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Analysis of relative humidity and its implications for the planning of tropical cities in Nigeria

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Abstract

This study examines the nature of relative humidity in the tropical urban troposphere and its characteristic implications for the planning of modern cities to attain sustainable development with specific focus on Benin City in Nigeria. It utilizes authentic data obtained from two synoptic meteorological stations sited within and outside of Benin City which is the current study area. It observes, inter-alia, the routine circulation of adequate water vapour of yearly values from 81% to 84% in the urban troposphere in the mornings and evenings which transforms into mists, dews, drizzles and rains and appearance of clear skies in the afternoons. Factors as effective radiation, evaporation, transpiration, convective forces, maritime winds and temperature flux spurred the ascent of moisture in the city. Based on the findings, the study identifies suitable areas where relative humidity values can be used in the contemporary Nigerian cities to achieve sustainable development. These areas span food and cash crops farming at the outskirts, planting of resistant grasses and trees to mitigate and combat surface denudation, reforestation in the cities to serve as effective wind shields to built infrastructures, viable transportation, clean water provision to the urban residents, perennial production of fruits and vegetables within the residential zones, healthy urban sanitation, and voluntary human drift to the outskirts for therapeutic fresh moisture, breeze, sunshine, adequate nutrition, spacious housing, beneficial clean fields and sinewy health.

Keywords: Relative Humidity; Implications; Planning; Sustainable Cities; Nigeria

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1. Introduction

The physical composition of the urban troposphere determines the nature, pace, direction and extent of human activities on the vast urban environment in the present scientific epoch. Specifically, observed meteorological occurrences such as water vapour, rainfall, dew, frost, hail, mist, lightning, storm, breeze, sunshine, radiation and temperature largely influence the exact time, period, extent and spatial success of human activities in the different climatic zones of the world. These activities range from the primary occupations like mining, quarrying, farming, fishing and forestry through industrial and construction works to tertiary engagements which span banking, transportation, commerce, tourism and recreation, sports, communications and global diplomatic duties.

Relative humidity which means the actual vapour content of the atmosphere is the original source of precipitation which forms in and radiates from the troposphere over the underlying earth's surface. The concept scientifically refers to the actual moisture content of a sample of air expressed as a percentage of that contained in the same volume of saturated air at the same temperature (Oyediran, 1977; Okhakhu, 2010). Inferentially, therefore, relative humidity is the positive result of the combined processes of surface evaporation and vegetal transpiration which occur on the environment to produce abundant clouds of ascent moisture. For adequate moisture to ascend the earth's troposphere from the bare lands, vegetal and water surfaces, solar radiation, pressure gradient force, evaporative surfaces, and warm convective currents must interact. The ascent moisture vapour is held by the circulating warm air in the diverse cloud types before it changes through the process of condensation via saturation into ice, hail, dew, drizzle, or rainfall which is finally received on the underlying earth's surface.

The water vapour content of the atmosphere is significant in modern climatic studies for a number of reasons, namely: it serves as the main source of all forms of condensation and precipitation across the universe; it absorbs both the solar and terrestrial radiation and plays the role of heat regulator within the earth-atmosphere realm; it influences the rates of evaporation and evapotranspiration on the earth's surface; it could be changed into liquid or solid form; it releases latent heat which is the direct source of energy required to propel the circulation of the earth's atmosphere and development of atmospheric turbulence; it influences the temperature which is sensed by the human skin thereby determining the physical and physiological comfort of the human body; finally, the vapour content determines the stability of air in a selected settlement. The stability of air is mandatorily necessary for the smooth transportation of people, goods and services on land, at the sea, and in the troposphere.

Relative humidity determines significantly the periodic frequency and occurrence of rainfall on the surface environment. Its inadequacy in the troposphere at any geographic settlement owing to factors of minimized radiation, decreased pressure gradient force, absence of natural turbulence and occurrence of cool water surfaces implies a direct halt to the rain forming processes and eventual physical absence of rainfall in the settlement affected. Consequently, drought or aridity becomes the climatic condition in the settlement. Drastically fluctuated relative humidity in the urban areas which produces rainfall owing to reckless human pollution of the urban troposphere could distort almost all human activities set aside for immediate implementation on the environment. This threat to effective sustenance of the urban areas in the humid West of Nigeria with focus on Benin City deserves efficacious planning using authentic humidity values derived from synoptic meteorological stations and direct manual observations of the troposphere.

Rainfall serves as the most indispensable universal environmental resource to the humans, animals, plants, micro-organisms and the pollinating agro-insects. It is often utilized to achieve numerous domestic, institutional, managerial, and industrial activities across the world in the current scientific age. Agricultural sectors require adequate rainwater for raising livestock, diverse crops, grasses and pollinating insects. Modern hospitals and primary healthcare centres need rainwater to achieve immense success in facilitating human health, environmental hygiene and laboratory experiments. Rainwater increases the volumes of streams, rivers and seas during torrential rainfall which are perpetually used for both domestic and foreign conveyance of people, goods and essential services across the world. Where it is experienced most frequently, as in the temperate countries, rainfall helps to mitigate and ameliorate the state of harsh weather in the urban environments. In fact, the diverse applications of rainwater across the world by the people, establishments, research institutes, industries and settlements have been documented accurately in published literature by contemporary university scientists (Iloeje, 1982; Ayoade, 1988; Oguntoyinbo, 1994; Okhakhu, 2010; 2016).

Ayoade (1988) refers to planning as a set of procedures for determining appropriate future actions through the sequences of choice. It entails the application of relevant scientific methods to policy decision making. Future-oriented in dimension, planning as a concept places emphasis on the utilization of physical and human resources in creating congenial and sustainable environment for man and his diverse activities. Based on this preface, modern city planning involves the use of scientific methods for making vital policy decisions where suitable climatic values and human resources are utilized with a view to creating and sustaining functional and comfortable city environments for the diverse urban people. In this context, there is adequate provision of food and cash crops for continuous human sustenance through commerce, construction of physical and socio-economic infrastructures for the protection and promotion of human lives, and existence of effective political stability which fosters social justice, equality, civilization, peaceful co-existence of the people and healthy unity among the diverse ethnic nations which constitute the city environment. This implies, therefore, that the essence of planning the contemporary tropical humid cities using relative humidity values is to create relatively standard, comfortable and healthy environments for the urban residents with their diverse physical facilities and perennial activities.

In Nigeria, particularly in the humid tropical mid-west of Benin City, adequate scientific analyses of relative humidity values in the urban troposphere and their characteristic implications for planning the city environment have not been carried out by contemporary urban climatologists. This current study in urban climatology attempts to bridge this research vacuum in the select urban environment.

2. Objectives of the study

This current study analyzes relative humidity in the urban troposphere and its characteristic implications for the planning of contemporary tropical cities in Nigeria with specific focus on Benin City in Edo State.

3. Materials and methods

This study utilized authentic climate literature available in the humid tropics, mid-latitude and temperate locations of the world. Also, essential first-hand data obtained from both reconnaissance and field surveys carried out in Benin City were utilized in the study. Specifically, reliable relative humidity values which covered 1988-2008 formed the main focus of the analysis. Random and selective physical observations of the urban troposphere were expedited between 2012 and 2016 with the aid of two digital hygrometers. These constituted vital data inputs which bridged the data vacuums and made the urban climate analysis a fruitful scientific reality. Eight relevant tables of relative humidity values and temperature indices were utilized in the empirical analyses. The choice of the relative humidity value was to discuss its salient place in the planning of cities to attain sustainable development in Nigeria. Direct physical observations revealed relative humidity as the fundamental source of wet clouds, mists, dews, drizzles, and rainfall which occur regularly in the city. It also induces the tertiary circulatory system, sunshine, and suitable weather. It is based on this background that the climatic cause-effect analysis, predictive, and the positive prescriptive approaches are utilized for presentation of results and discussion of findings in the study.

4. The study area

The study area is Benin City in Nigeria. The city serves as the current administrative centre for both Oredo Local Government Area and Edo State in Nigeria. Benin City is a humid tropical urban settlement which comprises three Local Government Areas namely Egor, Ikpoba Okha and Oredo. It is located within Latitudes $6^0 20^1$N and $6^0 58^1$N and Longitudes $5^0 35^1$E and $5^0 41^1$E (Okhakhu, 2010). It occupies a vast area of approximately 112.55^2 km. This vast spatial coverage suggests spatial variability of relative humidity in the city. As Buchanan and Pugh (1955) argued, Benin City lies in the southern corner of a dissected margin: a prominent topographical unit which lies north of the Niger Delta, west of the lower Niger Valley, and south of the Western Plains and Ranges.

The geologic structure of Benin City consists of two principal formations: these are the crystalline rocks of the Precambrian Basement Complex and the sedimentary rocks of the Cretaceous Tertiary and Miocene-Pleistocene Age. The city landscape contains lateritic soils mixed with abundant clay minerals. Its soils are derived from the profound physical and chemical weathering of the parent sedimentary rocks preferably the cemented hardened sandstones (Odemerho, 1988; Omiunu, 1988).

The Benin City hydrological basin is partitioned into two main units. The first unit consists of the Ikpoba River Basin which drains the whole eastern part of the city while the second unit covers the Ogba River Basin which drains the western part. In general, the rivers flow the north-south direction owing to the high elevation of Nigeria from its northern part (Okhakhu, 2014). Two air masses operate in the City. These are the tropical maritime and tropical continental. The tropical maritime air mass originates from the South Atlantic Zone. It causes rainfall which begins from the late January till its gradual subsidence in mid-November. The tropical continental air mass causes the dry season in the city.

The convective and relief types of rainfall are vastly experienced in Benin City owing to its unique radiation reception, rich vegetations, water bodies, and the hilly terrains. The total annual rainfall amount recorded in the city ranges from 2,000mm-3,000mm. It experiences the double rainfall cycles with the highest precipitation amounts occurring in the months of July and September. Also, high relative humidity values from 81%-84% have been observed in the city. These stabilize in the mornings, fluctuate in the afternoons, and enhance in the evenings owing to evaporation, transpiration, atmospheric pressure and the maritime winds. The city experiences a mean annual temperature of 27.5^{0}C which, throughout the year, owing to the interplay of torrential rains, hilly terrains, deforestation, related human activities, and rough characteristics of the urban surfaces is prone to fluctuation.

Benin City is located in the tropical rainy climate where cumulonimbus moist clouds, moderate temperatures, suitable sunshine, torrential rainfall, and favourable winds are experienced (Iloeje, 1982; Udo, 1987; Ayoade, 2004). These elements have facilitated the growth of tropical rainforest which is vastly evergreen and hugely deciduous in nature. When physically observed from the hilly Ikpoba summits in the north of the city, the rainforest exhibits evergreen canopy formation. The highest vegetal formation contains the robust and broadly tall trees which include Mahogany, Walnut and Cedar. The availability of these valuable tall trees has encouraged the establishment of diverse wood-works, small-scale paper industries and saw-milling factories in Benin City. These industries have provided life-sustaining jobs to the city residents over the years. Other services rendered by the factories include provision of income, supply of raw materials for furniture making, and deposition of saw-dusts for domestic fire preparations.

The rainforest which receives solar energy and circulating warm winds always transpires adequate moisture to the troposphere. This leads to heavy rainfall which is always experienced in the city. More so, the forest serves as a source of wild fruits and diverse herbs to the city residents. It enhances the fertility of the black soils through the process of leaf-decay. It further provides useful species of ropes, gums and refreshing breezes to the residents. Owing to its fertile soils, valuable economic tree and fruit products such as cashew, cocoa, rubber, coffee, kola-nuts, oil palms, oranges, grapes, cherries, paw-paw, bananas, pears, plantains, mangoes and guava are cultivated in the outskirts of the study area. Tomatoes, pepper, fresh vegetables, melon, ground nuts, maize and beans are also produced by the rural farmers who have settled at the outskirts owing to suitable humidity, rainfall, temperature, breeze and sunshine.

5. Results and discussion

5.1. The nature of relative humidity in Benin City, Nigeria

The data used in the current analysis of relative humidity in Benin City, Nigeria, covered a 21-year period, precisely from 1988-2008. These data were obtained from the synoptic meteorological stations at the Nigerian Institute for Oil Palm Research (NIFOR) and Domestic Airport administered by the Nigerian Meteorological Agency in Benin City. The choice of these meteorological data reflects the spatial variation which has been a prominent ancient characteristic of geographic studies. Further, the sites of the two synoptic meteorological stations enable us to expedite orderly and rigorous assessments of the prevailing state of relative humidity observed within and outside of the city metropolis. The apparatuses used in taking the relative humidity readings were the wet and dry bulb thermometers enclosed in a Stevenson's screen and the hygrometric psychrometers. The readings taken were read-off from the given hygrometric tables having obtained initially the values of the wet bulb depression. The fixed hours for instrumental measurements of relative humidity were 0900 and 1500 GMT.

The data analyzed in the study were divided into four major phases based on the 21-year period of instrumental observations, measurements and documentation at the two meteorological stations in Benin City. Phase 1 covered 1988-1992. Phase 2 spanned 1993-1997. Phase 3 extended from 1998-2002. Phase 4 covered 2003-2008. The first three Phases range from 1-5 years while the last Phase extends from 1-6 years owing to an addition of a year's records (Tables 1.2,3, 4). The choice of this period of assessment was strictly premised on the sophisticated meteorological apparatuses available and utilized in the observations and measurements of relative humidity at the two synoptic meteorological stations and efficient human skills involved in the holistic exercise. Of course, the data obtained were error-free, accurate, reliably valid, and consistently relevant for the planning of humid tropical cities in Nigeria.

The relative humidity in Phase 1 which spans 1988-1992 at 0900 hours during the rainy and dry seasons in the city was markedly high. In January, February and March 1988 at 0900 hours, the relative humidity values stood at 71.4%, 80.4%, and 82.9%. At 1500 hours of the corresponding months in 1988 as shown in Table 1, the relative humidity indices fluctuated. The higher humidity values recorded in the morning hours were direct reflections of the fluctuated radiation during the period. However, minimum temperatures are always higher during the rainy season. This makes the moisture content of the urban troposphere enhance significantly resulting to higher relative humidity in the city. On the other hand, the observed fluctuation in relative humidity at 1500 hours as shown in Table 1 apparently correlates the temperature increase which absorbed the water vapour in the immediate troposphere during the period under assessment.

Table 1. Percentage Relative Humidity from 1988-1992 in Benin City, Nigeria

Year	1988		1989		1990		1991		1992	
Month	0900	1500	0900	1500	0900	1500	0900	1500	0900	1500
Jan	71.4	58.0	58.4	47.7	83.9	58.7	86.2	66.5	63.4	60.3
Feb	80.4	55.9	70.6	40.7	83.9	55.1	84.1	63.1	72.1	55.8
Mar	82.9	66.0	77.0	58.1	75.3	55.7	83.5	61.6	80.5	62.9
Apr	80.4	63.7	79.6	56.9	77.5	59.6	83.7	67.7	79.2	63.3
May	81.4	66.8	81.2	62.8	80.5	63.9	81.4	66.9	81.9	66.6
June	83.4	71.2	85.2	66.5	84.3	69.1	88.6	66.4	85.2	72.3
July	87.6	80.4	85.8	72.3	89.8	80.8	89.5	72.0	89.7	73.3
Aug	87.0	82.6	88.6	75.8	94.1	75.6	86.1	74.6	89.6	72.8
Sep	87.0	80.3	86.7	73.2	86.5	71.9	85.8	73.4	87.0	72.9
Oct	84.6	73.4	83.5	70.1	83.7	68.8	84.7	72.0	84.2	72.7
Nov	81.9	61.3	80.0	57.5	84.5	68.9	84.1	68.0	83.5	67.7
Dec	81.6	64.6	80.7	50.7	85.1	69.4	79.0	67.2	83.5	67.7
Total	989.6	824.2	957.3	732.3	1009.1	797.5	1016.7	819.2	908.9	808.4
Mean	82.5	68.7	79.8	61.0	83.4	66.5	84.7	68.3	81.7	67.4

Source: Nigerian Meteorological Agency, Benin City, Nigeria, 1992

Table 2. Percentage Relative Humidity from 1993-1997 in Benin City, Nigeria

Year	1993		1994		1995		1996		1997	
Month	0900	1500	0900	1500	0900	1500	0900	1500	0900	1500
Jan	69.3	66.2	74.1	65.1	85.8	81.8	85.6	91.9	79.6	78.8
Feb	81.6	49.5	81.2	54.2	85.7	78.1	80.9	60.6	73.0	72.4
Mar	81.6	64.5	78.5	62.4	83.5	75.2	81.9	80.0	75.6	71.7
Apr	81.6	66.2	76.4	60.2	85.1	77.2	84.3	84.9	82.1	73.4
May	81.6	66.0	81.5	64.5	80.7	78.2	87.7	87.6	82.6	78.8
June	79.9	65.3	80.4	74.3	84.7	80.5	92.6	89.8	86.0	85.1
July	84.7	70.1	78.1	85.4	99.8	89.4	88.1	90.3	85.5	80.8
Aug	56.5	69.3	90.5	88.6	94.0	87.7	93.2	90.4	88.4	86.7
Sep	91.6	71.8	88.7	90.4	88.1	86.3	90.0	87.0	86.5	86.8
Oct	88.3	69.1	86.0	88.7	82.7	79.8	89.9	83.3	84.8	85.5
Nov	84.8	68.1	79.6	80.4	85.6	75.3	77.7	78.2	83.5	81.6
Dec	84.8	68.1	79.6	80.4	91.7	81.4	83.2	75.8	87.8	80.0
Total	959.6	877.5	965.2	886.6	1047.4	970.9	1035.1	999.8	989.4	961.7
Mean	79.9	73.1	80.4	73.9	87.3	80.9	88.3	83.3	82.5	80.1

Source: Nigerian Institute for Oil Palm Research, Benin City, Nigeria, 1997

From April to October, 1988, higher relative humidity values were observed in the city. These values were 80.4%, 81.4%, 83.4%, 87.6%, 87.0%, 87.0%, 87.0% and 84.6%. A corresponding increase of 81.9% and 81.6% in the same values were registered in November and December, 1988. The mean annual relative humidity values observed in Benin City at 0900 hours from 1988-1992 as shown in Table 1 were 82.5%, 79.8%, 84.3%, 84.7% and 81.7%. These values were relatively high owing to a consistently humid urban troposphere. At 1500 hours within the same periods of assessment (1988-1992), the mean annual relative humidity values observed declined, and these include 68.7%, 61.0%, 66.5%, 68.3% and 67.4%. These statistics indicated marked urban disparities of relative humidity observed in the city at 0900 and 1500 hours during the Phase 1 which illustrate the fundamental traits of meteorological variation and association in current climatic studies.

Table 3. Percentage Relative Humidity from 1998-2002 in Benin City, Nigeria

Year	1998		1999		2000		2001		2002	
Month	0900	1500	0900	1500	0900	1500	0900	1500	0900	1500
Jan	63.8	63.8	80.2	57.9	74.4	53.1	80.9	46.8	68.4	36.1
Feb	75.6	56.0	79.7	57.3	53.6	32.3	69.2	38.1	72.8	48.7
Mar	70.7	45.0	81.8	61.4	71.4	51.3	78.6	60.1	82.4	66.1
Apr	78.3	67.0	83.6	65.3	80.1	64.9	69.4	59.4	82.3	67.1
May	80.5	69.5	81.0	68.3	77.1	68.9	79.6	67.5	80.6	70.0
June	82.5	70.0	83.7	85.7	81.7	79.8	86.5	73.6	82.5	71.1
July	87.6	79.0	85.1	82.2	87.8	76.8	88.9	78.6	86.5	80.1
Aug	86.1	78.2	85.9	81.5	88.6	81.0	88.5	81.5	87.4	81.4
Sep	87.9	80.3	86.3	79.0	85.1	79.9	83.8	79.5	86.0	77.0
Oct	84.0	77.2	86.0	78.3	80.4	72.0	83.1	70.0	83.7	75.8
Nov	83.3	63.3	79.9	54.4	79.8	63.4	79.7	58.7	83.7	60.1
Dec	79.6	53.4	78.0	52.9	73.7	50.3	79.8	51.3	69.3	47.2
Total	959.2	805.0	992.0	824.5	193.2	764.8	978.0	765.1	965.6	780.7
Mean	79.9	67.1	82.8	68.7	77.6	63.7	81.5	63.8	80.5	65.1

Source: Nigerian Institute for Oil Palm Research, Benin City, Nigeria, 2002

Table 4. Percentage Relative Humidity from 2003-2008 in Benin City, Nigeria

Years	2003		2004		2005		2006		2007		2008	
Month	0900	1500	0900	1500	0900	1500	0900	1500	0900	1500	0900	1500
Jan	82.7	55.9	78.4	50.7	66.7	45.1	85.7	61.1	59.7	33.5	64.3	47.2
Feb	83.3	58.5	72.8	50.4	79.8	52.4	81.8	59.8	80.8	50.6	65.1	36.7
Mar	80.1	59.5	72.6	50.6	81.7	65.2	81.9	60.0	81.4	50.8	80.8	58.0
Apr	81.0	64.4	83.3	69.0	81.8	67.1	82.1	61.6	80.8	67.4	82.4	62.6
May	88.2	65.5	84.8	67.0	83.4	68.2	82.7	72.6	82.3	68.6	80.4	67.4
June	84.6	71.0	87.8	65.2	85.9	75.5	84.0	70.6	76.5	66.5	81.7	69.0
July	83.4	75.8	87.5	79.3	86.4	81.0	86.2	78.0	87.0	79.5	88.5	80.3
Aug	87.6	78.5	90.0	85.2	89.0	78.6	88.4	83.0	92.0	86.0	87.7	71.7
Sep	87.5	83.9	86.1	75.1	86.3	73.8	85.7	87.0	78.7	72.2	85.2	76.0
Oct	83.4	69.9	82.9	70.3	84.8	69.1	84.7	70.4	76.0	64.0	80.7	67.7
Nov	84.3	65.0	82.5	64.8	80.1	56.4	78.8	56.5	59.6	47.8	76.3	57.5
Dec	79.1	54.6	82.9	56.3	83.6	61.5	76.4	49.4	74.8	54.5	76.6	56.1
Total	1006	803	992	784	990	794	999	804	930	742	950	750
Mean	83.8	66.9	82.6	65.3	82.5	66.2	83.3	67.0	77.5	61.8	79.1	62.5

Source: Nigerian Institute for Oil Palm Research, Benin City, Nigeria, 2008

The spatial disparities in relative humidity values in Benin City in Phase 1 are justifiably reflective of vital environmental and human factors such as the mean annual temperatures, length of days, roles of tropical maritime winds, land and sea breezes, anabatic and katabatic circulations, nature of urban surfaces and related human activities.

The Phase 2 of the analysis covered 1993-1997 (Table 2). In 1993, 1994, 1995 and 1996, high mean annual relative humidity values which extend from 79.9%, 80.4% and 87.3% to 88.3% were observed in the city at 0900 hours. At 1500 hours during the same periods, slight variations in the relative humidity values occurred at specific differences of between 6.0% and 7.00%. Favourable factors as fluctuated mean maximum and minimum temperatures (Table 5), uneven evaporation with transpiration, and the influence of warm maritime winds from the South Atlantic Ocean accounted for these high relative humidity values.

Table 5. Mean Maximum and Minimum Temperatures in ^{0}C from 1994-1998 in Benin City

Year	1994		1995		1996		1997		1998	
Month	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
Jan	31.7	22.4	43.0	20.2	31.5	23.5	33.5	22.8	32.2	19.1
Feb	33.8	23.3	33.7	23.14	31.6	22.8	34.9	20.4	36.1	24.3
Mar	33.9	22.8	33.5	22.7	33.6	23.6	33.6	22.9	36.7	24.3
Apr	27.3	19.6	33.2	23.7	29.6	22.4	32.6	23.0	34.9	23.8
May	32.6	22.7	31.8	22.5	31.9	20.8	32.2	22.6	33.0	24.0
Jun	31.7	21.8	31.8	21.9	27.2	21.6	31.0	22.7	32.1	23.0
July	28.8	21.7	29.0	22.6	30.5	20.7	29.4	22.0	29.8	23.0
Aug	27.8	22.1	30.0	22.3	28.6	22.5	28.6	22.4	28.6	22.8
Sep	27.8	22.5	30.1	22.4	29.1	22.4	30.4	24.4	25.9	22.4
Oct	29.6	22.6	30.2	19.5	32.1	25.5	31.4	22.5	30.0	22.3
Nov	32.6	22.9	32.9	21.4	33.2	21.3	32.4	22.9	31.2	23.2
Dec	33.1	17.0	33.0	22.6	33.3	23.6	32.6	21.9	33.3	21.9
Total	370.7	261.4	383.2	264.9	371.8	270.7	382.6	270.5	383.2	274.4
Mean	30.9	21.8	31.9	22.1	31.0	22.6	31.9	22.5	31.9	22.9

Source: Nigerian Meteorological Agency, Benin City, 1998

Table 6. Mean Maximum and Minimum Temperatures in ^{0}C from 1999-2003 in Benin City

Year	1999		2000		2001		2002		2003	
Month	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
Jan	32.2	22.0	33.8	21.1	33.6	20.7	33.5	20.2	34.0	21.8
Feb	35.8	23.4	35.3	19.4	34.9	22.6	35.4	21.4	35.8	24.4
Mar	34.7	23.6	34.8	21.9	34.4	22.2	33.6	22.4	34.4	24.2
Apr	33.2	23.0	33.6	22.5	33.2	21.9	32.7	22.5	32.0	23.9
May	32.7	22.4	33.1	22.5	32.3	21.9	32.3	22.4	33.3	23.0
Jun	31.2	22.5	30.5	21.1	30.4	21.7	30.6	21.7	30.3	21.1
July	29.0	19.5	29.3	21.3	29.1	21.7	29.7	22.2	28.4	22.3
Aug	29.4	19.9	28.4	24.5	27.6	21.4	29.1	22.8	29.8	23.0
Sep	29.5	20.2	29.6	25.9	29.0	21.3	30.0	22.0	29.2	21.6
Oct	30.1	20.1	30.8	21.4	31.5	21.8	31.8	21.9	31.8	21.9
Nov	32.9	20.4	32.8	22.6	33.5	22.8	32.9	22.6	32.6	22.3
Dec	33.8	19.7	33.3	20.3	34.0	23.1	34.8	21.5	34.1	20.8
Total	384.5	256.7	385.3	264.5	383.5	263.1	386.4	263.6	385.7	270.3
Mean	32.0	21.4	32.1	22.0	32.0	21.9	32.2	21.9	32.1	22.5

Source: Nigerian Institute for Oil Palm Research, Benin City, 2003

The Phase 3 covered 1998-2002. It was marked by fluctuating vapour content with slight moisture increase. This state of moisture content is shown in Table 3. The relative humidity values at 0900 hours were 79.97%, 82.8%, 77.6%, 81.5% and 80.5%. In 2000 at 0900 hours, a marked decrease of 77.7% in the atmospheric water content was observed, and at 1500 hours, 63.7% was recorded. However, the 82.8% enhancement in relative humidity earlier observed and documented in 1999 was directly induced by the extensive ascension of water from the Ogba and Ikpoba Rivers into the troposphere while the fluctuated value experienced in 2000 was reflective of the distorted urban surface convection initiated by haphazard human activities and soared temperature factors in the city metropolis (Table 6).

Where the surface drainage basin of a city is altered owing to chaotic human activities which span deforestation, urban constructions and renewal, and extensive borehole drilling (Okhakhu, 2016), it is expected that the content of its urban atmospheric water vapour would be disrupted with its natural properties. This is the authentic state of the moisture content observed in the urban atmosphere in Benin City from 1998-2002 with specific reference to the evening records (Table 3).

The Phase 4 which spanned 2003-2008, shown in Table 4, witnessed a sustained increase in the water vapour content in Benin City. Mean annual relative humidity values of 83.8%, 82.6%, 82.5% and 83.2% were observed at 0900 hours in 2003, 2004, 2005 and 2006. The water vapour indices indicated the humid and viability traits of the urban atmosphere towards the development of dews, drizzles, and heavy rainfall in the city. Continuous evaporation and evapotranspiration taking place within and outside of the city metropolis were accountable for these developments. Proximity of the city to the Atlantic Ocean in the South, impact of the tertiary circulatory systems, and the suitable characteristics of the landscape also precipitated these observed relative humidity values. The period 2007-2008 experienced slight variations in the mean annual relative humidity in Benin City which declined to 77.5% and 79.1% at 0900 hours and 61.8% and 62.5% at 1500 hours. This fluctuation in the relative humidity content of the urban atmosphere did not affect much of the rainfall amounts in the city.

Authentic atmospheric observations which spanned 2010-2016 carried out in Benin City using the modern hygrometers and clouds searchlights showed the consistent presence of humid cumulus and cumulonimbus clouds. These suggest that the relative humidity values between 70%-84% which can induce mists, dews, drizzles and rains are recorded in the city environment, even in August which is largely known as the August-Break when rainfall gradually fluctuates in received amount, frequency, intensity, and occurrence.

Based on this analysis, it is true that the urban troposphere is replete with water vapour which can stimulate sufficient dews, drizzles and rains within a ten-month annual duration in Benin City. Although inadequate surface drains and trenches have given rise to devastating surface flooding in some parts of the city in the previous years, this climatic hazard is yet to be suppressed owing to poor city planning deficient of the use of urban atmospheric moisture. Four decades ago, according to the field respondents, flooding was less frequent in Benin City. As it is currently, owing to exacerbated poor urban renewal, there is a possibility this hazard would proceed into the future in a worse destructive frequency if this climatic resource with its transformed elements of mists, dews, drizzles and heavy rains is left out in the city planning process.

5.2. Characteristic implications of relative humidity values for the planning of modern cities in Nigeria

High relative humidity values between 80.5% and 84.4% were recorded within and outside of the city from 1988-2008.This is a validly acceptable 21-year climatic period. Founded on this analysis and using the predictive approach, it is relevant to suggest that these humidity values could induce adequate clouds, dews, drizzles, and convective rains in the city. The country sides, in their four cardinal designations, as the study reveals, receive and retain adequate morning dew, sunshine, fresh breezes, and rains. Based on the symbiotic interaction of these elements which results to vast fertility of the soils, these areas should be diligently used for the production of subsistence food and commercial crops for domestic consumption, sale, and regional exchange in Nigeria. Intensive domestic gardening could also start within the residential areas where vacant soils are available. Harvests of vegetables, fruits, and poultry would be realized. These nutritious resources would help combat diseases and provide enough vitamins, oxygenated blood, and functional energy for the human body to carry out its essential services (Tables 6 and 7).

More so, the vast areas liable to seasonal and annual surface flooding should be constructed with efficient trenches which are able to accept, retain, and allow the flood waters to percolate the layers beneath. Consequently, the stored, transformed, and agglomerated subterranean water could be sunk to supply adequate water necessary for the production of rice, bananas, plantains, fruits, snails, fish and pigs using modern technology and water-related facilities in addition to the application of rich fertilizers to the soils under expert management (Table 8).

Planned rain water storage in overhead, surface, and subterranean facilities could be executed in the remote areas of the city rather than allowing the run-off to cause detrimental environmental flooding and surface constraints of mudflows, insects breeding and water-borne diseases to the city residents. The increase in streams and rivers caused by the convective rains could evolve income-yielding fishing activity during the rainy season, stimulate local transportation of residents, develop riverside trades on fish and food crops, and ensure the sale of stored rainwater for domestic income generation in the outskirts.

Table 7. Relative Humidity (RH) in the Urban Troposphere and Induced Characteristics

% RH	RH Level	Transformed Characteristics of Tables 1, 2, 3, 4.
01-20	Low	Poor aerosol dews, low drizzles, absence of normal rains.
21-40	Mild	Low dews, light drizzles, sporadic rains, lightning, thunderstorms
41-60	Moderate	Normal dews, drizzles, normal rains, heavy rains, thunderstorms.
61-80	Normal	Mists, dews, drizzles, normal rains, heavy rains, thunderstorms.
81-100	High	Heavy mists, dews, drizzles, frequent rains, long torrential rains.

Source: Field Surveys, Benin City, 2017
Legend: RH-Relative Humidity.

Table 8. Relative Humidity (RH) and Characteristic Implications for the Planning of Cities in Nigeria

S/N	% RH	RH Level	Implications for the Planning of Modern Cities in Nigeria
1	01-20	Low	Poor rains, dry farming, harsh weather, limited urban constructions.
2	21-40	Mild	Low rains, water conservation projects, grass planting, few activities.
3	41-60	Moderate	Subsistence farming, extensive urban constructions, water storage.
4	61-80	Normal	Modern farming, diverse urban activities, run-off uses, city renewal.
5	81-100	High	Modern planning, diverse activities, huge funds, high expertise, etc

Source: Field Surveys, Benin City, 2017

Adequate atmospheric water vapour supports and promotes grass cultivation, market gardening, production of fruits and forest with tree regeneration programs in modern cities of the world. These vital vegetal resources are not only capable of preventing gusty winds which directly attack and destroy houses but they are also much life-sustaining as they provide enough vitamins for healthy human physiology in the cities. Benin City in Nigeria must follow these efficient developments in the modern western cities of the temperate world.

At the city centre, adequate sanitation is recommended for permanent local and state execution. This should be supervised by a retinue of experts in the environmental sciences such as architects, health workers, climatologists, mechanical and civil engineers, road safety corps, civil defense officials, medical doctors, and skilled truck drivers. The presence of morning dews and drizzles directly destroys all kinds of papers, silos, waste-bags, animal excreta, human faeces, and dead bodies on the urban surface. Dews and drizzles could dissolve and make these waste materials decay within hours of deposition on the urban surfaces thereby causing some environmental ailments to the city residents. Adequate environmental hygiene is recommended as the panacea to this singular environmental threat to human safety and protection in the humid tropical cities of the developing world (Tables 7 and 8).

The study shows the presence of wet clouds in the mornings, light clouds in the afternoons and enhanced dew clouds in the evenings in Benin City. These cloud differentials have direct implications on urban transportation. In the morning, there is minimized urban transportation owing to impaired visibility on the roads and in the atmosphere in the city. This improves in the afternoon because of the clear skies and reduces in the evening owing to acceleration of water vapour clouds. This situation suggests that the convenient take-off and smooth landing of domestic airplanes at the city airport should be fixed between

10.00am and 5.00pm daily. These realities would help control and eliminate both road and air disasters. Human lives would therefore receive adequate safety from these levels of transport in the city. No doubt, a boost of socio-economic and political activities would also take place in Benin City. However, airplanes and helicopters fixed with sophisticated high resolution radars could land and take-off at the Benin City airport at any time irrespective of the nature of cloud cover and prevailing atmospheric turbulence.

The presence of high water content in the morning atmosphere prevents rapid emission of urban heat into space. This implies a relative retention of the outgoing radiation within the city exotic surfaces and diverse facilities which results to mild urban warming which is good for human health in the morning. However, excessive heat makes the urban residents most uncomfortable. It also causes decay of the built urban facilities that require huge capital to rehabilitate. The construction of urban surfaces with suitable albedo capacities and subterranean heat percolation and diffusion channels is a permanent panacea to this urban challenge.

The latent heat which is released by the moisture vapour content of the troposphere propels permanent urban atmospheric circulation and dispersion of natural pollutants where other interactive factors as radiation, temperature, and pressure gradient force are beyond the equilibrium with the natural state of the city environment.

The water vapour content of the troposphere creates suitable and tranquil conditions in the buildings settled by the residents particularly in the peripheral areas. These conditions facilitate the stable health of body and mind of the residents and ensure sustained decision making with regard to state and national planning for improved development of Benin City and Nigeria.

A suitable integration of relative humidity values with adequate morning sunshine would promote a perfect development of the human body physiology. This development would be evident in the proper constitution of the human cells and tissues, strong bone formation, and efficient functioning of the human skeleton. In constructing recreational and leisure facilities for human body sustenance and development, the roles of relative humidity values and natural sunshine must be integrated in the development planning process in Benin City and elsewhere in Nigeria.

Benin City is sited within the normal and high zones of moisture vapour of the urban troposphere indicated in Tables 7 and 8 of the study. These zones, marked S/N 4 and 5, are 61-80% range and 81-100% range. The normal and high moisture vapour available in these zones could induce warm clouds, heavy mists, mild mists, dews, drizzles, normal rains, frequent rains, and heavy rainfall in the city. It could also induce tertiary systems, cool weather, sunshine and swift turbulence. The positive contributions of these climatic essentials in the planning of tropical modern cities to attain sustainable development in Nigeria are strongly underscored in the study.

Finally, the possibility of surplus food for immediate human consumption and adequate cash crops for regular and sustained marketing in the country-sides would stimulate a gradual relocation of some metropolitan residents there. In addition, the presence of fresh breezes, nutritious insects, fresh bush meat and the rehabilitative sunshine for the healthy formation of the human body structures and organized body functions would further strengthen this urban self redistribution process to the rural country-side. At the urban metropolis, unbearable heat stresses, chaotic noises, breathing of impure air by the residents and generation of diverse smokes by traversing cars would be prevented. Consequently, a refined city atmosphere filled with healthy relative humidity values would be restored. These suggestions could apply successfully in other humid tropical cities in Nigeria.

6. Summary and conclusion

This study has examined the nature of relative humidity in the urban troposphere and its characteristic implications for the planning of tropical modern cities in Nigeria. It used authentic data obtained from two synoptic meteorological stations sited within and outside of Benin City which served as the study area. The analyses revealed, inter-alia, adequate presence of ascent moisture vapour in the city troposphere during the mornings and evenings and appearance of clear skies in the afternoons. Based on this background, the study indicated diverse areas where relative humidity values could be utilized to attain effective planning and ensure sustainable development of modern cities in Nigeria. These include, inter-alia, food and cash crops farming at the outskirts, grass planting for urban surface resistance to denudation, reforestation in the city centre to serve as wind-breaks, transportation safety, adequate water provision to the urban residents, practice of orchard, ranching and market gardening within fenced residential zones, prevention and mitigation of heat-island crises in the city and pollution in the urban troposphere, and voluntary human relocation to the outskirts for fresh breezes, adequate nutrition, and healthy physiological stability.

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