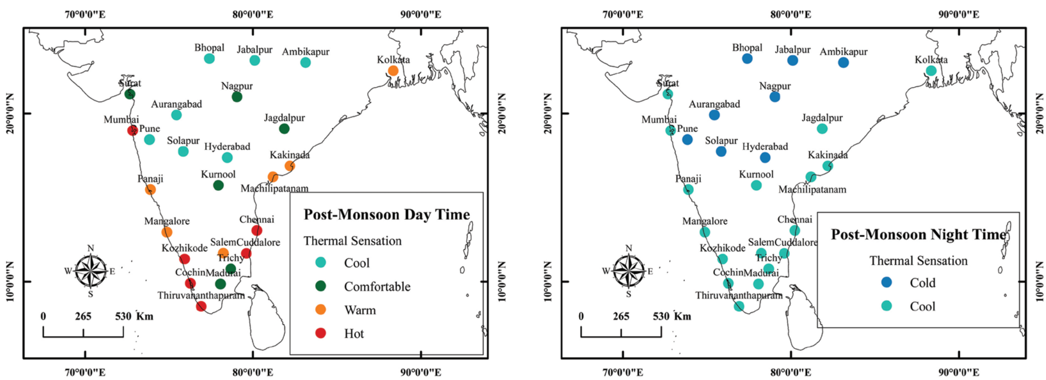

Fig. 5: Post-monsoon day-night thermal sensations

maximum temperature, thermal comfort was witnessed between cool (17°C-21°C ET) and hot (23°C-27°C ET) regimes. Selected stations in the south of 17°N latitude perceived hot discomfort sensation during daytime except for Trichy and Madurai which lay in the comfortable regime. On the other hand, Mangalore, Panjim, Salem, Machilipatnam and Kakinada fell under the warm regime. It clearly shown that there is a large difference in ET during day and night times, more prominently over selected coastal stations than continental stations. Continental cities did not show much variation during day and night. Thus, effective temperature calculated with mean temperature showed overall more comfortability.

Winter

The winter season- December to February- presents an overall cool to cold thermal sensation over the selected stations from southern India. These cities experienced thermal sensations ranging from cold (1°C-9°C ET) to warm (21°C-23°C ET) in various cities except for Bhopal which was very cold (less than 1°C ET) type of thermal regime during winter nights. Thiruvananthapuram and Kozhikode cities in Kerala coast were the stations that experienced warm thermal sensation whereas Kolkata in the eastern coast and Surat in the western coast experience cool thermal sensation during the day, while other coastal stations showed comfortable thermal sensation during daytime.

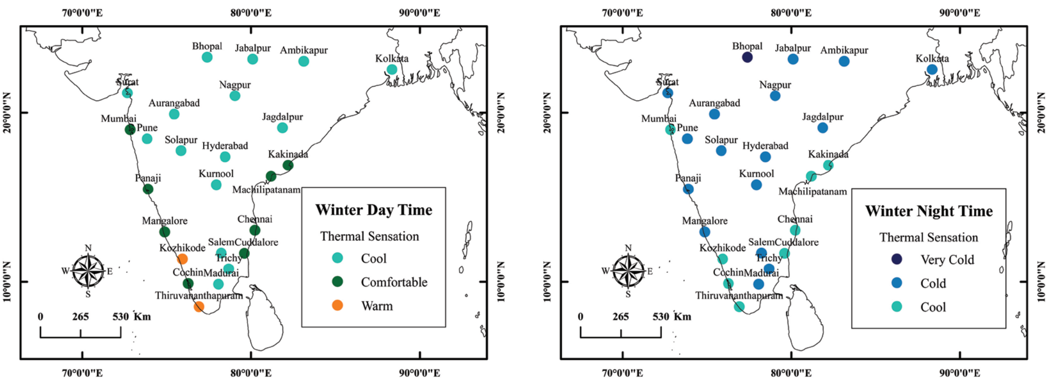

Fig. 6: Winter day-night thermal sensations

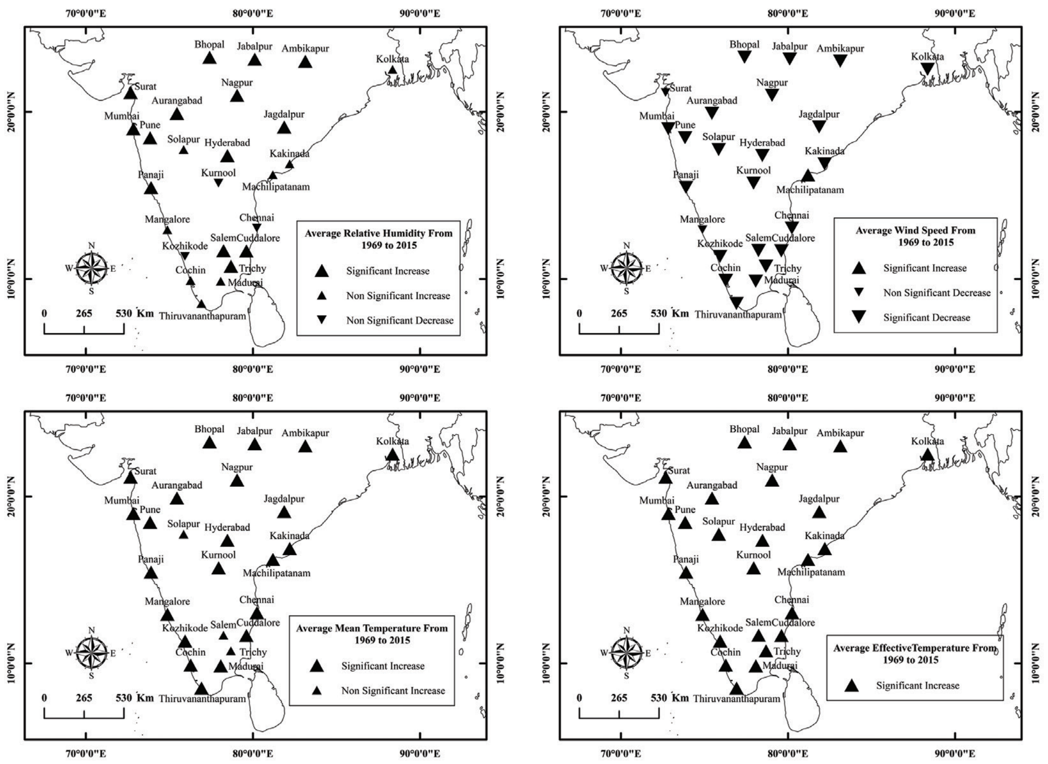

Fig. 7: Maps showing significant/non-significant trends in RH, WS, mean temperature and ET

All the continental stations except Bhopal registered cool thermal sensations during the day but cold thermal sensations at night time. All the selected cities experienced cold to cool thermal sensation when evaluated for night-time by using minimum tempearature (Figure 6). It was revealed from the analysis that the winter nights are more uncomfortable

Table 2: Student t-test results

Null hypothesis: There is no significant trend in ET/RH/WS/MT. Alternate hypothesis: There is a significant trend in ET/RH/WS/MT.				
Null hypothesis tested at 95% confidence level				
Stations	ET	RH	WS	MT
Chennai	Reject	Accept	Reject	Reject
Cochin	Reject	Accept	Reject	Reject
Cuddalore	Reject	Reject	Reject	Reject
Kakinada	Reject	Accept	Reject	Reject
Kolkata	Reject	Accept	Reject	Reject
Kozhikode	Reject	Accept	Reject	Reject
Machallipattanam	Reject	Accept	Reject	Reject
Mangalore	Reject	Accept	Accept	Reject
Mumbai	Reject	Reject	Reject	Reject
Panjim	Reject	Reject	Reject	Reject
Surat	Reject	Reject	Accept	Reject
Thiruvanantpuram	Reject	Accept	Reject	Reject
Ambikapur	Reject	Reject	Reject	Reject
Aurangabad	Reject	Reject	Reject	Reject
Bhopal	Reject	Reject	Reject	Reject
Hyderabad	Reject	Reject	Reject	Reject
Jabalpur	Reject	Reject	Reject	Reject
Jagdalpur	Reject	Reject	Reject	Reject
Kurnool	Reject	Accept	Reject	Reject
Madurai	Reject	Accept	Reject	Reject
Nagpur	Reject	Reject	Reject	Reject
Pune	Reject	Reject	Reject	Reject
Salem	Reject	Reject	Reject	Accept
Solapur	Reject	Accept	Reject	Accept
Trichy	Reject	Reject	Reject	Accept

than the days at all the selected stations, especially at Bhopal. The coastal cities were seen to be slightly warmer if compared to continental stations during winter nights. RH decreases from post-monsoon to winter season with decrease in temperature. It was seen that RH affects ET by 46.8 percent while temperature affected 32.6 percent. The effect of wind speed on ET is only 18.6 percent in the winter season.

Trends over selected cities in south India

The role of relative humidity, wind speed, mean temperature and thermal comfort

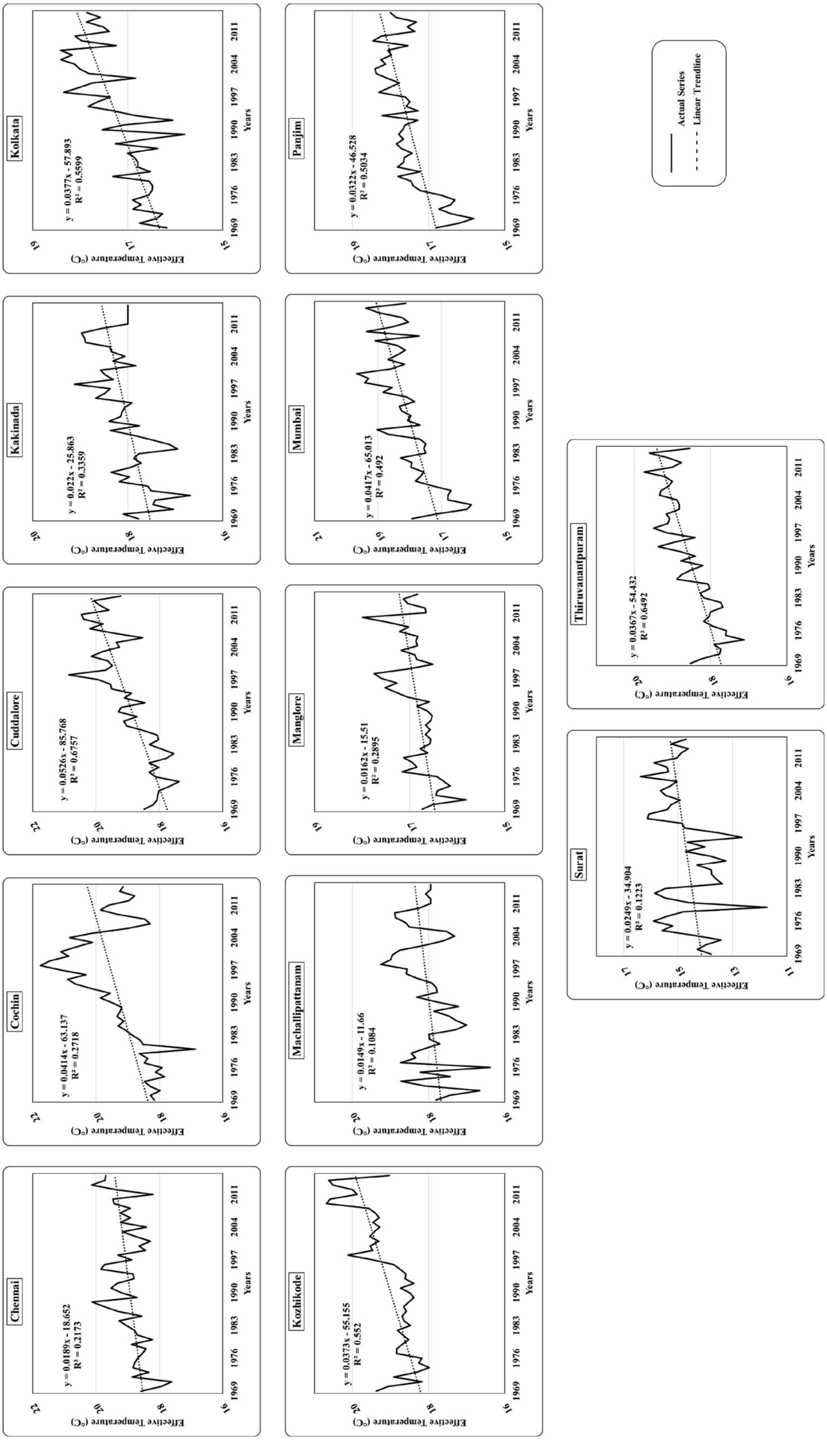

Fig. 8 a : Trends in effective temperature at selected coastal stations

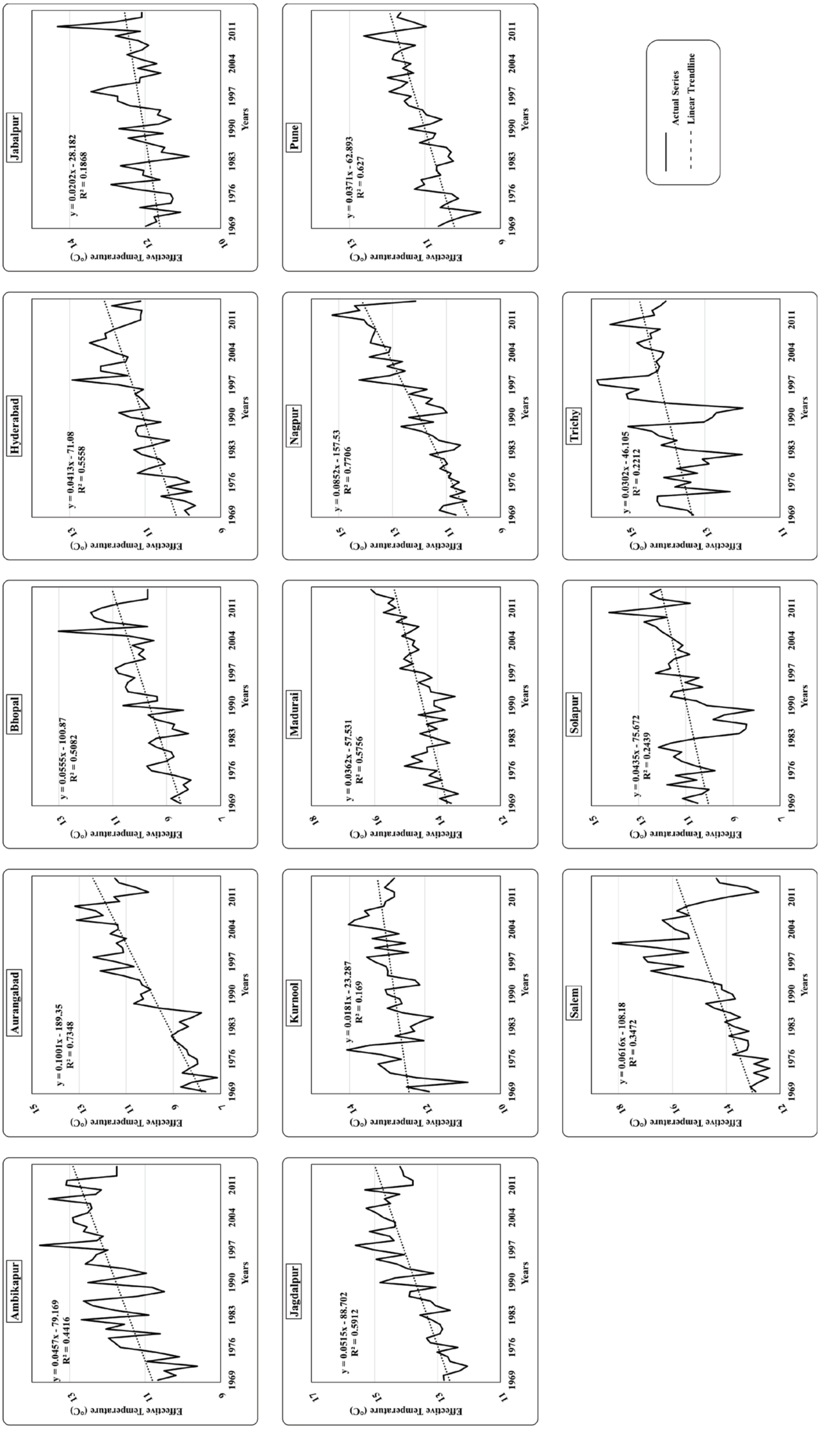

Fig. 8 b: Trends in effective temperature at selected landlocked stations or discomfort trends were also analysed, particularly focusing on the evaluation of ET and its parameters over 25 stations of southern peninsula as far as the annual pattern is concerned.

Mean temperature

The present study indicates accentuation in global warming and temperature increase in different regions. The study revealed statistically significant increasing trends in mean temperature at 95 percent confidence level over the selected 25 stations for the period 1969 to 2015. Only the stations such as Trichy, Salem and Solapur did not show significant increase in temperature (Table 2). Figure 7 shows significant rise in mean temperature over the remaining 22 cities located in south India.

Relative humidity

A linear trend equation was applied to each series of RH, WS, mean temperature and ET for all 25 stations. Student t-test was used to reveal a significant increase or decrease in the variables. The linear trend line of the 46 years data revealed that three cities namely Chennai, Kozhikode and Kurnool showed a downward trend. However, the statistical tests did not show the decrease over these stations to be highly significant. Similarly, Cochin, Kakinada, Mangalore, Thiruvanantpuram, Kolkata, Machilipatnam, Madurai and Solapur were the stations that showed increasing relative humidity, but that was also not statistically significant. However as many as 14 of the 25 stations viz. Cuddalore, Mumbai, Panaji, Surat, Ambikapur, Aurangabad, Bhopal, Hyderabad, Jabalpur, Jagdalpur, Nagpur, Pune, Salem and Trichy showed a significant increase in relative humidity with 95 percent confidence level in a time span of 46 years (1969 to 2015), while remaining 11 cities did not show any significant change (Figure 7 & Table 2).

Wind speed

Wind speed was the least influencing factor in the evaluation of effective temperature. Still, it was necessary to understand the trend in wind speed over the selected stations. The linear trend lines added to the series showed a decreasing trend in wind speed except for Machilipatnam, which showed a statistically significant increase in the wind speed. Also, the results of student t-test showed that the wind speed decreases non significantly at Surat whereas increases significantly at Machilipatanam (Figure 7 & Table 2). Increasing urban canopy could be the major factor in decreasing wind speed over a span of 46 years. Unplanned cities and denser structures in urban areas cause higher friction between surface and winds leading to lowering of the wind speed. This analysis is consistent with the results of a study by Jaswal and Koppar (2012) regarding the reduction in wind speed for a study of 1961-2008.

Effective temperature

It was observed that the effective temperature has been below the average till 1993, except

Table 3: Pearson's correlation (**: at 0.01 significance level)

	ET	RH	WS	MT
ET	1	0.868**	-0.927**	0.746**
RH	0.868**	1	-0.697**	0.380**
WS	-0.927**	-0.697**	1	-0.703**
MT	0.746**	0.380**	-0.703**	1

for two years in 1988 and 1990. There is however an overall increasing trend in effective temperature detected over the span of 46 years from 1969 to 2015 at each selected station (Figure 8 a & b). Student t-test revealed that the trends are significant at 95 percent confidence.

Table 2 reveals the results of the same. Mann-Kendall test used to verify the trend results also confirmed an increasing trend in ET over all the selected 25 stations with a confidence level of 95 percent. Sen's slope was used to estimate the magnitude of a positive/negative slope that showed a positive change in the effective temperature with a magnitude of 0.0406. The results were then compared with the linear trend analysis and it confirmed the positive trend of 0.04°C/year in effective temperature. This indicates that the effective temperature will merely increase by 0.4 °C/decade. Therefore, owing to a very little change in effective temperature, it should not lead to any significant change in comfort/discomfort of people in the study area. Hence, the people residing in these areas can easily acclimatize to the changes in effective temperature.

Pearson's correlation

Pearson's correlation was used to analyse relationship between ET and the parameters that affect the calculation of ET, such as relative humidity, wind speed and mean temperature. Results pointed to a strong negative correlation at 99 percent confidence level between ET and WS whereas the ET was positively correlated with relative humidity and mean temperature (Table 3).

Conclusion

There are various thermal comfort/discomfort indices. The present study focused on effective temperature to analyze thermal discomfort level over south Indian cities. Effective temperature comprises environmental parameters such as relative humidity, wind speed and mean temperature. Among these parameters, relative humidity influences ET the most, and WS the least. WS showed a significantly strong negative correlation with ET in sharp contrast to RH and mean temperature. The results showed decrease in ET with increasing altitude. A study for 46 years (1969-2015) showed that average effective temperature is increasing by 0.04°C per year collectively for all the selected 25 stations, which may not greatly affect the people residing in these areas who can easily acclimatize to such changes in effective temperature. However, the increase in ET varies from 0.01°C to 0.1°C per year. Variation at 14 stations, namely Machallipattanam, Manglore, Jabalpur, Kurnool, Chennai, Kakinada, Trichy, Surat, Panjim, Pune, Kozhikode, Thiruvanantpuram, Madurai and Kolkata is less than the average i.e. less than 0.04°C per year. The remaining 11 stations such as Solapur, Mumbai, Hyderabad, Ambikapur, Jagdalpur, Cuddalore, Bhopal, Cochin, Salem, Nagpur and Aurangabad registered higher increase in ET. The rise in effective temperature at Salem, Nagpur and Aurangabad is 0.07, 0.08 and 0.10°C per year respectively. These 3 stations will be greatly exposed to thermal discomfort in the near future. Citizens residing in such areas may need to take precautionary measures to avoid heat stress related ailments. It was also revealed from the trend analysis that the relative humidity is increasing significantly over 14 of the 25 stations. On the other hand, wind speed is decreasing significantly over all the cities except three. Machilipatnam is the only city that showed a significant rise in wind speed. When it comes to temperature, Trichy, Salem and Solapur did not show a significant increase in mean temperature, unlike all the other stations which showed a significant rise in mean temperature. ET being a thermal comfort index, indicates thermally more comfortable nights compared to the day. The analysis reveals that the four monsoon months are the most comfortable period of the year. The strong negative correlation between ET and altitude does vindicate the fact that the former decreases with increase in altitude. Highland areas would be more comfortable than the low-lying areas. Overall, the study infers that since the effective temperature is increasing very slowly, people can acclimatize with it though there are chances that the thermal discomfort may increase in the future over some parts of the study area.

Acknowledgments:

Authors are grateful to India Meteorological Department (IMD) for provoding the necessary data.

References:

Ali, S. B., & Patnaik, S. (2017). Thermal comfort in urban open spaces: Objectives assessment and subjective perception study in tropical city of Bhopal, India. *Urban Climate*, 24, 954-967.

Alwetaishi, M. (2016). Impact of building function on thermal comfort. *American journal of Engineering and Applied Sciences*, vol. 9-4, 928-945.

Amirtham, L. R., Horrison, E., & Rajkumar, S. (2014). Study on the microclimatic conditions and thermal comfort in an institutional campus in hot humid climate. *International Plea Conference* . CEPT University, Ahmedabad.

Blazejczyk, K., Epstein, Y., Jendritzky, G., Staiger, H., & Tinz, B. (2012). Comparison of UTCI to selected thermal incices. *International Journal Biometeology*, vol 56, 515-535.

Bretherton, C.S., Smith, C., & Wallace, J. M. (1992). An intercomparison of methods for finding coupled patterns in climatic data. *Journal of Climate*, vol 5, 541-560.

Cheng, C. S., Campbell, M., Li, Q., Li, G., Auld, H., Day, N., Pengelly, D., Gingrich, S. & Yap, D. (2007). A synoptic climatological approach to assess climatic impact on air quality in south-central Canada. Part I: Historical analysis. *Water Air Soil Pollut*, vol 182, 131-148.

Choudhury, A. R., Majumdar, P. K., & Datta, C. (2011). Factors affecting comfort: human physiology and the role of clothing. In *Improving comfort in clothing* (pp. 3-60). Woodhead Publishing. doi:10.1533/9780857090645.1.3

Dash, S. K., Jenamani, R. K., Kalsi, S. R., & Panda, S. K. (2007). Some enidences of climate change in twentieth-century, India. *Climate Change*, vol 85, 299-321.

Desai, M. S., & Dhorde, A. G. (2017). Trends in thermal discomfort indices over western coastal cities of India. *Theoretical and Applied Climatology (2018)*, vol 131, 1305-1321.

Dhanya, P., & Ramchandran, A. (2015). Farmer's perceptions of climate change and the proposed agriculture adaption strategies in a semi arid region of south India. *Journal of Integrative Environmental Sciences*, vol 13(1), 1-18.

Fantozzi, F., & Rocca, M. (2020). An extensive collection of evaluation indicators to assess occupants' health and comfort in indoor environment. *Atmosphere*, vol 11(90), 1-37.

Feidas, H., Karagiannidis, A., Keppas, S., Vaitis, M., Kontos, T., Zanis, P., Melas, D., Anadranistakis, E. (2013). Modeling and mapping temperature and precipitation climate data in Greece using topographical and geographical parameters. *Theoretical Applied Climatology*, 118(1-2), 133-146.

Flach, E. (1981). Human bioclimatology. *World Survey of Climatology*, vol 3, 1-187.

Gadgil, A., & Dhorde, A. (2005). Temperature trends in twentieth century at Pune, India. *Atmospheric Environment*, vol 39, 6550-6556.

Gregorczuk, M. (1968). Biometeorological and hygienic assessment of negative effective temperatures. *Hygiene and Sanitation*, vol 33, 400-403 (English Translate).

Hentschel, G. (1987). A human biometeorology classification of climate for large and local scales. *WMO/WHO/UNEP International Symposium on Climate and Human Health*, vol 1. Leningrad: WCPA-No.1, WMO, 120-138.

Jaswal, A. K., & Koppar, A. L. (2012). Climatology and trends in near-surface wind speed over India during 1961-2008. *Mausam*, vol 64, 417-436.

Kim, H. S., Ho, C. H., Chu, P. S., & Kim, J. H. (2010). Seasonal prediction of summertime tropical cyclone activity over the East China Sea using the least absolute deviation regression and the Poisson regression. *International Journal of Climatology: A Journal of the Royal Meteorological Society, 30*(2), 210-219.

Lam, K. C., & Cheng, S. (1998). A synoptic climatological approach of sulfur dioxide in Hong Kong. *Environmental Pollution*, vol 101, 183-191.

Landsberg, H. (1972). The assessment of Human Bioclimate, A Limited Review of Physical Parameters. *World Meteorological Organization* (Technical note no. 123). Geneva: WMO-No. 331.

Li, P. W., & Chan, S. T. (2000). Application of a weather stress index for alerting the public to stressful weather in Hong Kong. *Meteorological Applications*, vol 7, 369-375.

Missenard, F. (1933). Température effective d'une atmosphere Généralisation température résultante d'un milieu. In: Encyclopédie Industrielle et Commerciale, Etude physiologique et technique de la ventilation. *Librerie de l'Enseignement Technique*, Paris, 131-185.

Oliver, J. E., & Wilson, L. (1987). Climate classification. *In:The Encyclopedia of Climatology, Van Nostrand Reinhold Company*, New York, 218-227.

Smith, J. (2001). *The Facts on file Dictionary of weather and climate.* Aylesbury, UK: Market House Book Ltd.

Wu, J., Gao, X., Giorgi, F., & Chen, D. (2017). Changes of effective temperature and cold/ hot days in late decades over China based on a high-resolution gridded observation dataset. *International Journal of Climatology,* vol 37(1), 788-800.

Tanmay S. Jadhav
Research Scholar,
Department of Geography
Savitribai Phule Pune University, Pune

Amit G. Dhorde*
Professor,
Department of Geography,
Savitribai Phule Pune University, Pune

* Author for Correspondence
E-mail: amitdhorde@unipune.ac.in