TEMPORAL ANALYSIS OF THE PRESENT AND FUTURE CLIMATE OF THE LAGOS COASTAL ENVIRONMENT

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ABSTRACT

The Lagos coastal environment, a very delicate assemblage of coastal ecosystems, lies in the tropical lowland forest zone of southwest Nigeria. This paper analyses the long-term present and future climatic trend over the Lagos coastal environment using historical station-measured rainfall and temperature data for Ikeja, Lagos Island and Ijebu Ode stations and modeled data from the CMIP3 archive. The results suggest that long term mean annual rainfall over the Lagos coastal environment decreased by about -1.75mm per yr^{-1} from 1892 to 2015 and much of this was caused by the drastic rainfall decline of about -13mm per yr^{-1} in the period 1961-1990. Standardized rainfall anomaly suggests more year to year variations in rainfall in the Lagos coastal environment than experienced for Nigeria generally. Mean maximum temperature suggests a warming by about 0.012°C per yr^{-1} from 1944 to 2015. The future climate suggests an increase of about 0.6mm per yr^{-1} from 2016 to 2079 and a temperature rise of about 3°C above the present in 100years under a business as usual scenario. The results have severe implications for the ecosystems of the Lagos coastal environment and urban flooding and heat-related health impacts in the Lagos megalopolis.

Keywords: Rainfall, Temperature, Present climate, future climate, Lagos Coastal Environment

1. INTRODUCTION

Climate change is a serious environmental phenomenon inhibiting the development of coastal cities and environments across the world. Land-use changes and increasing use of fossil fuel significantly contribute to global greenhouse gases emission with concomitant warming impacts on the earth’s climate (UNFCCC, 2007). The earth’s climate is changing with temperatures rising, rainfall patterns shifting, and the frequency of extreme climatic events- such as heavy rainstorms and record high temperatures - on the rise (USEPA, 2014). The global climate in recent years have continued to experience significant variations from the normal. For example, the year 2015 was reported to be the warmest in human historical records (Justin, 2016). Climate change is expected to result in heavier rainfall in the coastal areas with increasing intensity and frequency of runoff and flooding (EPA, 2016).

Of significance is the vulnerability of the coastal environment to climate change. The coastal area represents the interphase domain between atmosphere, land and sea (Talaue-McManus, 2003), extending inland to include all areas strongly influenced by the proximity to the ocean. The Millennium Ecosystems Assessment (MEA, 2005) delimits the extent of the coastal ecosystem to include area extending landward to a distance of 100 kilometers from the shore and includes coral reefs, inter-tidal zones, estuaries, coastal aquaculture, and sea grass communities. Coastal areas are generally low-lying areas and are thus susceptible to heavy precipitation and ocean surges, causing damage to property, transport systems, fragile ecosystem and general human wellbeing (NPC, 2010, Kuenza and Renaud, 2012). Coastal zone worldwide is an area of intense natural and human processes. Over three billion people live within 200km of a coastline (PRB, 2003) and over two-third of the cities with 2million people and above are located in coastal areas (Pernetta and Milliman, 1995). About 40% of Africans live in the coastal areas and derive their livelihood from the coastal zone (Wandiga, 2006). This implies increasing pressure on coastal resources and the ecosystems which elevates its vulnerability to climate change.

A substantial number of the most significant cities and centers and sources of economic activities of national importance in Nigeria are found in the coastal environment. Eleven of the thirty-six states are littoral with about 60 million people (PRB, 2016). Climate change has severe implications for the coastal environment of Nigeria including coastal flooding, storm surges, population displacement and ecosystems changes. The Lagos coastal environment (LCE) is a very unique interphase between the coast and the sea where the lagoonal systems prevent direct discharge of upland rivers into the ocean creating a very unique and delicate assemblages of ecosystems. Adelekan and Asiyanbi (2015) submits that one of the most significant impacts of climate change in the city of Lagos is the increased frequency and severity of both inland and coastal floods resulting from increase in the intensity of rainstorm which is one of the biggest challenges for over half of the residents of the Lagos city. While the number of rainy days have been declining, the storm intensity has been rising. This suggests more torrential, high intensity rainfall over fewer rainy days. The same scenario could be hypothesized for most other coastal cities in Nigeria.

Oguntunde et al. (2011), SEDEC (2008) and FGN (2014) have attempted to analyze the pattern of the present climate over Nigeria; while Abiodun et al. (2012), in addition to the present climate, examined the future climate and climate change effect over Nigeria using modelling experiment. However, the specific pattern in climate and environmental change impacts in the Nigerian coast has not been comprehensively estimated due to paucity in collection of data (Olaniyi et al. 2013). In particular, the pattern of climate and environmental change in the LCE as an ecological unit is perhaps one of the least studied as suggested by lack of literature on the climate and ecological profile of the area. For such a high-density coastal environment, the implication of the climate and climate change on the people, resources and ecosystems could be better imagined both in the present and the future. An understanding of the present and expected future pattern in climate of the LCE will aid better preparation and development of effective mitigation and adaptation options. Thus, the objective of this paper is to analyze the present and projected future climate of the LCE and examine its implications for the human environment and the natural ecosystems.

2. MATERIALS AND METHOD

2.1 The Study Area

The study area is roughly defined by Latitudes 6°22' and 6°52', and Longitudes 2°42' and 4°18. It covers an area of about 11,000km^2, extending from the coastline to about 50-53km inland (covering Lagos and southern parts of Ogun States), and a west-east coastline distance of about 180km (Fig 1).

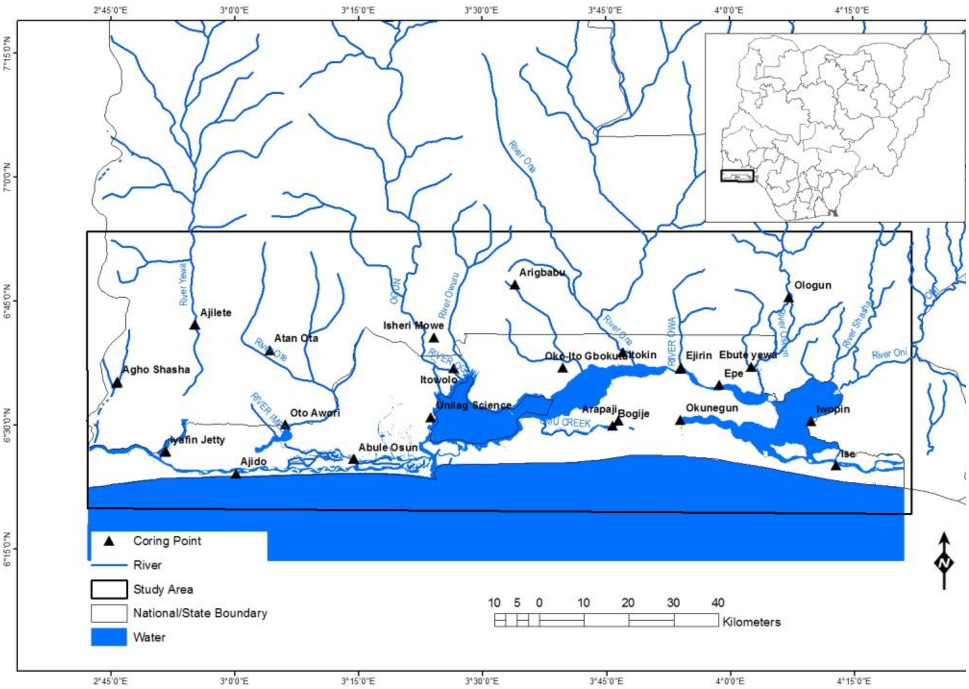

Figure 1: The Lagos Coastal Environment

rainfall and temperature for most parts of the year. The rainy season which stretches from March to November (with peaks in July and September) is substantially driven by the West Africa monsoon system (driven by the movement of the inter-tropical discontinuity) as well as mesoscale processes (Omotosho and Abiodun, 2007). The mean annual rainfall is about 1600mm and mean annual temperature is around 27^{o}C.

The LCE geologically straddles the entire sedimentary formations of southwest Nigeria including: Abeokuta, Ewekoro, and Ilaro formations as well as the coastal plains sands and recent alluvium (Jones and Hockey, 1964). The coastal vegetation is a combination of the mangrove forest and other coastal vegetation developed under the brackish water conditions. Forested freshwater swamp dominates the lagoon fringes and the river floodplain complexes which are extensive around the Lekki and Ologe lagoons and Badagry creek; as well as along the Yewa, Ogun, Shasha and Oshun rivers floodplains. By far the most extensive land-cover is the disturbed, subclimax secondary vegetation interspersed with cultivated lands. They are more extensive in the western part which has been characterized as part of the Dahomey Gap – an unusual zone of the Guinea-Congolian forest zone comprising of mosaic of savanna and the drier type of lowland rainforest forest (Sowunmi, 2004). The Lagos urban conurbation accounts for about 16% of the area and exerts tremendous impacts on the climate and ecosystems of the LCE.

2.2 Data collection and analysis

Observed mean monthly rainfall and maximum temperature data for 10 stations within and around the LCE were evaluated from the archive of the Nigerian Meteorological Agency (NIMET). The stations are: Lagos Island, Ikeja, Ijebu Ode, Abeokuta, Ibadan, Oshogbo, Akure, Ondo, Benin and Warri. Initial data inspection was done to select those with long term data and a second level geographic surface analysis performed to detect those that have influence on the Lagos coastal environment based on proximity. Eventually, three stations were selected (Table 1).

Table 1: Characteristics of climate data used

Sn	Station	Location		Rainfall		Temperature	
		Lat.	Long.	Data Length	Duration (Years)	Data Length	Duration (Years)
1	Lagos Island	06.27´N	03.24´E	1892-2015	123	1952-2015	63
2	Ikeja	06.35´N	03.20´E	1943-2015	72	1944-2015	71
3	Ijebu-ode	06.50´N	03.56´E	1974-2015	41	1982-2015	33

Time series analysis was performed to examine the behavior of the climate elements over time. Regression method of fitting trend lines was adopted and analysis of variance with p-values done to test the significance of the trend. The non-parametric Mann-Kendall test for identifying trends was used to compare the relative magnitudes of sample data (Gilbert, 1987) where the data values are evaluated as an ordered time series and each data value is compared to all subsequent data values.

Climate models use quantitative methods to simulate the interactions of the important driver of climate, including atmosphere, oceans, land surface and ice and they are important tools for improving our understanding and predictability of climate behaviour on seasonal, annual, decadal, and centennial time scales (Meehl et al, 2007).

For the future climate, downscaled climate data were downloaded from the World Climate Research Program's (WCRP) Coupled Model Inter-comparison Project Phase 3 (CMIP 3, www.engr.scu.edu/~emaurer/globaldata/) multi-model data tool archive (Meehl et al, 2007). The CMIP 3 archive contains general circulation models (GCM) output from simulations of the past, present and future climate collected by the Program for Climate Model Diagnosis and Inter-comparison (PCMDI) which is the Coupled Modelling working group of the World Climate Research Programme (WCRP). The CMIP3 is an ensemble set of global climate model simulations. It was developed and used for the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report as well as the third U.S. National Climate Assessment (NCA) report. CMIP3 promotes a standard set of model simulations and provides simulation and projections of past and future climate trends (Meehl et al, 2007).

Out of the models downloaded from the CMIP3 archive, the MRI-CGCM 2.3.2 model was adopted based on Cook and Vizy (2006). They evaluated 18 coupled

GCM outputs at process levels and concluded that the MRI CGCM 2.3.2 provides the most reliable simulation of the twenty-first century climate over West Africa and this informs our choice of the model for the LCE future climate. The future climate data was downloaded in NetCDF format and imported into the ArcGIS Software (www.esri.com) for spatial processing to derive the rainfall and temperature values for the stations around LCE. This was further processed for trend analysis.

3. RESULT

3.1 Trends of Rainfall and Temperature in the Lagos Coastal Environment

Table 2 shows the long term mean and standard deviation (SD) for rainfall and temperature for the stations.

Table 2: Long term mean and Standard deviation of the stations

	Rainfall (mm)		**Maximum Temperature (°C)**	
Station	**Long-term mean**	**Stdev**	**Long-term mean**	**Stdev**
Ijebu-Ode	1601.6	266.2	31.4	0.4
Ikeja	1535.6	365.7	31	0.5
Lagos VI	1812.4	296	30	0.6
Average	1649.9	309.3	30.8	0.5

The mean annual rainfall for the LCE during the last 123 years (1892-2015) is about 1650mm (with 309 σ) and mean annual maximum temperature is about 30.8°C (with 0.5°C σ).

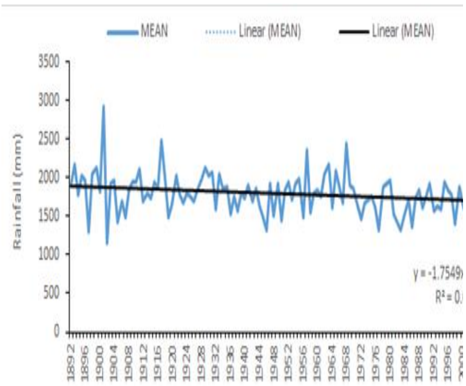

Figure 2: Rainfall Trend over the Lagos Coastal Environment (1892-2015)

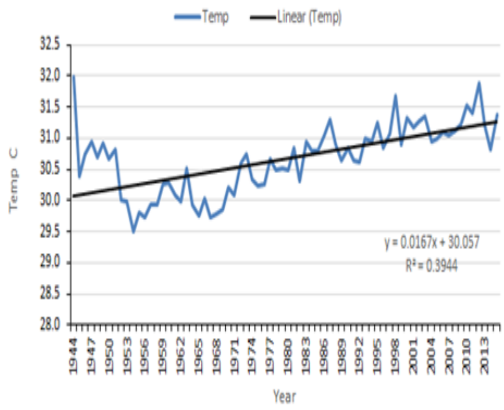

Figure 3: Trend in the Mean Maximum Temperature over the Lagos Coastal Environment (1944-2015)

The trend of total annual rainfall over the LCE (Fig 2) suggests a decrease of about -1.75mm per yr^{-1} (i.e. about -17.5mm per decade) from 1892 to 2015. This trend in rainfall is consistent with the findings of Oguntunde et al. (2011) which shows decline in rainfall in the mangrove (-1.3mm yr^{-1}), freshwater swamp (-1.56mm yr^{-1}) and rainforest (-0.96mm yr^{-1}) zones of Nigeria from 1901 to 2000.
The mean maximum temperature has ranged between 29.5^{o}C and 32^{o}C and the trend suggests a warming trend from 1944 to 2015 by as much as 0.012^{o}C per annum (0.12^{o}C per decade). This is consistent with general warming trend and rise in temperature experienced over Nigeria during the period (Abiodun et al. 2012). In summary, while rainfall has been on decline in the LCE, temperature has been on the increase. This is generally consistent with global decline in rainfall and a rise in surface temperature across the globe attributed to climate change.

3.2 Rainfall and Temperature Anomalies

The standardized rainfall anomaly over the LCE suggests year to year variations (fluctuations) in rainfall that is more than what is generally experienced over Nigeria during the same period (SEDEC, 2008, FGN, 2014). The standardized rainfall anomaly (Fig 4) suggests about eight different periods: a generally wet period (interspersed with dry years) from 1892 to 1904; a short dry period between 1905 to 1907, another long wet period from 1908 to 1935 (interspersed with few normal and dry years); another oscillation of dry and wet years between 1936 and 1956; a significantly wet period between 1957 and 1969; a significantly dry period from 1970 to 1977; a short wet period between 1978 and 1980; and a substantially dry period between 1981 to about 2013. The periods 1892 to 1918 and 1951 to 1970 are the wettest periods while the period 1971 to 1977 and 1980 to the present remain the driest.

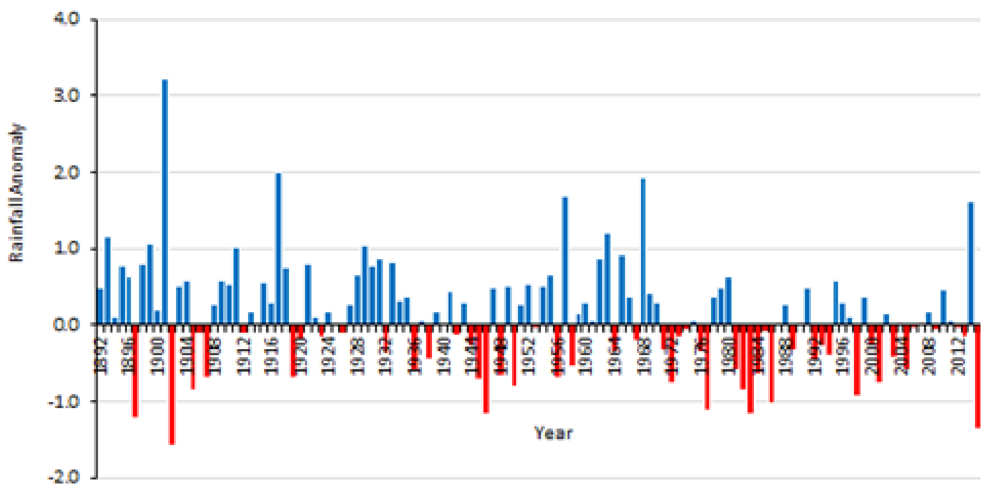

Figure 4: Standardized rainfall anomaly over the Lagos Costal Area (1892-2015)

Compared to the LCE, Oguntunde et al. (2011) observed three rainfall periods over Nigeria from 1901-2000: i.e. 1901 to 1915 with an apparently random succession of seven dry years, four ‘‘normal’’ years and 4 wet years; 1916 to 1969, a series of 26 wet years, 4 dry years and 24‘‘normal’’ years; and 1970 to 2000 with 15 dry years, 12 ‘‘normal’’ years and four wet years. However, the results agreed with Oguntunde et al (2011), SEDEC (2008) and FGN (2014) that the 1980s was the driest decade while the 1950s was the wettest decade. In general, the results suggest that rainfall variability and oscillation is more pronounced in the LCE than the Nigeria average. This has implication for the ecosystems and human activities of the LCE.

The standardized anomalies for the wet seasons (which shows how wet the wet seasons have been) suggests that during the wet seasons for 1892-1911, 1921-1943, and 1961-1970, LCE are wetter than normal (i.e. more than the long-term mean); while 1912-1920, 1944-1960 and 1971 to 2013 shows the wet seasons to be less wet than normal. On the other hand, the standardized anomalies for the dry seasons (which shows how dry the dry seasons have been) suggest that for 1892-1896, 1914-1919, 1926-1944, 1952-1960 and 2003-2006 the dry seasons are less dry than normal, while for 1897-1913, 1920-1951, 1961-1974,1981-2002, and 2007 to the present the dry seasons are drier than normal. Wet seasons that are wetter than normal suggest years of flood in the urban environments while dry seasons that are drier than normal suggest years of climate drought with implication for water availability for agriculture and the coastal ecosystems.

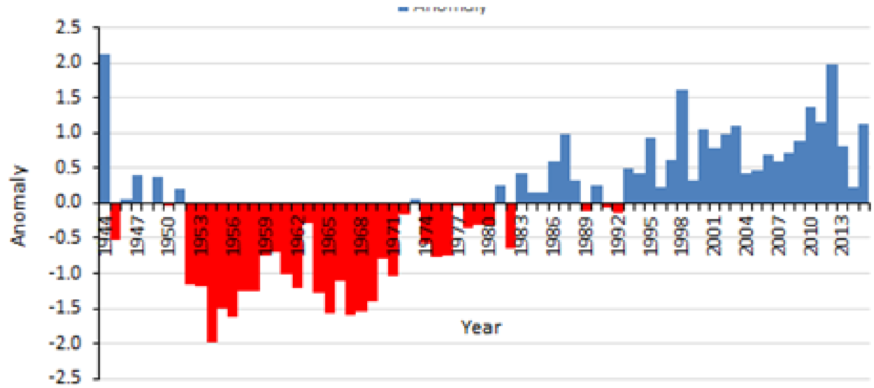

Figure 5: Standardized Maximum Temperature Anomaly over the Lagos Coastal Environment (1944-2015)

Figure 5 shows the standardized maximum temperature anomalies for the LCE. The standardized anomaly suggests that maximum temperature anomaly has ranged between -2σ to 2.1σ. Warming trend was experienced in 1944, 1947, 1949 and 1951, and has been consistent from 1983 to 2015 with the exception of 1989 and 1992. The high warming trend experienced in the recent is consistent with the general warming trend around the globe (IPCC, 2007).

3.3 Rainfall and Temperature Trend based on the WMO Standard Years

The World Meteorological Organization (WMO) recommended a 30-year reference period for climatological studies (Oguntunde et al. 2011). This 30-year average often referred to as climatological normal is good for monitoring, determination and representation of micro and/or macro climate of a particular location because it is less influenced by year to year variability or fluctuations (Keely 2011). Rainfall and maximum temperature trends were computed for the LCE based on a 30-year period. Figures 6a-d show the linear trend analysis for rainfall in the LCE based on 30-year periods 1901-1930, 1931-1960, 1961-1990 and 1991-2015 (25 years representing the present).

Rainfall shows positive trend for all the periods except 1961-1990.

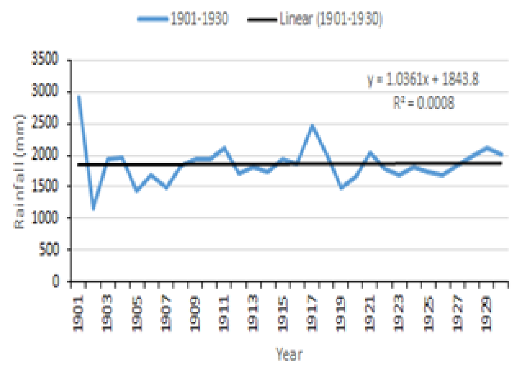

Figure 6a: Rainfall Trend in the Lagos Coastal Environment (1901-1930)

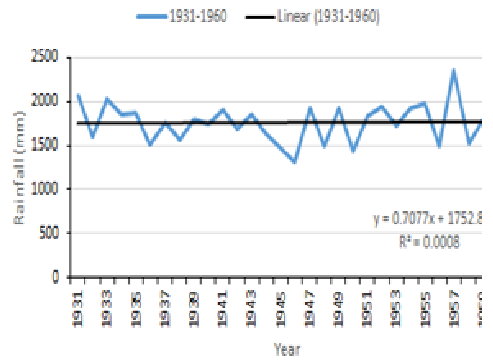

Figure 6b: Rainfall Trend in the Lagos Coastal Environment (1931-1960)

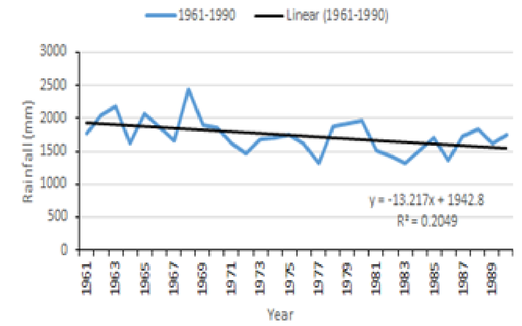

Figure 6c: Rainfall Trend in the Lagos Coastal Environment (1961-1990)

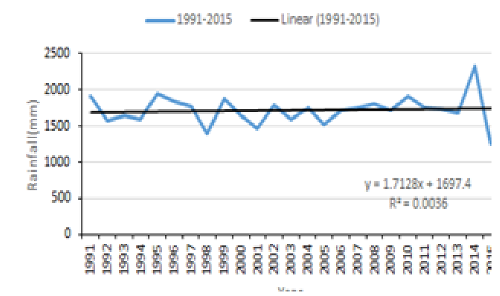

Figure 6d: Rainfall Trend in the Lagos Coastal Environment (1991-2015)

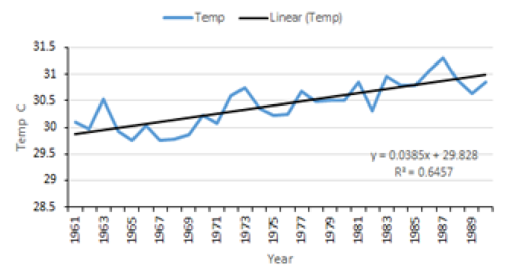

Figure 7a: Maximum Temperature Trend in the Lagos Coastal Environment (1961-1990)

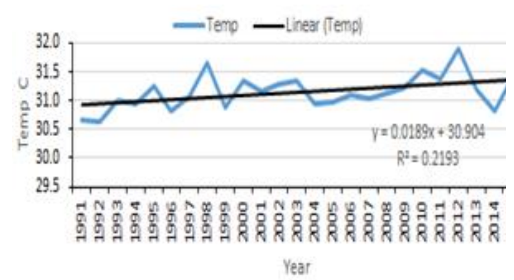

Figure 7b: Maximum Temperature Trend in the Lagos Coastal Environment (1991-2015)

Rainfall increased by about 1mm per yr^{-1} in the period 1901-1930, 0.7mm per yr^{-1} in 1931-1960, declined by about -13mm per yr^{-1} in 1961-1990 and recovered again at about 1.7mm per yr^{-1} in 1990-2015.This clearly shows the period 1961-1990 as the driest years with drastic decline in rainfall which is significantly responsible for the overall long-term negative trend of rainfall in the LCE. This is consistent with what has been observed in the general pattern of rainfall over Nigeria with the drought (generally referred to as the Sahelian drought) of the 1980s and 1990s noted as the most severe in modern day Nigeria (Oguntunde et al. 2011, SEDEC, 2008, FGN, 2014).

For maximum temperature, the data covers two periods 1961-1990 and 1991-2015 (i.e. 25 years). The trend analysis suggests that the maximum temperature rise by about 0.04^{o}C per yr^{-1} (i.e. 0.4^{o}C per decade) in the period 1961 to 1990 and 0.02^{o}C per yr^{-1} (i.e. 0.2^{o}C per decade) in the period 1991-2015. This reinforces that the periods 1961-1990 with less rainfall is also a very warm period. Although warming of the LCE persists in the latter period but with less severity.

3.4 Future Climate of the LCE

Figures 8 and 9 shows the trend in mean rainfall and maximum temperature from 2016 to 2079 for the LCE as retrieved from the MRI CGCM 2.3.2 downscaled climate model downloaded from the World Climatic Research Program's (WCRP) Coupled Model Inter-comparison Project Phase 3 archive (Meehl et al, 2007, Cook and Vizy, 2006). The long term future rainfall trend suggests an increase of about 0.6mm per yr-^{1} from 2016 to 2079 for the LCE. This is consistent with the increase in rainfall projected for the coastal mangrove and forest region of Nigeria in future climate scenario (Abiodun et al 2012). This is also significant because it means more flooding in the Lagos megalopolitan area.

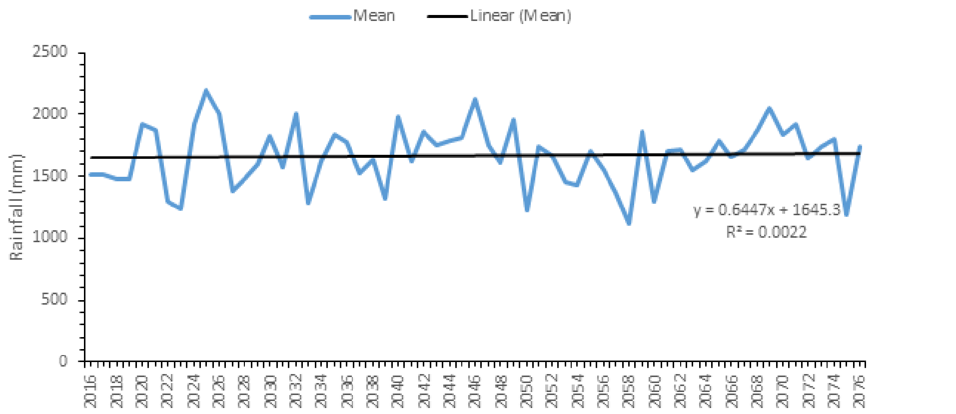

Figure 8: Trend of mean Rainfall over the Lagos Coastal Environment (2016-2076)

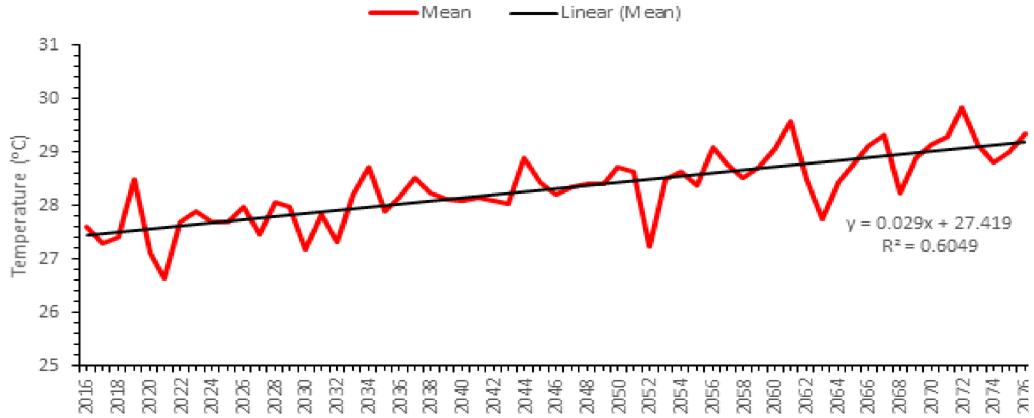

Figure 9: Trend of mean maximum Temperature over the Lagos Coastal Environment (2016-2076)

The trend in mean maximum temperature over the LCE suggests an increase of about 0.03°C per yr^{-1} (i.e. 0.3°C per decade). This suggests that given a business as usual scenario, the temperature of the LCE will rise by about 3°C above the present in 100year i.e. by the year 2116. This is will have significant impact on the coastal ecosystems and the very large population of the area.

4. DISCUSSION

This study has analyzed the trend in rainfall and maximum temperature for the LCE in the present and future climates using station measured data and modelled data. The results suggest that while rainfall generally decline over the last 120 years, temperature has been on the rise and this is generally consistent with global decline in rainfall and increase in surface temperature attributed to climate change. Year to year variations (fluctuations) in rainfall in the LCE is more pronounced than what is generally experienced over Nigeria. Warming trend has been largely consistent from 1983 to 2015.

Based on the standard 30-year climate normal, rainfall shows positive trend for all the periods except 1961-1990. It increased by about 1mm per yr^{-1} in the period 1901-1930, 0.7mm per yr^{-1} in 1931-1960, declined by about -13mm per yr^{-1} in 1961-1990 and recovered again at about 1.7mm per yr^{-1} in 1990-2015. The period 1961-1990 is the driest period with drastic decline in rainfall that had significant impact on the long-term negative trend recorded for rainfall in the LCE. Maximum temperature rose by about 0.04^{o}C per yr^{-1} (i.e. 0.4^{o}C per decade) in the period 1961 to 1990 and 0.02^{o}C per yr^{-1} (i.e. 0.2^{o}C per decade) in the period 1991-2015. It reinforces the period 1961-1990 as the warmest period so far in the LCE.

The future climate trend suggests an increase in rainfall by about 0.6mm per yr^{-1} from 2016 to 2079 for the LCE. This is consistent with the increase in rainfall projected for the coastal mangrove and forest region of Nigeria in future climate in other studies. Given a business as usual scenario, the temperature of the LCE will rise by about 3^{o}C above the present in 100years. This has severe impact for people (especially with regards to urban flooding and thermal comfort in the Lagos megalopolis) and the ecosystems in the LCE.

With regards to the ecosystems, the wet and dry cycles which is clearly shown in the present study, appeared to have dominated the climate and shape the vegetation and land-cover of the LCE over thousands of year before present (Sowumi, 2004). This oscillation between dry and wet periods are also very evident in the land-cover derived from remote sensing data between 1984 and 2015. Thus high rainfall and high evapotranspiration will significantly affect the structure of the present ecosystem in the LCE.

The findings also underscore the need for more preparation and effective and efficient mitigation and adaptation options with regards to future urban flooding in the Lagos megalopolitan area. Rainfall in the LCE appears to have recovered in the decades 2000s. This may continue for some time with more high intensity storms over short number of rainy days which will exacerbate urban flooding. The consistent increase in temperature also necessitates the preparation for thermal comfort and heat-related health issues including heat waves and meningitis. In recent times, such heat-related impacts, especially in the dry season, have been reported in some other coastal cities around the world. The time to begin preparation for such in the LCE is already here.

5. CONCLUSIONS

The LCE is an area of enormous pressure on the land resources due to rapidly expanding urbanization. The city of Lagos has grown tremendously from a colonial outpost to a sprawling megalopolis in the LCE in the last 50 years. Future population and land-use change projections suggest increased expansion in the spatial extent of the Lagos Megalopolis. Environmental sustainability is the basic life support systems on which social and economic sustainability rest. Urban flooding resulting from urban storm runoff during the rainy season has become a perennial problem in Lagos. The future climate for the LCE suggests an increase in both rainfall and temperature from 2017-2079. Increased rainfall may translate into increased urban flooding around the built up areas. Warmer temperature in the LCE has implications for urban livability indices including heat stress and thermal comfort, among others. Therefore, in the context of sustainable and climate compatible city planning, there is the need to begin the process of mainstreaming climate mitigation and adaptation options into the planning and management of the urban areas around the LCE to reduce the future impact of the climate system.

Acknowledgement:

Research and outreach activities described in this paper are part of the Palynological and GIS Modelling of Climate and Land-Cover Changes around the Lagos Coastal Environment Project supported by the TETFUND-NRF (2015 – 2017). Special thanks to NIMET for providing the present day climate data.

The comments from the two reviewers are gratefully acknowledged.

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