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Assessment of the Urban Climate of Benin City, Nigeria

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Abstract
This study which utilizes field data and recent climate literature, examines the nature and characteristics of the urban climate of Benin City, Nigeria. Specifically, it assesses the place of rainfall in city planning to resist extreme climatic forces. The study argues that essential urban climate principles are often excluded from the urban planning and development process by the physical authorities in Benin City. It observes the existence of deforested landscapes, unsuitable exotic urban surfaces, inadequate flood drains, modified hydro-terrestrial basins, abundant rainfall and mixed urban canopy formations in the urban area. As a result of these features, the city is currently facing severe environmental challenges of surface inundation, mudflows in the streets, submergence of built houses by floods, traffic congestion, infrastructural damages, displacement of residents, heat-induced ailments, depressed workforce, and reduced socio-economic activities. To overcome these challenges, the study suggests, inter-alia, that the utilization of vital climatic elements in the physical planning and development process would restore Benin City into an environmentally healthy, productive, and sustainable cultural habitat immune from the frequent attacks of cataclysmic extreme climatic forces.
Key words: Urban climate, Benin City, rainfall, utilization, sustainable habitat.

Introduction and Research Problem

Urban environments, as considered in contemporary urban climatology, refer to the man-made surroundings which provide the broad setting for efficient planning, implementation and realization of different human activities. These human activities, according to Oguntoyinbo (1994), include agricultural, industrial, commercial, recreational, healthand communication services. Different security agencies including transport, sanitation, education, and waste management services also constitute these modern urban characteristics. In a concise spatial placement, urban environments are the recognized towns and cities which are characterized by high population densities owing to continuous reception of migrants from different rural and urban locations, different political, socio-economic infrastructures and services, altered hydro-atmospheric elements, extensively tamed flora and fauna, different communities and nationalities based essentially on character anonymity, and vastly modified physical geomorphic basins (Okhakhu, 2010).

As Akintola (1994) contends, urbanization has been a major process through which the physical landscape over most areas of the world has been altered. The process of urbanization, according to him, involves the clearing of natural forests for construction of houses and farming, leveling of the topography for infrastructural construction, planned transfer of soils for reclaiming swamps and filling up of areas of weak soils, alteration in the natural drainage patterns, different land-use practices over the un-built areas of the city, and the disposal of wastes on various parts of the landscape. These diverse activities could exert strong influence on the natural climate cycle of the urban area in such a broad dimension that peculiar urban climatic characteristics are produced permanently called *Urban Climate*. Also, there could be clear existence of some essential climatic differences in such observed atmospheric elements as rainfall, temperature, wind, relative humidity, pressure, solar energy and dynamic cloud cover between the rural areas and urban environments (Omogbai, 1985; Oguntoyinbo, 1994; Okhakhu, 2010).

The objectives of contemporary urban climate studies, according to Oke (1986), are to provide better living conditions, secure working environments, adequate food, health care, sanitation, energy and safe drinking water for the urban people while also conserving these resources in adequate state for future users. Other objectives include the prevention of infrastructural damages during the occurrences of extreme winds, violent rainstorms and floods particularly in coastal locations and unstable environments, reduction of pollution in urban areas, and stimulation of viable communication and transportation networks in cities of the world. The objectives also extend to taking the best policy decisions on the location of buildings in suitable level surfaces having carried out efficacious geophysical assessments of the landscapes selected for housing construction. Above all, there exists the mandatory proposal to recognize, calibrate, collect, and document regularly urban climate data using both conventional and automatic weather instruments installed in meteorological stations at the seas, on the earth's surface, and in outer space. The vital data obtained from these meteorological stations are used for making valid atmospheric prognostications concerning immediate and likely future occurrences of hurricanes, severe typhoons, violent rainstorms, extreme daily winds and temperatures including flood periods in current world's cities. In essence, these reliable predictions are timely utilized to plan adequately against and prevent the

future occurrences of extreme climatic forces which are capable of wrecking diverse havocs on contemporary cities of the world. These measures are currently being implemented in some American, Asian and European cities which are always plagued by extreme violent winds, rainstorms and surface inundations (Lee and Hilda, 2010; Okhakhu, 2013; 2014).

Man's cultural advancement takes place normally within, on and above the earth's surface. Most times, the advancement approach which lacks adequate planning is also poorly directed by non-specialists. This leads to visible malevolent changes within the physical, social, economic, and political environments particularly in the developing humid tropics of the world (Omogbai, 1985). The social, economic, political and technological sophistication of the current scientific age, coupled with the urbanization process, results in fundamental changes in the nature of urban surfaces and atmospheric properties. These transformations are physically caused by the continuous replacement of beneficial natural green spaces with non-commensurate artificial bricks, concretes, asphalts, iron materials, marbles and bare grounds which are clearly recipient of abundant solar radiation as well as impenetrable to excess urban surface run-off. Also, the unabated injection of diverse pollutants into the urban environments owing to unregulated human activities exacerbates these deplorable conditions, with vast adverse consequences on human populations, plants and animals in terms of heat-island stresses, dehydration, poor respiration, migration of diverse species to unknown points, extinction of vital resources, prevalence of floods, infrastructural damages, food scarcity, human displacement, and extensive decimation of virgin environments (Barry and Chorley, 2009; Okhakhu, 2010; 2014).

The adverse consequence of man's unplanned interference on the natural environment is widely observed in a change from the beneficial country-side climate characterized by clean breeze, precipitation, mild temperature, bone-building sunshine, therapeutic humidity and refreshing rain water to fairly polluted and turbulent atmospheric conditions of the urban environment. Of course, this visible alteration of the natural environment through careless anthropogenic activities leads to extensive permanent damages in geomorphic, thermal, hydrological, vegetal and atmospheric characteristics of the urban areas on which human, animal, insect and micro-organic species depend heavily for their continuous sustenance (Ojo, 1991; Okhakhu, 2010).

In the humid tropical climates, using Ibadan in Nigeria and Africa in general as case studies, Oguntoyinbo (1986; 1994) observed that relevant climatic considerations which include precipitation, temperature, wind, and relative humidity were not incorporated and utilized by the various urban planning authorities in the complex urban development processes. Also, examining urbanization and thermal properties of tropical cities, using Lagos, Nigeria, as a case study, Ojo (1988) argues that city creation, specifically in the developing humid tropics, is premised on the need by its government to attain strategic, political and economic benefits rather than its overall safety, recreational values and sustainability based on the utilization of essential climatic elements such as rainfall, temperatures and winds.

In Nigeria, urbanization preceded industrialization (Mabogunje, 1968; Oke, 1986). This situation, as Oke (1986) explains, developed owing to continuous human migration from the vast agricultural locations. The few towns and cities established although generally poor in terms of wealth and basic infrastructures were inadequately planned by the urban authorities (Sada, 1988; Ojeifo, 2005). All over the developing tropical cities then, different urban surfaces such as impenetrable concretes, asphalts, bricks, and modified iron railings which constituted some unique canopies were turned out. Further modifications occurred in the natural hydrological, geomorphic and thermal stability of the tropical urban environments. Specifically, in the various urban development programs implemented on the landscapes, essential climatic elements were not incorporated and utilized. As a result, these urban environments could not provide the basic services and human needs in terms of balanced diet, adequate housing, gainful employment, stable energy, clean drinking water, safe health care, authentic education, sanitation, transport and communication networks, recreation, and stable government (Onokerhoraye, 1988; Aderamo, 2003; Segynola, 2003; 2005).

Adequate and authentic climate information, no doubt, could be utilized for carrying out important urban activities which could be long-lasting and life-preserving. These activities include harvesting of marine with other environmental resources such as fish and crude oil, establishment of land, sea and atmospheric transport networks, and the construction of diverse physical structures on the earth's surface (Phillips, 1989). As Phillips (1989) and Ayoade (2004) observed, the relative stability, longevity and sustainability of the built urban environments can only be realized when climatic essentials are considered, incorporated and continually utilized in the 'complex urban system' by the various urban planners and builders. In Benin City, our study area, essential climatic elements particularly rainfall, temperature, humidity and wind are neither incorporated into its complex environmental planning processes nor utilized in its continuous urban development activities. Also, the

dynamic nature and characteristics of the urban climate of Benin City have not been assessed from authentic scientific perspectives. These integrated weaknesses, no doubt, have given rise to serious challenges on the physical environment which relate to floods, infrastructural damages, traffic delays, prevalence of water-borne diseases, weakened work-force, poor commercial activities, and residents' protests over dissatisfaction with the government performance.

Benin City is selected for a close assessment owing to three important reasons. At present, it has all the recognized characteristics of an urban area which include social infrastructures, diverse rough surfaces, dense human populations, complex urban canopy layers, and numerous small-scale firms and industries with lucrative financial and commercial institutions. The study area has two functional synoptic meteorological stations which are currently administered by the Nigerian Meteorological Agency and Nigerian Institute for Oil Palm Research where recent and authentic climate data can be obtained for utilization in both theoretical studies and empirical planning activities. The city has experienced the diverse processes of climatic modifications owing to urbanization process over the years, and these include modifications in its dense vegetal and rich fauna species, geomorphic, atmospheric, thermal, and hydrological characteristics (Okhakhu, 2010).

It is essential to mention in the current study that authentic scientific studies which examined urban climates have been carried out in Brazil, China, Canada, Germany, India, Mexico and some parts of Africa (Carlos Augusto, 1986; Chow, 1986; Oke, 1986; Baumuller, 1986; Padmanabhamurty, 1986; Ernesto, 1986; Oguntoyinbo, 1986).The findings and recommendations of these tropical and temperate studies helped to establish, among others, essential guidelines for constructing sustainable cities which are adequately shielded from extreme climatic forces and closely related environmentally induced challenges like floods and sea surges. Currently, the urban climate of Benin City has not been assessed adequately by atmospheric scientists along these beneficial scientific guidelines. Specifically, the essence of rainfall in the development process of the city has not been considered by the urban planning authorities. The urgent need to bridge this development vacuum in Benin City based on permanent recognizance, incorporation and utilization of climatic elements has spurred this current study.

The Aim and Objectives of the Study

The aim of this study is to assess the urban climate of Benin City, Nigeria. In line with this aim, this current study examines the nature and characteristics of the urban climate of Benin City and its rainfall pattern.

Research Materials and Methods

This study benefits from recent climate literature in the humid tropics, mid-latitude and temperate locations of the world. Also, authentic first-hand data obtained from both reconnaissance and field surveys carried out in Benin City were utilized in the study. Specifically, authentic climate information on rainfall covering 1984-2011 constituted the main focus of the assessment. Random and selective physical assessments of the state of urban troposphere in the city from 2012-2014 carried out with the aid of twelve conventional rain gauges helped to bridge the information vacuum which made the urban climate analysis a fruitful scientific reality. Four essential tables of rainfall statistics in millimeters with appropriate sources were utilized to present, at a glance, the state of urban climate in the City. The choice of the single rainfall variable is to infuse feasible understanding in the assessment because it is the most influential climatic element currently in the city. As observed in the field, the rainfall element stands as a cumulative beneficial consequence of the mutual interactions among the various climatic elements which include solar energy, temperature, humidity, cloud cover, wind and pressure. Direct physical observation reveals rainfall as the major cause of most urban challenges such as soil degradation and environmental inundation in the city. It is based on this background that the climatic cause-effect analysis and the positive prescriptive approach are utilized in the presentation of results and discussions.

The Study Area

The study area is Benin City in Nigeria. The city serves as the principal administrative and socio-economic 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 broadly occupies an area of approximately 112.55^{2} km. This extensive coverage suggests spatial variability of weather and climatic elements. As Buchanan and Pugh (1955) observed, Benin City lies visibly in the southern most 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 rock of the Precambrian basement complex and the sedimentary rock of the cretaceous tertiary and quartenary formation of Miocene-Pleistocene age (Pritchard, 1985; Odemerho, 1988; Balogun and Okoduwa, 2000). Benin City, as Udo (1978) describes it, is a tilted plain which slopes in a south-west direction. Its highest elevation occurs around the Esan and Asaba Plateaux which rise steeply from the lower Niger Valley and are bordered on the northern edge by a steep slope. Other than the Ikpoba Hills which form an integral part of these plateaux in the north-west corner of the city region and Aduwawa areas, the rest of Benin City region is relatively undulating terrain (Udo, 1978; Omiunu, 1988).The city landscape contains laterite soils mixed with abundant clay minerals. Its soils, according to Omiunu (1988), are derived from the deep chemical weathering of the parent sedimentary rocks preferably the hardened sandstones.

The natural solar energy received at Ikpoba Hills during the daytime helps to stimulate regular surface evaporation which leads to increased atmospheric water contents in the study area. Consequently, evenly distributed relief rains are experienced in this part of the City. The received rain waters on the urban surface facilitate direct increase in the volume of water in Ikpoba River which is found on the valley floors. There is also intermittent moderation in the cloud cover of the area particularly during the early morning hours, and this is associated with the nature of the Hills. These hydro-geomorphic characteristics have strong climatic implications with particular reference to the processes and patterns of precipitation, temperatures, relative humidity and wind, flood occurrences, and land with atmospheric transportation in Benin City. In the west and south of the city, the sandy coastal plain which is generally below 121.92 meters is a common geomorphic feature. It is observed that the highest contour of 121.92 meters occurs in the north-west corner of the city. This undulating terrain characteristic of the city makes the surface run-off very slow thus resulting in frequent urban inundations whenever torrential precipitation occurs (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. Although smaller rivers are found in some parts of the peripheral locations of the study area, in general, the hydrological basin clearly shows a north-south direction of flow owing to the high elevation of Nigeria from its northern part (Okhakhu, 2014). Fishing, irrigation, domestic consumption, industrial utilization, animal husbandry, recreation, environmental sanitation and research activities are some of the functions of rivers found in Benin City.

Rainfall, temperature, wind and relative humidity are the most significant climatic elements in Benin City. According to Agboola and Hodder (1979), the rainfall element strongly determines the occurrence of the wet and dry seasons in the study area. As observed during the assessment of the urban troposphere using sensitive rain gauges of the American origin, the rainfall amount, its intensity, duration as well as its distribution throughout the city are determined by the prevailing maritime winds, changing clouds, temperatures and circulating pressures. Two principal air masses prevail in the City. These are the tropical maritime and tropical continental. The tropical maritime air mass which is essentially humid, warm, moisture-borne, and widely resident in Benin City for almost twelve months, originates from the South Atlantic Zone. It causes rainfall which begins from the late January till its gradual subsidence in mid-November. The arrival of rainfall in the study area brings welcome relief to the urban residents from the prevailing moderately dry and cold wind periods which normally occur between late December and the end of January. Three important thematic maps which depict clearly the climatic regions, rainy season, maritime winds, the dry season and tropical continental winds in Nigeria have been presented in a previous in-depth study (Okhakhu, 2010; see pages 24, 25, and 26).

Convective and relief types of rainfall are widely experienced in Benin City owing to its unique solar energy reception, rich vegetations, water bodies, and the hilly terrains. The total annual rainfall amount recorded in the city ranges between 2,000mm and 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 between 75% and 85% is regularly experienced in the area. This stabilizes in the mornings, fluctuates in the afternoons, and improves during the evening and night hours owing to dynamic environmental factors particularly evaporation, transpiration, atmospheric pressure and dominance of maritime winds. The city experiences a mean annual temperature of 27.5^0C which, throughout the year, owing to occurrence of torrential rains, hilly terrains, unregulated deforestation, related anthropogenic activities, and the rough characteristics of the urban physical surfaces is prone to fluctuations. Some cases of temperature extremes between 30^0C and 35^0C have been recorded in the city metropolis in November and December (Omogbai, 1985; Okhakhu, 2010). As a result of its tropical location and observed climatic characteristics, Benin City experiences the 'humid sub-equatorial climate.'

Benin City is located in the sub-equatorial climatic zone where cumulus moist clouds, high rainfall, sunshine, relative humidity, fluctuating temperatures and favourable winds are experienced (Iloeje, 1982; Udo, 1987). These climatic elements have stimulated the growth of tropical rainforest which is fairly evergreen and characteristically deciduous in nature. When physically observed from the hilly Ikpoba peaks in the north of the city, the rainforest exhibits evergreen canopy formation. Rare vegetal species such as ferns, mosses, mushrooms and other varieties of lower grasses and plants occupy the ground floor which is intermittently swampy and muddy during the peaks of rainy reason. A multitude of climbing lianas, epiphytes and fairly tall trees of less than 10 meters are found in the middle canopy formation. The highest vegetal formation contains the robust and broadly tall trees which include Mahogany, Walnut and Cedar. The availability of these valuable trees has encouraged the establishment of many 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 construction raw materials, saw-dusts for domestic fire making and production of furniture items.

The humid rainforest, on reception of heat energy and circulating winds, gives off adequate moisture into the urban troposphere. This contributes towards the high rainfall which is always experienced in the city. In the cosmopolitan areas which have dense forests, environmental challenges like soil degradation, flooding, muddy water surfaces, and occurrence of swampy diseases are not rampant. The humid forest forms a natural habitat for a colony of wildlife which include birds, monkeys, pigs, rats, snakes, alligators, cats, insects, chimpanzees, and antelopes. 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. As a result of 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 study area. Tomatoes, pepper, fresh vegetables, melon, ground nuts, maize, beans and okro are also produced on small-scale by the rural farmers.

The original inhabitants of Benin City are called the Edo or Benin people. A large section of Ibo, Hausa, Fulani, Igbira, Urhobo, Yoruba, Ibibio, Tiv, Itsekiri and Isoko nationalities have since migrated into the city to join the original Benin people. At the completion of the 1991 national census, the city population stood at 780,976. In 2006, the population attained 1,149,584 (NPC, Benin City, 2006). Currently, the occupations of the urban residents revolve around trading, quarrying, mining of sands for diverse construction works, farming, fishing, education, distribution of goods, and banking services. Other lucrative activities include medium-scale manufacturing, transport, and communication services

The Nature and Characteristics of the Urban Climate of Benin City

The Benin City urban landscape is extensively rendered bare of natural grasses and related vegetal covers owing to construction of different classes of modern buildings and pursuit of diverse industrial, commercial, recreational, and partly agricultural activities by the city residents. This virtually bare nature of the city has made it predisposed to extreme climatic forces like torrential rainstorms and gusty winds. Diverse environmental challenges of flooding, soil degradation, muddy surfaces, traffic congestion, infrastructural damages, dwindled commercial services and spread of water diseases as cholera and malaria are observed. These problems, as observed in the field, have adverse health implications on the urban residents, efficiency of workers in the different workplaces, turn-out of output in agro-industrial sites, income generation, distribution, and utilization, and routine infrastructural provision in the city. Areas in the city mostly affected by these challenges include Ugbowo, Uselu, Okhoro, Ramat Park, Aduwawa, Ikpoba Hills, Ogbeson, Ekenwan, and the New Benin axis.

The urban drainage system constructed on the environment is always clogged by a body of refuse and solid debris thrown recklessly about by the city residents. These obstruct the normal flow of excess rain water in time. This hydrological occurrence reduces fundamentally the natural seepage capacity of the city environment resulting in exacerbated soil degradation, accelerated flash floods and prolonged inundations in some parts of the city which were originally immune from these human-induced environmental disasters. This observed situation suggests that inadequate physical planning which disregards the beneficial objectives of contemporary urban climate studies as emphasized at the outset is certainly the prevailing order in Benin City.

There is local generation of heat energy in the city through continuous human activities in industries, daily construction of infrastructures, utilization of different energy generators in private residences owing to public power failure and routine vehicular movement on the roads (Okhakhu, 2015). The resurgence in migration of people into Benin City and untamed human congestion in few buildings during the night hours have also contributed to heat generation, accumulation and distribution in the urban environment which is partly devoid of

natural and human grown vegetations which refreshing breezes would have reduced and purified the hot city weather.

The Benin City urban canopy formation and immediate underlying surfaces have become rougher owing to construction of many storey-buildings, private residences and regular utilization of foreign building materials such as cements, concretes, asphalts, stones, glasses, diverse electrical fittings and different iron railings which practically do not suit the humid tropical climate of the study area. Of course, these built surfaces are extensively recognized for being heat absorptive, retentive, conductive, and less reflective leading to urban heat-island effects in the city. Night restlessness owing to profuse sweating, prickly skins, poor concentration, dehydration, and human body debility are observable consequences of heat-island occurrence.

Some modern cities sited and established in the humid tropics of the world are currently susceptible to the rising challenges of hydro-terrestrial and atmospheric pollutions. These pollution challenges have emerged as a result of different human activities carried out on the delicate environments which were poorly planned and implemented by non-specialists. The construction of infrastructures for private and public utilization, agricultural practices, quarry works, use of dangerous chemicals for river fishing, deforestation for logs and fire woods, and crude oil refinement in refineries are the most dominant in the series of activities contributing to environmental degradation and pollution. These observed urban characteristics and activities in the humid tropics authentically represent the current experiences in Benin City, Nigeria.

At the city centre which consists of the King's Square, New Benin and the Mission axis, a partly dense urban canopy formation is visibly observed. The differently patterned storey buildings which formed this urban canopy layer currently constitute serious obstructions to the circulating atmospheric, land and sea breezes in the city centre. Also, the continuous emission of infra-red radiation from the compact and rough urban surfaces is fundamentally retarded owing to the much absorptive and retentive capacities of diverse foreign materials utilized in the urban construction activities. These physical developments, as observed in the field assessments, have accumulatively exacerbated the heat-island effects in the city environment. Fluctuating mean monthly temperatures between 27^0C and 34^0C have been observed in the city metropolis through direct traverse temperature profiling using digital thermometers in March, June, September and November in 2000, 2002, 2004, 2006, 2008, and 2010 (Okhakhu, 2010). Anthropogenic heat production in residential areas, factory exhausts from machinery utilization, continuous reception of solar energy by exotic surfaces, vehicular exhausts, and associated absence of breeze providing trees in the city are identified as causes of these unstable urban temperatures.

The Rainfall Pattern of Benin City

The assessment of the urban climate of Benin City in this aspect of the study focuses solely on the rainfall element. The rainfall cycle selected for analysis covers a period of 28 years which extend specifically from 1984-2011 (Tables 1.1, 1.2, 1.3 and 1.4).The choice of this rainfall cycle is based on three essential factors. First, it distinctly represents one of the wettest periods in the climate history of the city when numerous urban challenges such as damages of buildings, roads, business malls, flooding of built infrastructures and traffic congestion occurred. Second, the rainfall statistics obtained during this period of assessment represent some of the most reliable climate information in the city. Third, rainfall is a cumulative positive effect of the mutual interactions among essential climatic elements which include insolation, temperature, wind, atmospheric moisture, cloud cover and pressure. The choice of the single rainfall element in the current assessment does not constitute a meteorological aberration but serves directly as a fundamental climate innovation.

Table 1.1 Monthly Rainfall (mm) in Benin City, Nigeria, From 1984-1991.

Month	1984	1985	1986	1987	1988	1989	1990	1991
Jan	21.2	10.2	25.0	13.7	13.6	16.4	10.4	7.6
Feb	89.1	10.7	23.6	120.2	24.6	36.4	44.2	120.6
Mar	44.2	20.6	14.7	30.7	42.8	36.6	50.4	128.6
Apr	230.0	120.4	213.4	200.1	128.7	209.1	141.6	179.1
May	173.0	242.3	239.0	161.7	186.6	131.3	214.4	178.6
Jun	233.2	224.3	226.7	246.7	251.3	361.4	314.2	364.1
Jul	359.5	206.5	368.1	420.4	441.6	314.6	487.3	321.2
Aug	529.0	230.4	271.2	243.7	286.7	312.1	224.6	244.5
Sep	309.3	485.1	401.2	278.1	361.2	346.7	304.7	371.6
Oct	252.5	271.4	241.6	210.4	231.9	264.4	201.4	304.7
Nov	40.4	20.2	19.6	10.2	7.1	3.4	15.6	100.1
Dec	38.2	0.0	10.2	3.1	1.2	9.4	4.8	44.0
Total	2,319.6	1,842.1	2,054.3	1,939.0	1,977.3	2,041.8	2,013.6	2,364.7

Source: Nigerian Meteorological Agency, Benin City, 1992.

Tables 1.1, 1.2, 1.3 and 1.4 show the rainfall statistics (in millimeters) of Benin City from 1984-2011. Based on these statistics and coupled with authentic field observations carried out, some essential inferences on the nature, distribution, variation, temporal-spatial characteristics, intensity, and frequency of rainfall over the city are drawn. The overall essence of this assessment is to evolve an acceptable rainfall predictive model for the urban area which would help prevent the occurrences of extreme rainfall forces now and in the future as the urban development process continues.

Frequent convective rains accompanied by lightning flashes, thunderstorms and gusty winds are observed in Benin City almost throughout the year. The rains start in January and subside in December. For examples, the January and December rainfall totals stood at 0.1mm in 2002, 2005, 2010, and 2011 which represent the lowest rainfall statistics in the city for 12-year period. From 2000-2011, June, July, August, September and October received the highest rainfall amounts of 3,426.3mm, 3,395.4mm, 2,820.7mm, 3,296mm and 2,854.3mm. These rainfall statistics suggest that most of the climate-induced urban environmental challenges such as soil erosion, excessive surface flooding, building deterioration, landscape degradation, traffic congestion, automobile accidents, break-down of some social infrastructures as roads, water and energy distribution facilities including low economic activities are experienced during these periods in the study area. Authentically random reconnaissance surveys carried out in the city between January 2012 and December 2014 have clearly validated these suggestions. These surveys could help predict that similar rainfall frequency, intensity, distribution and duration might take place some years ahead in the city. The impact of climate change, presence of two huge rivers, dense vegetal community in the rural locations, high radiation and dominance of maritime winds owing to proximity to the Atlantic Ocean in the south would ensure continuous rainfall in the city. Suggesting pragmatic measures to tackle these rain-induced environmental challenges in the city based on the prevailing rainfall conditions would become a feasible responsibility on the part of government, corporate establishments, and the citizenry.

Table 1.2 Monthly Rainfall (mm) in Benin City, Nigeria, From 1992-1999.

Month	1992	1993	1994	1995	1996	1997	1998	1999
Jan	10.6	8.2	6.5	5.2	27	41.6	9.5	29.8
Feb	72.3	137.6	93.4	6.8	22.6	0.0	20.0	54.4
Mar	82.1	164.7	68.4	151.2	96.4	114.1	50.4	89.1
Apr	268.1	242.6	102.7	127.2	216.7	108.6	129.8	166.6
May	201.4	302.1	216.8	210.6	281.2	280.1	143.2	262.1
Jun	354.2	237.8	242.7	234.4	232.2	315	177.5	236
Jul	276.1	239.7	242.7	266.5	371.4	161.5	246.6	241.5
Aug	149.1	231.4	414.7	264.4	287.4	152	59.9	172.9
Sep	261.4	442.1	344.1	342.2	351.7	232.1	449.5	399.3
Oct	240.7	204.2	233.1	281.2	263.1	253.3	251	282.5
Nov	120.4	84.2	56.7	19.1	16.7	47.8	28.0	23.8
Dec	1.2	2.1	15.7	1.0	6.4	0.9	0.0	0.0
Total	2,037.6	2,296.7	2,037.5	1,909.8	2,177.8	1,706.9	1,565.4	1,957.7

Source: Nigerian Meteorological Agency, Benin City, 2000.

A double rainfall regime is experienced in Benin City in June-July and September-October on a yearly basis. This rainfall regime coincides with the global shift and movement of the Sun from the Northern Hemisphere to the South Hemisphere and vice-versa. In the city, rainfall is unevenly distributed and this has become a common atmospheric feature over the years. In reality, the rains are higher in frequency and intensity in the country-side like Aduwawa, Okhoro, Ugbowo, Ekiadolor and Ogbeson than in the metropolitan areas consisting of the King's Square, Uselu, Ekenwan, New Benin and Akpakpava because of increased evaporation from the earth's surface. However, inadequate urban planning and existence of dysfunctional flood drains have given rise to seasonal challenges of soil degradation, mudflows, traffic congestion and inundations of streets and roads in June, July and September yearly.

In the humid rainforest South of Nigeria, the August Break in the rains makes it possible to recognize four seasons. These are the long rainy season between March and July, the short dry season in August, the short rainy season from September to October, and the long dry season which extends from November to February (Udo, 1987). These rainfall seasons are partly observed in Benin City with slight variations. As shown in Tables 1.1 and 1.2, frequent south-west monsoon rainfall begins normally in the city in February and attains its peak in July-August. This February-July period represents the long rainy season when torrential rains and different climate-induced urban environmental challenges cited at the outset are experienced in the study area. Increased surface evaporation, vegetal impact, influence of Rivers Ikpoba and Ogba, moist atmosphere, and the moisture-bearing role of the south-west maritime winds from the Atlantic Ocean are causes of the long rainy season. Although some fluctuations in rainfall are observed throughout the August-October period in the city, it is,

however, characterized by atmospheric instabilities, dynamic showers with intermittent thunderstorms, moisture-filled cumulonimbus clouds, and sporadic daytime bursts of sunshine. Based on the rainfall observations in the field and documented statistics assessed, two main types of season are experienced in Benin City, Nigeria. These are the Long Rainy Season (March-October) and the Short Dry Season (November-February). These seasons are visibly illustrated in the four tables for the past twenty-eight years.

Table 1.3 Monthly Rainfall (mm) in Benin City from 2000-2005.

Month	2000	2001	2002	2003	2004	2005
Jan	5.8	11.0	0.0	49.3	35.2	0.0
Feb	11.8	1.0	27.8	26.9	13.5	15.7
Mar	61.9	152.3	133.6	68.3	55.3	167.2
Apr	153.1	237.7	209.8	250.8	106.4	114.4
May	92.4	182.1	201.5	181.2	323.4	138.9
Jun	434.9	251.9	356.6	162.9	355.7	292.7
July	220.8	253.2	437.3	155.0	214.3	406.8
Aug	241.9	139.8	308.5	170.1	298.6	80.9
Sept	348.8	343.3	180.9	313.5	251.1	177.3
Oct	228.2	114.4	237.1	293.7	247.0	167.2
Nov	16.7	18.9	42.7	31.3	28.3	33.9
Dec	0.0	3.9	0.0	0.0	0.0	0.0
Total	1,816.3	1,709.5	2,135.8	1,703	1,928.8	1,595

Source: NIFOR, Benin City, Nigeria, 2005.

For effective environmental planning, weather prediction, implementation and realization of different urban development activities such as the construction of physical, socio-economic and political infrastructures in Benin City, the short dry season which runs through November to February is preferred to the long rainy season. This season is suggested as it is suitably immune from severe rain-induced environmental challenges which include flash inundation, landscape degradation, mudflows, and sudden infrastructural collapse which take place immediately urban constructions have been completed by the physical urban authorities.

As a result of its south-west location, Benin City enjoys the characteristic West African monsoonal climate which is marked by distinct seasonal shift in the wind pattern. Between March and October, the city is under the strong influence of the moist maritime south-west monsoon wind which blows inland from the Atlantic Ocean in the coastal South of Nigeria (Oguntoyinbo, 1994). This monsoon wind causes rainfall and extends the rainy season during this period. The dry season begins in December and subsides in late January. During the season, the dry dust-laden winds called the cold continental winds would blow from the Sahara Desert in Mali, Republic of Niger and Chad into the city. Little pockets of insignificant rains are experienced occasionally in the city particularly at Ikpoba Hills, Ekiadolor, Ugbowo, Uselu, Aduwawa, and Ogbeson. As observed in the field, the dry season rains were experienced in the city on December 18 and 28, 2008, and on January 4 and 9, 2009. The recorded rainfall amounts peaked at exactly 5.6mm. This figure indicated a positive correlation with the weather report provided in Table 1.2. During the dry season, early morning mist often occurs and persists for about an hour or two after sunrise. As the morning radiation accelerates in intensity, it bursts through the mist and rolls it away. As the rainy season begins with full force in March, misty clouds and the dust-laden continental winds are forced to shift inland towards the Northern Part of Nigeria by the prevailing south-west maritime winds.

From March to October, there is marked development of the cumulus moist clouds which yield high rainfall amounts in the city. As a result of increased humidity in the urban troposphere, high radiation and accelerated temperatures, rainfall occurs in extensive sharp showers and continuous drizzles in Benin City. This is the period of pronounced thunderstorm activities accompanied by lightning flashes which are characteristics of a well developed rainy season. Within some weeks in the city, torrential rains would occur continually for two to three days, and owing to clogged and inadequate drainage systems including the impenetrable nature of some parts of the urban surfaces, excess rain water flows freely on the modified surfaces resulting in soil degradation and flooding of the streets, main roads, residential and institutional buildings.

Table 1.4 Monthly Rainfall (mm) in Benin City from 2006-2011.

Month	2006	2007	2008	2009	2010	2 2011
Jan	22.5	0.0	1.2	1.6	0.0	0.0
Feb	10.5	104.2	4.6	134.9	57.5	116.2
Mar	61.1	56.2	72.4	78.3	38.7	84.9
Apr	158.0	197.7	187.2	226.6	219.9	118.3
May	246.8	246.2	208.6	248.6	125.4	264.0
Jun	172.5	380.9	360.7	207.7	174.6	275.2
July	289.0	284.7	297.5	148.7	257.8	430.3
Aug	335.9	171.4	186.4	254.0	355.4	277.8
Sept	347.4	256.0	266.6	278.1	282.1	250.9
Oct	304.5	285.0	270.1	192.8	273.5	240.8
Nov	24.7	37.1	32.4	19.4	29.4	28.8
Dec	0.0	17.1	4.0	1.3	0.0	0.1
Total	1,972.9	2,036.5	1,891.7	1,792	1,814.3	2,087.3

Source: NIFOR, Benin City, Nigeria, 2011.

Another significant feature of the rainfall element derives from its distinct nature of variation. Torrential rainfall which amounted to 1,816.3mm was recorded in 2000. The rainfall decreased from 1,709.5mm in 2001 to 1,703mm in 2003 (Table 1.1). It increased to 2,135.8mm in 2002 and fluctuated in 2004 and 2005 from 1,928.8mm to 1,595mm. Table 1.2 further shows increases and decreases in the rainfall amounts in the city from 2006-2011. The increases in rainfall amounts are attributed to relief and hydrological effects of Ikpoba Hills and the Ikpoba River, release of moisture from the humid environment into the warm urban troposphere through radiation-induced process, and the prevalence of moisture-bearing south-west maritime winds in the city. This similar rainfall variation occurred in the city from 1984-1999 (Tables 1.1 and 1.2).

This rainfall variation practically suggests that different rain-induced urban environmental challenges are experienced in Benin City. In Ogbeson and nearby Ikpoba Hills, landscape degradation and hill slope flooding are experienced. At Ugbowo and Uselu, excessive flash inundation which submerges the roads and destroys properties is observed. This hydrological hazard also disrupts traffic flow and commercial activities. At Okhoro, Ogiso and Ekenwan, landscape degradation, muddy water surfaces and land-borne diseases are identified. In King's Square, commercial, financial and distribution activities are markedly retarded. Disruption of urban transport services and excessive noise pollution are also experienced. Towards Akpakpava and the Mission areas, daily road accidents and urban inundations are rampant. These environmental challenges influence adversely the state of health of the urban residents and their resolve to carry out meaningful urban activities. Of course, inadequate understanding of the rainfall variation by residents has resulted in poor physical infrastructural construction in Benin City.

Authentic atmospheric observations, rainfall statistics in tables 1.1, 1.2, 1.3 and 1.4 and the current analyses indicate that abundant rainfall is received within ten months in Benin City on a yearly cycle. This rainwater resource, when effectively developed and managed by climatologists, hydrologists and mechanical engineers, alongside the fresh water available in Rivers Ikpoba and Ogba, could facilitate the realization of diverse domestic and industrial activities. These include site selection, assessment, and erection of new buildings in the city to prevent future inundations, implementation of irrigation projects to sustain intensive urban agriculture during the dry season, promotion of aquatic tourism, and rearing of both terrestrial and aquatic animals in residential and open places for domestic and market consumption. Other important uses of rain and river waters are environmental sanitation and hygienic needs in hospitals, cooling of small-scale industrial machinery, water and drink refinement in industries, fire prevention and mitigation in low and high-rise buildings, cleaning of storm sewers, and household utilization such as drinking, cooking, washing, bathing, sanitation, waste disposal, sprinkling of house lawns, and irrigation of gardens.

Rainfall, as assessed in the current study, is the most influential element of climate in Benin City. As shown in the 28-year documented rainfall statistics including authentic field observations and predictions made, there is no doubt that rains are always heavy in the city, frequently occurring, routinely accompanied by gusty winds, unevenly distributed throughout the area, and characteristically thunderstorm-oriented in some parts of the season. Based on the spatial climatic characteristics assessed, we suggest in the current study that sustainable development activities in the city should be carried out on rain-free days within the months of December and February annually. This period is selected and so designated because its significance would be felt extensively in the aspects of solid and long-lasting physical, socio-economic and technological structures which would be put in place in Benin City, Nigeria.

Research Findings

Based on the assessment of the urban climate of Benin City, the following findings are made.

The study notes that urbanization process and diverse anthropogenic activities have led to alterations in the physical equilibrium of the city environment and its natural climate cycle to produce urban climate. The impacts of these operations are observed in distinct climatic differences particularly in rainfall throughout the different parts of the study area.

The continuous alteration of the natural environment caused by different anthropogenic activities leads to fundamental changes in the geomorphic, thermal, hydrological and atmospheric characteristics of the city on which human, animal, plant and micro-organic species depend heavily for their continuous sustenance and longevity.

The study observes that city creation in the humid tropics of the world is premised on the need to attain strategic, political, and economic benefits rather than its overall safety, recreational values and sustainability based on the utilization of very essential climatic elements of rainfall, temperature, humidity and wind.

The study shows that all over the cities in the humid tropics, different exotic urban surfaces made up of impenetrable concretes, asphalts, bricks and modified iron railings which constitute some unique urban canopies are turned out. These exotic characteristics represent the urban situation in Benin City in contemporary time.

The Benin City urban environment is vastly devoid of protective natural vegetal cover owing to construction of modern classes of buildings and pursuit of different industrial, commercial, recreational, and agricultural activities by the residents. This virtually bare nature of the environment has made the city predisposed to extreme climatic forces specifically torrential rainstorms, gusty winds and invisible clouds. Environmental challenges of inundation, soil degradation, muddy surfaces, traffic congestion, infrastructural damages and spread of water-borne diseases such as cholera and malaria are observed.

The built urban drainage system which is inadequate in physical dimension is often clogged by a body of sticky refuse and solid debris which prevent easy flow and infiltration of excess rain water in the city environment. This physical planning negligence has exacerbated the incidents of surface degradation, flash floods, and prolonged inundation of some parts of the city after the occurrence of torrential rainstorms.

The study observes the existence of heat-island crises in some parts of the city owing to local heat generation, accumulation and distribution caused by the rough exotic surfaces, human activities in industries, routine construction of infrastructures, utilization of different energy generators in private and public houses, vehicular movement on the roads, and unregulated human congestion in few buildings at night hours.

The study reveals that some modern cities established in the developing humid tropics of the world are susceptible to the contemporary rising challenges of hydro-terrestrial and atmospheric pollutions induced by inadequately planned and poorly managed human activities on the delicate environments.

A vastly dense urban canopy formation is visibly observed at the city centre. These differently patterned storey buildings currently constitute formidable obstructions to the circulating atmospheric, vegetal, land, and sea breezes in the city metropolis during the day and night hours. This occurrence worsens the heat-island crisis in Benin City.

Frequently heavy convective rains which range from 1,500mm-3,426mm characterized by lightning flashes, thunderstorms and gusty winds are observed in Benin City from March to October on a yearly cycle. This represents the period when different climate-induced urban environmental challenges such as excessive surface flooding, building deterioration and landscape degradation are experienced in the city. This is the season when the state authorities must plan how to implement defining measures to eradicate these urban challenges.
The study observes the existence of two main seasons in Benin City. These are the long rainy season and the short dry season. It notes that for effective environmental planning, weather prediction, implementation and realization of different urban development activities in the city, the short dry season which spans from November to February is selected because it is virtually rainless, conducive, and characteristically immune from climate-induced environmental disturbances such as flash flooding, surface degradation and infrastructural collapse.
Finally, the study reveals that on annual basis, abundant rainfall is frequently received in Benin City. This rain water resource when adequately developed and managed by climatologists, hydrologists, hydrological, mechanical, civil and structural engineers, architects, economists, and public administrators, alongside the fresh water available in Rivers Ikpoba and Ogba, would facilitate the realization of numerous domestic, corporate, and industrial activities in the city.

Recommendations

In the developing tropics of the world, there is need to ensure a properly planned urbanization process which is relatively implemented on the environment by a body of environmental scientists. Socio-economic activities must not precede the implementation of the urban process at the expense of objective environmental sanity which protects lives and preserves natural resources. Diverse anthropogenic activities mentioned at the outset which could alter the holistic physical equilibrium of the environment particularly reckless pollution causing works should be avoided right from the point of urban inception. Specifically, massive clearance of vegetal cover of the environment and persistent alterations of different terrestrial habitats and hydrological bodies in urban areas must be prevented by the physical planning authorities and other related development agencies. Although new urban climates would be produced at the end, however, the adverse consequences of their inception would be hardly experienced in the new cities of the world as long as these natural preservations are ensured as well as sustained.

On this note, the observed alterations in geomorphic, thermal, hydrological, terrestrial, and atmospheric characteristics of the developing tropical cities on which human, animal, plant, and micro-organic species depend for their survival would be gradually reversed to their natural dimension and composition. The City of Hawaii in the USA is a realistic illustration of our current suggestion.

In the continent of Africa specifically, very essential hydro-climatic, vegetal and geomorphic resources should be considered and incorporated in the urban physical planning process first before the consideration of the vast benefits accruing from the implementation of strategic, political, and socio-economic activities. Whenever this natural order of urban development is achieved first, cataclysmic extreme climatic forces would be kept at bay in African cities, and the envisioned development and sustainability of physical, socio-economic, and political projects would be attained in this part of the world.

The study observed the preponderance of vastly unsuitable rough exotic urban surfaces than the natural dominance of suitable grass covers and related vegetal surfaces in Benin City which led to heat-island crises and incidents of rainstorms. While it is scientifically essential to turn out rough exotic urban surfaces in some parts of the city owing to its hydro-geomorphic erosive vulnerability, it is also very necessary to raise soil compacting vegetation in areas prone to seasonal soil erosion and excessive flooding in the study area. Some construction activities which are capable of destroying the ecological stability of the environment should be avoided by the city residents, and if necessary, re-ordered in their overall implementation. A scientifically planned process of selective urban renewal could help re-order the dense canopy formation at the city centre which persistently obstructs the free circulation of refreshing atmospheric, relief, vegetal, land and river breezes in Benin City. The impact would be felt in strong but routine circulation of refreshing environmental breezes in the compact city metropolis by its residents.

Currently, Benin City bears the extensive impacts of flash and prolonged street-road inundations each time it experiences torrential rainfall on its environment as a result of inadequately dysfunctional drainage system. Based on its natural hydro-geomorphic and climatic orientation, Benin City does not need the services of a central storm dispensing system. It requires specifically the construction of a permanently functional drainage scheme which is partitioned into multi-channels on the basis of geomorphic street-road run-off frequency, intensity, and infiltration in trenches. Different trenches of receptive and infiltrative capacities should be constructed in suitable points where they are incapable of precipitating further erosion hazards and related damages in the city. This holistic urban storm project requires exceptional human skills immune from inadequacies, durably functional modern technology, adequate and regular state government's funds, routine digital monitoring and manual inspection, regular provision of spare technology for adequate maintenance, and a quarterly impact assessment reports to the Ministries of Lands and Surveys and the Environment for further policy decisions needed for its longevity and sustainability.

Relief and convective rains are frequently observed in Benin City. These types of rains combined to produce abundant rainfall in the city for ten-month duration within the year. Besides its applications for domestic, corporate and industrial activities, the abundant rainfall received and stored in Rivers Ikpoba and Ogba could be dammed for hydro-electric power generation and distribution in the city if all the needed resources are provided through the integrated efforts of the people and their government. The dam could provide nutritious fish and snails for human consumption. It could also provide processed portable water and recreational services to the city residents. We could derive realistic examples from the Tennessee River Basin experiences in the USA if physical doubts are envisioned in this regard.

Contemporary urban development must be experienced positively in improved standards of living of the city residents particularly in the developing humid tropics of the world. Of course, all the necessary urban sectors where these socio-economic, political, and strategic standards are derived should be ameliorated and sustained continually by government authorities. The private sector and corporate wealthy agencies could also play immense role in this aspect of urban development. The incorporation of very essential hydro-climatic, vegetal

and geomorphic resources in the urban development spectrum would help sustain and preserve the built physical, socio-economic and political infrastructures on the environment.

Conclusion

The study revealed urbanization process in the developing humid tropical countries of the world as virtually devoid of effective planning on the part of urban authorities. Under this observed urban situation, different physical, social, economic and political activities were carried out by the city residents. These activities resulted in extensive environmental distortions and modifications particularly in geomorphic, hydro-climatic, thermal, vegetal, fauna, and micro-organic characteristics of the urban areas to evolve unique urban climates. The nature, process and pattern of the urban climate produced, specifically in the aspects of rainfall occurrence, distribution, frequency, intensity and excess run-off infiltration in Benin City, Nigeria, were inadequately observed, valued, considered and incorporated in the overall development process in the city. This huge climatic negligence by the physical planners led to serious environmental challenges of surface inundations, soil degradation, mudflows, infrastructural damages, collapse of buildings, water-borne diseases, displacement of residents, poor market turn-out, and a depressed workforce in Benin City. In conclusion, the study clearly suggested among other important physical and human-related planning measures that the nature, process, pattern and other vital characteristics of the urban climate must be observed, considered and incorporated in the holistic urban development policies which would help restore Benin City into an environmentally balanced, productive, and sustainable cultural habitat immune from the frequent attacks of cataclysmic extreme climatic forces such as torrential rainfall and gusty winds.

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