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An Assessment of Effective Temperature, Relative Strain Index and Dew Point Temperature Over Southwest Nigeria

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Abstract

This study examined the variations in some bioclimatic characteristics of the south-western Nigeria and residents' coping strategies to heat stress. Climate (temperature, dew point temperature, relative strain index and effective temperature) data for 10 meteorological stations between 1961 and 2013, and responses of residents of the region were examined. The study showed that temperature has increased by about 1°C between 1961-1990 and 1991-2010 periods at most stations, and that the region close to the Atlantic coast are under heat stress conditions, which has increased in the 1991-2010 period. Coping and mitigation strategies of the vulnerable settlements are largely personal adjustments; mainly change of cloth/wear and sleeping outdoor at night–in rural settlements while main technological adjustment was through use of fan and air conditioners.

Keywords: Temperature change; Dewpoint temperature; Effective temperature; Relative strain index; Thermal climate

Introduction

The study of human comfort has generated interests across the world, because comfort often forms the basis for planning for housing, healthcare and recreation facilities [1,2]. Knowledge of the thermal comfort ensures adequate warning for future extreme climate scenarios and for adequate preparation of humans and their livelihood against extreme climate conditions [3].

The developing countries have been reported to be characterized by increasing population but relatively poor social infrastructural facilities to cope with extreme climate effects. While many studies have been carried out in temperate region and in developed countries, only a few studies have been done in many developing countries, including Nigeria [4,5].

Human thermal comfort is an expression of feeling of satisfaction with the prevailing weather condition [6,7]. Extreme climate conditions outside the comfort zone are conditions of heat and cold stresses. Stressful climatic conditions are known to decrease work productivity, and increase (heat-related) mortality or morbidity [3,8-10]. Thermal stresses in tropical environment are often associated with increased heat and cold stress, and are typically described in terms of too high or too low humidity, temperatures and in excess of certain thermal thresholds [5,11-13]. Thermal thresholds are usually in terms of unitary (temperature, humidity and other heat related climatic elements) and integrative indices [14].

Abuloye [15] modified a list of human thermal comfort indices by De Freitas and Grigorieva [14], and listed 82 integrative indices, out of which only three (Effective Temperature (ET), Relative Strain (RS) and Temperature Humidity Indices (THI)) have been extensively reported on Nigeria [3,4]. These previous studies have shown that the results from ET and THI are not significantly different for Nigeria, and that ET is more suitable for the country. In addition, the studies indicated that, since Nigeria is a large country (with a population of more than 140 million spread over an area of 923 800 km^2), each of the geographical regions deserve to be studied for variability in the thermal climate.

The south-western part of Nigeria is known as the most populated and industrialised within the country, especially as it is the location for the second most populated (Lagos), and second and third largest city in Africa (Ibadan and Ogbomosho, respectively). Studies on the south-western region have focused on the temporal changes in the temperature and relative humidity [12,16-20], and existing studies with regional focus is scarce to find.

In addition, each of these studies has focused on one settlement or another in the region, and relatively dated. Furthermore, published studies informing about the perception of residents of the region (and Nigeria, in general) to thermal comfort have only focused on the people in tertiary schools [21], and the perceptions of the people in either the rural or urban areas in this region are less reported. Studies on adaptation of humans to stressful thermal climatic conditions have nevertheless suggested that adaptive methods (which may be anticipatory or reactive; behavioural, physiological or psychological) can vary over space, and can inform about the coping capability of the people with climate change [22].

Subsequently, information presented in this study is aimed at enhancing policy issues on peoples' preparedness to extreme climatic conditions in the region. Specific objectives are to determine the spatial and temporal variations in the thermal conditions over the south-western Nigeria; and examine the adaptive methods of the residents of two purposively selected settlements for coping with extreme weather conditions in the region.

This study is presented as a case study for regional study of thermal comfort in developing countries. Indices evaluated for thermal conditions in this study are Effective Temperature (ET), Relative Strain

Index (RSI) and Dew Point temperature (Td), based on previous studies that showed that they are relevant to tropical climates. Although the Td is not a comfort index, it is a measure of humidity, and this also has significant implication for thermal stress [23]. The ET and RSI are also not state-of-the-art indicators because they do not take into consideration the effects of radiation and wind velocity, which are heat elements [7].

However, studies on the regional climate with respect to the indices and humidity are few, and the results from the traditional indices will provide a control for the understanding of the more state-of-the-art indices in the area.

Study Area

The southwest of Nigeria lies between 2°3'-6° E and 6°2'-8°4' N (Figure 1), and is characterised by the tropical rainforest in the south and tropical guinea savanna in the north. The climate of region is strongly influenced by the moisture-laden tropical maritime (mT) and dust-laden tropical continental (cT) air masses [24].

The southern sub-region is characterized by a general low relief (0-200 m above sea level), and rises gently northwards to the area of crystalline rocks where inselbergs (981 m) rise abruptly above the surrounding plains [25]. In the urban centres, construction of roads, buildings, factories, manufacturing plants, bridges and culverts, farmlands and others have reduced drainage channels and erosion passages and or diverted the natural courses of others [26].

The population of the region, as at 2006 was over 36 million, and was projected to be about 183 million in 2015, and about 433 million by 2050. The total land area is about 166,361 km [27].

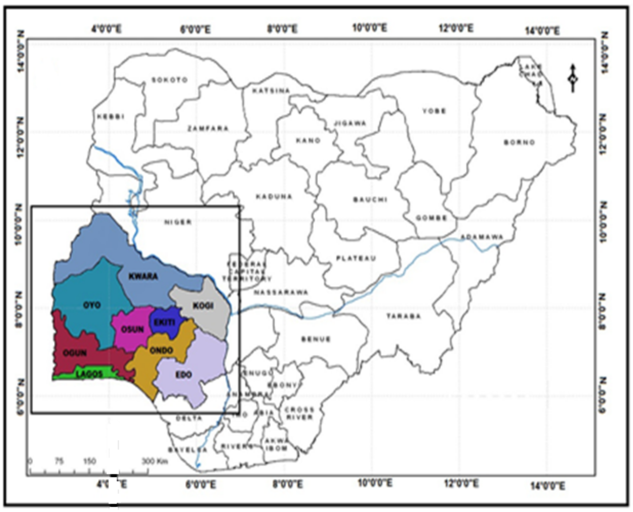

Figure 1: Map of Nigeria, showing the location of the states that make up the southwest region.

Previous studies showed evidence of regional difference in the climate of Nigeria, as typical of large countries, including India, United States of America and China [13,21,28].

Data

Data used for this study include the monthly temperature and relative humidity records for all the 10 synoptic stations (with the records from 1960 onwards) in the region (Figure 2) [29]. The data were obtained from the office of the Nigerian Meteorological Agency's office at Oshodi, Lagos. Data were examined for spurious values and evidence of non-climatic heterogeneity and instrumental errors as advised by the World Meteorological Organisation (1989).

The thermal comfort indices (ET, RSI and Td) were derived from the temperature and corresponding relative humidity data using equations i–iii [11,28] (for ET); Giles (for RSI); Wolkoff and Kjargaard [10] (for RSI)):

$$ET = T - 0.4(T - 10) \times (1 - \frac{RH}{100}) \quad (1)$$

$$RSI = \left(\frac{T - 21}{58 - e}\right) \quad (2a)$$

$$e = \frac{(RH \times Vp)}{100} \quad (2b)$$

$$Vp = 6.11 \times 10^{7.5\frac{T}{237.3} + T} \quad (2c)$$

$$T_d = T - \left(\frac{100 - RH}{5}\right) \quad (3)$$

Where ET: Effective Temperature, H_{rh}: Relative Humidity, RSI: Relative Strain Index, Vp: Vapour Pressure (hPa), T_d: Dewpoint Temperature, T: Air Temperature, RH: Relative Humidity, e: Actual Vapour Pressure.

The mean and variations of the elements and indices were computed for 1961-1990, 1991-2010 and 1961-2010, and descriptive maps were produced with the moving average interpolation statistics in geographic information systems, for the periods. For the generation of comfort map for the study area, comfortable region for Td, RSI and ET were 17.5–23°C [23], 0.1–0.2 [30] and 18.9–25.6°C [11,31]. Areas outside these thresholds were mapped as discomfort zone in the study.

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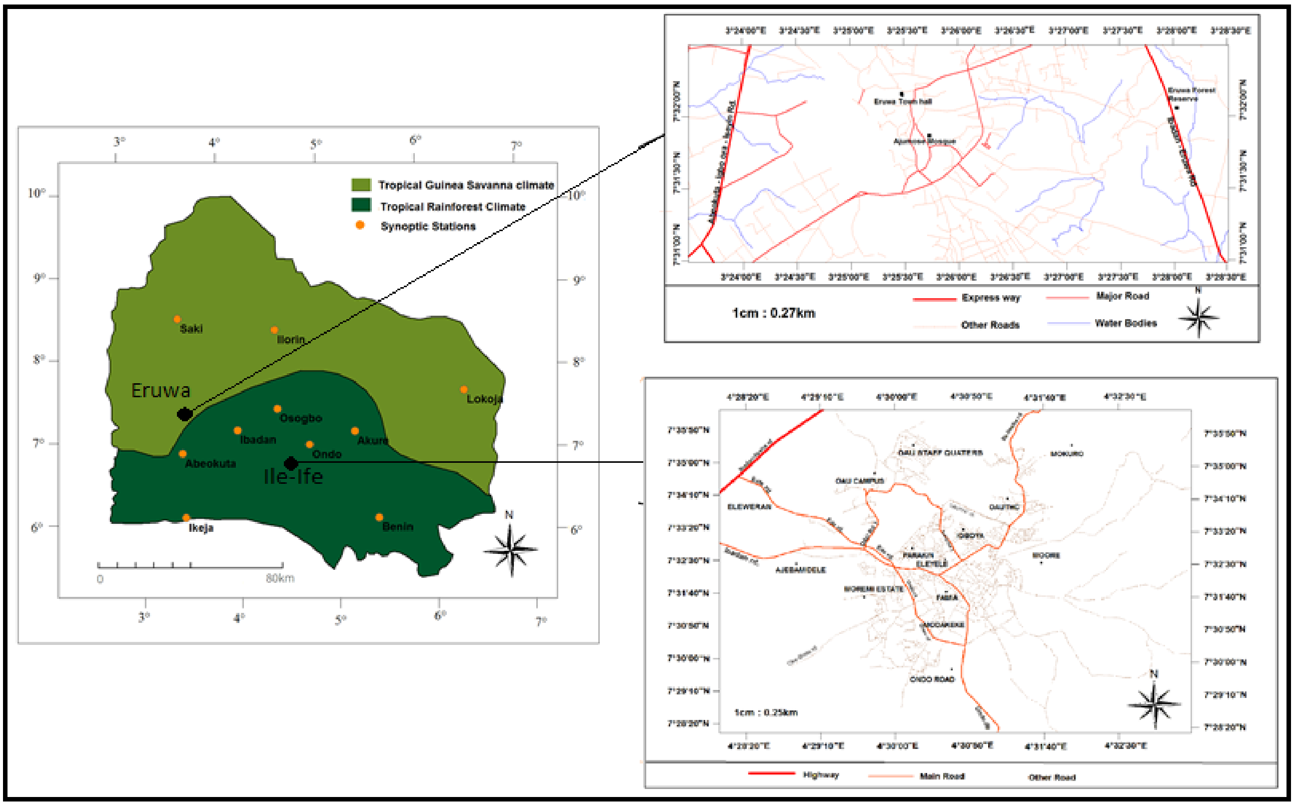

Figure 2: Selected meteorological stations and settlements for the perception study.

In addition, responses of residents of two purposively (based on convenience and relatively small size, and significant dichotomy across different landuse areas) selected settlements (Ile-Ife, a medium-size University town, and Eruwa, a semi-rural settlement in the region) were elicited with a semi structured questionnaire (Appendix). These settlements also represent locations in the two (tropical rainforest and guinea savanna) main ecological zones in the regions (Figure 2). In each settlement, occupants of every third building in a street) were sampled in identified residential, industrial (e.g. sawmills and a metal scrapping and smelting firm in Ile-Ife) and commercial (markets) areas in each settlement. In all, 501 (321 and 180, in Ile-Ife and Eruwa, respectively) copies of questionnaire, which represents the responses of about 0.5% of the entire population of the two communities were returned after two weeks of administration by ten field personnel. Most of the copies of questionnaire for the residential areas were administered in the evening and weekends, because most respondents were not often in the house in the other periods (Table 1).

Results

Regional pattern of temperature and thermal variables

Mean variations, trends and change in 1960-1990 and 1991-2013 means: The summary statistics for the 50 (1961–2010) year mean monthly temperatures (minimum, average and maximum) and those of ET, RSI and Td at all the selected stations are presented in Tables 2 and 3, respectively. Minimum temperature over the region varied between 21.1 and 22.9°C while maximum temperature varied between 30.9 and 32.2°C; mean temperature was from 26.2 to 28.1°C. Dewpoint temperature values that varied from 21.3 to 24.4°C while RSI values ranged from 0.09 to 0.15 (no unit). The ET values were between 24.6 and 26.7°C. The temporal variations in the temperature variables were generally below 10%. Furthermore, whilst Akure (a medium-size administrative city in the region) exhibited decreasing trend in all the temperature variables, other stations exhibited increasing trends in minimum (except Ibadan and Ikeja) and maximum (except Ilorin and Lokoja) over the years. Correspondingly, relative humidity has increased in Akure, and Saki. Comparison of the 1961–1990 and 1991–2010 values of the temperature variables indicated significant ($p \leq 0.05$) increase (though with small 30-year average in most cases) at most stations (except Ilorin for mean and minimum temperature, Benin for maximum, Lokoja and Osogbo, for the mean temperature). Relative humidity also significantly reduced at most stations, except at Saki, Lokoja and Akure ($p \geq 0.05$).

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Variable	Option	Percentage (Frequency)	
		Ile-Ife	Eruwa
Age (years)	<18	1.9 (6)	-
	18-30	33.7 (106)	-
	31-60	51.1 (161)	76.1 (137)
	>60	13.3 (42)	23.9 (43)
Gender	Male	49.8 (160)	48.9 (88)
	Female	50.2 (161)	51.1 (92)
Height (meter)	<1.2	2.0 (6)	-
	1.2-1.79	46.4 (140)	15.9 (28)
	>1.8	51.7 (156)	84.1 (148)
Body type	Slim	13.1 (42)	8.9 (16)
	Moderate	60.4 (194)	52.2 (94)
	Fat	26.5 (85)	38.9 (70)
Marital status	Single	38.2 (120)	-
	Married	61.8 (194)	100 (180)
Minimum educational qualification	No formal education	1.9 (6)	-
	Primary	1.2 (4)	4.4 (8)
	Secondary/technical	42.7 (137)	31.7 (57)
	Tertiary	54.2 (174)	63.9 (115)
Job category	Student	18.7 (60)	-
	Self Employed	28.7 (92)	21.1 (38)
	Government Employee	35.5 (114)	34.4 (62)
	Private Employee	17.1 (55)	44.4 (80)
No of dependant(s)	None	27.9 (88)	-
	<5	62.9 (198)	97.2 (175)
	>5	9.2 (29)	2.8 (5)
Monthly income (in Naira (N))	<20,000	21.6 (69)	-
	20,000-50,000	51.1 (164)	40.6 (73)
	>50,000	27.4 (88)	59.4 (107)
Approximate No of work hour (Hours)	<5	8.7 (28)	2.2 (94)
	5-8	65.4 (210)	92.8 (167)
	>8	25.9 (83)	5.0 (9)
Category of occupants	Outdoor under shade	35.4 (107)	18.9 (34)
	Outdoor without shade	9.3 (28)	5.0 (9)
	Indoor	55.3 (167)	76.1 (137)

Table 1: Demographic and socio-economic characteristics of the respondents.

The patterns of temporal change in RS, Td and ET were different across the stations. Whereas the Td trend at most of the stations showed significant increase between the 1961–1990 and 1991–2010 values (except at Akure, Benin and Ilorin, where it significantly decreased, or Ondo and Saki, where changes in Td was not significant), RSI significantly reduced at most of the stations (except Saki, where it has significantly increased and other stations, where such variation was not significant). Significant 1960–1990 and 1991–2013 change occurred in the values of ET at all but the Ibadan station, and such trend of change was negative for most stations (except Abeokuta, Ikeja and Saki) (Table 3).

	Station	Mean (Min-Max) (°C)	CV (%)	Trend (a ± b(x)) (R2 in parenthesis)	1961-1990 (mean) (°C)	1991-2010 (mean) (°C)	Variation	
							ANOVA	
							P-value	F-value
Minimum temperature	Abeokuta	23.6 (15.7-26.5)	5.8	0.01x+21.3 (0.1)	23.2	23.9	0.002	609.8
	Akure	21.4 (13.2-23.8)	6.7	-0.001x+21.8 (0.01)	21.6	21.4	0.001	39.9
	Benin	22.9 (18.4-26.3)	4.3	0.003x+22.2(0.2)	23.1	23.5	0.002	252
	Ibadan	22.3 (16.4-29.8)	5.2	-0.003x+21.5 (0.2)	22.6	22.8	0.001	14.7
	Ikeja	23.3 (20-29)	5.7	0.005x+22 (0.3)	23.5	24.1	0.002	399.1
	Ilorin	21.3 (14.5-25)	7.8	0.002x+20.7 (0.05)	21.7	21.7	0.535	0.7
	Lokoja	22.8 (14.1-27.7)	9	0.001x+22.4 (0.01)	22.7	23.3	0.002	129.8
	Ondo	22.2 (18.5-25.1)	4.1	0.002x+21.8 (0.07)	22.3	22.5	0.001	57.9
	Osogbo	21.1 (13.5-24.3)	7.5	0.003x+21.1 (0.001)	21.5	21	0.001	122.9
	Saki	22.7 (19.5-25.4)	4.8	0.002x+21.7 (0.03)	22.6	22.8	0.003	44.8
	Summary	22.4 (13.5-29.8)	6		22.48	22.7	0.06	167.2
Maximum temperature	Abeokuta	32.7 (28.0-38.1)	8	0.003x+31.7 (0.03)	32.7	32.9	0.002	9.44
	Akure	31.0 (26.5-36.5)	8	-0.01x+32.9 (0.03)	31.4	30.9	0.002	92.68
	Benin	31.4 (27.0-37.0)	6	0.002x+31 (0.02)	31.7	31.7	0.749	0.102
	Ibadan	31.3 (23.7-38.0)	8	0.002x+30.8 (0.02)	31.6	31.9	0.003	18.17
	Ikeja	30.9 (26.9-35.3)	6	0.002x+30.5 (0.02)	31	31.4	0	66.33
	Ilorin	32.2 (27.5-37.9)	8	-0.001x+32.6 (0.01)	32.2	32	0.031	4.666
	Lokoja	33.1 (28.0-39.1)	7	-0.001x+33.1 (0.001)	33.7	33.1	0.002	110.9
	Ondo	30.9 (26.1-34.2)	8	0.03x+30.0 (0.03)	30.9	31.4	0.003	57.87
	Osogbo	31.2 (25.0-37.2)	8	0.001x+30.9 (0.01)	31.3	31.5	0.001	11.26
	Saki	31.6 (25.0-37.2)	7	0.002x+30.8 (0.004)	31.5	31.7	0.013	6.165
	Summary	31.6 (25-38.1)	7		31.8	31.9	0.08	37.8
Mean temperature	Abeokuta	28.1 (23.9-32.2)	5.9	0.004x+26.5(0.05)	27.9	28.4	0.002	138.9
	Akure	26.2 (22.4-30.1)	5.3	-0.03x+27.3 (0.04)	26.5	26.1	0.001	128.6
	Benin	27.2 (24.3-31.3)	4.9	0.002x+26.5 (0.07)	27.4	27.6	0.003	28.6
	Ibadan	26.8 (23.4-31.4)	5.9	0.03x+26.1 (0.1)	27.1	27.3	0.003	21.46
	Ikeja	27.2 (21.6-31.3)	5.4	0.003x+26.2 (0.1)	27.2	27.7	0	205.2
	Ilorin	26.8 (22.3-30.7)	6.1	0.001x+26.2 (0.01)	26.9	26.8	0.041	4.185
	Lokoja	28.0 (23.9-32.9)	6.2	0.001x+26.2 (0.003)	28.2	28.2	0.571	0.32
	Ondo	26.5 (23.5-38.9)	5.2	0.002x+25.9 (0.1)	26.6	26.9	0.002	100.9
	Osogbo	26.2 (23.1-30.2)	5.5	0.001x+26.0 (0.01)	26.4	26.3	0.119	2.44
	Saki	27.1 (24.8-30.4)	5.2	0.002x+26.2 (0.01)	27	27.2	0.001	20.42
	Summary	27 (22.3-38.9)	5.5		27.1	27.3	0.07	65.1

Table 2: Mean, range, variation, trend (change of values over time) and temporal variations in temperature variables over selected station in southwest Nigeria (1961-2010).

	Station	Mean (Min-Max) (°C)	CV (%)	Trend (a ± b(x)) (R2 in parenthesis)	1961-1990 (mean) (°C)	1991-2010 (mean) (°C)	Variation ANOVA P-value	F-value
Effective temperature Index	Abeokuta	26.7 (20.1-29.9)	5.4	0.01x+25.4 (0.04)	26.6	26.9	0.002	94.2
	Akure	24.6 (17.6-28.0)	1	-0.01x+26.5(0.03)	25.1	24.2	0.004	209.9
	Benin	26.0 (19.2-30.4)	0.8	-0.003x+25.3 (0.1)	26.2	26.5	0.001	33.8
	Ibadan	25.5 (22.0-29.8)	5	0.002x+24.9 (0.1)	25.8	25.8	0.252	1.32
	Ikeja	25.9 (21.2-29.5)	4.8	0.001x+25.2 (0.004)	25.8	26.4	0.003	392.5
	Ilorin	24.9 (16.1-28.8)	6.9	-0.001x+25.1 (0.004)	25	24.7	0.005	39.49
	Lokoja	25.6 (18.6-29.6)	12	-0.001x+26.0 (0.01)	26.1	25.3	0.004	99.79
	Ondo	25.3 (19.4-36.2)	4.4	-0.002x+24.9 (0.1)	25.5	25.7	0.002	54.5
	Osogbo	25.0 (21.1-28.5)	4.5	-0.001x+24.8 (0.01)	25.2	25	0.001	42.23
	Saki	25.3 (21.8-27.6)	4.1	0.002x+24.5 (0.02)	25.3	25.4	0.001	13.52
	Summary	25.5 (16.1-36.2)	6.6		25.7	25.6	0.03	98.1
Relative Strain Index (no unit)	Abeokuta	0.12 (0.05-0.19)	23	1.0-0.03x (0.04)	0.12	0.13	0.002	120.1
	Akure	0.09 (-0.4-0.17)	53	0.1-0.01x (0.004)	0.09	0.09	0.004	65.3
	Benin	0.15 (-0.41-0.18)	37	0.09 +0.1x (0.04)	0.11	0.11	0.2	25.1
	Ibadan	0.1 (0.04-0.18)	27	0.1+0.1x (0.06)	0.11	0.11	0.3	21.5
	Ikeja	0.11 (0.01-0.18)	24	0.1-0.02x (0.1)	0.11	0.12	0.001	205.2
	Ilorin	0.1 (-0.39-0.17)	25	0.1+0.08x (0.01)	0.1	0.1	0.2	17.4
	Lokoja	0.09 (-0.39-0.20)	28	0.1-0.03x (0.001)	0.12	0.11	0.001	71.8
	Ondo	0.11 (0.04-0.31)	28	0.08+0.25x (0.06)	0.1	0.1	0.4	89.7
	Osogbo	0.1 (0.04-0.16)	36	0.1+0.38x (0.01)	0.09	0.09	0.119	2.43
	Saki	0.11 (0.07-0.16)	60	0.1+0.04x (0.01)	0.1	0.11	0.01	20.5
	Summary	0.1 (-0.39-0.31)	34		0.11	0.11	0.02	63.9
Dewpoint temperature (°C)	Abeokuta	24.4 (6.9-27.8)	8	0.003x+23.2 (0.02)	24.3	24.5	0.003	27.3
	Akure	21.3 (6.2-25.4)	19	-0.01x+25.9 (0.06)	22.4	20.7	0.001	296.5
	Benin	23.8 (2.2-29.3)	10	-0.002x+23.2 (0.02)	23.9	24.3	0.002	35.9
	Ibadan	22.9 (15.7-27.6)	6.5	0.002x+22.5 (0.02)	23.2	23.1	0.006	22.9
	Ikeja	23.5 (14.6-27.4)	6.1	0.001x+23.1 (0.03)	23.1	23.9	0.004	559.9
	Ilorin	21.5 (3.2-26.6)	13	-0.002x+22.1 (0.01)	21.5	21	0.002	45.8
	Lokoja	22.0 (7.4-27.6)	19	0.003x+22.9 (0.01)	22.6	21.3	0.003	123.8
	Ondo	23.0 (5.7-34.3)	6.5	0.001x+22.7 (0.02)	23.2	23.2	0.965	0.326
	Osogbo	22.6 (14.7-26.6)	6.3	0.001x+22.4 (0.01)	22.9	22.5	0.001	135.7
	Saki	22.0 (11.5-25.6)	12	0.002x+21.1(0.004)	22	22.1	0.721	0.396
	Summary	22.7 (2.2-34.3)	11		22.6	22.5	0.189	135.7

Table 3: Mean, range, variation, trend (change of values over time) and temporal variations in effective temperature, relative strain index and dewpoint temperature over selected station in southwest Nigeria (1961-2010).

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Descriptive thermal maps for the region: The results of the moving average interpolation of the thermal climate variables investigated in this study are presented as Figures 3-6. Minimum temperature appears to decrease as one move away from the coastal areas, whereas maximum temperature was slightly higher around Lokoja than the other parts of the region. Except for the area around Abeokuta, where both minimum and maximum temperatures were higher than most part of the surroundings, maximum temperature tend to vary inversely with minimum temperature over the region (Figure 3). Both Td and ET were also higher around Abeokuta–Ikeja axis and Benin in the south than the settlements in the other part of the southwestern Nigeria while the RSI interpolation showed lower values in the inner settlements (Osogbo–Ondo-Akure –Ilorin axis) of the region than the other parts (Figure 3d-3f). Furthermore, whereas the values of minimum and mean temperature around the Ikeja and Lokoja axes have generally increased by 1°C, in 1991-2010 period, when compared to the 1961-1990 means, there was a decrease in the maximum temperature, also, by about 1°C around Lokoja in 1991-2010 period (Figure 4). In addition, Td and ET interpolations over the study area exhibited an increase of at about 1°C, over the coastal region of the Atlantic Ocean, and a converse decrease by 1°N in the northern sub-region. The RSI unit was also lower around the northern part in the 1991-2010 periods (Figure 5).

Assessment of the Td, RSI and ET over the study area with the recommended thresholds of 17.5–23°C, 0.1–0.2 and 18.9–25.6°C, respectively, showed that areas further into the interior of the region are more thermally comfortable than the coastal region, especially with respect to Td and ET but RSI results describes the entire region as thermally comfortable, however (Figure 6).

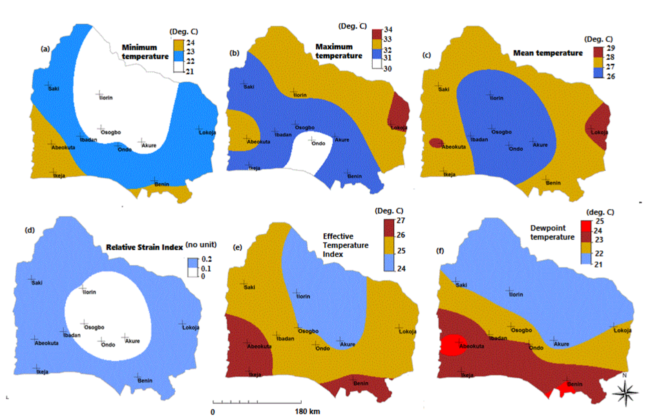

Figure 3: 50 (1961–2010)–year Average temperature (minimum, maximum and mean), relative strain index, effective temperature and dewpoint temperature over the southwest Nigeria. The cross indicates the location of the meteorological station whose data were interpolated.

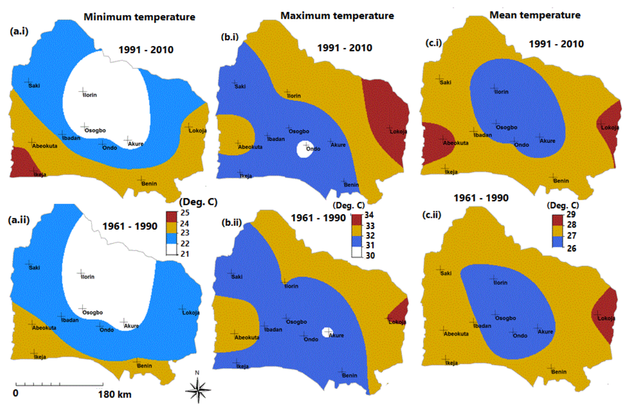

Figure 4: Variation in the minimum, mean and maximum temperature over the southwest Nigeria in 1961-1990 and 1991–2010 years periods. The cross indicates the location of the meteorological station whose data were interpolated.

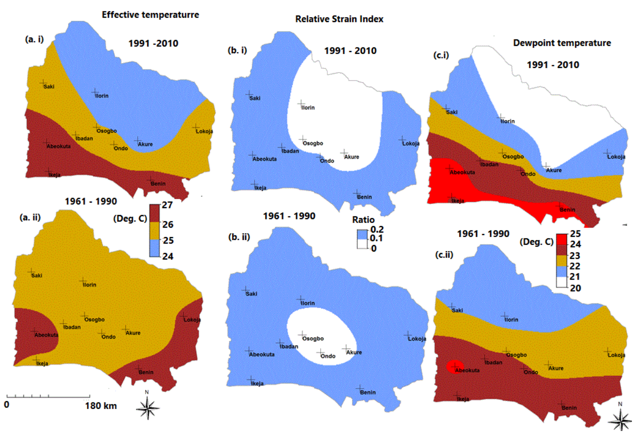

Figure 5: Variation in the effective temperature index, relative strain index and dewpoint temperature over southwest Nigeria in 1961-1990 and 1991–2010 years periods. The cross indicates the location of the meteorological station whose data were interpolated.

When compared across the 1961-1990 and 1991-2010 periods, the results of the interpolation indicate that whereas thermal discomfort has aggravated in more areas in the western sub-region of the study area, the thermal condition in eastern region has improved in the 1991-2010, than the preceding 30-year period (Figure 6).

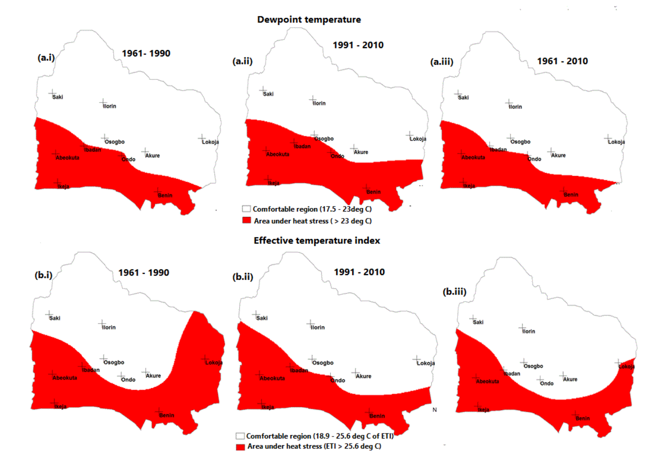

Figure 6: Computed variations in dewpoint temperature and effective temperature index for 1961-1990, 1991–2010 and 1961–2010 means. The relative strain index is not presented because the entire region was homogenously classified as comfortable in the study period.

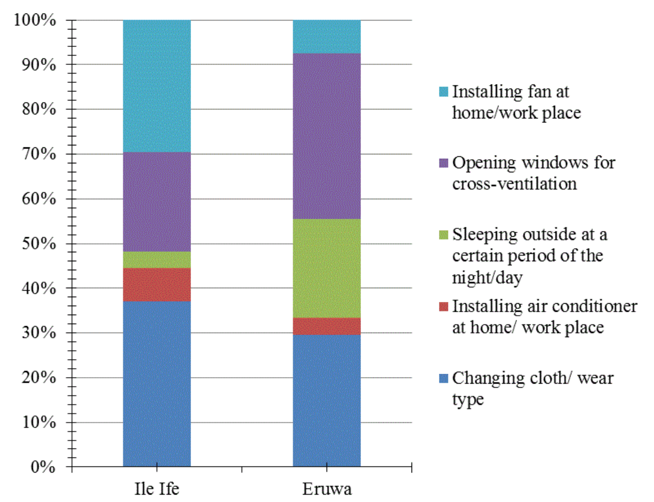

Figure 7: Distribution of prominent coping strategies to thermal stress in the selected settlements in Southwest Nigeria.

Perception of residents of selected settlements on comfortable weather condition

Characteristics of respondents: Over 94% of the respondents in both settlements have had at least primary education and were able to understand the content of the questionnaire and its purpose. The entire sampled population at Eruwa were aged above 30 years and majority of the respondents from Ile Ife were at least 18 years. About 81% of the respondents were employed and made at least N20, 000 ($100) monthly while more than 70% have dependants, and worked for a minimum of 5 h daily. In addition, majority of the respondents work indoor (55.3% and 76.1% respectively in Ile Ife and Eruwa) and under shade, if outdoor (35.4 and 18.9%, respectively) (Table 1).

Coping strategies to extreme weather conditions in the southwest Nigeria: Concerns were raised over heat stress in the study area. At least 80% of the respondents at both the settlements of Eruwa and Ile-Ife considered the time between 0800 and 1200 Nigerian Local Standard Time (LST) as comfortable, and the periods between 1200 and 1800 LST as thermally uncomfortable. The period between 1800 and 2100 LST was also considered as comfortable by about 70% of the respondents. There was no significant ($p \leq 0.05$) difference in the perceptions of the different categories of residents (those outdoor, undershade, outdoor without shade, and indoor) at the periods.

Coping strategies, however, varied among the different the majority of people in the two locations (Ile-Ife and Eruwa). Whilst the first three coping preferences at Ile-Ife were cloth/wear type, (ii) installation of fan and (iii) installation of air conditioners at home and offices, the most important preferences at Eruwa (in order of importance) were (ii) opening of ventilation for cross ventilation, (i) changing changing of cloth or wear type, and (iii) sleeping outside the house (outdoor) at certain times of the night or day (Figure 7).

Discussion

A number of recent studies have focused on the thermal comfort of Nigeria, probably because of the increased awareness on climate change and its effects on the people and their livelihoods [32-36]. Nigeria is a typical developing country where people have been noted to be vulnerable to the effects of extreme climatic conditions because of poor economic, political and technological responses [2,37,38]. Studies have noted that many sub-Saharan countries are vulnerable to conditions of livelihoods (e.g., food insecurity, water scarcity and environmental degradation) due to the intensive effects of climate-related causes, including decortication, desertification and temperature increase [39].

In Nigeria, our previous studies [4,21], among others have indicated that human comfort in the southwest Nigeria may be under heat stress in the recent years, but we could not determine the certainty of the stretch of the vulnerable area in the region, since the studies-like majority of other previous studies from other sources-have been based on smaller, country-wide scale. In the present larger, regional-scale study, the southern (coastal) settlements- consisting of the areas around Benin, Abeokuta, Ikeja, Ondo and Ibadan, which are mainly traditional large cities in the southwest Nigeria, are characterized by heat stress, as typical of many large cities, globally [40-42]. A major difference between the countries in developing and developed economies is however the reaction to the increasing thermal discomfort. Whilst in the southwest Nigeria, the common mitigating/ coping strategies to heat stress are personal adjustments (changing personal variables, such as clothing, moving to a different location, etc.), and few instances of technological or environmental adjustments (e.g., opening or closing windows or shades, turning on of fans and/or air conditioners, especially among economically buoyant populations), approaches for coping strategies in many developed countries have developed into policy issues, early warning system and speedy responses. Metcalf et al. [43], for example, noted the development of urban greening as a social movement in New York whereas the few capital cities (e.g., Ikeja and Akure) that promote urban greening in Nigeria do it for aesthetic justification. Again, while studies have reported the adoption of early warning system on impending heat stress in north-eastern North America [3], cases of heat stress are still rarely reported in Nigerian hospitals. In our study area, majority of respondents argued that effects of climatic discomfort are 'not-life-threatening', and do not require reporting in hospitals. Nonetheless, heat stress has been linked with violence, heat stroke, rashes and meningitis among people [9,44,45].

Furthermore, this study has shown an increase in temperature by about 1°C in the southwest Nigeria between 1960–1990 and 1991–2013. Temperature increase in the southwest Nigeria may be associated with increased urbanization, transportation and industrial activities in the region, especially with its role as the commercial and industrial hub of the country. Recent studies have reported massive industrial plans for the area, but these plans are often unassociated with a parallel policy on impact assessment and mitigation [46,47]. For example, Oketola and Osibanjo noted that rapid and haphazard industrialization has taken place in part of the southwest Nigeria without environmental considerations, and that pollution abatement technologies are largely absent. Earlier, Hettige et al. [48] has also indicated that many developing countries (including Nigeria) lack the necessary information to set priorities, strategies, and action plans on environmental protection issues. Studies have also linked urbanization and associated activities with development of urban heat islands in some major cities in the region [20,32]. Also, studies have shown that a number of heat-related mortality cases have been reported in Nigeria and neighboring countries [49,50]. Similarly, concerns for sustainable development have increased, globally with the post Kyoto Protocol assessments that indicate the increased culpability of developing countries to contribute to global warming.

Conclusion

The study showed that there was significant increase in temperature and selected indices of thermal comfort at most studied stations in 1991-2013 over 1960-1990, and that while the thermal variables have increased, relative humidity exhibited significant decrease. It also showed that resident's coping strategies were mainly of personal adjustment, with few cases of environmental adjustments in urban settlements, or among economically buoyant population. Subsequently, there is need for policy re-drive in the region towards sustainable urbanization and development, and with concerns for the impact of many developmental actions on the humans.

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