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Basic Evaluation of Bioclimatic Conditions over Southwest Nigeria

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Abstract
This study examined the magnitude and spatio-temporal variation of outdoor bioclimatic conditions using observed mean monthly values of air temperature (°C), relative humidity (%), wind speed (m/s), vapor pressure (hpa) and cloud cover (octas) for the period of 1983 to 2012. The data were obtained from the Nigerian Meteorological Agency (NIMET) for five southwest-Nigerian stations. The bioclimatic indices adopted to evaluate the outdoor thermal comfort based on the thermal physiological balance of the human body in this study, are the Temperature-Humidity Index (THI) and Physiological Equivalent Temperature (PET). Radiation and Human Bioclimate (RayMan) model was used to simulate PET and Mean Radiant Temperature (MRT) in just one run based on the human energy balance model such as the Munich Energy Balance Model for Individual (MEMI). The estimated THI and PET were classified into different categories of thermal perceptions based on the established classes for Nigeria. The monthly, seasonal, and spatial variations of meteorological variables and thermal indices were also analysed. Results indicated air temperature to be the highest contributing meteorological parameter to thermal conditions. The discomfort level deteriorated over the years, most noticeable is the last decade between 2003 to 2012 of the study period. The years 1987 and 1998 were marked as period of peak discomfort in the entire region. The result also showed three different grades of thermal discomfort conditions namely; slightly warm, warm and hot over the tropical wet, and tropical wet and dry zones. In conclusion, thermal discomfort was observed to decrease from the northern part of the region towards the southern part of the region in the examined period. This work could be of great interest for the stakeholders involved in public health and tourism industry sectors in decision making process.
Keywords: Bioclimatic condition, PET, THI, Thermal discomfort.

1. Introduction

The state of mind that is satisfied with the thermal environment and the condition of minimal stimulation of the skin's heat sensors and of the heat-sensing portion of the brain is referred to as the thermal comfort (ASHREA, 2004). The role of the human thermoregulatory system is to control the heat balance, and carrying away of heat is mostly done by evaporating water through the skin, as well as by thermal conduction, convection and radiation. However, a thermally comfortable environment is a task humans has continuously striven to achieve, the environmental conditions conducive for thermal comfort are not absolute, but rather vary with the individual's metabolism, nature of the activity engaged in, and the body's ability to adjust to a wider or narrower range of ambient conditions. The thermal sensation of heat discomfort is experienced under "steady State" conditions, when the average skin temperature is elevated above the level corresponding to the State of comfort such that it is about 32-33°C under sedentary conditions (Robaa, 2011). People vary sometimes markedly, in their feeling of comfort according to their metabolic rate, type of clothing, work load, age, sex, diet, emotions, cultural influences, past climatic experience and climatic zone among others. Outdoor workers also tolerate higher temperatures than sedentary workers while older individuals tend to prefer warmer conditions than younger individuals (Stewart and Oke, 2010; Jendritzky and Tinz 2009). Human health and thermal comfort are affected more by climate than by any other element of man's physical environment (Lenzuni *et al*., 2008). The effects of climate on human being, particularly his thermal comfort, physical and mental efficiency constitute a major theme of the science of human biometeorology). Previous studies have used several bioclimatic indices to investigate both indoor and outdoor thermal comfort (Swaid *et al*., 1993; Nikolopoulou *et al*., 2001; Givoni *et al*., 2003; Spagnolo and de Dear, 2003; Matzarakis A., 2010; Omonijo and Matzarakis, 2011). For instance, Chirag (2010) found that Physiological Equivalent Temperature (PET) is very effective, as a single thermal index, to evaluate the thermal component of any given microclimate. The increase in urbanization is loading urban areas with complex networks of built environments and human activity, the changes and developments in the built environment invariably affect the microclimate, The changed microclimate has various effects on the built environment and in turn on their inhabitants, like effect on health, increased energy consumption in buildings, increased awareness for design for vegetation and landscapes. Matzarakis A. (2010) using Radiation and Human Bioclimate (RayMan) model suggested that the mean radiant temperature and also the thermal bioclimate conditions in urban areas can be affected strongly by the urban configuration. Width, height and orientation of an urban canyon are also very important parameters for the evaluation of specific thermal bioclimatic conditions. Three different grades of physiological stress exist over the two zones of Ondo State, Nigeria, detailing that few periods of comfortable and slight warm thermal sensations exist during the wet season and few periods of hot exist during the dry season over humid forest zone while thermal sensations range from slight warm and warm during the wet season to hot during dry season derived savannah zone (Omonijo and Matzarakis, 2011). Eludoyin *et al.,* (2014) revealed that the effective temperature (ET), THI and relative strain index (RSI) provided contrasting expressions of thermal comfort of Nigeria because of its varied climate thereby suggesting that Nigeria thermal comfort climate is heterogeneous and requires analysis of multiple thermal indices. Studies on the bioclimatic conditions of the southwestern Nigeria in which both an index that accounts for thermal physiology or heat balance of the human body (PET) and an index that accounts for physiologic temperature (THI) in addition to meteorological parameters were utilized is very rare.

The thermal bioclimate is of great interest not only for the stakeholders involved in the public health and tourism sectors (De Freitas *et al*. 2007), but also for the general public due to the close relationship between the thermoregulatory mechanism and the circulatory system (Höppe 1993; Nastos and Matzarakis 2006). It is also important to note that climatic parameters rainfall and air temperature, have profound influence on both malaria and pneumonia occurrence and are responsible directly for intractable increase of the diseases (Oluleye and Akinbobola, 2010).Hence, the need for the knowledge of the thermal climate owing to the rapid growth of urbanization process (Ishola *et al*., 2016) in the Southwest, Nigeria for planning on health, urban development , tourism and migration.In this regard, this study seek to assess the outdoor bioclimatic conditions over Southwest, Nigeria by determining the relationship between some selected meteorological parameters and estimated thermal conditions; and the magnitude and spatio-temporal variation of bioclimatic conditions, which will enhance early warning against climate-related sickness such as measles, cerebra spina meningitis e.t.c, thermal stress, holiday planning, migration, tourism and urbanization process.

2. Methodology

2.1 Study Area

The southwest of Nigeria lies between 2°3'-6° E and 6°2'-8°4' N. It consists of six States which includes Ekiti, Ogun, Ondo, Osun, Lagos, and Oyo State. It is in the tropical region of Nigeria and shares land borders with Edo and Kogi States in the East, Republic of Benin in the west, Kogi State in the North, and lies south on the Gulf of Guinea on the Atlantic Ocean (see fig. 1). The details of the geographical locations of each meteorological stations for different states used are presented in Table 1.

Table 1: Nigerian Meteorological Agency Stations located within Study Area.

	STATION NUMBER	STATION NAME	LATITUDE	LONGITUDE	STATE	ELEVATION
1	65208	IBADAN	07.26'N	03.54'E	OYO	227.2
2	65213	ABEOKUTA	07.10'N	03.20'E	OGUN	77.0
3	65201	IKEJA	06.35'N	03.20'E	LAGOS	39.4
4	65232	AKURE	07.17'N	05.18'E	ONDO	375.0
5	65215	OSHOGBO	07.47'N	04.29'E	OSUN	302.0

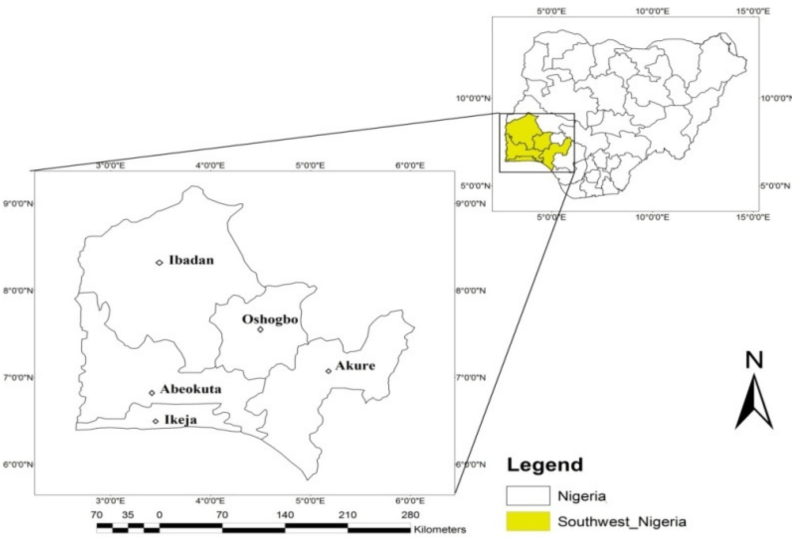


Fig. 1: Maps showing the location of the study area and position of the meteorological stations

2.2 Data

Mean monthly observed dataset of air temperature, relative humidity, vapour pressure, cloud cover and wind speed of the study area were obtained at 1500 Local Standard Time (LST) from the archives of Nigerian Meteorological Agency in accordance with standards recommended by world meteorological organisation (WMO). The dataset span from 1983 to 2012.

2.3 Method of analysis

The annual linear trends, monthly variations, seasonal variations and spatial variations of thermal conditions and meteorological parameters were analysed. Monthly variations of meteorological parameters and thermal conditions of the various stations were achieved through creating time series plots of their monthly values for the entire duration of the study (1983 – 2012). The analysis of the annual averages were estimated by the mean values for all months put together (January – December) across specific years and stations which was used to plot the annual trends of the variables. In computing the Seasonal variations, two seasons (wet and dry) were accounted for. April to October was taken as wet season while November to March was used as the dry season. Meteorological and thermal conditions during wet season were obtained by computing their average values from April to October for the study duration. In a like manner, meteorological parameters and thermal condition during the dry season were obtained by computing their average value from November to March for the study period. Monthly, seasonal and spatial variations of meteorological parameters and thermal conditions were obtained through the use of ArcGIS 10.1 software.

Estimation of THI and PET

THI was estimated with the algorithm modified by (Nieuwolt, 1977) which is;

$$\mathrm{THI} = 0.8 \times \mathrm{t} + \frac{\mathrm{RH} \times \mathrm{t}}{500} \qquad (1)$$

Where: t – is air Temperature; and RH – is Relative Humidity.

The Estimated THI values were then classified into different categories of thermal perceptions as shown in table 2

Table 2: Thermal perceptions with corresponding THI and PET classes for Nigeria (Ayoade, 1978; Olaniran, 1982; Omonijo and Matzarakis, 2011).

THI Classes for Nigeria (°C)	PET Classes for Nigeria(°C)	Thermal Perception	Level of Thermal Stress
<14	<11	Very cold	Extreme cold stress
14 – 17	11 – 15	Cold	Strong cold stress
18 – 19.5	16 – 19	Cool	Moderate cold stress
20 – 22	20 – 23	Slightly cool	Slight cold stress
23 – 24.6	24 – 27	Neutral	No thermal stress
24.7 – 27	28 – 31	Slightly warm	Slight heat stress
28 – 30	32 – 36	Warm	Moderate heat stress
31 – 34	37 – 42	Hot	Strong heat stress
>34	>42	Very hot	Extreme heat stress

PET was estimated through the use of the Radiation and Human Bioclimate (RayMan) model developed by Andreas Matzarakis. RayMan model is a numerical software that ensures the computation of radiation fluxes in simple and complex environments (Matzarakis *et al.*2007 2010). The estimated PET was classified into different categories of thermal perceptions (see Table 2 above)

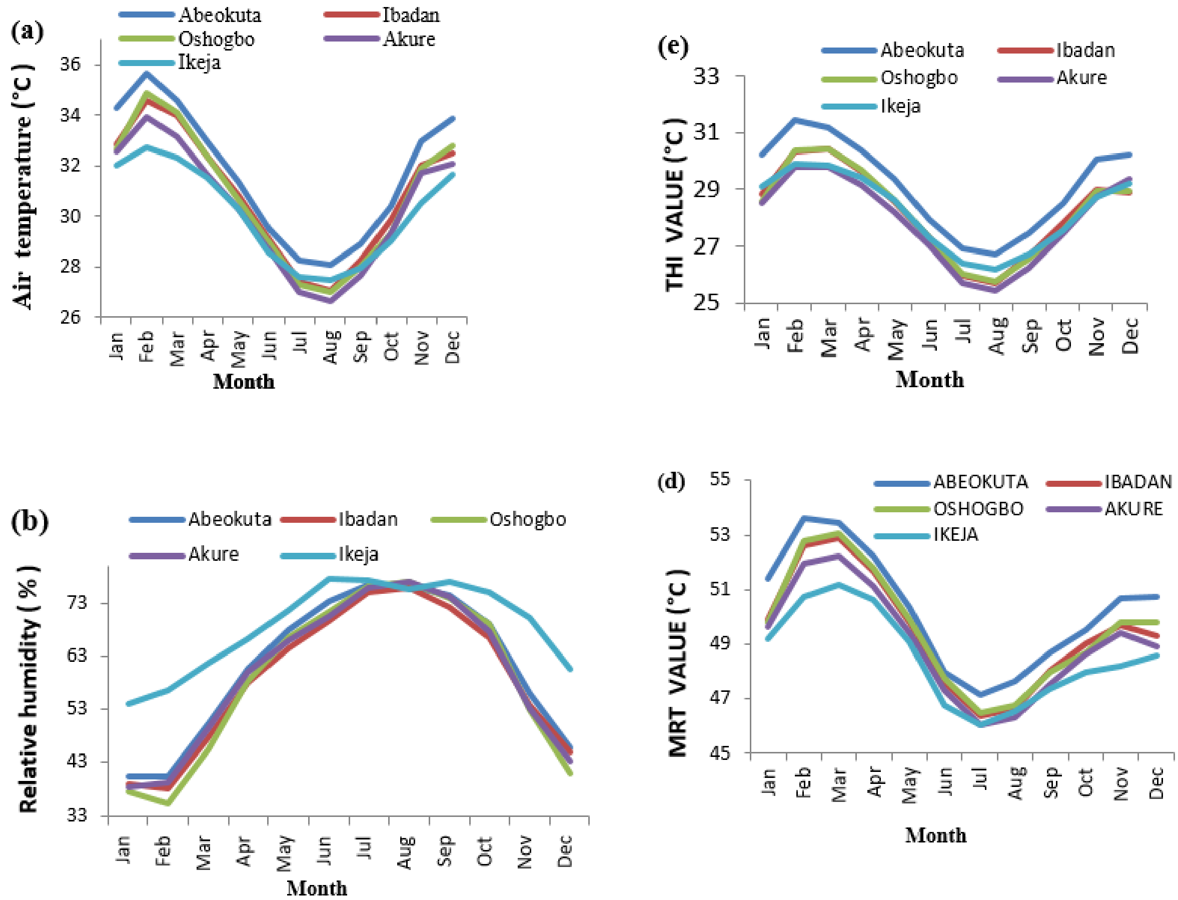
Parameters that describes the surroundings of human body (albedo, view factor and emisivity of different solid surface and sky view factor) and atmospheric parameters (diffuse and direct solar radiation, atmospheric long wave radiation, reflected short wave and long wave radiation from different solid surfaces) were utilized by RayMan model in computing the mean radiant temperature (MRT). The MRT in models for human energy balance can be defined as a suitable measure of the stress on humans due to the heat effect of radiation from the surrounding environment (Jendritzky 1990).

3. Results and Discussion

3.1 Monthly, Seasonal and Inter-annual variability of meteorological variables and thermal indices

The monthly and seasonal trends of mean values of air temperature, relative humidity, vapor pressure and MRT are presented in Fig 2(a – f) for the period (1983 – 2012). It was observed that the month of February depicts as the month with the highest value of air temperature for all stations while August depicts the month with the lowest value of air temperature in all stations i.e air temperature values were found to be lower during the wet season (April – October) than during the dry season (November – March). Air temperature values ranges between 26.6°C and 35.7°C. The highest and lowest values of air temperature were observed for Abeokuta and Akure stations respectively (Fig 2a). January – February is characterized by lowest values of relative humidity for all stations while June – August was observed as the most humid months i.e the wet season was more humid than the dry season. Mean values of relative humidity range between 35.20% and 77.73%. Oshogbo and Ikeja stations were observed to have the lowest and highest values of relative humidity respectively (fig 2b). The months of January and May are indicated by lowest and highest values of vapor pressure respectively. The wet season was more characterized by vapor pressure than the dry season. Mean values of vapor pressure ranges between 18.15hpa and 30.72hpa. Oshogbo and Ikeja were observed to have the lowest and highest value of vapour pressure respectively (fig 2c). The monthly trend of MRT is represented on fig 2(d), the plot show February – March as the months characterized by highest mean values of MRT while month of July is characterized by lowest MRT values. The dry seasons have higher MRT values than the wet season due to cloud cover during the wet months. MRT value ranges between 46.03°C and 53.62°C, Abeokuta and Akure were observed to have the highest and lowest value of mean MRT respectively.

Fig 2(e – f) represent monthly trend of thermal conditions with regards to THI and PET estimates for the study duration (1983 – 2012). In fig 2(e), it can be seen that between the months of October and May for the observed period studied. THI estimates for all stations were between 27.45°C and 31.41°C. These values fall within the slightly warm (slight heat stress), warm (moderate heat stress) and hot (strong heat stress) categories of thermal stress level. This implies that thermal conditions deteriorated between the months of October and May in all stations. THI estimates for the months of June, July, August and September show that thermal conditions are more tolerable within these months, where THI values for all stations were observed to be in range 25.41°C and 27.95°C, these values fall within the neutral (no heat stress) and slightly warm (slight heat stress) categories of THI classification, this implies that thermal conditions were better in the month of June, July, August and September. The thermal discomfort deteriorated between the months of October and June for PET (fig 2f) so it can be seen that the values of PET estimates for all stations were in the range 28.96°C and 41.67°C. This value fall within the slightly warm (slight thermal stress), warm (moderate heat stress) and hot (strong heat stress) classification of thermal stress level. PET estimates show that in the month of July, August and September thermal stress were at a more tolerable threshold level in all but one station (PET estimate for Abeokuta was 32.57°C). The value of PET estimates for all stations range from 26.80°C to 31.21°C within July – September period. This value fall within the Neutral (no thermal stress), slightly warm (slight thermal stress) classification of thermal stress level, in the month of September. These fall into the hot (strong thermal stress) classification of thermal stress level.



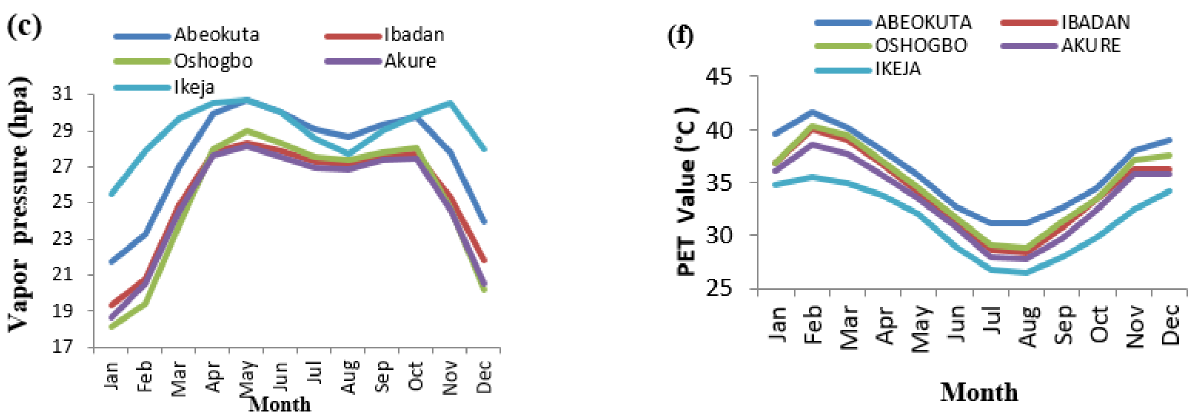


Fig 2: Monthly variability of (a)air temperature, (b) RH, (c) Vapor pressure (d) MRT (e) THI and (f) PET for the period (1983 – 2012)

The annual trend of air temperature, relative humidity, MRT, vapor pressure, THI and PET for the period (1983 – 2012) are presented in fig 3(a – f) respectively. Air temperatures range between 29.64°C and 32.61°C and were found to increase considerably in 1987 and 1998 as compared to other years (fig 3a). The annual trend pattern of relative humidity presented in fig 3(b) depicts that the highest value of 71.91% relative humidity was observed at Ikeja station in the year 2012 while the lowest value of 55.16% relative humidity was observed at Akure station in the year 2000. Vapor pressure was observed to range between 23.19hpa and 30.47hpa, the lowest and highest value was observed in 1992 and 2010 respectively. The annual trend pattern of MRT is presented in fig 3(d). The values of MRT ranges between 46.03°C and 53.62°C for all the stations investigated. The lowest and highest values occurred in 1999 and 1987 respectively. Fig 3(e) represent THI annual trend for the period.THI lowest (27.44°C) and highest (29.88°C) values were observed in 1992 and 1987 in Akure and Abeokuta stations respectively. Fig 3(f) represent PET annual trend for the period. PET lowest (30.07°C) and highest (37.80°C) values were observed in 1999 and 1987 in Ikeja and Abeokuta stations respectively

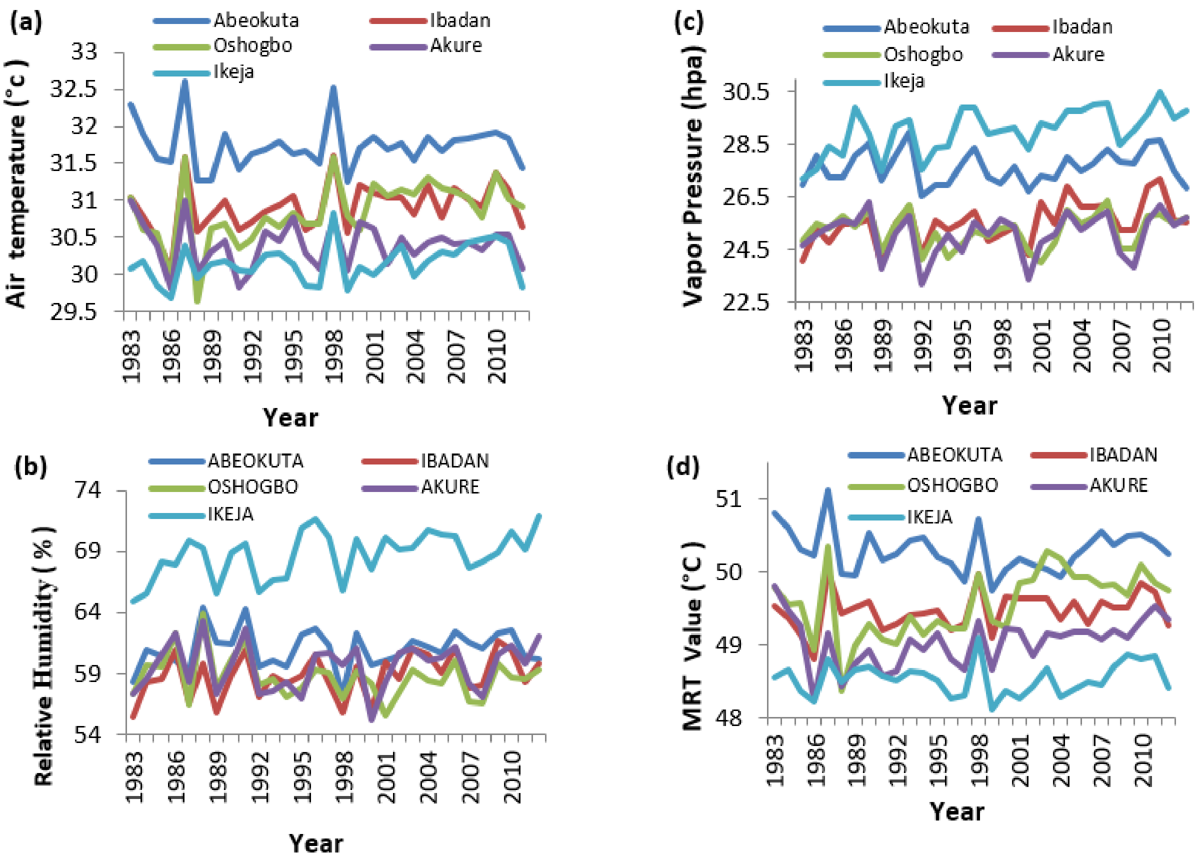


Fig 3(a – d): Interannual variability of air temperature, R.H, Vapor pressure and MRT.

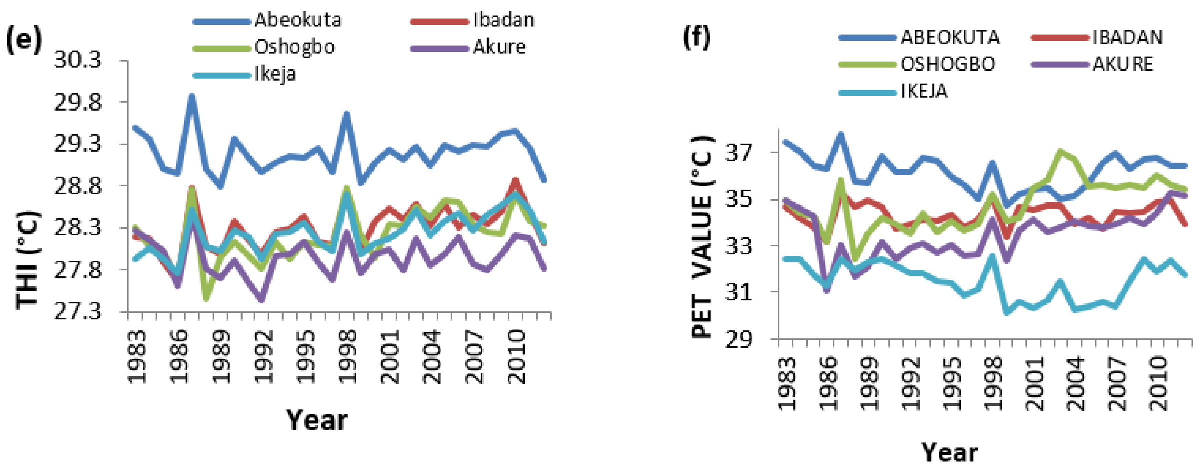


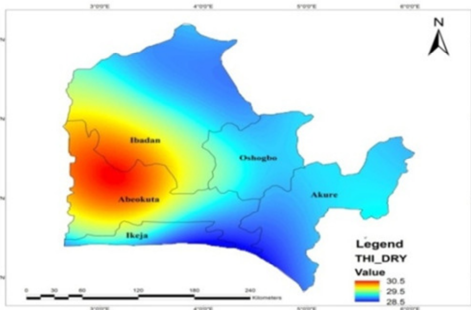
Fig 3(e and f): Interannnual variability of THI and PET

3.2 Spatial-temporal distribution of thermal indices

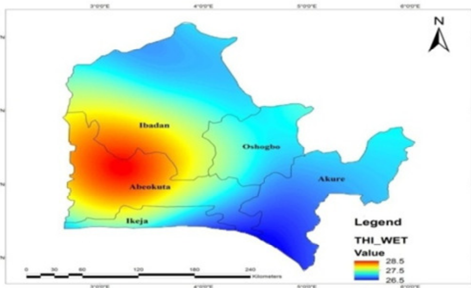
The spatial variations of mean values of THI and PET estimates are presented in fig 4(a – e). All stations were characterized by THI value that fall within the warm (moderate heat stress) category of classifications in the dry months as seen in fig 4(a). While, fig 4(b) shows that in the wet months all stations except Abeokuta were characterized by THI value that fall within the slightly warm (slight heat stress) category of classification. Abeokuta was characterized by warm (moderate heat stress). PET estimates for dry season represented in fig 4(c) shows that Ikeja and Akure were characterized with PET values that fall within the warm (moderate heat stress) category of classification while Abeokuta. Ibadan and Oshogbo were characterized with PET values that fall within the hot (strong heat stress) category of classification. PET estimates for wet season represented in fig 4(d) indicates that Abeokuta and Oshogbo stations were characterized by PET values that fall within the warm (moderate heat stress) category of classification while, Ibadan, Akure and Ikeja stations were characterized by PET values that fall within the slightly warm (slight heat stress) category used classifications.

The distribution of thermal conditions over the three decade period (1983 – 1992, 1993 – 2002, and 2003 – 2012) of this study is presented in fig 4(e) and (f). The mean value of THI estimates for all stations in the first decade range between 27.89°C and 29.19°C. Abeokuta had the highest level of thermal discomfort, while Akure was the station which recorded the most comfortable conditions. The second decade show that discomfort spread from Abeokuta towards Oshogbo and Akure respectively. The mean value of THI estimates for all stations range between 27.94°C and 29.34°C. This shows that thermal conditions deteriorated more in the second decade than the first decade for all stations. The third decade exhibit that thermal condition deteriorated progressively from the first to third decades in all stations spreading visibly to Oshogbo station. The mean values of THI estimates range between 28.00°C and 29.53°C for all stations. PET estimates are represented by fig 4 (f). The mean value of PET estimates for all stations in the first decade range between 32.08°C and 36.56°C. Abeokuta station had the highest level of thermal discomfort while Ikeja was the most comfortable station. The second decade show that discomfort spread from Abeokuta towards Oshogbo and Akure respectively. The mean value of PET estimates for all stations range between 31.08°C and 35.74°C. The third decade experienced more discomfort than other decades, Oshogbo and Akure stations were most noticeable. The mean values of PET estimates range between 34.22°C and 36.21°C for all stations. This means that Abeokuta had highest level of thermal discomfort while Ikeja was most comfortable in all the decades according to PET estimates. The study revealed that the most recent decade exhibit the most discomfort period in all the stations. This can be attributed to increased urbanization, transportation and industrial/mining activities in the region. It is worthy to note that these stations are the major commercial and industrial hub of the region, at large, the country. On the other hand, natural resources' extraction and mining also produce several backward, forward and final-demand linkages with other sectors of the economy. For instance, in order to maximize economic returns, natural resources are mined more quickly especially in large quantities without minding its environmental effects. This has harmful impact on the environment in terms of significant solid, liquid and gaseous wastes which often pollute the environment through the release of trace elements and other materials which engender human well-being especially in the area of water use, ecological, air-use and socio-economic consequences. Igbozurike (1983) also notes the specific negative impact as "land surface devastation (including erosion), land subsidence, disruption of drainage systems, deforestation which modify the microclimate in essence affect the comfort condition.

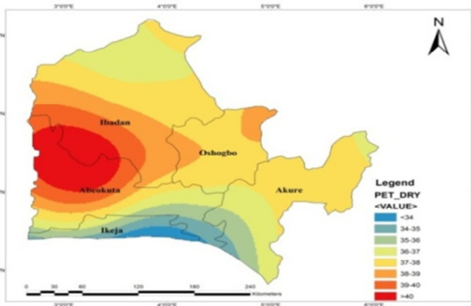
(a)



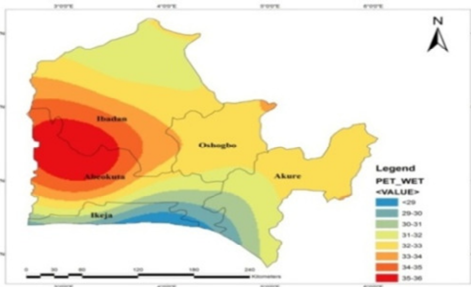
(b)



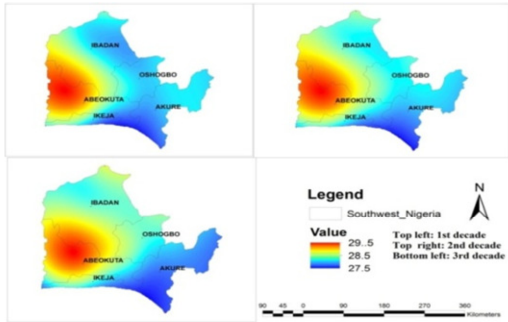
(c)



(d)



(e)



(f)

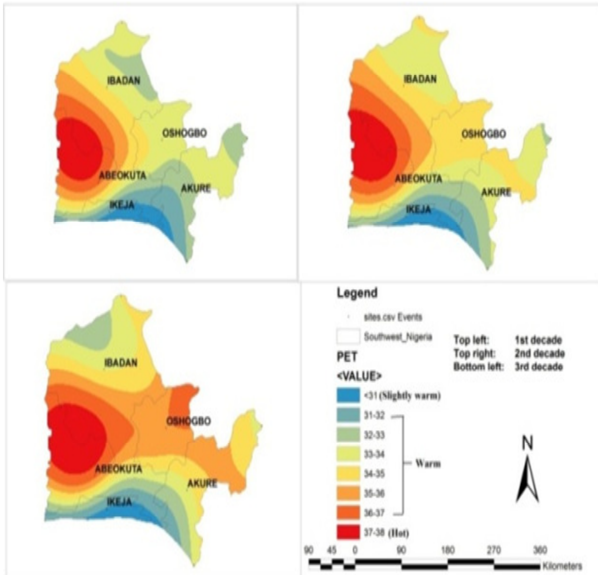


Fig. 4: THI wet and dry (a – b), PET wet and dry (c –d), THI and PET decadal (e – f).

Fig. 4: THI wet and dry (a – b), PET wet and dry (c –d), THI and PET decadal (e – f).

3.3 Relationship between meteorological variables and thermal indices

This section examines the relationship between the meteorological parameters utilized and the estimated indices. The relationship between THI estimates and air temperature is presented in fig 5(a) where THI estimates have 0.91 correlations with air temperature. It implies that a positive and strong relationship exist between THI estimates and air temperature values. The correlation between THI and relative humidity is 0.19 which implies that, weak

and negative correlations exist between THI estimates and relative humidity (fig 5 b). The relationship between PET estimates and air temperature values is shown in fig 5(c), PET estimates have 0.77 correlations with air temperature values. The implication is that a positive and strong relationship exists between PET estimates and air temperature values. However, RH was negatively correlated with PET with a weak value of 0.3 (fig 5d). MRT also had strong positive correlation with PET with a value of 0.94 (fig 5e). Fig 7(f) represent the relationship between PET estimates and vapor pressure value, PET estimates have 0.15 correlations with vapor pressure value. This means that a positive and weak relationship exist between PET estimates and vapor pressure.).Finally, estimated PET and windspeed show inverse relationship with correlation value of 0.55 (fig 5g).From the above correlations, it was observed that air temperature has the strongest correlations with THI estimates and therefore has the strongest influence on thermal conditions, while relative humidity has the least correlations with THI estimates and therefore has the least influence on thermal conditions. It has also been observed that MRT has the strongest correlations with PET estimates and therefore has the strongest influence on thermal conditions.
These correlations are significant at 95% confidence level.

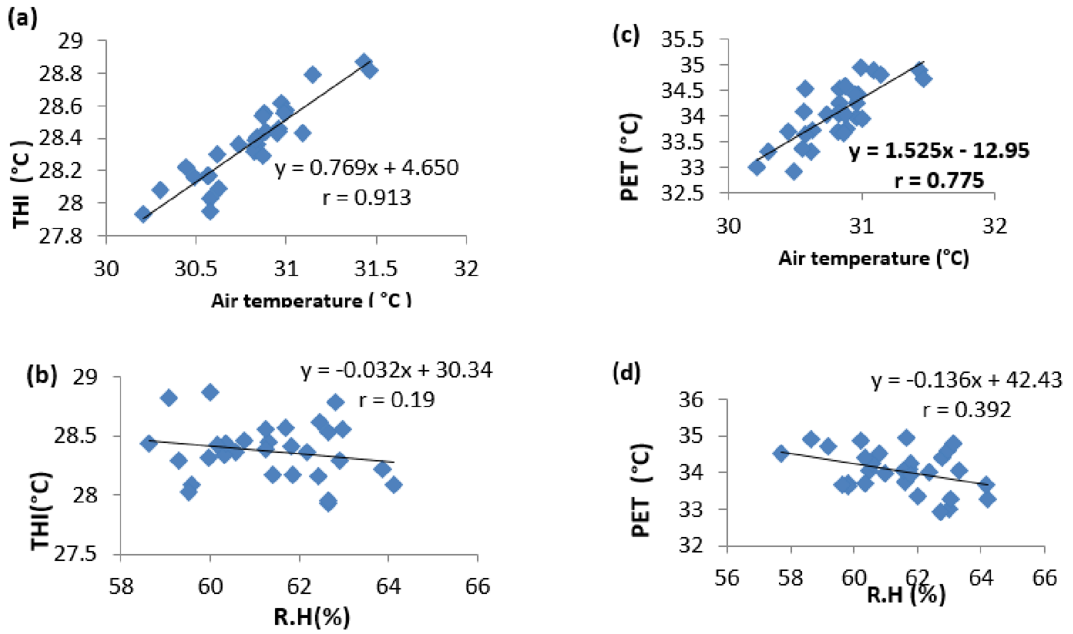


Fig 5(a – d) :Relationship between;THI and air temperature, THI and R.H , PET and air temperature, PET and R.H.

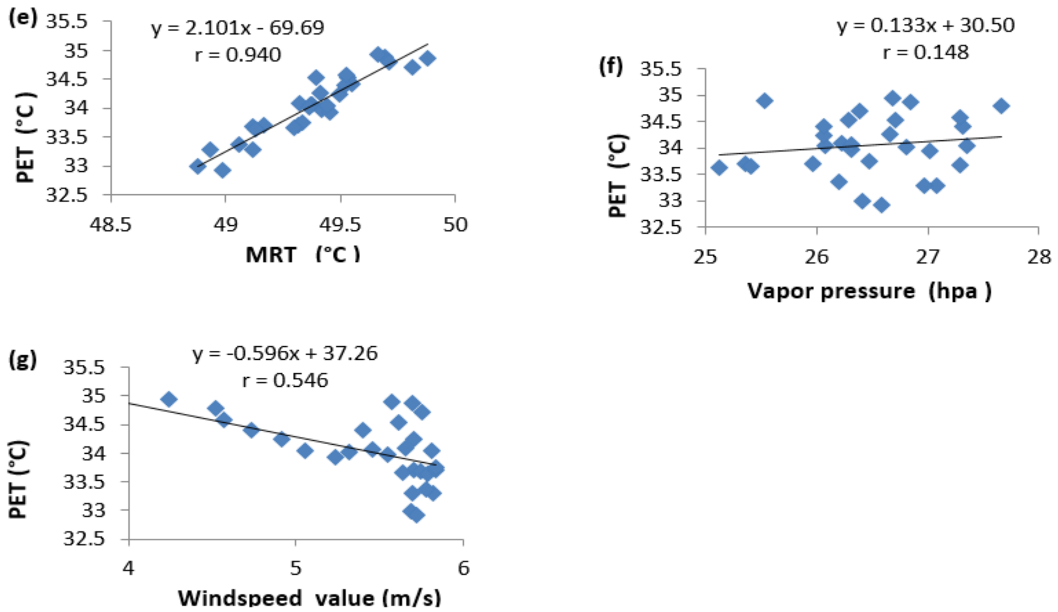


Fig. 5(e – g) : Relationship between PET and MRT, PET and vapor pressure, PET and windspeed for the period (1983 – 2012)

4. Conclusions

The results of this research work show seasonal and spatial variations in thermal comfort over Southwest Nigeria. Thermal conditions observed range from periods of neutral (no heat stress) to slightly warm (slight heat stress) and few periods of warm (moderate heat stress) in wet season (June, July, and August). Thermal conditions in dry season (Jan, Feb, Mar) was observed to range from period of warm (moderate heat stress) to few period of hot (strong heat stress). The tropical wet region were more comfortable than the tropical wet and dry region. Air temperature was observed to be the highest contributor to thermal conditions. The study observed that thermal conditions deteriorated from the first decade to the third decade of this study period. The month of February was the month characterized by peak level of thermal discomfort while July and August were characterized by lowest level of thermal discomfort. Thus, it is suggested that case studies of bioclimatic conditions should be considered as input in urban and regional planning, tourism and architecture designs. This approach has a great potential in analysing building performance as it uses a strategic approach to achieve the best quality in building users.

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