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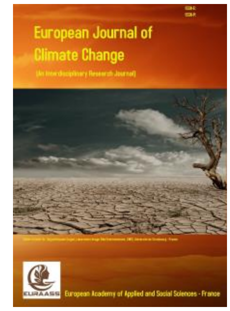

Research Article

Thermal comfort level in Chennai Metropolis under present and future climate scenarios

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Abstract

Climate change poses unprecedented challenges to urban inhabitants. Thermal comfort is one of the major issues in cities and it is expected to change in future due to climate change. The change of climate parameters particularly, temperature and relative humidity will affect the thermal comfort environments of people. Discomfort levels are largely preventable and requires prior assessment. In this study, the observed and projected thermal comfort level of Chennai Metropolis are calculated using Thermo-Hygrometric Index (THI) under present and future climate scenarios. The observed climate data of Chennai Metropolis for the period 1951-2010 procured from IMD are used to find the long term changes in observed thermal comfort. Monthly trends of THI are calculated for different periods to understand the thermal comfort behaviour in recent decades. On long term observation, high discomfort level is noticed during May and June months followed by July, August, April and September months. While there is a sharp increase in THI during winter months of recent decades. There is a considerable increase in discomfort level notice in post-monsoon season especially in December and November months. Future THI is calculated using high-resolution future climate scenarios developed using PRECIS. The deviations of THI from baseline to mid-century (2041-2070) and end-century period (2071-2099) are calculated and geospatially mapped using ArcGIS. There would be 2.0°C increase of THI is expected during winter and post monsoon months in mid-century scenario. Changes in future THI warrants the need for better cooling requirements and city planning to adapt with the future trends of external environment. Thus the study urges urban planners to evolve climate smart adaptation strategies to provide the congenial climate for a better living.

Keywords:

Urban, discomfort, THI, climate scenarios.

1. Introduction

Climate change is one of the major definite challenges of our age. It causes special consequence for urban areas because it accentuates distinctive behaviour, producing a more hazardous and less comfortable environment to the urban community. Climate change is increasingly acknowledged as a serious threat to population health (Buscail et al., 2012). People living in urban areas are subsequently exposed to the increased heat-related health risk (McCarthy et al., 2010). Global climate change is expected to be

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accompanied by an increase in the frequency and intensity of heat waves, as well as warmer summers and milder winters (IPCC, 2007). A number of observational studies conducted across the world have shown an association between high temperatures and heat-related mortality. The impact of extreme heat on human health may be exacerbated by increases in humidity (Gaffen & Ross, 1998; Gawith et al., 1999). Combined with the increased humidity, abnormal high temperatures could create more uncomfortable conditions and may even become lethal at times. Thermal comfort is a major issue in cities and it is expected to change in the future due to the changing climate (Cheung & Hart, 2012). Thermal comfort is defined as the condition of mind that expresses satisfaction with the thermal environment (Yilmaz et al 2007). Total or partial effects of urban areas with their different aspects of human thermal comfort are now under the consideration of many scientists from different parts of the world (Toy & Yilmaz, 2010). Matzarakis et al. (1999) discussed the need for human bio-meteorological assessment of thermal component of an urban microclimate. Many of the research studies on thermal comfort tried to find a way of describing the thermal environment which correlates well with human response, thus enabling reliable predictions to be made, and define the range of conditions found to be pleasant or tolerable by the population concerned (Humphreys 1976). The thermal comfort may be expressed by a large number of bio-meteorological indices which is used to quantify the integral effects of the heat exchange between the human body and the thermal environment (Nastos & Matzarakis, 2006; Jendritzky & de Dear, 2009).

Human thermal comfort or discomfort conditions may be determined by a large number of theoretical and empirical indices requesting a larger or smaller number of various parameters (Unger 1999) such as air temperature, radiation, humidity, clothing, etc. Among them, Thom's (1959) Discomfort Index (DI), Givoni's (1963) Standard Equivalent Temperature (SET), Fanger's (1970) Predicted Mean Vote (PMV) and Höppe's (1999) Physiological Equivalent Temperature (PET) are major and most used ones (Toy & Yilmaz, 2010). Some of these indices, such as DI, use only the relative effects of a few meteorological parameters on human thermal comfort, whereas others (e.g. PET and PMV) consider not only the effects of almost all meteorological parameters but also combined effects of personal features and other factors such as performed activity and the effects of clothing. While one of the best simple indices estimating the effective temperature was developed by Thom (1959) called the thermo-hygrometric index or temperature humidity index (THI). The IPCC report described the effect of weather and climate on humans with a simple index based on a combination of air temperature and relative humidity (IPCC 2001). The thermal comfort conditions can be evaluated by using a widely and easily used bio-meteorological index. The thermo-hygrometric index requires only temperature and humidity data (Toy et al., 2007) and it has been used widely in urban, rural and urban forest areas (Matsoukis et al., 2009).

Now, several researchers have begun to estimate the thermal comfort based on GCM and RCM projections of future climate scenarios. A study by Donaldson et al. (2001) on potential impacts of climate change on human health revealed that there could be a rise to 2,800 heat related deaths per year by the 2050s under a medium-high climate change scenario. Matzarakis & Endler, (2010) estimated the future PET in Freiburg, Germany using the RCM, REMO. Thorsson et al. (2011) undertook a similar study in Gothenburg, Sweden utilizing simulation output from ECHAM5-GCM. Cheung & Hart (2012) studied thermal comfort in Hong Kong under future climatic scenarios and concluded that there would be an increase in days experiencing heat stress and a decrease in days experiencing cold stress, thus affecting thermal comfort conditions.

The present study makes an attempt to find the changes on thermal comfort level in one of the major metropolis in India, Chennai is the fourth largest metropolis in India and the capital of Tamil Nadu State. It is a hot and humid coastal city situated at the Bay of Bengal. Chennai is one of fast growing industrial and economic growth center not only in India but also in South Asian Region. It is 36th largest build up urban area in the world with a population density of 10100 persons per sq.km ((Demographia 2018). Recent report states that the temperature has increased over the past 60 years that too in the last two decades (Jeganathan and Andimuthu, 2013). Combined with the increasing temperature, humidity could create more uncomfortable conditions and may even become lethal at times. Hence, the present study attempts to unveil the existence of the comfort level in the Chennai Metropolis under present and future climate scenarios.

2. Materials and methods

One of the most popular thermal indices, THI is used in the analysis in order to describe the effect of climate on comfort level in Chennai Metropolis. The THI was used originally used to determine the discomfort due to heat stress, subsequently it has been used in many studies for its easiness and over a wider range of conditions (Kyle 1994; Yoram & Moran, 2006). The equation for THI using air temperature (t) measured in degrees Celsius and with f as the relative humidity is

$$THI(^{o}C) = t - (0.55 - 0.0055f)(t - 14.5) \quad (1)$$

For observed changes, 60 years (1951-2010) daily maximum temperature and relative humidity data of Chennai station procured from India Meteorological Department (IMD) are used. IMD is the reliable source of meteorological data in providing complete climate dataset with quality control. The daily data are computed for monthly analysis; then monthly indices for different periods (1951–1980; 1981–2010) are calculated to find the trends and behavior in two phases. The temporal changes are analyzed by Mann Kendall rank statistics to confirm the significance of the observed trend. This study uses a high resolution (25 km) future climate scenarios developed at the Centre for Climate Change and Adaptation Research, Anna University, Chennai with the help of UK Met Office's PRECIS (Providing REgional Climate for Impacts Studies) Regional Climate Model software. HadCM3Q0-Q16 is used as Lateral boundary conditions for the simulation of PRECIS RCM. The future comfort level for mid-century (2041-2070) and end-century (2071-2099) periods are calculated. The changes from the baseline (BL) to mid-century (MC) and end-century (EC) period are calculated and spatially mapped through ArcGIS Software.

3. Results and discussion

The long term analysis on comfort level in Chennai shows there is a steady increase of discomfort in the city. Table 1 depicts the mean monthly value for different periods. On long term basis, May and June months show high discomfort level above 32°C followed by July, August, April and September months which recorded above 31°C. The discomfort level in March and October months are 30.2°C and 30.1°C respectively. Less discomfort is noticed in December and January months; the THI for these months are in the range of 27°C. Discomfort indices have a significant trend on the monthly scale for all the months in the whole study period. In the national context, a number of studies in India show that the country is experiencing extreme weather events for the past few decades, particularly after the 1990s and there was an increasing trend of discomfort seen from 20th April till June end (Dogra and Srivastava 2012). Srivatsava et al. (2007) calculated the discomfort level over six major cities of India using THI on the pentad and monthly scales for the months of April, May and June and noticed significant increasing trends of discomfort indices in some cities. THI values for tropical countries like India are always greater than 28.5°C in major parts of the country. In tropical countries the value will be always high, the higher the THI value, more is the discomfort level. The frequency of the occurrence of hot days in summer is found to have significantly increased over the region (Kothawale et al., 2010). The same line of observation was made by Das & Padmanabhamurthy (2007) for Delhi during summer and they pointed out that the entire city was found to be falling under discomfort and partial discomfort category. In general, there was a significant increasing trend in the discomfort indices during the summer over most of the Indian cities (Srivastava et al., 2007).

Table 1: Mean monthly THI values for different periods.

Month	1951-1980 (^{0}C)	1981-2010 (^{0}C)	1951-2010 (^{0}C)
Jan	26.8	27.8	27.3
Feb	28.1	29.2	28.7
Mar	29.7	30.7	30.2
Apr	30.9	31.8	31.3
May	32.3	33.0	32.6
Jun	32.0	32.5	32.3
Jul	31.3	32.0	31.6
Aug	31.1	31.7	31.4
Sep	31.0	31.7	31.3
Oct	29.7	30.4	30.1
Nov	27.7	28.5	28.1
Dec	26.7	27.5	27.1

Mann–Kendall analysis shows a significant increasing trend in all the months at the 0.01 level during 1951-2010. During 1951-1980 all January, February, August and October months show insignificant increasing trend, while other months show a significant increasing trend of THI. During 1981-2010, majority of the months shown a significant increasing trend of THI except in June, August and September months. Table 2 shows monthly Kendall Tau and p values for different periods with significance level.

Figure 1 shows the changes in comfort level in two different phases, i.e., 1951–1980 and 1981–2010 for all months. The time periods have been chosen to illustrate the changes in the strength of discomfort level over the study period. The change in discomfort level has a regular increase in the second phase during 1981 to 2010 when compared to the first phase. Though the discomfort has increased in almost all months, the significant high increase is noticed in February (1.1ºC) followed by January and March months (1ºC). The increase of temperature in winter season might also one of the reason for increasing trends in discomfort in these months. While the period analysis shows, there is a sharp increase in discomfort level in winter months during 1981-2010. In recent times, an increase in winter temperature was well noticed in many parts of the world. Chennai too witnessed the increases in maximum temperature during winter months and the increase is as high as 2.0°C; the increase of minimum temperature is 1.4°C during 1951-2010 (Jeganathan and Andimuthu, 2013). The considerable discomfort increase is noticed in April month followed by post-monsoon months i.e November and December months.

Table 2: Kendall Tau and p values for different periods and their significance level

	1951-1980		1981-2010		1951-2010	
	Kendall's tau	p-value	Kendall's tau	p-value	Kendall's tau	p-value
Jan	0.208	0.112	0.541*	0.001	0.591*	< 0.0001
Feb	0.145	0.272	0.353*	0.007	0.504*	< 0.0001
Mar	0.380*	0.003	0.379*	0.004	0.581*	< 0.0001
Apr	0.546*	< 0.0001	0.313*	0.016	0.608*	< 0.0001
May	0.446*	0.001	0.304*	0.019	0.455*	< 0.0001
Jun	0.377*	0.004	0.081	0.544	0.333*	< 0.0001
Jul	0.482*	0.000	0.251*	0.054	0.518*	0.0
Aug	0.124	0.344	0.198	0.129	0.35*	< 0.0001
Sep	0.285*	0.028	0.131	0.321	0.423*	< 0.0001
Oct	0.111	0.402	0.454*	0	0.474*	0.001
Nov	0.308*	0.018	0.474*	0	0.517*	0.001
Dec	0.159	0.225	0.549*	< 0.0001	0.535*	0.001

* Significance at 0.01 level

Then, monthly THI values are computed for future climate change scenarios. The changes of THI from observed (baseline) to mid-century (2041-2070) and end-century (2071-2099) scenarios are shown in Figure 2. In the baseline period, THI value is very high in May month followed by April and June and all summer months show high discomfort value. The monsoon season shows moderate comfort; post-monsoon season and winter season show less discomfort level or comfortable environment in Chennai Metropolis. While current mean monthly THI for winter and post-monsoon months would be increased by an average of 2.0°C in mid-century scenario and in summer months, it would increase by an average of 1.7°C. When compared to other seasons, monsoon months would have less increase as 1.5°C from the baseline period. In the end-century scenario, there is an average of 4.6°C increase in THI values from the baseline period and the summer months show the maximum increase in THI as an average of 5°C from the baseline period. The winter month (January) and post-monsoon months November and December show the increase as 4.1°C from the baseline period. Changes in future THI are differed on the monthly and seasonal scale although cooling requirements became more onerous in the summer, more will be needed in future to adapt with trends of the external environment.

Spatial variations of discomfort level in the city under three different scenarios are shown in Figure 3. The majority of the study area showed severe discomfort level during end-century period. The western and south-western part of Chennai show higher discomfort level than the rest of the area under future climate conditions and energy demand for maintaining the comfort level would be much more than the current scenario. The increases in discomfort level in cities will demand more energy for cooling purpose in the commercial and residential buildings to maintain a comfort level (Padmanabhamurty, 1999) and this increased demand for energy leads to higher emissions of greenhouse gases which ultimately contribute to global warming and climate change.

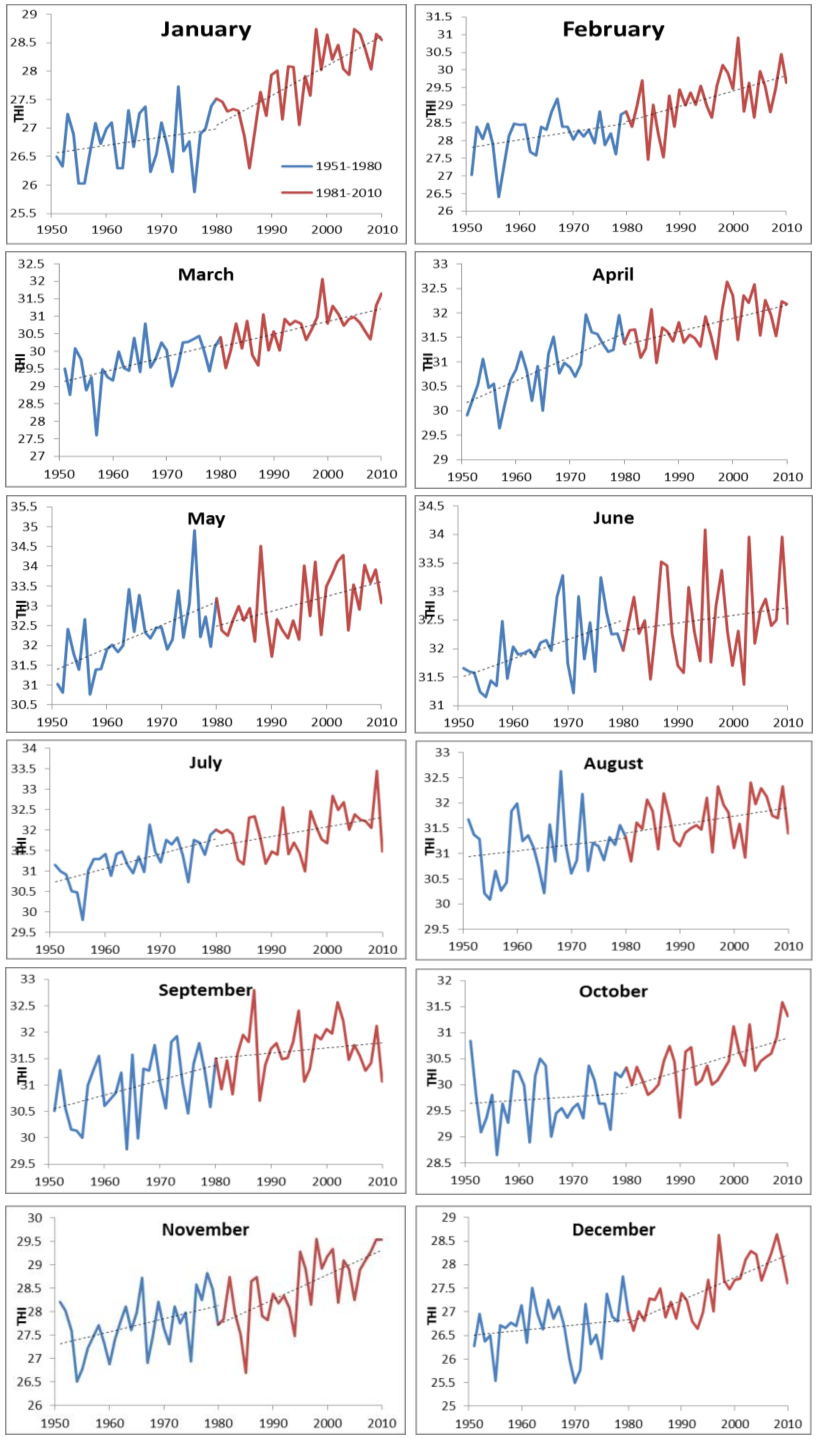

Figure 1. Monthly THI trends in two different phases, i.e., 1951–1980 and 1981–2010.

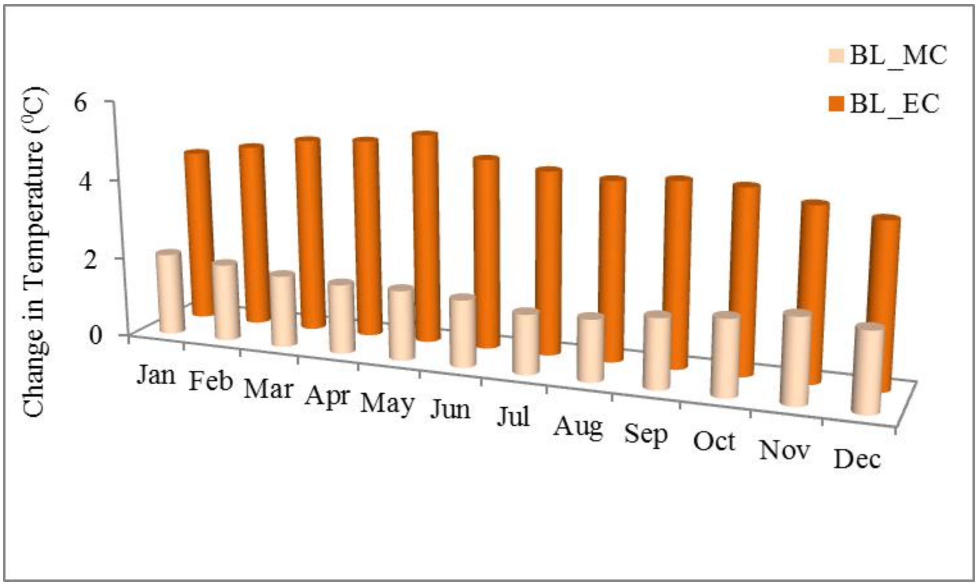

Figure 2. Changes in monthly THI values for MC, EC scenarios from the baseline period.

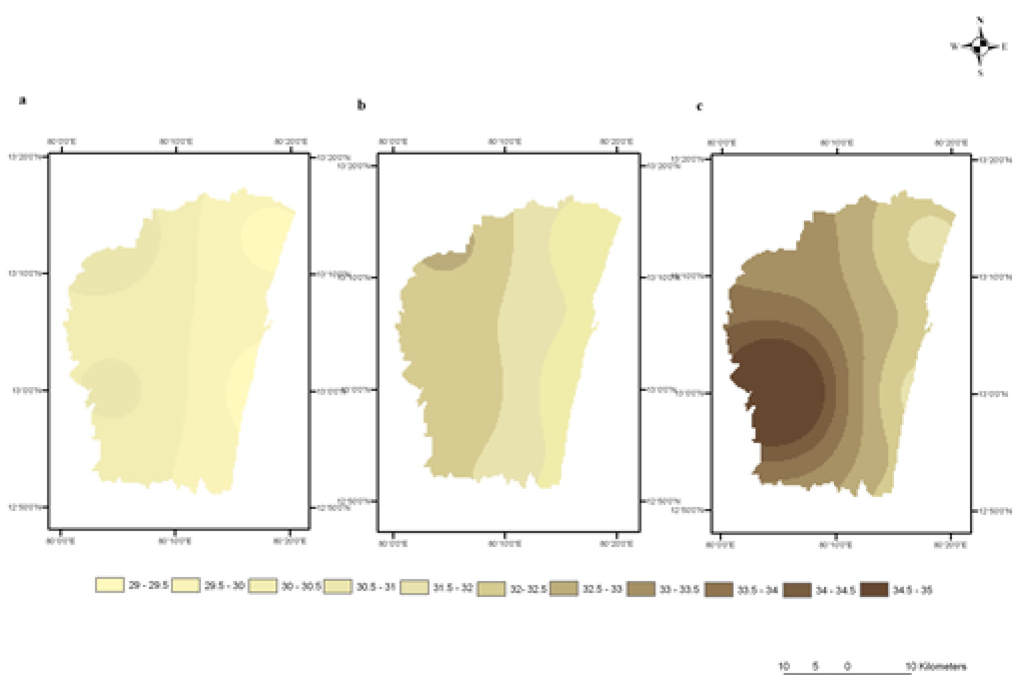

Figure 3. Spatial variation of THI in Chennai Metropolis under a) BL, b) MC and c) EC scenarios.

4. Conclusion

The present study exposes significant changes of discomfort level in Chennai under present and future climate scenarios. There is a significant increasing trend of discomfort level observed in the city. Even though April, May, June, July, August, and September months show high discomfort level during the study period, an alarming indication of higher discomfort noticed in winter month's i.e January and February and in March month in recent decades. The sharp increasing trend of discomfort level in winter months is a distressing fact. The more intense discomfort is virtually certain to occur in the warmer future. THI for winter and post-monsoon months would be increased by an average of 2.0°C in the mid-century scenario. Thus, it is necessary that both bio-physical and societal approach should be considered together to enable society to adapt to future conditions. Consequently, the impacts of thermal discomfort can be reduced and may adaptable, through implementation of effective measures such as public health warning systems, sustainable land management, more green wedges, regulating anthropogenic emissions and solid waste disposal, identification and regular monitoring of vulnerable zones and/or exposed individuals. The scientific knowledge of the mitigation and adaptive measures of thermal discomfort should be effectively translated into an intelligent climate-proof urban design to make people comfortable.

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