Journal of Informatics
Electrical and Electronics Engineering, 2023,
Vol. 04, Iss. 03, S. No. 062, pp. 1-15
ISSN (Online):2582-7006

A Study of Human Physiological Comfort in Lagos Metropolis Using Landsat Satellite Imagery Between 1984 and 2013

Uwadiegwu Ibeabuchi[1]*, Feyi Oni[2], Olusegun A. Adeaga[3]

[1, 2, 3]Department of Geography, Faculty of Social Science, University of Lagos, Lagos, Nigeria
*ibeabuchi09@gmail.com[1], onifeyi@gmail.com[2], oadeaga@unilag.edu.ng[3]

How to cite this paper: U. Ibeabuchi, F. Oni, and O. A. Adeaga, "*A Study of Human Physiological Comfort in Lagos Metropolis Using Landsat Satellite Imagery Between 1984 and 2013,*" *Journal of Informatics Electrical and Electronics Engineering* (*JIEEE*), Vol. 04, Iss. 03, S No. 062, pp. 1–15, 2023.

https://doi.org/10.54060/jieee.2023.62
Received: 08/02/2023
Accepted: 01/08/2023
Online First: 13/08/2023
Published: 25/11/2023

Abstract

Our cities today are exposed more too urban atmospheric conditions that influence man's comfort, health and behavior. As cities grow changes in land use have altered man's physiological comfort experienced today. Landsat satellite imagery was used to study human physiological comfort in Lagos metropolis between 1984 and 2013. So, to achieve this remote sensing data acquired from Landsat satellite imagery and Geographic Information System (GIS) were used to derive, namely: land use land cover, land surface and air temperature, and relative humidity index for 1984, 2000 and 2013. While Temperature Humidity Index (THI) was computed from air temperature and relative humidity index which was used to assess human physiological out-door comfort in relation to land use activities. In this study, the health implications of physiological stress and thermal sensation were highlighted and addressed from the environmental and health perspectives as it relates to land use. This study thrown open the door of environmental efficiency, well-being and the health of citizens which is influenced by physiological comfort through developing and maintaining comfortable environmental conditions that will enhance the quality of urban life.

Keywords

Temperature Humidity Index, Physiological comfort, Physiological stress, Thermal sensation, Lagos metropolis

1. Introduction

Cities land surfaces are made from different urban materials and morphology which have significant thermal properties and reflectance with different heat capacity, thermal conductivity and surface radiative properties (albedo and emissivity) when compared with surrounding rural areas [1]. This alteration therefore inevitably results in the redistribution of incoming solar radiation, thereby inducing urban-rural contrasts, in surface radiance and air temperatures [1], [2]. Thus, changes in energy fluxes in urban areas often led to higher temperatures, which alter human thermal comfort observed in cities. Human health and thermal comfort are affected more by climate than by any other element of man's physical environment [3]. The effects of climate on man, particularly his thermal comfort, physical and mental efficiency, constitute a major theme of the science of human biometeorology. Thermal comfort therefore can be defined as a state of feeling in which a person has no wish to increase or decrease insulation or to adjust the ambient thermal environment [4]. Temperature is the most significant component in the experience of comfort in a space [5].

Various aspects of humanity are concerned with the visual, acoustic and thermal components of the surrounding environment [6]. Human beings are sensitive to slight temperature changes yet cannot perceive differences in relative humidity levels within the range of 60% and above. However, people vary, sometimes markedly, in their feeling of comfort according to their metabolic rate, type of clothing, workload, age, diet, emotions, cultural influences, past climatic experience and climatic zone among others. Thus, women generally prefer slightly higher air temperatures than men. People from the tropical regions tend to accept as comfortable higher levels of air temperature and humidity than people from temperate zones. Outdoor workers also tolerate higher temperatures than sedentary workers while older individuals tend to prefer warmer conditions than younger individuals [7], [8].

Our cities today are exposed more too urban atmospheric conditions that influence man's comfort, health and behavior. Weather conditions play a vital role in the growth and propagation of disease, but per se does not cause disease but determine the type and population of diseases pathogens prevalent in a given area. The heat exchange between the human body and his environment is governed by radiation, convection, and evaporation. It is the heat imbalance that the body reacts to and restores through various physiological responses [9]. But physiological responses of man to work, play, reaction and to other environmental condition depend on the interaction between man, his environment and weather [10]. According to Ayode [9], physiologic comfort is determined by both meteorological and non-meteorological factors. The thermal factors comprise such meteorological variables as air temperature, air humidity, wind velocity, short and long wave radiation, which have a thermo-physiological effect on man's outdoors and indoors activities; the significance to health and tourism is associated with thermoregulation and circulatory regulation [11],[12].

This study aims at understanding human physiological comfort in Lagos metropolis using Landsat satellite imagery as a measure to analyze comfort, health and the environment as key issues in our urban - climate system. Most research carried out was done outside Lagos with few works dealing with the urban climate in Lagos metropolis. However, one striking feature observed in reviewing few studies in Thermal Humidity Index (THI) in Lagos metropolis is the lack of the urban climate as well as remote sensing as input parameters in their consideration. So, this research adopts the use of remote sensing data and Geographic Information Systems (GIS) technique as tools to study human physiological comfort in Lagos metropolis. In order to address this knowledge gap, we estimate land surface and air temperature, and relative humidity index between 1984 and 2013 (a span of 29 years) across Lagos metropolis to improve our understanding of the thermal environment. While THI for Lagos metropolis in 1984, 2000 and 2013 was computed and used to classify human physiological comfort zones. The purpose of this study is to investigate the thermo-physiological comfort using Physiological Equivalent Temperature (PET) which was used to characterize the outdoor environment and their impact on human thermal comfort based on the different climatic characteristics experienced in Lagos metropolis. This approach is a quantitative approach which gives us a detailed view of thermal discomfort zone in Lagos metropolis. For proper comprehension, the study is divided into the following: 1. Effect of changes in land use on Lagos metropolis; 2. Effect of changes in temperature on Lagos metropolis; 3. Effect of changes in relative humidity index on Lagos metropolis; 4. Effect of changes in temperature humidity index (THI) on Lagos metropolis; and 5. Effect of changes in thermal human comfort on Lagos metropolis using GIS techniques.

2. Methodology

This research adopts GIS (Geographic Information System) technique in studying human physiological comfort in Lagos metropolis using Landsat satellite imagery between 1984 and 2013. Data collected for this study includes: 1. Landsat satellite imagery acquired from Landsat Thematic Mapper (TM) 5 in 1984, Enhanced Thematic Mapper Plus (ETM+) 7 in 2000 and Operational Land Imager (OLI) 8 in 2013 from USGS-Earth Explorer (Table 1); 2. Field survey, this includes: GPS reading and ground trotting. Field survey was carried out to get information about the land use and dynamics of change in-relation to human thermal comfort; 3. Administrative map (GIS vector shapefile (shp) format) of the study area, this was acquired from Guinea Current Large Marine Ecosystem (GCLME) and Unilag Regional Centre for Environmental Management, University of Lagos, Nigeria; and 4. Temperature data for 1984, 2000 and 2013, this was acquired from NIMET (Nigerian Meteorological Agency); Oshodi met (meteorological) station, Lagos Nigeria. The study area covers Lagos metropolis which is located within Lagos state as shown in Figure 1, created in 1967 [13]. Lagos metropolis lies in Southwestern Nigeria, on the Atlantic coast. It is located between longitude 3° 4' East to 3° 40' East and between latitudes 6° 23' North to 6° 42' North [14]. Lagos metropolis covers 1171km^2 area of which 221km^2 is Lagoons and waterways.

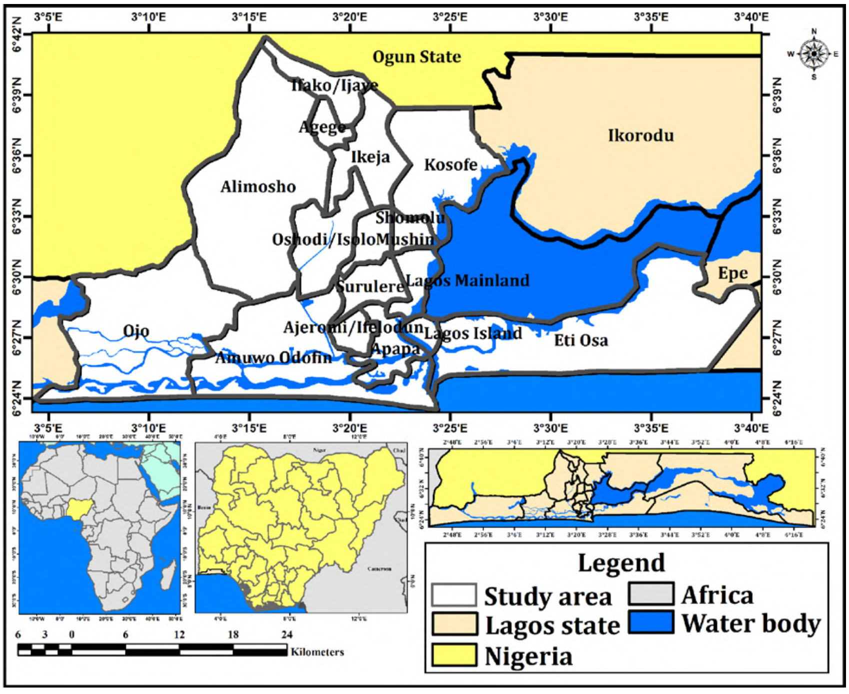

Figure 1. Geographical location of Lagos metropolis.

Landsat satellite imagery was used to derive land use/land cover (LULC) of Lagos metropolis by: Selecting band 4, 5, and 7 from Landsat TM 5 in 1984, ETM+ 7 in 2000 and OLI 8 in 2013 (Table 1), which was mosaic and enhanced. Then, supervised classification method was adopted to define training sites, extract signatures and classify the remotely sensed imagery using maximum likelihood classification procedure into nine classes, namely: *High* and *low density residential area, bare ground/open space, agricultural land, other built-up area, commercial/industrial service, public/educational institution, forest land, wetland* and *water body,* implemented in Idrisi Selva software. The derived output was used to study the effect of changes in LULC on temperature, temperature humidity index and human thermal comfort in Lagos metropolis.

Table 1. Landsat TM, ETM+ and OLI sensor and characteristics.

Sensor	Path/Row	Spectral Range (µm)	Band	Resolution (Meters)	Time Acquired	Date Acquired
TM 5- Multi Spectral	191/055,056	0.45 - 2.35	3, 4, 5 & 7	30	9:33 AM	12/18/1984
TM 5- TIRS*		10.40 - 12.50	6	120		
ETM+ 7- Multi Spectral		0.45 - 2.35	3, 4, 5 & 7	30	9:56 AM	02/06/2000
ETM+ 7-TIRS*		10.40 – 12.50	6.2	60		
OLI 8-Multi Spectral		0.53 - 2.29	3,4, 5 & 7	30	10:04 AM	03/25/2013
OLI 8-TIRS*		10.6–12.51	10	100		

* TIRS -Thermal Infrared Sensor

The temperature of Lagos metropolis was extracted using Landsat satellite imagery; two parameters were derived, namely: land surface temperature and air temperature. Land Surface Temperature (LST) was derived from thermal band (from TIRS in Table 1) of Landsat TM 5 for 1984 in equation 1(insert band 6), ETM+ 7 for 2000 in equation 2 (insert band 6.2) and OLI 8 for 2013 in equation 3 (insert band 10) as stated below using Idrisi Selva software:

$$L_\lambda = offset + gain \times DN \tag{1}$$

$$L_\lambda = \frac{(L\min - L\max)}{255} \times DN + L\min \tag{2}$$

$$L_\lambda = M_L Q_{Cal} + A_L \tag{3}$$

$$T_B = \frac{K_2}{\ln[(K_1 / L_\lambda) + 1]} \tag{4}$$

Where, *offset*, *gain*, K_1 *and* K_2 = User defined parameters, L_λ = Cell value as radiance (W/m^{-2}sr^{-1}µm^{-1}), *DN*= Digital number of the thermal imagery, *Lmax* and *Lmin* = Derived temperature depending on gain status, M_L = Band-specific multiplicative rescaling factor, A_L = Band-specific additive rescaling factor, Q_{cal} = Quantized and calibrated standard product pixel values (*DN*), and T_B = Blackbody temperature. Land Surface Temperature (LST) (*K*) (in degree Kelvin) was derived based on the blackbody temperature using equation 4. The conversion was carried out through the following:

$$T_{LST}(K) = \frac{T_B}{1 + \lambda \times T_B / \rho \times \ln \varepsilon} \tag{5}$$

Where, T_{LST} *(K)* = Land Surface Temperature (in degree Kelvin); λ= Wave length of emitted radiance (11.5µm); $\rho = h \times C/\sigma$ = 1.438×10^{-2} (m K); σ = Stefan Boltzman constant = 1.38×10^{-23} J/K; *C* = Light velocity = 2.998×10^{-8}ms^{-1}; *h*= Planck's constant = 6.626×10^{-34}Js, and ε = Emissivity in the range between 0 and 1. Emissivity (ε) was computed using NDVI (Normalized Difference Vegetation Index) [15] expressed as:

$$\varepsilon = f_v \varepsilon_v + (1 - f_v)\varepsilon_s \tag{6}$$

Where, ε = Composite emissivity, ε_v = Vegetation emissivity, ε_s = Soil emissivity, and f_v = Fractional vegetation cover. Fractional vegetation cover was computed using equation 7 [16] expressed as:

$$f_v = 1 - \left(\frac{NDVI \;\; - NDVI_{Min}}{NDVI_{MAX} - NDVI_{MIN}} \right)^{\alpha} \tag{7}$$

Where, $NDVI_{Max}$ = $NDVI$ for a complete vegetation cover and $NDVI_{Min}$ = $NDVI$ for bare soil. $NDVI_{Max}$ and $NDVI_{Min}$ were assigned $NDVI$ values derived from Landsat TM 5 for 1984, ETM+ 7 for 2000 and OLI 8 for 2013. The coefficient α is a function of leaf orientation distribution within the canopy, where erectophile to planophile canopies have values between 0.6 and 1.25. A value of 0.6 was used in the current investigation. The fractional vegetation cover was compared with limited ground observations and the results were consistent. Emissivity was then estimated using the derived fractional vegetation cover and the specified emissivity values of soil and vegetation in equation 7. Using equation 8, the Land Surface Temperature (LST) was converted from degree Kelvin to degree Celsius:

$$T_{LST}(°C) = T_{LST}(K) - 273.16 \tag{8}$$

Where, T_{LST} (°C) = Land Surface Temperature in degree Celsius (°C) and T_{LST} (K) = Land Surface Temperature in degree Kelvin (K). The derived output was used as input in computing air temperature and also used in studying the effect of changes in temperature on Lagos metropolis. Air temperature was estimated from sensible heat flux [17] using equation 9 below expressed as:

$$H = \frac{\rho_{air} C_p (T_s - T_a)}{r_a H} \tag{9}$$

Where, H = Sensible heat flux (W/m^{-2}), ρ_{air} = Density of air humidity (kgm^{-3}), C_P= Air specific heat in constant pressure (J/Kg^{-1}K^{-1}), T_s = LST (K), T_a= Air temperature (K), and r_aH = Aerodynamic resistance (sm^{-1}). The result was converted from degree Kelvin to degree Celsius using equation 8. The derived output was used as input in computing Temperature Humidity Index (THI) and used in studying the effect of changes in temperature on Lagos metropolis. Air temperature values derived from Landsat imagery were validated using in-situ data from NIMET meteorological station with respect to its mean, using Spearman's rho non-parametric correlation model in SPSS 20 software.

Temperature Humidity Index (THI) was used to investigate human comfort in Lagos metropolis for 1984, 2000 and 2013. This method produces an index for studying the effects of heat condition on human comfort and could be derived from air temperature and relative humidity using equation 10 [18] below:

$$THI = 0.81T_a + \frac{(RHI \times T_a)}{500} \tag{10}$$

Where, THI = Temperature Humidity Index (°C); T_a= Air temperature; 0.81 and 500 = Constant factors for wet and dry climate regions [19], while RHI = Relative humidity index (%) and this was derived using equation 11 below expressed as:

$$RHI(\%) = \frac{e_a}{e_s} * 100 \tag{11}$$

Where, RHI = Relative Humidity Index (%), e_a = Actual water vapor pressure (Kpa), and e_s = Saturate water vapor pressure

(*Kpa*). The derived output (THI) was used to study the effect of changes in THI on Lagos metropolis using the LULC and administrative area for 1984, 2000 and 2013.

In order to study human comfort, Physiological Equivalent Temperature (PET) a thermo-physiological index was used to model thermal conditions of the human body in a physiologically relevant way. This was derived from THI in equation 10 for 1984, 2000 and 2013. In this study, an elaborate attempt was made to classify THI output into different grades of thermal sensations and physiological stress using the criteria listed in Table 2 for Lagos metropolis. The derived output was used to study the effect of changes in human comfort on Lagos metropolis using the LULC and the administrative area for 1984, 2000 and 2013.

Table 2. Physiological Equivalent Temperature (PET) (°C) class for thermal sensation and physiological stress in Nigeria.

S/N	Physiological Equivalent Temperature (PET) (°C)	Thermal Sensation	Physiological Stress
1	< (Less than) 4	Very cold	Extreme cold
2	8-4	Cold	Strong cold
3	13-8	Cool	Moderate cold
4	13-18	Slightly cool	Slight cold
5	18-23	Comfortable	No thermal
6	23-29	Slightly warm	Slight heat
7	29-35	Warm	Moderate heat
8	35-41	Hot	Strong heat
9	> (Greater than) 41	Very Hot	Extreme heat

Source: Matzarakis and Mayer [12]; Matzarakis et al. [20].

3. Results and Discussion

For proper comprehension, the study is divided into the following: 1. Effect of changes in land use on Lagos metropolis, 2. effect of changes in temperature on Lagos metropolis, 3. effect of changes in relative humidity index on Lagos metropolis, 4. effect of changes in temperature humidity index on Lagos metropolis, and 5. effect of changes in thermal human comfort on Lagos metropolis between 1984 and 2013.

3. 1. Effect of changes in Land use on Lagos metropolis

Based on the adopted land use/land cover (LULC) classification, Figure 2 shows the LULC of Lagos metropolis for 1984, 2000 and 2013 while Table 3 shows the LULC changes between 1984 and 2013. Agricultural area decreased from 155.74Km^2 in 1984 to 116.89Km^2 in 2000, and then to 16.96Km^2 in 2013. While commercial/industrial area and public/educational institution increased from 23.52Km^2 to 104.58Km^2 and 62.03 Km^2 to 133.23 Km^2 from 1984 to 2000 and decreased to 45.57Km^2 and 73.10 Km^2 in 2013. Forest land decreased from 109.52Km^2 to 39.95Km^2 from 1984 to 2000, and then to 30.25Km^2 in 2013. Low density residential area increased from 168.11Km^2 to 171.76Km^2 and then to 240.78Km^2 while high density residential area increased from 65.35Km^2 to 68.20Km^2 and then to 159.59Km^2 for 1984, 2000 and 2013. Result in Table 3 reveals that built-up areas increase at the expense of agricultural land, water bodies, wetland, and forest land. In spite of these changes in LULC, prompt variations in temperature were observed to accompany these changes in Lagos metropolis. Furthermore, the rapid depletion of vegetation cover has reduced the natural cooling effects of shades and evapotranspiration of plants and shrubs which has increased the urban discomfort experienced in Lagos metropolis.

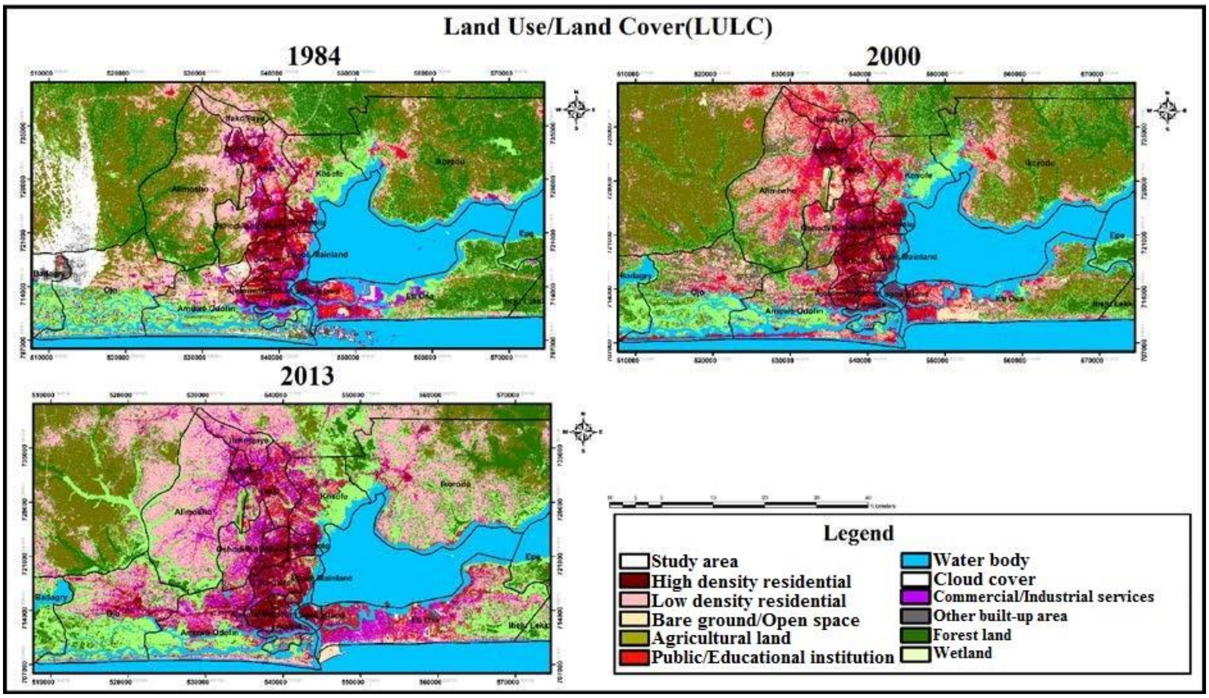

Figure 2. Land use/Land cover (LULC) of Lagos metropolis for 1984, 2000 and 2013.

Table 3. Changes in Land Use/Land Cover (LULC) of Lagos metropolis between 1984 and 2013.

	Area (Km^2)		
Land Use/Land Cover (LULC)	**1984**	**2000**	**2013**
High density residential area	65.35	68.20	159.59
Low density residential area	168.12	171.76	240.78
Bare ground/Open space	46.26	54.49	32.64
Agricultural land	155.84	116.90	16.96
Public/Educational institution	62.03	133.23	73.10
Other built-up area	67.46	44.41	106.60
Commercial/Industrial service	23.52	104.58	45.57
Forest land	109.58	39.95	30.25
Wetland	152.73	125.77	201.28
Water body	107.16	133.63	91.60

3. 2. Effect of changes in Temperature on Lagos metropolis

Changes in temperature were studied using Land Surface Temperature (LST) and air temperature for Lagos metropolis for 1984, 2000 and 2013. Figure 3 shows the Land Surface Temperature (LST) of Lagos metropolis and Figure 4 show the air temperature of Lagos metropolis derived from Landsat- TM 5, ETM+ 7 and O L I 8 thermal imagery for 1984, 2000 and 2013.

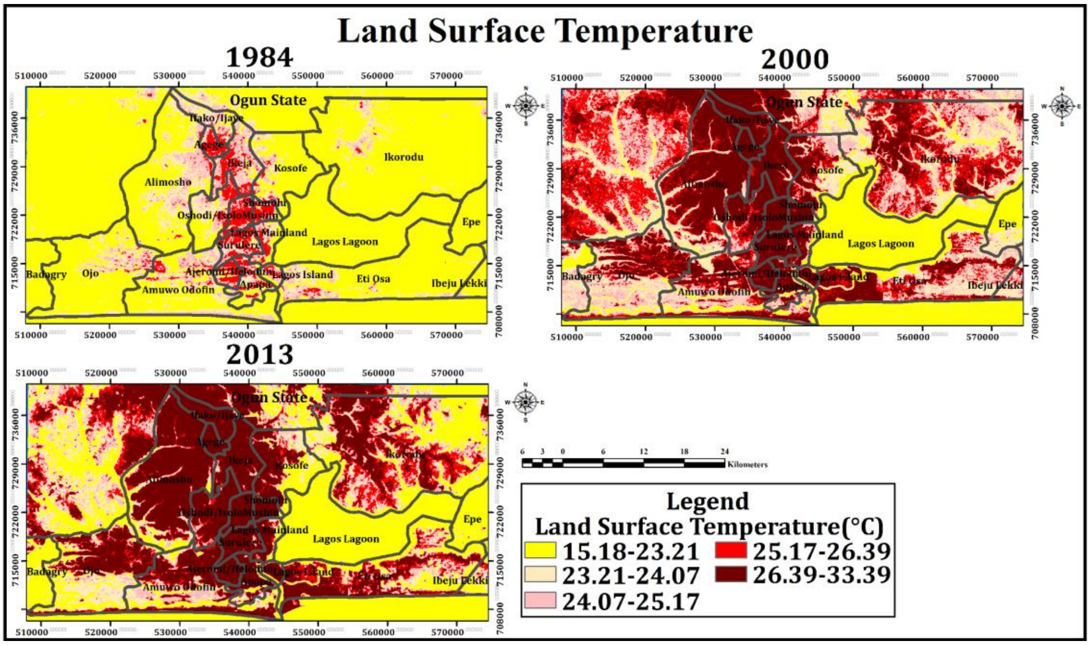

Figure 3. Land Surface Temperature (LST) of Lagos metropolis in 1984, 2000 and 2013.

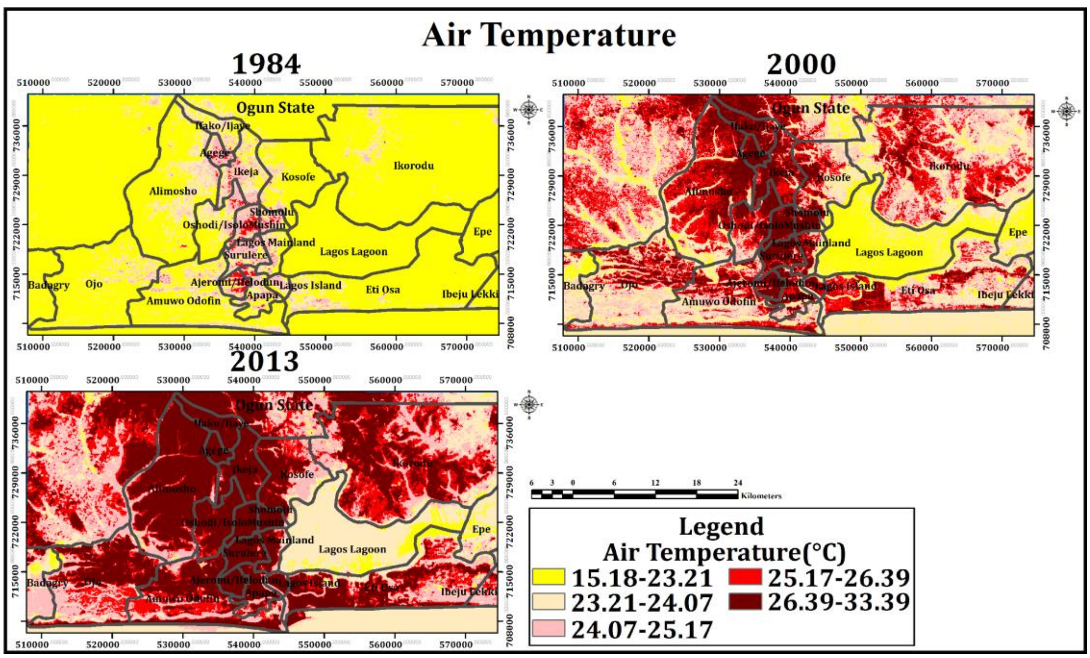

Figure 4. Air temperature of Lagos metropolis in 1984, 2000 and 2013.

In Lagos metropolis, LST minimum was observed to be 17.90°C, 21.25°C and 20.63°C for 1984, 2000 and 2013. LST maximum was observed to be 27.90°C, 35.80°C and 33.59°C for 1984, 2000 and 2013. While LST mean was observed to be 23.05°C, 25.99°C and 26.66°C for 1984, 2000 and 2013. While for air temperature, minimum of 17.29°C, 19.79°C and 20.89°C for 1984, 2000 and 2013 was observed. Air temperature maximum was observed to be 25.96°C, 30.19°C and 31.47°C for 1984, 2000 and 2013. Air temperature mean was observed to be 22.91°C, 25.40°C and 26.95°C for 1984, 2000 and 2013. Table 4a shows changes in the Land Surface Temperature (LST) of land use/land cover while Table 4b shows changes in the air temperature of land use/land cover in Lagos metropolis between 1984 and 2013. From the result presented in Table 4 based on LULC, LST as well as air temperature is high for public/educational institution and commercial/industrial service, and then followed by high density residential area and bare ground/open space.

Table 4. (a) Changes in Land Surface Temperature (LST) of the Land Use/Land Cover (LULC) for Lagos metropolis between 1984 and 2013; and (b) changes in air temperature of the Land Use/Land Cover (LULC) between 1984 and 2013 for Lagos metropolis.

Land use/Land Cover (LULC)	(a) Land Surface Temperature (LST) (°C)								
	1984			2000			2013		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean
High density residential area	20.20	27.30	25.41	22.39	31.40	28.52	22.64	33.42	29.86
Low density residential area	19.30	26.80	23.82	22.10	33.23	26.99	21.34	32.80	27.47
Bare ground/Open space	19.50	27.10	24.43	22.67	33.75	27.69	22.59	32.63	27.56
Agricultural land	17.90	26.40	22.55	22.39	30.87	25.17	22.32	31.16	25.74
Public/Educational institution	20.00	27.30	24.60	22.10	35.80	27.75	20.89	33.14	28.32
Other built-up area	19.70	27.70	24.28	22.10	31.66	27.77	20.91	33.60	28.37
Commercial/Industrial service	19.30	27.90	22.81	21.82	34.52	26.27	20.71	32.97	26.33
Forest land	18.10	24.40	21.55	22.10	29.27	23.75	21.22	27.96	23.03
Wetland	17.90	25.30	22.14	21.82	29.54	24.13	20.63	30.93	24.09
Water body	18.80	25.10	22.15	21.25	30.07	23.32	20.78	29.25	22.32

Land use/Land Cover (LULC)	(b) Air Temperature (°C)								
	1984			2000			2013		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean
High density residential area	19.72	26.50	24.61	21.61	29.87	27.19	23.27	32.78	29.76
Low density residential area	17.78	26.25	23.24	19.93	31.08	25.93	21.67	32.32	27.74
Bare ground/Open Space	18.96	26.25	23.50	20.84	31.59	26.27	22.63	31.80	27.74
Agricultural land	16.10	26.35	22.41	18.32	29.68	24.72	20.65	30.93	26.40
Public/Educational institution	18.93	26.47	23.89	20.74	32.82	26.52	20.25	32.62	28.45
Other built-up area	18.31	26.52	23.64	21.70	29.78	26.55	20.20	33.02	28.51
Commercial/Industrial service	16.30	26.55	22.44	19.84	31.91	25.41	20.35	32.50	26.95
Forest land	15.96	24.09	21.56	17.44	28.32	23.62	20.03	28.67	24.59
Wetland	15.97	25.01	22.13	18.68	28.27	24.01	19.78	30.70	25.32
Water body	16.93	25.21	22.52	18.77	28.54	23.77	20.10	29.33	24.06

It is observed that variations in temperature are mainly due to the kind of activities that go on in the various land use. Reduction in forest/natural landscape has increased and modified the micro-climate of Lagos metropolis due to the replacement of depleted vegetation cover/open land with impervious surfaces which has robbed the city of the natural cooling effects provided by shade and evapotranspiration of plants and shrubs. Surface and air temperature has increased in high and low density residential area, commercial/industrial service, and public/educational institution compared to forest and natural landscape (Table 4), this in-turn has increased the difference between surface and air temperature which also, has made surface temperature higher. Validation was performed using meteorological data from weather station compared with derived air temperature from thermal infrared band (using Landsat satellite imagery) for 1984, 2000 and 2013, and the results reveals that the relationship is statistically significant ($F_{cal}>F_{tab}$=12.62 > 0.18) at 95% level of confidence with R^2 = 85.70%.

3.3. Effect of changes in Relative Humidity Index on Lagos metropolis

Relative humidity index (RHI) for Lagos metropolis was estimated from Landsat- TM 5, ETM+ 7 and O L I 8 thermal imagery as represented in Figure 5. The minimum, maximum, and mean relative humidity index for 1984, 2000 and 2013 is presented in Table 5. In Lagos metropolis, 82.16% minimum and 88.28% maximum with a mean relative humidity index of 85.79% was observed for 1984. A relative humidity index of 87.55% minimum and 94.01% maximum with a mean of 90.94% was observed for 2000. While in 2013, 97.58% minimum and 98.63% maximum with a mean relative humidity index of 98.12% for 2013 was observed. Based on the result, relative humidity index was found to be high throughout the year and may not be less than 82.00% to 99.00% in Lagos metropolis as confirmed by Abegunde [14].

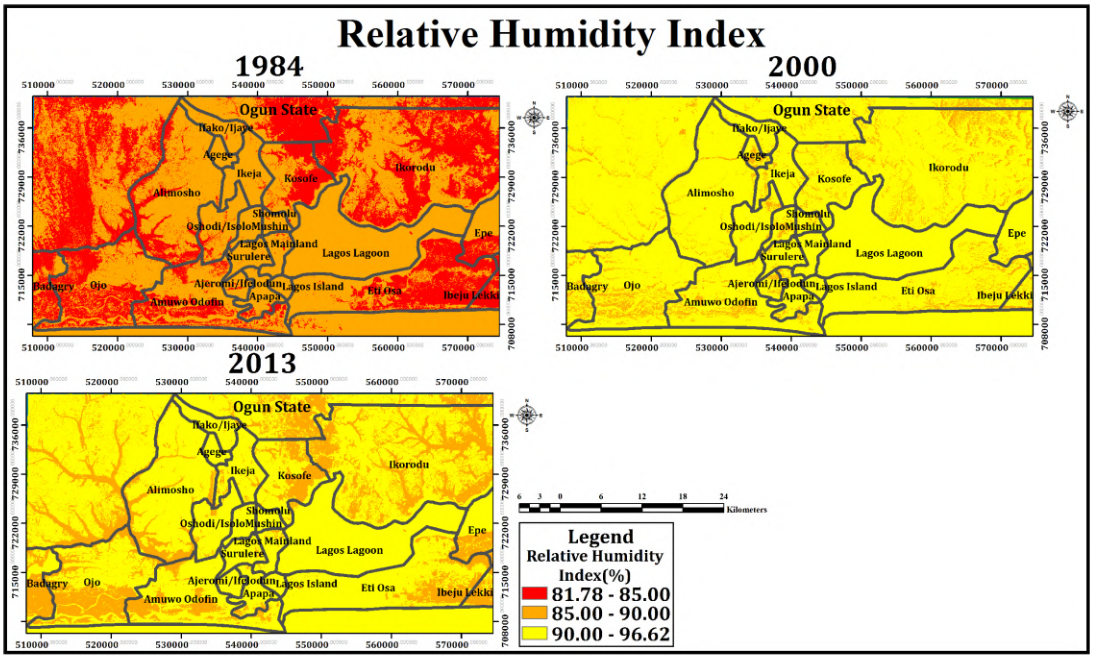

Figure 5. Relative Humidity Index (RHI) of Lagos metropolis for 1984, 2000 and 2013.

Table 5. Relative Humidity Index (RHI) (%) minimum, maximum and mean of Lagos metropolis for 1984, 2000 and 2013.

	Minimum	Maximum	Mean
1984	82.16	88.28	85.79
2000	87.55	94.01	90.94
2013	97.58	98.63	98.12

3.4. Effect of changes in Temperature Humidity Index (THI) on Lagos metropolis

Temperature Humidity Index (THI) in Lagos metropolis was estimated from air temperature and relative humidity index derived from Landsat- TM 5, ETM+ 7 and O L I 8 thermal imagery for 1984, 2000 and 2013 as presented by Figure 6. Table 6 shows changes in the distribution of THI for the LULC of Lagos metropolis between 1984 and 2013. In Lagos metropolis, the minimum THI of 15.38°C for 1984, 17.21°C for 2000, and 20.91°C for 2013 was observed. While maximum THI of 25.88°C for 1984, 31.51°C for 2000 and 32.91°C for 2013 was observed. THI means 22.13°C for 1984, 24.86°C for 2000 and 28.18°C for 2013 was observed.

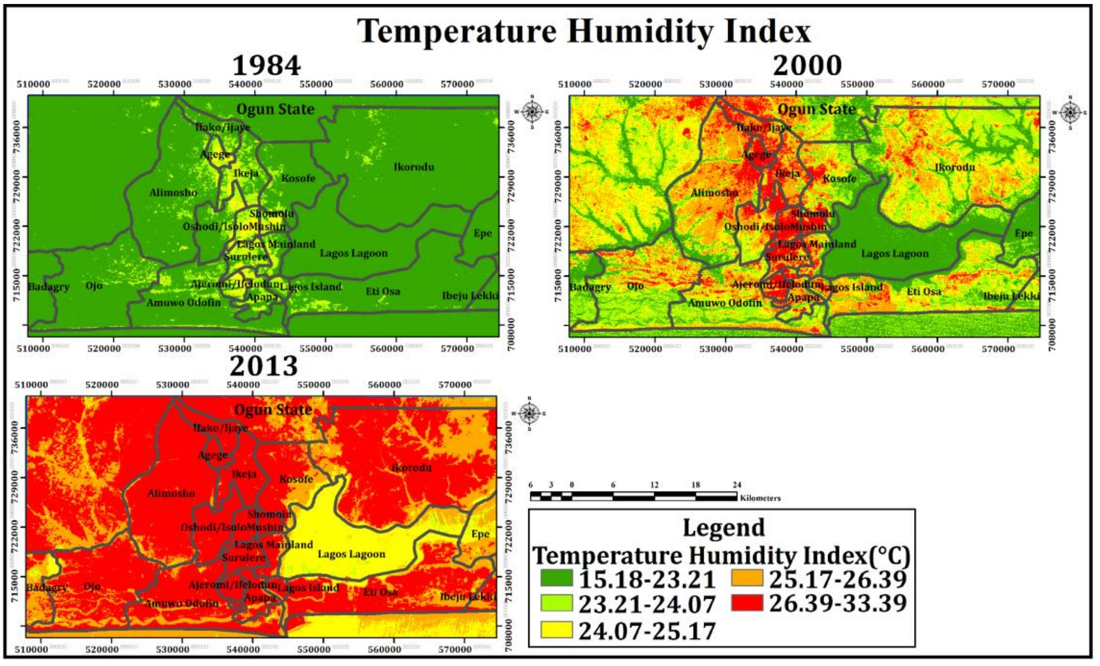

Figure 6. Temperature Humidity Index (THI) of Lagos metropolis for1984, 2000 and 2013.

Table 6. Changes in Thermal Humidity Index (THI) (°C) of the Land Use/Land Cover (LULC) for Lagos metropolis between 1984 and 2013.

Land Use Land Cover (LULC)	1984			2000			2013		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean
High density residential area	19.17	25.83	23.97	21.34	29.21	26.66	23.20	32.64	29.64
Low density residential area	17.14	25.59	22.61	19.68	30.36	25.46	21.61	32.19	27.63
Bare ground/Open space	18.43	25.59	22.87	20.56	30.84	25.78	22.64	31.66	27.64
Agricultural land	15.52	25.69	21.78	18.07	29.03	24.28	20.58	30.81	26.29
Public/Educational institution	18.40	25.80	23.26	20.46	31.51	26.02	20.18	32.48	28.34
Other built-up area	17.79	25.85	23.01	21.38	29.13	26.05	20.13	32.88	28.40
Commercial/Industrial service	15.83	25.88	21.79	19.57	31.14	24.95	20.30	32.36	26.85
Forest land	15.38	23.41	20.84	17.21	27.74	23.18	19.96	28.56	24.49
Wetland	15.39	24.40	21.42	18.41	27.70	23.57	19.71	30.57	25.22
Water body	16.50	24.63	21.95	18.58	27.95	23.41	20.05	29.21	23.99

An observed change with resultant increase was recorded for 1984, 2000 and 2013 for Thermal Humidity Index in Lagos metropolis. This could be attributed to changes in land use/land cover which modifies the local climate between 9:33AM to 10:02AM in the morning (Table 1). From the result presented in Table 6, THI is high for high density residential area, public/educational institution, commercial/industrial service, and bare ground/open space. This is due to the known activities engaged in these areas with few or no trees around the different structures, pavement and tiled environment. The observed modification due to LULC change and alterations has increased the THI values recorded in Lagos metropolis in relation to its spatiotemporal characteristics. In other words, this has increased thermal discomfort observed in Lagos metropolis.

3.5. Effect of changes in Thermal Human Comfort on Lagos metropolis

Based on the Thermal Humidity Index (THI) in Figure 6, human thermal comfort was classified using physiological stress and thermal sensation derived from the criteria stated in Table 2 for Lagos metropolis and shown in Figure 7 for 1984, 2000 and 2013. This is based on Physiological Equivalent Temperature (PET) which takes into account all basic thermoregulatory processes [21] and is based on a thermo-physiological heat balance model called Munich Energy balance Model for Individuals (MEMI) [22],[23].

Based on the land use land cover (LULC), using the criteria stated in Table 2, the following LULC are classified according to their physiological stress and thermal sensation categories using the THI tabulated for LULC in Table 6. Based on the THI in Table 6, PET mean range of 23.00°C to 29.00°C in 1984, 2000 and 2013 for Lagos metropolis was classified as having a slight heat stress/slight warm thermal sensation which was observed in all land use class excluding 1984 for low density residential area, forest land, agricultural land, bare ground/open space, wetland, and water body. Conventionally, high density residential areas, public/educational institutions and commercial/industrial area are regarded as having a higher physiological stress rate than other land uses. At this threshold range of 23.00–29.00°C; work, living condition, educational environment, and recreation lifestyle of people in the affected land use/land cover is influenced by slight heat stress/slight warm sensation which is regarded as a hot environment. In hot environment the following symptoms are observed to elevate sensory threshold, change in reaction time, fatigue, loss in concentration, increased error rate, slowed decision-making, and increased cardiac rhythm, internal temperature, and respiration rate. This is due to exceeding the mean threshold of 26.00°C for thermal comfort as observed in Lagos metropolis for 2000 and 2013.

The area extent covered (in Km^2) by physiological stress and thermal sensation is presented in Table 7 and area extent covered by physiological stress and thermal sensation in percent (%) for Lagos metropolis is presented in Table 8 for 1984, 2000 and 2013. In 1984 based on Table 7 and 8, 0.13%(1.30km^2) of the study area is classified as experiencing slightly cold sensation/slight cold stress, 76.77%(760.88km^2) is classified as experiencing comfortable sensation/no thermal stress, and 23.10%(229.02km^2) was classified as experiencing slight warm sensation/slight heat stress. In 2000, 0.00%(0.00km^2) of the study area was classified as experiencing slightly cold sensation/slightly cold stress, 8.98%(89.23km^2) was classified as experiencing comfortable sensation/no thermal stress, and 91.02%(901.97km^2) was classified as experiencing slight warm sensation/slight heat stress and 0.00%(0.00km^2) was classified as experiencing warm sensation/moderate heat stress. While in 2013, 0.04%(0.42km^2) of the study area was classified as experiencing comfortable sensation/no thermal stress, 61.57%(610.24km^2) was classified as experiencing slight warm sensation/slight heat stress, and 38.39% (380.54km^2) was classified as experiencing slight warm sensation/slight heat stress. The result in Table 7 and 8 reveals that, high PET values were observed ranging from 23.00-29.00°C (slight heat stress/slight warm sensation) for 2000 and 2013 while 18.00–23.00°C (comfortable sensation/no thermal stress) covers vast majority of Lagos metropolis in 1984. Furthermore, this reveals that a shift was observed for Lagos metropolis, from comfortable sensation/no thermal stress to slight heat stress/slight warm sensation between 9:33AM to 10:02AM (Table 1) in the morning. The adverse symptoms are same as the ones presented above for Lagos metropolis.

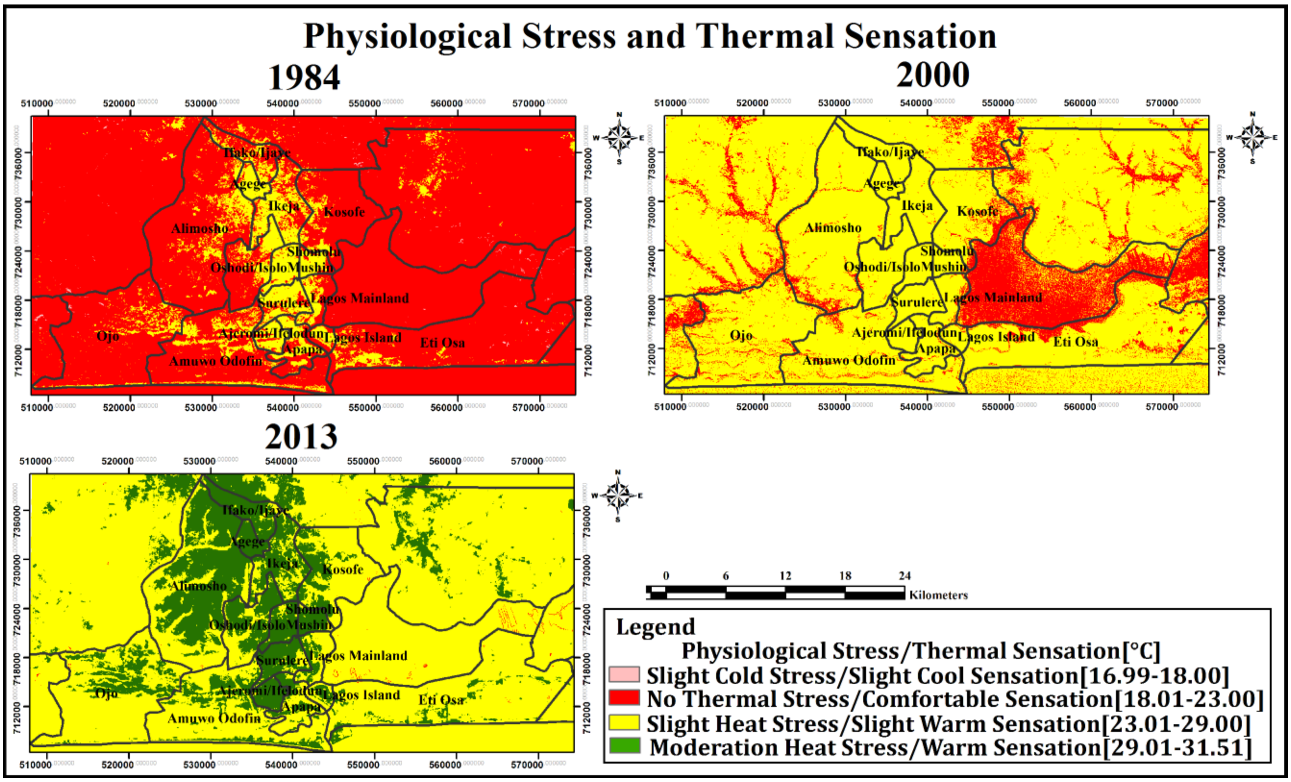

Figure 7. Physiological stress and thermal sensation of Lagos metropolis in 1984, 2000 and 2013.

Table 7. Area (Km^2) covered by Physiological Equivalent Temperature (PET) (°C) for thermal sensation and physiological stress in Lagos metropolis for 1984, 2000 and 2013.

PET (°C)	Physiological Stress	Thermal Sensation	1984	2000	2013
13-18	Slight cold	Slight cold	1.30	0.00	0.00
18-23	No thermal	Comfortable	760.88	89.23	0.42
23-29	Slight heat	Slight warm	229.02	901.97	610.24
29-35	Moderate heat	Warm	0.00	0.00	380.54
35-41	Strong heat	Hot	0.00	0.00	0.00

Table 8. Area in percent (%) covered by Physiological Equivalent Temperature (PET) (°C) for thermal sensation and physiological stress in Lagos metropolis for 1984, 2000 and 2013.

PET (°C)	PhysiologicalStress	ThermalSensation	1984	2000	2013
13-18	Slight cold	Slight cold	0.13	0.00	0.00
18-23	No thermal	Comfortable	76.77	8.98	0.04
23-29	Slight heat	Slight warm	23.10	91.02	61.57
29-35	Moderate heat	Warm	0.00	0.00	38.39
35-41	Strong heat	Hot	0.00	0.00	0.00

Conclusion

This research described the methodology and findings obtained from an outdoor thermal comfort study carried out in Lagos metropolis. This study design has proved to be appropriate to acquire land surface and air (atmospheric) temperature, and relative humidity index values for 1984, 2000 and 2013 using Landsat satellite imagery which was used to model thermal humidity index appropriate to study human physiological stress and thermal sensation. Also, thermal humidity index has thrown some light on the possible behavioral reactions of people to the overall thermal conditions and how land use activities have influenced it. This research has highlighted the importance of physiological stress on workers performances, tourism, home comfort, education, and sites selection which are of importance to government, planners, educationist, and other stakeholders that hold the environment so dear to them. The high rate of heat stress on the environment was found to have an effect on the health of the people which could lead to heat related diseases such as fatigue, sunstroke, muscle cramps, heat stroke and heat exhaustion. This study has thrown open the door of environmental efficiency, well-being and the health of the citizens which is positively (or negatively) influenced by thermal comfort and physiological stress, by developing and maintaining comfortable environmental conditions that will enhance the quality of urban life.

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