Standard Scientific Research and Essays Vol 2(10): 516-523, October 2014 (ISSN: 2310-7502)
http://www.standresjournals.org/journals/SSRE

Research Article

Trend in Climate Change and Vulnerability Assessment of Nigerian Gulf of Guinea

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Accepted 28 October 2014

Abstract

The study was carried out to assess level of climate change along the Nigerian Atlantic coast (Gulf of Guinea). Historic data on annual mean temperature (1970 – 2006); rainfall (1931 – 2008); mean sea level (1989 – 1992) and relative humidity (1990 – 2009) for Port Harcourt City and Bonny on the coastal zone of Nigeria were analyzed by moving averages to determine the trends of the climate change for the purpose of forecasting future variations. The observed mean maximum temperature rise per decade was 1.8^{o}C while the mean minimum rise was 2.21^{o}C per decade. The rising temperature coupled with increasing rainfall of 55.2mm per decade would cause a predicted sea level rise of 8.3cm per decade. These predictions would impact negatively on sustainable development, ecological systems and biodiversity. The predicted sea level rise may be simulated on Digital Terrain Model to assess the level of vulnerability of the coastal settlements. The rising sea level combined with extreme rainfall will exacerbate the risk of coastal flooding and insecurity to coastal communities and infrastructure. Consequently, higher return period events must be provided to account for climate change.

Keywords: Climate Change, trend analysis, tide, coastal flooding and mean sea level, Gulf of Guinea.

INTRODUCTION

The climate of the earth is governed by a balance between incoming sunlight and the outgoing infrared radiation. The outgoing infrared radiation is absorbed by green house gases and clouds and converting them into heat, thus increasing the surface temperature of the earth and oceans. The culpable anthropogenic greenhouse gases are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and Chlorofluoro carbon (CFCs).

Solar radiation is the main heat engine of the earth, thus, most phenomena such as flooding, rainfall, relative humidity, sea level rise etc, are strongly dependent on temperature rise. As a result, changes in climate system are intimately linked with temperature rise and trends of climate data have been used as indicators of climate change. According to Houghton et al. (1993) the Intergovernmental Panel on Climate Change (IPCC) model's predictions show that temperatures have increased on global average of 0.8^{o}C since the late nineteenth century and rainfall by 3.4mm/yr since satellite measurement started in 1993 and these results are equally found elsewhere in literature (Mintzer, 1993; Revelle, 1983; Ologhadien, 2005; Hall and O'Connel,1972; Douglas and Peltier, 2002 and Ayensu, 2004). Furthermore, IPCC regional predictions for West and Central Africa gave the following negative impacts of climate change:

i) Decline in crop yield; ii) Possible agricultural Gross Domestic Product (GDP) losses ranging from 2% to 4%; iii) Coastal settlement could be affected by projected rise in sea levels and flooding; and iv) Coastal vegetation degradation and negative impacts on fisheries and tourism (Ayensu, 2004).

Douglas and Peltier (2002) performed trend analysis of climatic data, but the impacts were not related to the environmental hazards due to climate change. The purpose of this study, therefore is to quantify the trends due to climate change using time series analyses and moving averages to historic data. The historic data lengths are 4-, 37-, 78-, and 20-years for mean sea levels, temperature, rainfall and relative humidity, respectively.

MATERIALS AND METHOD

Study Area

The Nigerian Atlantic Coastline otherwise known as Gulf of Guinea along the southern part defines the study area. Two major cities in the study area are Port Harcourt (4.46^{o}N 7.01^{o}E) and Bonny (4^{o}25'59"N and 7^o 9'0"E); both the coastline and its upland are part of the Niger Delta (see Figure 1). This region is the centre of oil and gas activities in Nigeria since 1956 the first oil well was drilled at Olobiri in Bayelsa State. Oil and gas exploration and exploitation, both offshore and upland are besieged with gas flaring, with its greenhouse effects, a contributory factor to global warming and climate change.

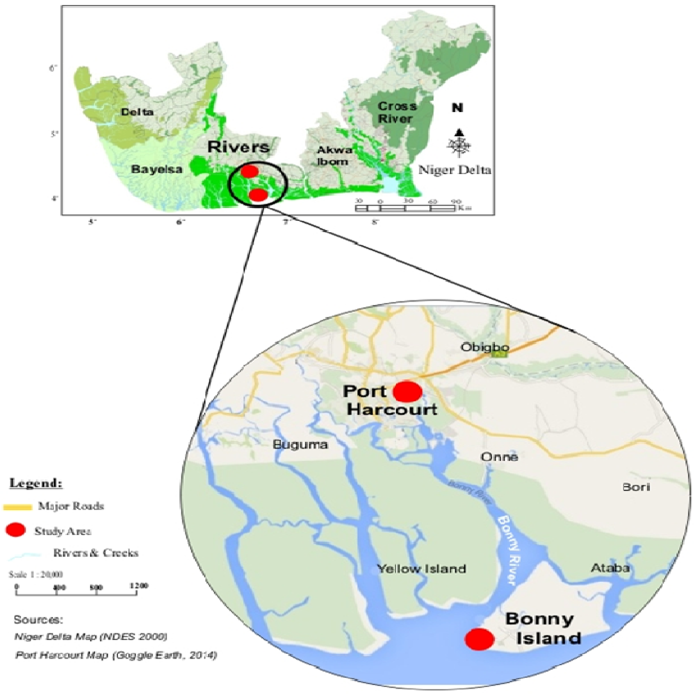

Figure 1. Map of the study area

DATA COLLECTION AND ANALYSIS

Sea Level Rise

The warming of the ocean gives rise to thermal expansion of coastal water with concomitant rise in sea level. Data on sea level rise were obtained from tidal measurement (gauges) along the coast of the study area. These tidal measurements are indicative of how much thermal expansion there is. Also the Nigerian Gulf of Guinea is not known for sinking, these data have been used as a guide. The analyses of the tidal data include:

i) An estimate of the tidal harmonic constants (34 components) on a monthly and half yearly basis (see Table 1); and

ii) Trend analysis of the monthly heights of mean sea level (MSL).

The relative importance of diurnal and semi-diurnal harmonics can be determined from the ratio, F:

$$F = (K_1 + O_1) / (M_2 + S_2) \quad \text{……………………………………} (1)$$

Where: K_1 = Solar – lunar constituent; O_1 = Principal lunar diurnal constituent;
M_2 = Principal lunar tide; and O_2 = Principal solar tide.

Temperature, Rainfall and Relative Humidity

The annual mean, minimum and maximum temperatures (1970-2006, 37 years); annual rainfall (1931-2008, 78 years); and annual relative humidity (1990-2009, 20 years), were collected from Nigerian Meteorological Department (NIMET), Oshodi Lagos, Nigeria. The rainfall data were extracted from FORM MET 141 (Tabulation of Autographic Rain Gauge Records).

Part of the data analyses are the plotting of temperature (^{o}C), rainfall (mm); and relative humidity (%) as dependent variables against the year (as independent variable). Altogether three separate graphs were plotted to help establish the trend; the first is that of raw data; second, the 5-year moving average; and third, the linear regression. From the slopes of the regression lines are extracted the applicable climate change parameter in degree centigrade; millimeter (mm) or percent (%) per decade for temperature, rainfall, and relative humidity, respectively.

The data analysis equally investigated the issues of periodicity, particularly the annual rainfall data. The linear regression was carried out in 10-year period (interval) for a total of 8No. Periods. If the resulting slopes of each of the 8No. periods, are consistently negative or positive, then, periodicity is not evident, otherwise it is.

Table 1. Summary of Harmonic Analysis

S/No.	Name of constituent	Amplitude	Phase G)	Frequency	(V_o + U)	V
1	SSA	5.891	36.2	0.082137	287.7	1.000
2	MM	2.433	1.0	0.544374	109.7	0.961
3	MF	2.059	340.6	1.098033	83.8	1.167
4	SN	1.298	93.5	1.560270	242.1	0.989
5	25M	0.290	249.3	2.031791	266.2	0.979
6	$2Q_1$	0.359	129.8	12.85428	108.5	1.075
7	Q_1	0.622	115.3	13.39866	217.5	1.075
8	0_1	2.244	345.0	13.94303	326.6	1.217
9	M_1	0.346	322.5	14.49669	139.7	1.047
10	K_1	12.678	16.8	15.04106	226.9	1.000
11	P_I	4.011	13.4	14.95854	111.1	1.075
12	J_I	1.316	13.4	15.58593	339.4	1.267
13	OO_1	0.496	85.5	16.13910	314.2	0.968
14	$3MS_2$	0.233	200.4	26.95231	290.8	0.979
15	MN_2	0.604	154.2	27.42383	314.8	0.989
16	MUZ	1.879	187.2	27.96820	61.8	0.989
17	N_2	3.458	124.0	28.43972	87.9	0.989
18	NU	2.611	142.0	28.51258	170.8	0.989
19	M_2	70.151	147.7	28.98410	196.9	1.219
20	L_2	2.488	161.8	29.52847	136.2	1.00
21	S_2	23.053	181.5	30.00000	330.0	1.102
22	K_2	6.547	181.5	30.08213	274.3	0.979
23	MSN_2	0.693	317.8	30.54437	79.0	0.989
24	$25M_2$	1.293	15.5	31.01589	103.1	0.063
25	$M0_3$	0.887	18.7	42.92713	163.5	0.984
26	M_3	9.863	267.1	43.47615	295.4	0.968
27	$2MNS_4$	0.225	178.4	56.40793	151.7	0.979
28	MN_4	1.770	77.8	57.42383	284.8	0.979
29	M_4	5.789	101.2	57.96820	33.8	0.979
30	SN_4	0.463	158.0	58.43972	57.9	0.989
31	MS_4	3.289	153.2	58.98410	166.9	0.989
32	$3SM_4$	0.284	54.0	61.01589	73.1	0.989
33	$3MO_5$	0.540	187.0	73.00927	264.2	1.041
34	M_6	1.131	17.5	86.95231	230.0	0.968

RESULTS AND DISCUSSION

Analysis of Mean Sea Level (MSL)

The tidal analysis for Bonny estuary was carried out using the GETYSIS software package developed by Delft Hydraulic Limited (DHL, 1989). The six month tidal data of the estuary were inputed into the harmonic analysis software.

The computer output (Table 1) includes the list of harmonic constituents for Bonny estuary. The form of tide (F) found in the Nigerian Atlantic coast was calculated by substituting the corresponding amplitudes of K_1, O_1, M_2 and S_2 of Table 1 into Equation (1). The value of F calculated is 0.1601. Thus, the form of tide may be classified as semi-diurnal with two high and two low waters of approximately the same height.

Also, time series analysis consisting of graphical plots of raw data, moving average and linear regression were performed on monthly values of mean sea level (MSL). Figure 2 shows the plots of the MSL data. The trend calculated using the fitted linear equation shows that the MSL is rising at the rate of 8.3cm per decade. Furthermore, the time series plot (Figure 2) follows a long-term, periodic and seasonal movement. The presence of a periodic component in any hydrological time series is attributable to the astronomical events which are periodic; for example, the rotation of the earth about the sun gives rise to within-year variation of temperature, relative humidity and tidal level (Hall and O'Connel, 1972).

Analysis of Temperature

The trends of the irregular variations of annual mean, minimum and maximum temperatures are represented in Figures 2 and 3. Table 2 illustrates the characteristics of the data indicating the temperature rise per decade, estimated as gradient of the trend line (negative value represents decrease). The annual mean maximum temperature is rising at the rate of 1.8°C per decade while for annual mean minimum temperature is 2.21°C. This shows that the rise in annual mean minimum temperature (2.21°C) is higher than the annual mean maximum temperature (1.81°C). The higher growth of minimum temperature is an evidence of climate change.

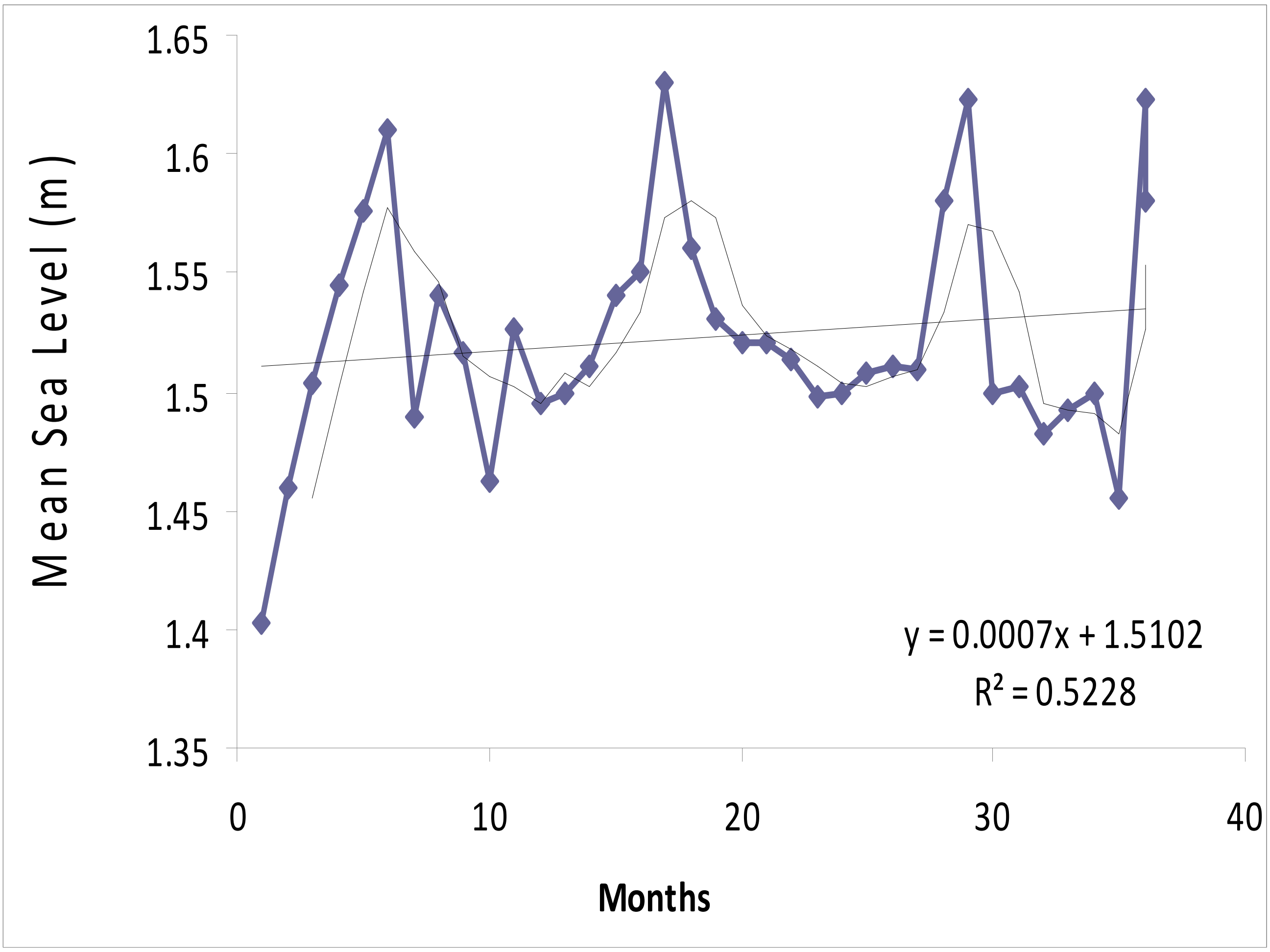

Figure 2. Mean Monthly Sea Levels (1989-1992)

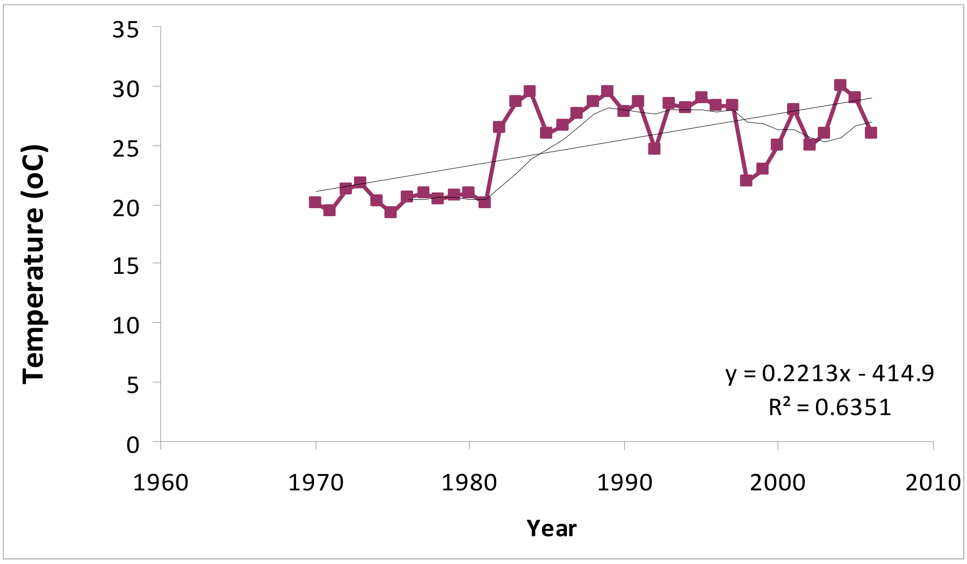

Figure 3. Annual Mean Min. Temp. (1970-2006)

Table 2. Trend Equations

Parameter	Equation	Rise per decade
Mean Sea Level (MSL)	$MSL = 6.9 \times 10^{-4} x + 1.510$	8.3cm
Temperature Maximum	$T_{max} = 0.181x + 31$	1.81°C
Temperature Minimum	$T_{min} = 0.211x + 20$	2.21°C
Rainfall	$R = 5.520x - 8378$	55.2mm
Relative Humidity	$RH = 0.90x - 1706$	9%

Analysis of Rainfall Data

The annual rainfall data between 1931 and 2008 are plotted, and a linear regression trend line equally established in Figure 4. To remove any temporal variations in data and to identify the periodicity, a 5 year moving average was superimposed. The rainfall in the study area shows periodicity which could be revealed from Table 3.

The alternating of positive and negative slopes in the fitted trend equations per decade (see Table 3) confirms the apparent periodicities associated with the rainfall data (1931 – 2008). However the overall trend in rainfall rise (55.2mm/decade) is exemplified in Figure 4.

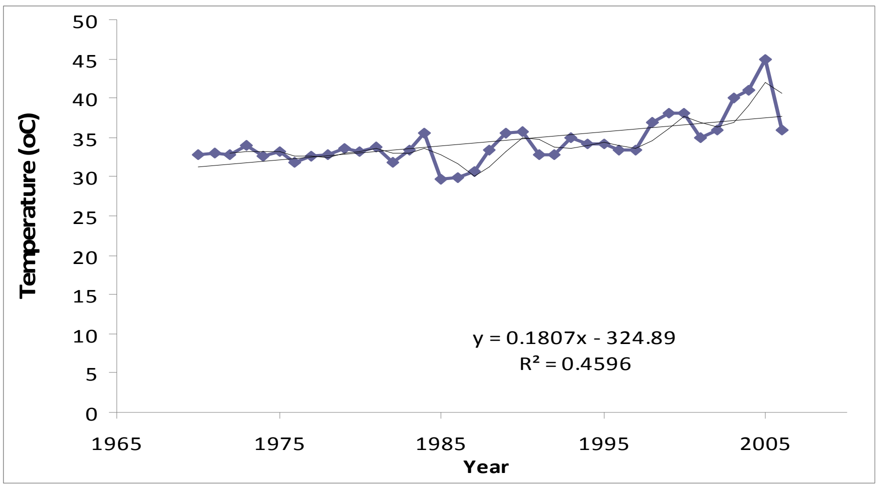

Figure 4. Annual Mean Max. Temp. (1970-2006)

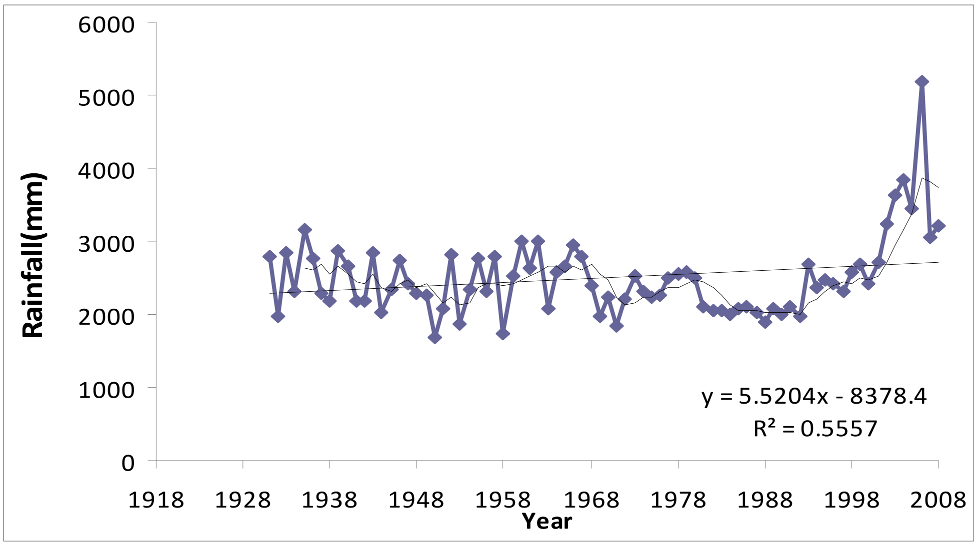

Figure 5. Annual Rainfall (1931-2008)

Table 3. Rainfall trends and Periodicity

Period	Trend Equations	Rainfall(mm)(rise or fall) per decade[±]
1931 – 1939	R = 4.583x – 6290	+45.83
1940 – 1949	R = -7.838x + 2439	-78.38
1950 – 1959	R = 37.77x + 2076	+378.0
1960 – 1969	R = -25.07x + 2799	-250.7
1970 – 1979	R = 53.44x + 2031	+534.4
1980 – 1989	R = -31.29x + 2258	-313
1990 - 1999	R = 63.82x + 2007	+638.2
2000 - 2008	R = 131.8x + 2754	+1318
Overall (1931 – 2008)	**R = 5.520x - 8378**	**+55.2mm**

[±]The positive and negative slopes in column 3 is a case of periodicity

Analysis of Relative Humidity

The relative Humidity is a measure of water vapour held in the atmosphere. Water vapour is intimately involved in the greenhouse issue because its concentration is linked with those of other gases through a "feedback mechanism". Warming, brought about by other green house gases, increases evaporation and allows the atmosphere to hold more water vapour, this in turn enhances the warming. Figure 6 shows the trend in relative humidity in the study area. The rise in relative humidity as estimated from the fitted trend line (Figure 6) is 9% per decade. The rise is an index of increasing warming and climate change.

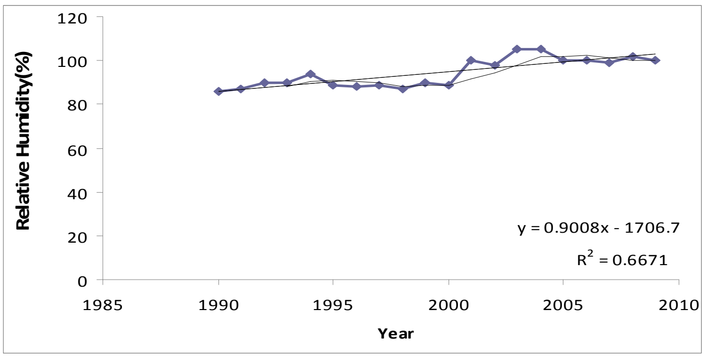

Figure 6. Relative Humidity (1990-2009)

Comparison of Study Predictions with Literature

The study predictions are compared with those of IPCC and others (Table 4). The observed increasing temperature, rainfall and mean sea level are indicative of ongoing climate change. In the long term, human habitation on Nigerian coast will become vulnerable to flooding. Despite the filtering of noise in the data by 5-year moving average, the trends in temperature, rainfall and mean sea level cannot be considered as mere fluctuations obscuring any underlying change. Also, urbanization and growth of cities cause warmer micro-climate changes. This is sufficient indication that the climate change is real and measures must be adopted for containment.

Table 4. Comparison with IPCC and other Predictions[±]

Parameter	Study Predictions	IPCC[a]	Ghana[b]	England[c]	Remarks
Temperature	1.8°C	1.5 – 4.5°C	0.11°C	NA	Per decade
Rainfall	55.2mm	NA	13mm	NA	Per decade
Mean Sea Level	8.3cm	6cm	2.2cm	4cm-6cm	Per decade

NA - Not Available; IPCC – Intergovernmental Panel on Climatic Change
[±]**Source:** a & c = Reeve et al (2004); b = Ayensu (2004).

Vulnerability assessment

Given the predicted mean rise in temperature of 1.81°C per decade, the sea level rise of 8.3cm per decade and thus, a sea level rise of 74.52cm by the year 2100. These predictions would be used to evaluate the vulnerability of the Nigerian coast to climate change, perhaps with a suitable Digital Terrain Model.

The consequences of sea level rise have both physical and environmental effects (Archier and Rahmstorf, 2012). Shoreline retreat by erosion, temporary flooding and salt water intrusion are the major permanent devastation that could affect the Niger Delta Areas. Many coastal areas with sufficient elevation to avoid flooding would be threatened by erosion. The attacks by sea waves on the coast would cause beaches to take a particular profile unsuitable for human habitation. The flooding and erosion of marshes and other wetlands will become critical to the reproduction cycles of many species. Salt intrusion will also threaten marine animals and vegetation.

For a given shore profile at equilibrium, a rise in water level will cause erosion to occur in order to provide sediments to the shore bottom to be elevated in proportion to the rise in water level, and the sea waves would then wear the beach deeper than before. Sea level rise would increase the salinity of rivers and estuaries. Because the level of rivers and estuaries, and the level of the water table are determined by sea level, a rise in sea level would cause the fresh water/salt water boundary to rise. The landward and upward shift of the boundary implies that certain freshwater wells may become salty.

In response to sea level rise, fish might swim further upstream, but water pollution could prevent such an adaptation from succeeding. Flooding would have a particular impact on environmental protection activities especially where low-lying areas are used in waste disposal sites.

CONCLUSION

As a result of climate change, the increase in mean maximum temperature per decade for the Nigerian coastal zone was found to be 1.81°C and the increase in rainfall per decade was found to be 55.2mm per decade, with subsequent predicted sea level rise of 74.52cm by the year 2100. The future variations of temperature, rainfall, relative humidity and mean sea level show a long-term trend, while rainfall, in particular exhibit some periodicities.

Evidently, low-lying sandy coastal areas of Nigerian Atlantic coast will be profoundly affected by direct inundation (or submergence), erosion of soft shores, loss of important biodiversity and wetlands, increase in salinity of estuaries and aquifer that the coastal savanna will tend to move up north to affect agricultural productivity of the forest zone.

The adverse consequences of global warming, sea level rise and increase in rainfall could be mitigated if timely measures are adopted to minimize greenhouse gas emission and deforestation.

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