Theor Appl Climatol (2013) 113:205–212
DOI 10.1007/s00704-012-0777-9

ORIGINAL PAPER

Relevance of thermal environment to human health: a case study of Ondo State, Nigeria

Akinyemi Gabriel Omonijo · Clement Olabinjo Adeofun · Olusegun Oguntoke · Andreas Matzarakis

Received: 2 September 2011 / Accepted: 2 October 2012 / Published online: 14 October 2012

Abstract The interconnection between weather and climate and the performance, well-being, and human health cannot be overemphasized. The relationship between them is of both local and global significance. Information about weather, climate, and thermal environment is very important to human health and medical practitioners. The most crucial environmental information needed by medical practitioners and for maintaining human health, performance, and well-being are thermal conditions. The study used meteorological variables: air temperature, relative humidity, wind speed, solar radiation, and RayMan model as an analytical tool to compute physiologically equivalent temperature (PET) in order to assess thermo-physiological thresholds in Ondo State. The study revealed that there are marked spatial and seasonal variations in the environmental thermal conditions in the study area. The results of physiologically equivalent temperature for different grades of thermal sensation and physiological stress on human beings indicate that about 60 % of the total study period (1998–2008) fall under physiological stress level of moderate heat stress (PET 31–36 °C). In derived savannah, 32.6 % out of the total study period was under strong heat stress. In view of this, the study concluded that Ondo State may likely be prone to heat-related ailments and that some of the death recorded in the State, in recent times, may be heat-related mortality, but this is difficult to ascertain because there is no postmortem records in Nigeria where it could be confirmed. This type of study is relevant to help government to improve health care interventions and achieve Millennium Development Goals in health sector.

A. G. Omonijo · A. Matzarakis
Meteorological Institute, Albert-Ludwigs-University of Freiburg,
Werthmannstr. 10,
79085 Freiburg, Germany

A. G. Omonijo
Department of Agricultural Technology, Rufus Giwa Polytechnic,
Owo, Ondo State, Nigeria

A. G. Omonijo (✉) · C. O. Adeofun
Department of Environmental Management & Toxicology,
University of Agriculture,
Abeokuta, Nigeria
e-mail: akingab@yahoo.com

O. Oguntoke
Department of Geography and Environmental Management,
University of Johannesburg,
Kingsway Campus,
Johannesburg, South Africa

1 Introduction

Weather, climate, and health are interconnected in many ways. The report of IPCC (2001) concluded that, based on the new and strong evidence, not only was much of the global warming observed over the last 50 years attributable to human activities but also that climate change could affect human health (IPCC 2001). The effects can be direct such as through increased heat stress and loss of life in floods and storms as presently experienced in Southwestern Nigeria (including Ondo State) or indirect through changes in the ranges of disease vectors such as mosquitoes, water-borne diseases, and water and air quality as well as inadequate food availability and quality, but this paper focuses on relevance of thermal environment on human health.

Climate and weather are predominantly considered based on standard climate parameters such as air temperature or precipitation in time and space. In environmental health, most of the studies only relate air temperature to data of health outcome (Kovats and Jendritzky 2006). The term "thermal environment" encompasses both the atmospheric heat exchanges with the body (thermal stress) and the body's physiological response (thermal strain) (Jendritzky and Tinz 2009). Human beings feel the impact of the thermal component of atmospheric environment on daily bases. The heat exchange between the human body and the thermal environment can be described in the form of the energy balance equation, an application of the first theorem of thermodynamics applied to the body's heat sources (metabolism and environment) and the various ways of heat loss to the environment (Mayer and Höppe 1987).

Internal heat is produced via metabolic activity required to perform mental and physical activities. The body exchanges heat by convection, conduction, evaporation, radiation, and respiration. Therefore, a complete heat budget model that takes all mechanisms of heat exchange into consideration is required for the assessment of human thermal environment (Fanger 1970; Landsberg 1972; Driscoll 1992; Matzarakis and Mayer 1996; Parsons 2003).

However, people vary, sometimes markedly, in their feeling of comfort according to their metabolic rate, type of clothing, work load, age, diet, emotions, cultural influences, past climatic experience, and climatic zone among others. People from tropical regions tend to accept as comfortable higher levels of air temperature and humidity than people from temperate zones (Stewart and Oke 2010). Based on the impacts of current and predicted weather extremes over African region, this paper is therefore aimed at evaluating the thermal conditions of Ondo State, Nigeria, in a physiologically significant manner and also examines its implications on human health.

1.1 Health implications of heat waves and extreme temperatures

Extremes of heat and temperature have a broad and far-reaching set of impacts on the nation. These include significant loss of life and illness and economic costs in transportation, agriculture, production, energy, and infrastructures. The most rigorously documented of all are the health impacts, based to a large extent on epidemiological studies conducted by several researchers and health institutions across the globe; among are Spickett et al. (2011) and IRI (2011).

During the extreme heat events, weather changes slowly or rapidly, leading to high temperature and/ or humidity that body may find difficult to adjust to. There is typically lack of nighttime cooling, and the air quality during this period is often poor. It has been suggested that the four atmospheric environmental parameters that interact together to make it hot enough to put health at risk are high air temperature, high air moisture content (often expressed as relative humidity), radiation (sun), and lack of air movement (wind which usually moderates the negative effects of the other factors) (Matzarakis 2007; McArthur et al. 2010; Shiue and Matzarakis 2011). Studies have indicated that, in order for bodies to function properly, its inner core temperature should be close to 37 °C, and that a core temperature of 40 or 41 °C is considered to be life threatening (Meehl and Tebaldi 2004; Robinson 2001).

It was on record that the July 1995 heat wave resulted to death of about 520 people in Chicago alone, while another study by the US Centers for Disease Control and Prevention found that an average of 384 people died by excessive heat each year during the period 1979–1992 (NOAA 1995). In 2003, one of the hottest summers on record was reported in Europe which led to the death of about 35,000 people across the European continent (Chase et al. 2006; McClung 2006; Henson 2008). Also, there was a record of heat wave in 2006, 2007, and 2010 in Europe. The Northern Hemisphere summer heat wave of 2010 affected many areas across the Northern Hemisphere, especially parts of Northern China and Southern Russia which resulted to many causalities. However, heat wave is a global issue and not limited to a particular region alone.

There are several other heat-related ailments such as heat exhaustion, syncope (fainting), cramps, cerebral meningitis, and heat stroke among others. Heat stroke is the most serious and usually fatal. It occurs when the core temperature exceeds the tolerance range. Outbreak of cerebral meningitis over sub-Saharan Africa which afflicting about 25,000 to 250,000 people annually is prevalent between February and May during the hot dry season accompany by extreme high temperature and heat (Yaka et al. 2008).

2 Materials and methods

2.1 Location and description of study area

The study area is Ondo State which is situated between longitudes 4°15′ E and 6°00′ E and latitudes 5°45′ N and 7°45′ N which is the north of the equator in the Southwestern Nigeria (Figs. 1 and 2). The State has 18 local government areas with a population of about 3,440,000 of which the rural population constitutes about 1.7 million and land area of 14,606 km^2 (NPC 2006). The State consists of coastal plains basically alluvium which occupy about 20 %; lowland and undulating plains constitute about 60 % of the land mass, while undulating lands with scattered rocks and hills occupy the remaining 20 % of the land area. It has the tropical wet-and-dry climate. The State has a mean annual rainfall of 1,500 and 2,000 mm in the derived savannah and humid forest zones, respectively, while the mean annual maximum air temperature is about 34 °C, and a mean minimum air temperature, of about 20 °C (Adefolalu 1997).

The climate of Ondo State is also affected by intertropical discontinuity as a result of seasonal winds that blow from the north (North African anticyclone) and the one from the

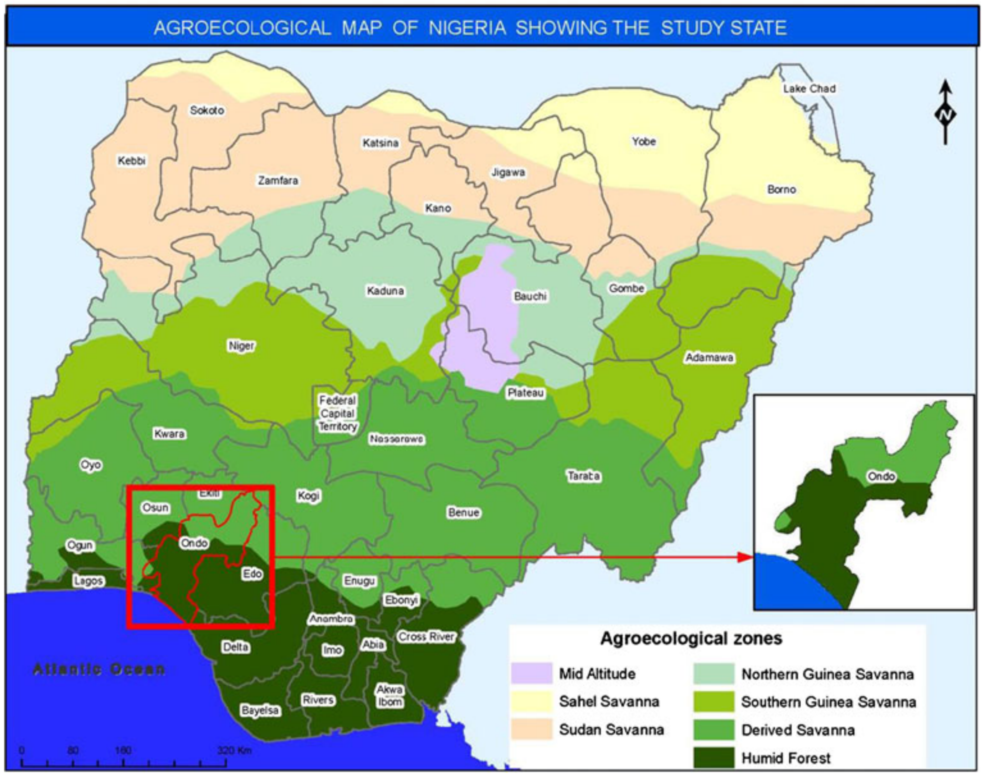

Fig. 1 Map of Nigeria showing the study area (Ondo State)

south (St. Helena anticyclone) during dry months. During the wet season, the climate is affected by Azores anticyclone from the north and St. Helena anticyclone from the south. Other factors that influence the climate of Ondo State are its location near the Atlantic Ocean and the existence of vegetation/ forest and mountains. Generally, the climate from March to November is marked by rainfall, while December to February is dry season over humid forest zone of Ondo State. In derived savannah, months of April to October are rainy season, while the dry season is from November to March. The dry season is also characterized by Harmattan dust haze and hot and dry northerly winds that blow from the Sahara Desert over West Africa.

2.2 Data

The climatic data used for this study consist of daily mean air temperature (in degree celsius), relative humidity (in percent), solar radiation (in watts per square meter), and wind speed (in meters per second) for 11 consecutive years (1998–2008). The data were collected from the synoptic weather stations located in humid forest zone on longitude 4.45° E and latitude 6.38° N with elevation of about 100 m (Okitipupa) and derived savannah zone on longitude 5.45° E and latitude 7.22° N with elevation of more than 300 m (Akoko Southwest). The data used daily average measurement. These stations were established and maintained by the Agroclimatological and Ecological Monitoring Unit, Ministry of Environment and Natural Resources, Ondo State, coupled with those collected from the Nigerian Meteorological Agency, Lagos. The Nigerian Meteorological Agency is the official organization charged with the responsibilities of collecting, collating, and documenting weather data, among other things in Nigeria.

2.3 Calculation of physiologically equivalent temperature

There are several physiological thermal indices derived from the human energy balance (Höppe 1993; Tinz and Jendritzky 2003; Spagnolo and de Dear 2003, overview in Blazejczyk et al. 2011). One of these is the physiologically equivalent temperature (PET) which will be used as thermal comfort indicator in this study. The physiologically equivalent temperature is based on the Munich Energy-Balance Model of Individuals (MEMI), which models the thermal conditions of the human body in a physiologically relevant way. PET is defined as the air temperature at which, in a typical indoor setting (without wind and solar radiation), the heat budget of the human body is balanced with the same core and skin temperature as under the complex outdoor conditions to be assessed (VDI 1998; Höppe 1999).

In calculating PET, the following assumptions and procedures were followed:

1. Mean radiant temperature (T_{mrt}) equals to air temperature ($T_{mrt}=T_a$).

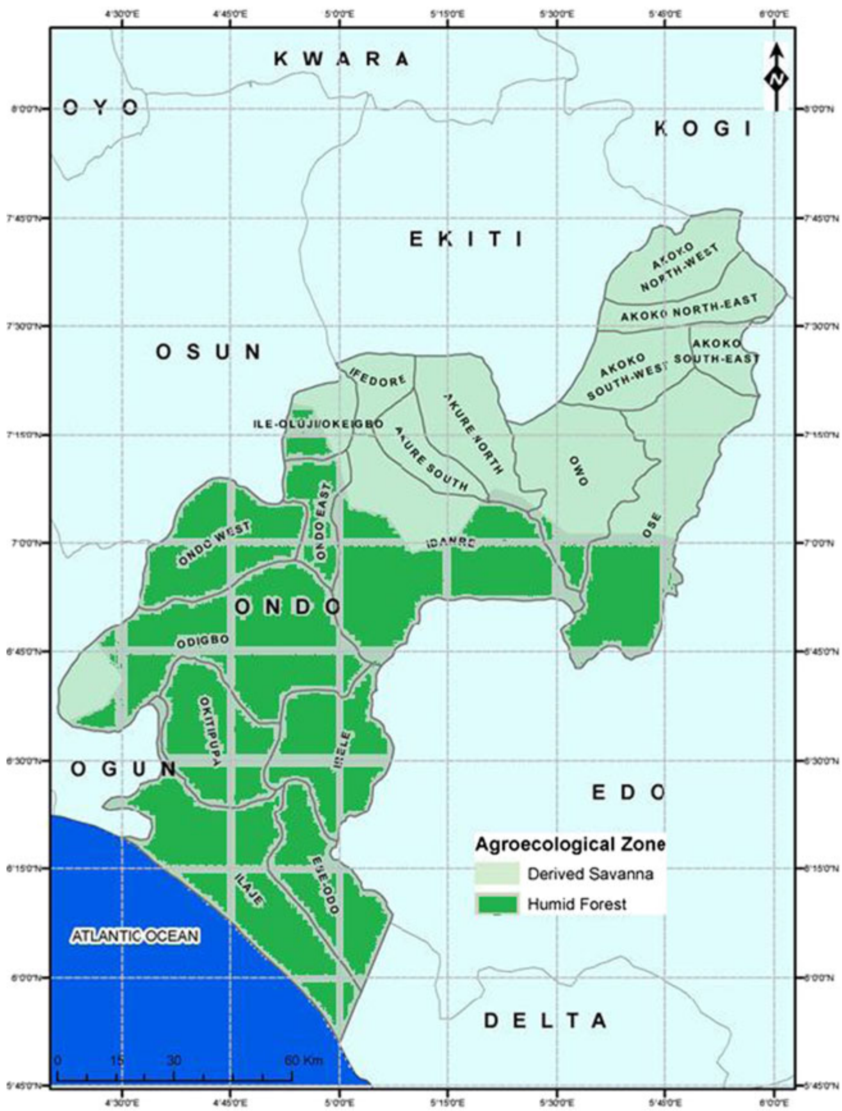

Fig. 2 Map of Ondo State (study area) showing the two ecoclimatic zones and local government areas

2. Air velocity (wind speed) is fixed at v=0.1 ms^{-1}.
3. Water vapor pressure (VP) is set to 12 hPa (approximately equivalent to a relative humidity of 50 % at T_a=20 °C).
4. Calculation of the thermal conditions of the body with MEMI for a given combination of meteorological parameters.
5. Insertion of the calculated values for mean skin temperature and core temperature into the model MEMI and solving the energy balance equation system for air temperature T_a (with v=0.1 ms^{-1}, VP=12 hPa, and T_{mrt}=T_a).
6. The resulting air temperature is equivalent to PET.

PET is a universally used index for characterizing the thermal bioclimate (Matzarakis 2008) just like the frequently used predicted mean vote (PMV) index (Fanger 1970; Jendritzky and Tinz 2009). It also allows the evaluation of thermal conditions in a physiologically significant manner (Matzarakis 2008). In 1996, Matzarakis and Mayer transferred ranges of PMV for thermal perception and grade of physiological stress on human beings (Fanger 1970; Mayer 1993) into corresponding PET ranges. This was adapted and modified by Omonijo and Matzarakis (2011) for Nigeria environment (Table 1).

The above-mentioned climatic data were arranged and fed into RayMan model for the calculation of PET and mean radiant temperature for this analysis. RayMan model is one of the recently used radiation and bioclimate models for the calculation of radiation fluxes (Matzarakis et al. 1999, 2000, 2007). The RayMan model, which was developed according to the Guideline 3787 of the German Association of Engineers (VDI 1998), can comfortably be used to calculate the radiation flux in simple and complex environments on the basis of various parameters, such as air temperature, air humidity, degree of cloud cover, time of day and year, albedo of the surrounding surfaces, and their solid-angle proportions (Matzarakis et al. 2000, 2007).

Table 1 Physiologically equivalent temperature for different grades of thermal sensation and physiological stress on human beings

Thermal sensation	Physiological stress level	PET range for Western/Central Europe[a] (°C)	PET range for Nigeria[b] (°C)
Very cold	Extreme cold stress	"≤4"	"≤11"
Cold	Strong cold stress	">4≤8"	">11≤15"
Cool	Moderate cold stress	">8≤13"	">15≤19"
Slightly cool	Slight cold stress	">13≤18"	">19≤23"
Comfortable	No thermal stress	">18≤23"	">23≤27"
Slightly warm	Slight heat stress	">23≤29"	">27≤31"
Warm	Moderate heat stress	">29≤35"	">31≤36"
Hot	Strong heat stress	">35≤41"	">36≤42"
Very hot	Extreme heat stress	">41"	">42"

[a]Matzarakis and Mayer (1996)
[b]Omonijo and Matzarakis (2011)

2.4 Methods of analysis

The output of PET values on daily basis was analyzed and categorized into grades of physiological stress on human beings as indicated in Table 1. This gives detail analysis about the number of days in each grade of thermal threshold within the study period. Also, PET bioclimatic diagram was produced to assess the frequency of occurrence of each grade of thermal threshold within the study period. Furthermore, quantitative analysis was employed to compute the seasonal trends of PET. This involves the use of average to determine the seasonal trends in line with the seasonal pattern of Ondo State according to Adefolalu (1995): dry months (January and February), transition to wet season (March and April), wet season I (May to July), little dry season (August), wet season II (September and October), and transition to dry season (November and December).

3 Results

There are seasonal and spatial variations in the values of PET. The pattern of PET in Fig. 3 shows that PET values are lower in humid forest zone than in the derived savannah zone. Daily mean values of physiologically equivalent temperature within the study period ranges from 26.5 to 35.5 °C over humid forest zone of the State, while that of derived savannah zone ranges from 29.5 to 38.0 °C. The lowest and highest values of PET were noticed in the period of little dry season (August) and dry months (January and February) as shown in Figs. 4 and 5.

The values of physiologically equivalent temperature over humid forest and derived savannah ecoclimatic zones of Ondo State within the study period were classified into different grades of thermal sensation and physiological stress on human beings in line with Table 1. The frequency diagram of PET in humid forest zone (Fig. 6) identified four classes of physiological threshold, namely, moderate heat stress with 61.6 % of the total study period, slight heat stress with 33.8 % of the total study period, followed by no thermal stress (2.6 %), and strong heat stress with 2.0 % of the total study period. In the derived savannah zone of the study area (Fig. 7), three major different grades of physiological stress are clearly known: moderate heat stress with 57.5 % of the total study period, strong heat stress with 32.6 %, and followed by slight heat stress with 9.8 % of the total study period; others are no thermal stress and extreme heat stress with 0.02 % each.

4 Discussion

The implication of the two prominent classes of physiological threshold (moderate heat stress and slight heat stress)

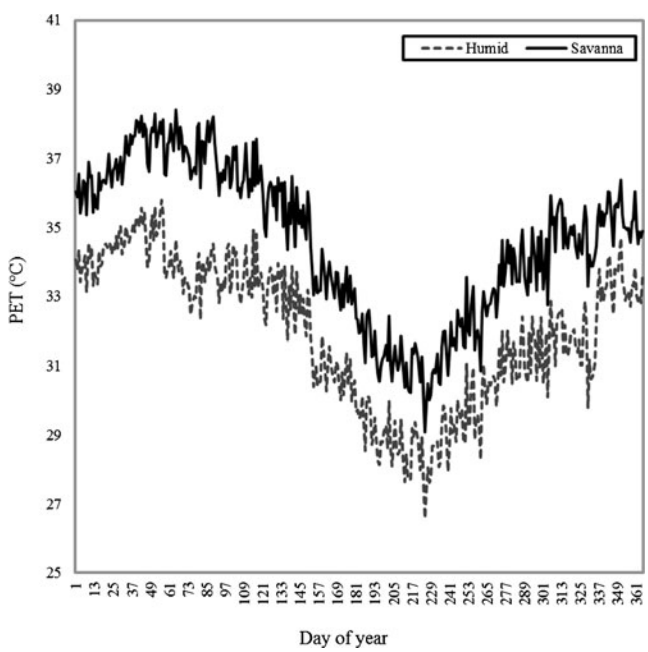

Fig. 3 Mean daily physiologically equivalent temperature pattern in humid forest (Okitipupa) and derived savannah (Akoko Southwest) ecoclimatic zones of Ondo State, Nigeria (1998–2008)

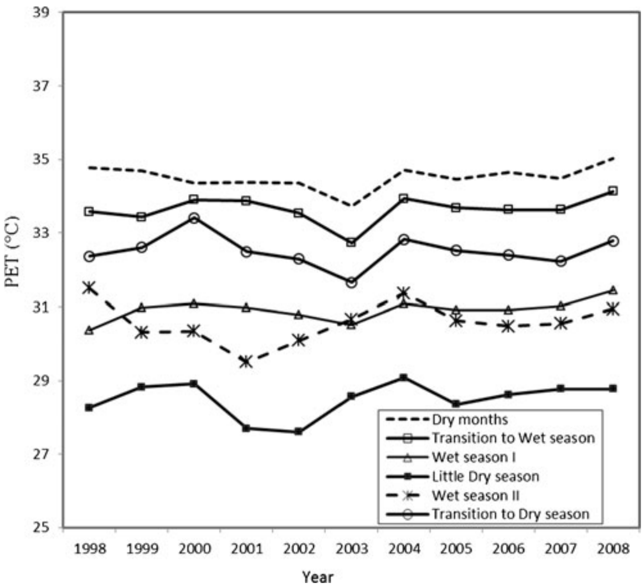

Fig. 4 Annual course of physiologically equivalent temperature in different seasons in humid forest (Okitipupa) ecoclimatic zone of Ondo State, Nigeria (1998–2008)

and less prominent (strong heat stress and no thermal stress) in humid forest zone on human beings with respect to thermal perception is that the condition of the environment ranges from short period of comfortable condition to few days of hot conditions, while slight warm and warm conditions dominate the larger percentage of the period. The three different grades of physiological stress noticed in the derived savannah zone of Ondo State imply that the environmental condition of the area ranges from slight warm to hot conditions. In this zone, moderate heat stress dominates,

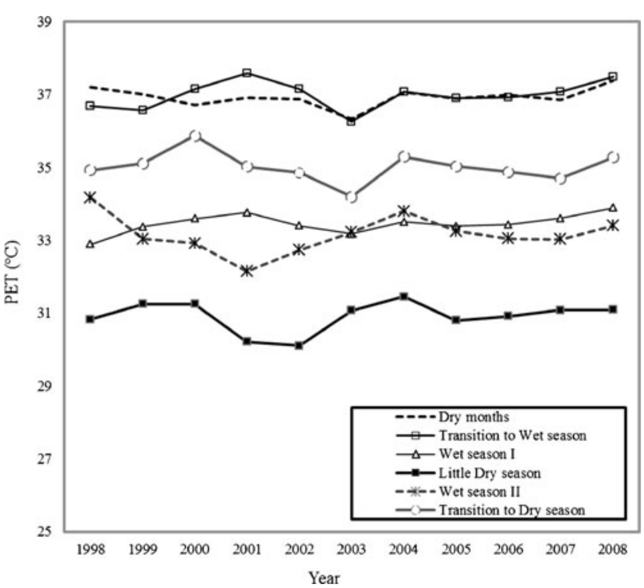

Fig. 5 Annual course of physiologically equivalent temperature in different seasons in derived savannah (Akoko Southwest) ecoclimatic zone of Ondo State, Nigeria (1998–2008)

followed by strong heat stress and slight heat stress. The study confirms the findings observed by Jendritzky and Tinz (2009) that a huge number of human beings were affected by heat stress in the tropics and subtropics, particularly in Asia and Africa. It also stated further that, in tropical and subtropical areas, where extreme heat load is already common, climate change will make "extreme heat load" even more "extreme" with significant impacts on health and well-being of populations living in these areas.

Furthermore, we assumed that amount of rainfall and number of rain days could have a modulating effect on the values of PET and, in turn, can influence thermal comfort of the environment. Therefore, both spatial and temporal variations in the values of PET in the two ecoclimatic zones could be as a result of the variation in amount of rainfall and number of rain days between humid forest zone and derived savannah zone as reported by Adefolalu (1997).

An important finding of this study is that this area may be prone to heat-related ailments such as heat exhaustion, syncope (fainting), cramps, heat stroke, and cerebral meningitis, among others. In 2009, there was a record of epidemic of cerebral meningitis in about two thirds of Nigeria's 36 states (Thomson Reuters 2009; UNICEF 2009); this ailment has been linked to extreme high air temperature and dryness (Adebayo 2001; Yaka et al. 2008). Also, there is a possibility of high number of cases of heat-related mortality in this area, but this is difficult to ascertain because of lack of adequate death records in Nigeria, and more so, there are no diagnostic records to show what actually causes someone's death.

5 Conclusion

The study suggests that since effects of climate on man, particularly his thermal comfort and physical and mental efficiencies, cannot be overemphasized, it will therefore be necessary to carry out a comprehensive human thermal comfort analysis on a local scale and relate it to heat-related ailments in order for people to know when and how to adapt to critical environmental conditions.

Also, temporal and spatial meteorological information with monthly resolution, including a combination of climatic parameters and human biometeorological thermal index such as PET that can describe the thermal environment of humans and give detailed meteorological and climatological information for health purposes, will be necessary. Other information from actinic parameters (UV radiation), air pollution, noise pollution, and odor can also be very useful to health practitioners.

Appropriate cities/towns/urban plan, planting of trees along the street, and appropriate building designs with good ventilation will be of help in maintaining comfortable thermal environment. This study is important for formulating

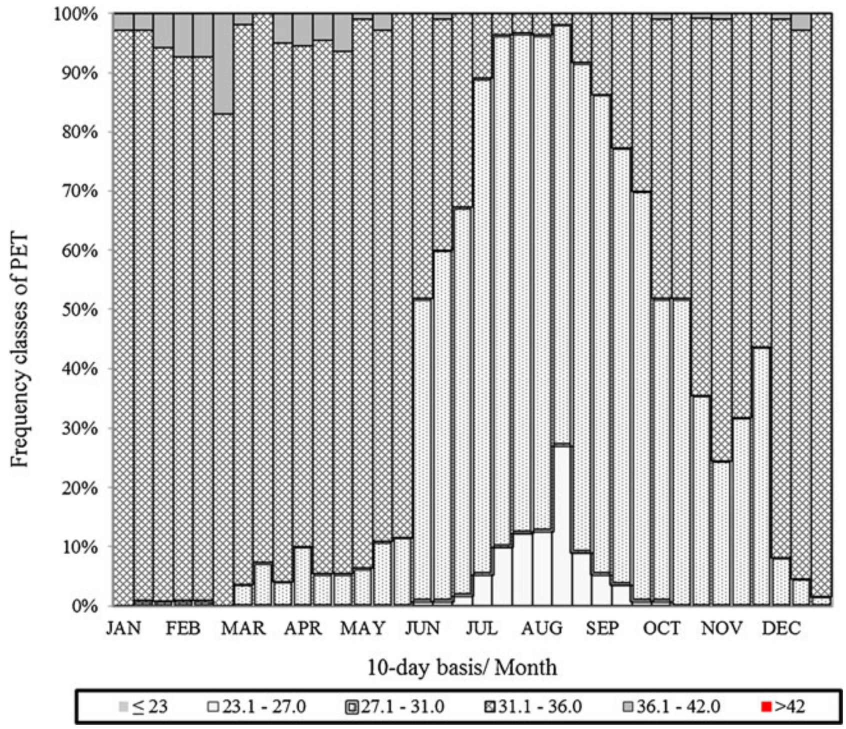

Fig. 6 Frequency diagram of physiologically equivalent temperature in humid forest (Okitipupa) ecoclimatic zone of Ondo State, Nigeria (1998–2008) (ref to Table 1)

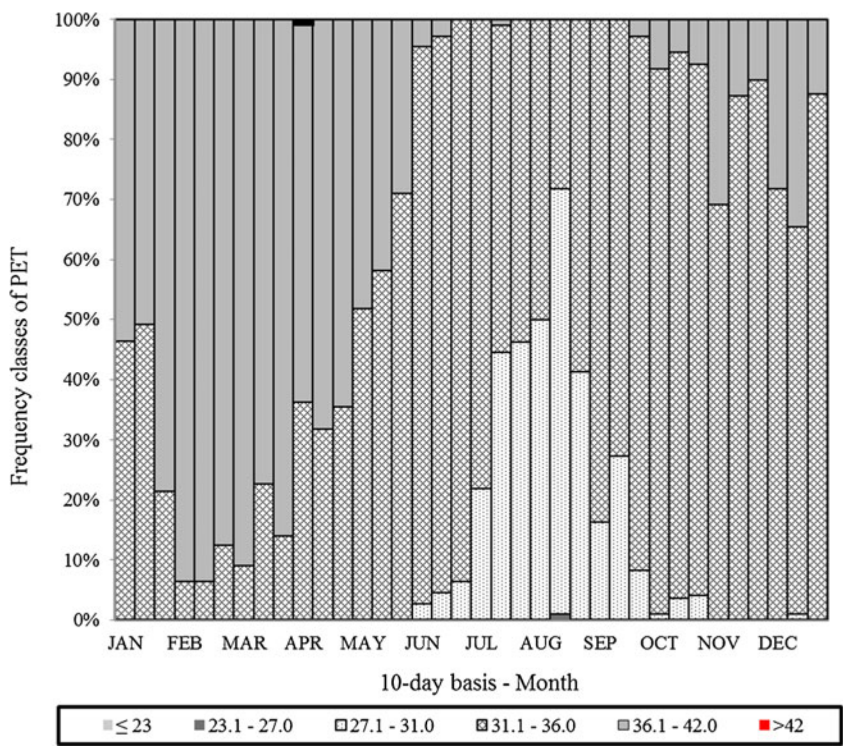

Fig. 7 Frequency diagram of physiologically equivalent temperature in derived savannah (Akoko Southwest) ecoclimatic zone of Ondo State, Nigeria (1998–2008) (ref to Table 1)

public interventions on climate change and adaptation activities (particularly on health) that will make people to respond to the impacts of climate change and climate variability in their respective localities.

Acknowledgments This research was partially funded by the African Doctoral Dissertation Research Fellowship offered by the African Population and Health Research Center (APHRC) in partnership with the International Development Research Centre (IDRC). The meteorological data were provided by the Agroclimatological and Ecological Monitoring Unit, Akure, Ondo State, and Nigerian Meteorological Agency, Lagos, Nigeria. We also thank the Alexander von Humboldt Foundation, Germany, for the award of International Climate Protection Fellowship to the lead author of this paper.

References

Adebayo AA (2001) Temperature variability and outbreak of meningitis and measles in Yola, Nigeria. Global J Pure Appl Sci 1:133–136

Adefolalu DO (1995) Agro-climatological and ecological zones study of Ondo State, Nigeria. Final report, phase III, vol 2. Prepared by Federal University of Technology, Minna, Niger State, Nigeria

Adefolalu DO (1997) Hydro-ecozone mapping of Ondo/Ekiti State, Nigeria. Ondo State project, final report, p 141

Blazejczyk K, Epstein Y, Jendritzky G, Staiger H, Tinz B (2011) Comparison of UTCI to selected thermal indices. Int J Biometeorol 56(3):515–535. doi:10.1007/s00484-011-0453-2

Chase TN, Wolter K, Pielke RA Sr, Rasool I (2006) Was the 2003 European summer heat wave unusual in global context? Geophys Res Lett 33:L23709. doi:10.1029/2006GL027470

Driscoll DM (1992) Thermal comfort indexes. Current uses and abuses. Nat Weather Digest 17:33–38

Fanger PO (1970) Thermal comfort, analysis and application in environmental engineering. Danish Technical Press, Copenhagen, Denmark

Henson R (2008) The rough guide to climate change. Rough Guides Ltd, London

Höppe P (1993) Heat balance modeling. Experientia 49:741–745

Höppe P (1999) The physiologically equivalent temperature—a universal index for the biometeorological assessment of the thermal environment. Int J Biometeorol 43:71–75

IPCC (2001) Climate change 2001: impacts, adaptations and vulnerability. Contribution of working group II to the third assessment report of the intergovernmental panel on climate change. Cambridge University Press, New York

IRI (2011) Technical report on the climate information for public health training course, May 16–27, 2011. International Research Institute for Climate and Society, the Earth Institute at Columbia University Palisades, New York

Jendritzky G, Tinz B (2009) The thermal environment of the human being on the global scale. Glob Health Action 2:1–18

Kovats SR, Jendritzky G (2006) Heat-waves and human health. In: Menne B, Ebi KL (eds) Climate change and adaptation strategies for human health. Steinkopff, Darmstadt, Germany, pp 63–97

Landsberg HE (1972) The assessment of human bioclimate, limited review of physical parameters. World Meteorological Organisation, Technical Note No. 123, WMO-No. 331

Matzarakis A (2007) Climate, human comfort and tourism. In: Amelung B, Blazejczyk K, Matzarakis A (eds) Climate change and tourism: assessment of coping strategies. Maastricht–Warsaw–Freiburg, pp 139–154

Matzarakis A (2008) Relevance of thermal bioclimate for tourism in Japan. Glob Environ Res 12(2):129–136

Matzarakis A, Mayer H (1996) Another kind of environmental stress: thermal stress. Newsletters No. 18, WHO Collaborating Centre for Air Quality Management and Air pollution Control, 7–10

Matzarakis A, Mayer H, Iziomon M (1999) Application of a universal thermal index: physiologically equivalent temperature. Int J Biometeorol 43:76–84

Matzarakis A, Rutz F, Mayer H (2000) Estimation and calculation of the mean radiant temperature within urban structures. In: de Dear RJ, Kalma JD, Oke TR, Auliciems A (eds) Biometeorology and urban climatology at the turn of the millennium. Selected Papers from the conference ICB-ICUC 1999, WCASP-50, WMO/TD No. 1026, Sydney 2000, 273–278

Matzarakis A, Rutz F, Mayer H (2007) Modelling radiation fluxes in easy and complex environments—application of the RayMan model. Int J Biometeorol 51:323–334

Mayer H (1993) Urban bioclimatology. Experientia 49:957–963

Mayer H, Höppe P (1987) Thermal comfort of man in different urban environments. Theor Appl Climatol 38:43–49

McArthur K, Dawson J, Walters M (2010) What is it with the weather and stroke? Exp Rev Neurother 10:243–249

McClung G (2006) "What causes heat waves, and why are they dangerous?" Home Weather Stations Guide. 10 December, 2006

Meehl GA, Tebaldi C (2004) More intense, more frequent, and longer lasting heat waves in the 21st Century. Science 305(5686):994

NOAA (1995) The July 1995 heat wave natural disaster survey report, U.S. Department of Commerce, National Oceanic and Atmospheric Administration. National Weather Service, Silver Spring, MD, December

NPC (2006) Nigeria population census report. National Population Commission, Abuja, Nigeria

Omonijo AG, Matzarakis A (2011) Climate and bioclimate analysis of Ondo State, Nigeria, Meteorol Z. doi:10.1127/0941-2948/2011/0268

Parsons KC (2003) Human thermal environments: the effects of hot, moderate and cold environments on human health, comfort and performance. Taylor and Francis, London and New York

Robinson PJ (2001) On the definition of a heat wave. J Appl Meteorol 40(4):762–775

Shiue I, Matzarakis A (2011) When stroke epidemiology meets weather and climate: a heat exposure index from human biometeorology. Int J Stroke 6:176–178

Spagnolo J, de Dear R (2003) A field study of thermal comfort in outdoor and semi-outdoor environments in subtropical Sydney Australia. Build Environ 38:721–738

Spickett JT, Brown HL, Rumchev K (2011) Climate change and air quality: the potential impact on health. Asia Pac J Public Health 23(2):37S–45S

Stewart ID, Oke TR (2010) Thermal differentiation of local climate zones using temperature observations from urban and rural field sites. In: Preprints, 9th Symposium, on Urban Environment, Keystone, CO, 2–6 August 2010

Thomson Reuters (2009) Nigeria meningitis death toll rises above 2,000. Available on at http://in.reuters.com/article/

Tinz B, Jendritzky G (2003) Europa- und Weltkarten der gefuhlten Temperatur. In: Chmielewski F-M, Foken Th (eds) Beitrage zur klima- und Meersforschung, Berlin und Bayreuth, 111–123

UNICEF (2009) Report on meningitis in West and Central Africa

VDI (1998) Methods for the human-biometeorological assessment of climate and air hygiene for urban and regional planning. Part I: climate. VDI Guideline 3787. Beuth, Berlin

Yaka P, Sultan B, Broutin H, Janicot S, Philippon S, Fourquet N (2008) Relationships between climate and year-to-year variability in meningitis outbreaks: a case study in Burkina Faso and Niger. Int J Health Geogr 7:34. doi:10.1186/1476-072X-7-34