70: Urban Climate and Bioclimate of Dar es Salaam, Tanzania – Preliminary results

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Abstract

Understanding of the urban climate of a city is important for future planning and human wellbeing. The well known Physiologically Equivalent Temperature (PET) and the Universal Thermal Climate Index (UTCI) indices were calculated with RayMan model using meteorological data (2001-2011) in order to study the human thermal bioclimate of Dar es Salaam. Results indicate that afternoons from late September to May is the heat stressful period. On the other hand, the June-August period is relatively a comfortable time of the year especially the morning hours. These results are however treated as preliminary to the detailed and reliable study that uses hourly datasets and of a long duration.

Keywords: Thermal bioclimate, Physiologically Equivalent Temperature, Universal Thermal Climate Index, Dar es Salaam, RayMan.

1. Introduction

Dar es Salaam (6 º 51´S, 39º18´ E), the largest and leading economic city in Tanzania, is one of the fastest growing cities in the world with an average annual growth for 2006 to 2020 at 4.4%, ranking 9th in the world. Its population is estimated at 3 million inhabitants and projected to be 5.1 million in 2020 [1]. Besides urbanization, Dar es Salaam is vulnerable to environmental problems like flash flooding, air pollution (partly due to traffic congestion) and urban bioclimate [2]. Climate change can exacerbate these problems and multidisciplinary study that makes use of climatic information is important to ensure a quality of life.

One particular characteristic feature of growing cities in developing countries is sprawling [3]. Without careful urban planning, sprawling could result into severe environmental problems including local climatic changes which can impact the human thermal bioclimatic conditions. Assessment of the human thermal bioclimatic is important for wellbeing of the increased population and quality of life. About one third of Tanzanian urban population currently lives in Dar es Salam and consists of over 70 % of unplanned settlements [4]. While application of human thermal bioclimate in tourism industry is growing [9]; perhaps need of human bioclimatic information in Tanzania is also equally important as the general weather forecast. It is clear that Dar es Salaam is the gateway to tourism industry of Tanzania including the islands of Zanzibar.

Although, generally urban climate studies in tropics are few, in Dar es Salaam, most studies have used simple thermal indices [6, 5]. While [6] used Temperature Humidity Index (THI) with 3 years synoptic to assess thermal comfort in Dar es Salaam, the works of [5] was too general as it covered the whole of Africa. Effective Temperature index (ET) was also used to assess the spatial, seasonal and diurnal variation of thermal stress in Kenya [7]. Both THI and ET use air temperature and relative humidity as input data, while other indices that base on the human body energy balance, use more weather elements [8, 11]. These include the Universal Thermal Climate Index (UTCI) [11, 12] and Physiologic Equivalent Temperature (PET) [8, 9, 10] as applied in this study. The study therefore aimed at assessing human thermal conditions as preliminary results to the study of climatic impacts of land cover changes in Dar es Salaam city.

2. Data and methods

2.1 Study area

Dar es Salaam (fig. 1) has an area of 1,393 km^2 of land mass and has a tropical wet/dry climate (Aw) [4, 6]. Annual mean rainfall is about 1050 mm and air temperature of 30 °C while air humidity usually ranges from 67 to 96 %.

2.2 Meteorological data and thermal indices

The microclimate of Dar es Salaam was assessed by determining the diurnal and seasonal patterns of various meteorological conditions. These include patterns of air temperature, wind field, relative humidity, cloud cover and vapour pressure.

Input data for the indices were air temperature, wind speed, air humidity and radiation fluxes as an estimated from cloud cover. The data was obtained from http://www.ogimet.com from 2001 to 2011 and calculation done with RayMan model [13, 14]. Though some records have missing values, correction and/or entirely deleting the records of some wrongly entered fields was done. In this case, datasets of 2007–2009 and 2011 had few missing values hence used to analyse the diurnal pattern and the 2001-2011 for the annual pattern but only at 6 and 15 local standard time (LST). The approach was to determine the frequency of occurrence of certain human thermal conditions as in tabulated in [9, 10, 11].

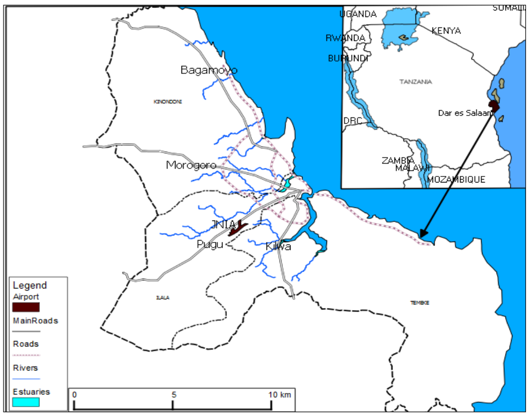

Fig. 1. Map of Dar es Salaam city. Synoptic meteorological data are collected at the airport.

3. Results

3.1 Meteorological conditions.

Wind distributions at Dar es Salaam indicate a lack of a pure westerly component (Fig. 2).

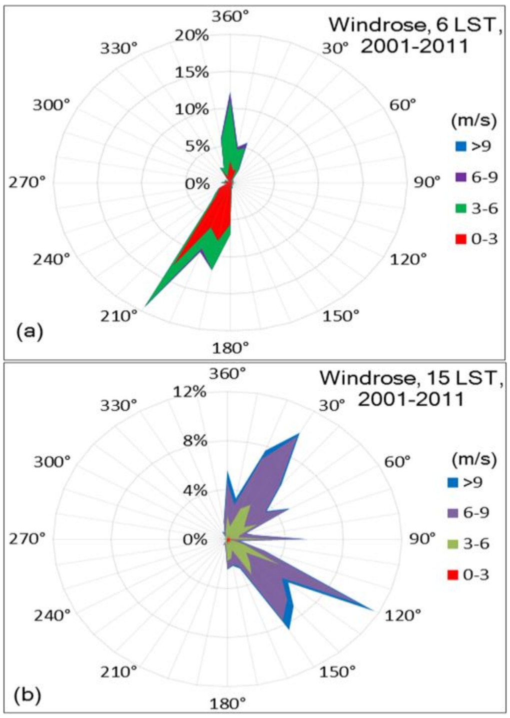

Fig.2. Wind roses at 6 and 15 LST (a, b).

The diurnal pattern of air temperature in terms of frequency of occurrence indicates a significant occurrence of temperature between, 30-35 °C at 12-15 LST and nearly insignificant occurrence of temperature above 35 °C. Cold temperature (bellow 20 °C) prevails from 0 and 6 LST (Fig.3a). The vapour pressure pattern (Fig. 3 b) shows a relatively high frequency for 28-31 hPa. At 9 LST the pattern show a drop meaning a high convection in afternoon. Cloudiness prevails between 9 and 18 LST (Fig. 3c).

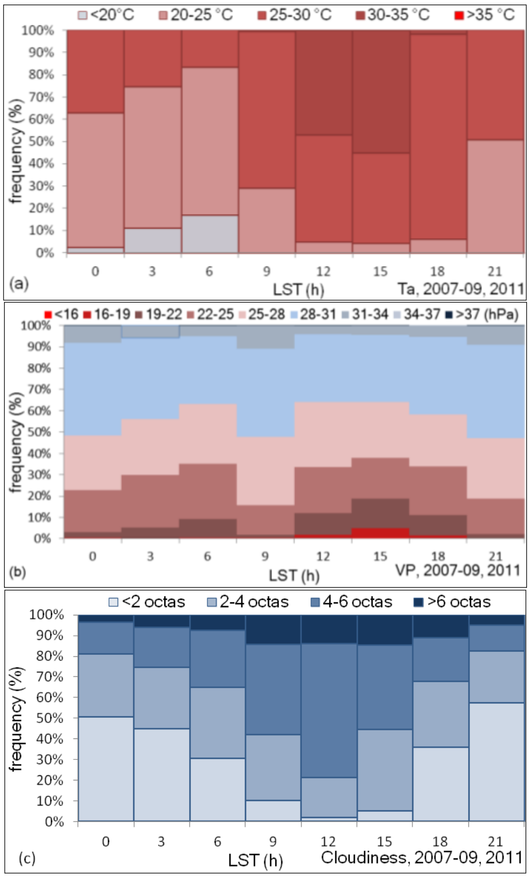

Fig. 3. Frequency of occurrence for the diurnal patterns of air temperature (a), vapour pressure (b) and cloudiness (c) for 2007-09 and 2011 data.

3.2 Human thermal bioclimatic conditions.

The annual pattern indicates at 6 LST, high prevalence of comfortable thermal perception according to thermal conditions for both PET and UTCI indices [9, 11, 14]. Figures 4 (a) and (b) shows nearly over 80 % and 70 % frequency of no thermal stress for PET and UTCI respectively. At 15 LST, PET index suggests a significant strong heat stress (35 – 41 °C) from mid-October to early May with some chances of extreme heat stress in October, December, February and March (Fig. 4c). While UTCI indicates significant strong heat stress from September to May with some extreme occurrences in December to April. However, in June to September, cold stress of up to 10 % frequency of occurrence is suggested by PET at 6 LST.

For the diurnal pattern analyses, human thermal bioclimate ranges from 7.7 to 53.6 °C and 4.6 to 78.9 °C for PET and UTCI respectively. Generally, both indices suggest that human thermal stress starts early the day as from 9 to 15 LST (fig. 5 a, b). It is however, surprising to see a relatively higher prevalence of extreme heat stress at 9 LST for PET and at 12 LST for UTCI than at 15 LST where usually maximum air temperature occurs.

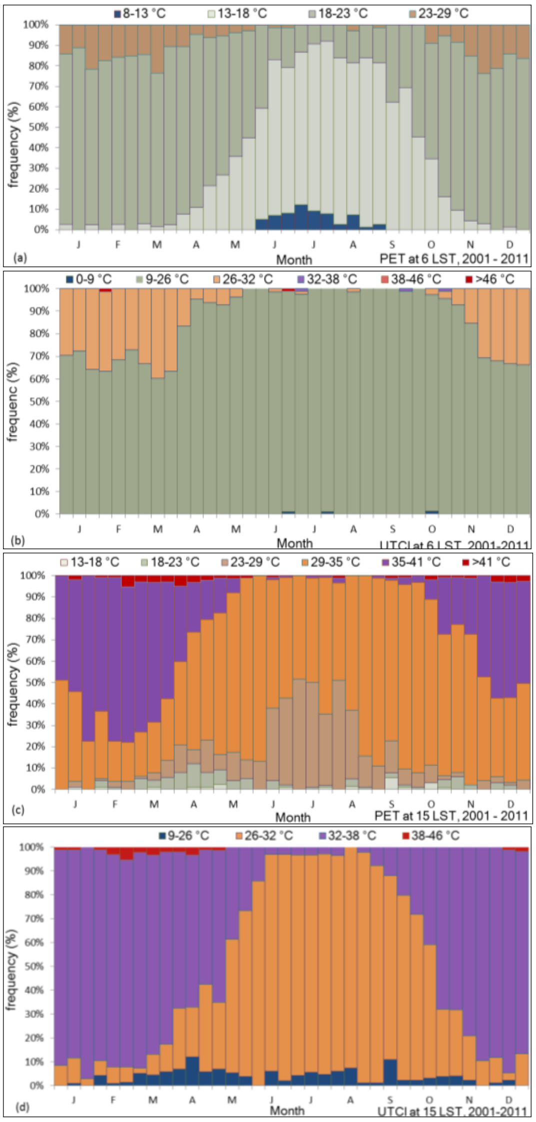

Fig.4. Annual patterns of human thermal bioclimate conditions as depicted by PET and UTCI indices at 6 LST (a, b) and at 15 LST (c, d).

Further, the seasonal cycle of the diurnal cycle by PET index indicates the range of 22 °C to 37 °C in the DJF season and 15 °C to 32 °C in the JJA season. The seasonal peak appears to occur earlier in a day during MAM at around noon time and late in the DJF season at around 15 LST.

4. Discussion

The analyses of meteorological conditions suggests an insignificant frequency occurrence of air temperatures above 35°C, prevalence of 28-31 hPa vapour pressure in most of the day, cloudiness from 9 to 18 LST as well a lack of pure westerly component of wind system. Though, Dar es Salaam is generally hot almost throughout the year; similar less events of air temperature above 35° C were also observed at both Kurasini and Airport weather stations [15]. The diurnal cycle of minimum temperature before dawn and maximum temperature in early afternoon also confirms the earlier study in Dar es Salaam and in the other similar hot humid tropical city of Colombo, Sri Lanka [15,16].

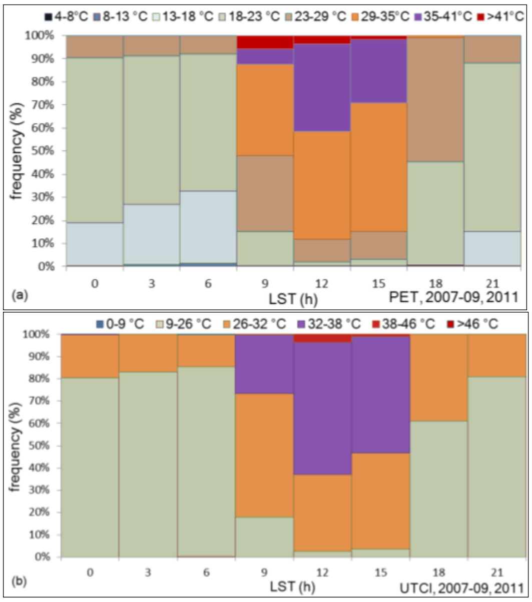

Fig. 5. Diurnal patterns of human thermal bioclimate conditions depicted by (a) PET and (b) UTCI (a, b), using 2007-2009 and 2011 datasets.

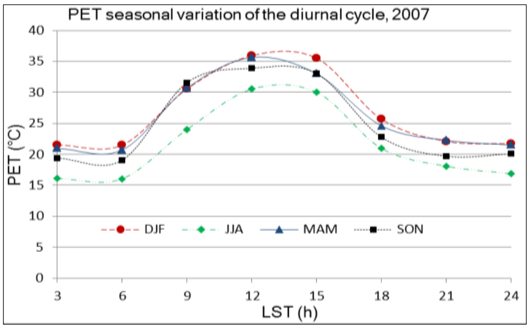

Fig. 6. Diurnal cycle of thermal stress in different seasons of the year, as depicted by PET index.

Perhaps, the relative occurrence of high frequency for 28-31 hPa vapour pressure in most of the day attributes the high humid conditions all year round [15]. Earlier studies have also confirmed the occurrence of minimum humidity at Kurasini and Airport stations at 15 LST which is also a time of maximum temperature [15]. The lack of the pure westerly component is explained by the northwest to southeast coastline which makes the winds to act purely in sea-land breeze manner [6]. The pattern also looks similar to that observed in earlier studies [6, 17]. The cloudiness pattern can also be explained by the prevalence development of convective clouds in afternoons in the tropics [6, 15].

For human thermal bioclimate, generally both indices suggest a significant human thermal stress in afternoons from late September to May, with some extreme cases in between and a morning cold stress in June to August.

Frequency of cold stress is rather more significant in the PET pattern at 6 LST than in the corresponding UTCI pattern which indicates some distinctive patterns in June, July and October. For the afternoons, UTCI indicates no any distinctive patterns of extreme stress from mid-May to mid-December which is unlike to PET. The relative high frequency of extreme stress by PET at 9 LST that at 15 LST, (fig. 5a) is likely answered by vapour pressure pattern (Fig. 2b). Such small differences between the two indices may be attributed to their structure of energy balance models and definitions of reference conditions [12]. However, the current study is not intended to compare performance of the two indices, rather to provide a general picture of bioclimatic conditions for human beings using indices that base on the human heat balance equation. Though, most indices are developed and often used in mid-latitudes, still can be used in Dar es Salaam. Thermal sensation survey can incorporate local adaptation and adjustment [18].

The most thermal stressful period is however in agreement to that reported in earlier thermal physiological studies though most of them used simple indices. Above 25 °C of THI in afternoons were found in October to May and sultry conditions by ET from December to April [5, 6]. Besides, daytime PET values above the suggested upper comfort zone limit of 33°C were found in the similar hot-humid city of Colombo Sri Lanka from 11 h and 16 h LST [16]. In our study, heat stress starts early the day as from 9 LST to 18 LST.

5. Conclusion

The preliminary analysis of the human biometeorological assessment of Dar es Salaam, a coastal tropic city highlights the importance of thermal bioclimate research in cities especially today where the population is become more urban. The general picture of thermal bioclimate is that Dar es Salaam is relatively thermally discomfort in afternoons especially from October to April. The use of thermal indices, in assessing human bioclimate is necessary in tropic cities though it is generally perceived that, people there are acclimatized or adapted to warm temperature [16]. Availability of longer and high resolution data could yield more accurate and reliable results in future.

6. Acknowledgements

Thanks are due to Ogimet website's owners for meteorological data and to the joint Tanzanian Ministry of Education and Germany Academic Exchange Service (DAAD-MOEVT) scholarship to E.L.N; as well the bursary support from ICUC8.

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