Projected Changes in the Physical Climate of the Niger Delta Region of Nigeria

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Abstract
Sea-level rise (SLR) due to increase in Greenhouse Gases (GHGs) is a serious global threat: The scientific evidence is now overwhelming. IPCC Ar4 predicted that the coastal region is likely to be inundated as the temperature increases in the atmosphere, the sea level (SL) will rise. Even if GHG concentrations were to be stabilized, global warming will continue for centuries due to the time scales associated with climate processes and feedbacks in the climate system. Thus, in the management of coastal areas, the prediction of changes in SL is important. This paper aims to provide a scheme for the simulation of gradual increase in the SL in Niger Delta region. Based on the current studies, a substantial relationship exists between SL changes and climatic variables such as Temperature (T) and Precipitation (P). Therefore these variables are used for SL simulation through GCMs. The study quantifies the presents and the future changes in SL in the Niger Delta region. IPCC Ar4 and Ar5 were the climate model simulations used to derive the changes in T, P and SL. The simulations were based on the SRES emissions scenarios, A2 over the reference period (1960–2080). Analysis of the SL changes over the Niger Delta confirmed IPCC Ar4 projected increase in SLR over the coastal area in the 21st century. Although the changes in SLs are more uncertain, but the result demonstrates that Nigeria Niger Delta is threatened by SLR and this suggest that coastal flooding from storm surges might becoming more frequent in this region.

Introduction
The impacts of global climate change on the natural and social environment are confirmed positive and negative by Intergovernmental Panel on Climate Change (IPCC). Changes in T, P and SLR over the next century are predicted Whitehead et al. [1]; Amir et al. [2]. These climate change and variability studies have shown that both anthropogenic and natural factors are responsible for it [3]. Understanding the effects at local and regional scales is a great challenge for addressing climate change in Africa. There is increasing anxiety over future climate especially the West African region, as human-induced global warming continues, since the population of the region depends essentially on agriculture and climate change may alter the availability of water resources IPCC, [4] especially in the coast. Recent research has shown that human actions such as fossil fuels, unsustainable agriculture, and deforestation have amplified the Earth’s natural greenhouse effect and are contributing to increase in GHGs in the atmosphere [5].

Reports have stated that as the planet warms, climate and weather variability would increase [4, 6]. Changes in the frequency and severity of extreme climate events and in the variability of weather patterns will have significant effects for human and natural systems. Increasing frequencies of heat stress, drought and flooding events are projected for the rest of this century. Also Food
and Agriculture Organization of the United Nations Rome reported in 2008 that rising SLs and increasing incidence of extreme events pose new risks for the assets of people living in affected zones, threatening livelihoods and increasing vulnerability to future food insecurity in all parts of the globe. Udo-Akuaibit SP [7] noticed that as a result of changes across the globe, Niger Delta region is under the threat of marine water intrusion and landward displacement of the brackish water ecosystem as well as seawater intrusion to coastal aquifer. This poses salinity stress on biodiversity in the mangrove ecosystem. This is worrying because the adaptive capacity is comparatively low in Nigeria and in Africa at large. Thus, a change in future climate may pose significant threats to the Nigeria Niger Delta region because is a low-lying area. The exposure of the delta to the effects of changing climate is a serious concern [4, 8]. Increases in sea surface temperatures cause thermal expansion, which increases the water level of the sea surface IPCC [9], and as a result, the shoreline moves farther inland which might further leads to SLR. SLR has numerous significances for low-lying coastal areas, such as inundation due to coastal flooding by incoming rivers and/or the sea, erosion, disarticulation of coastal wetlands, and inland interference of seawater [4, 10]. To carry out such assessment in Africa is critical, this is because Africa is mostly covered with semiarid regions known for their unpredictable rainfall regime that is highly inconstant on interseasonal, interannual and interdecadal time scales [11].

The climatic future of the Niger Delta remains ambiguous, due to discrepancy associated with climate models simulation. Climate change is likely to have a major influence not only on water resources, but also on food security and human society at large through its influences on climatic variability and extremes [12]. The anticipated warming climate caused by increasing intensity of GHGs is very likely to aggravate the present and future climatic variability and extremes in the region (Figure 1a). Consequently there is need to assess how much effects the future change would have on the Niger Delta and available water resources since the delta is the source of livelihood for the local community in this region.

Though, the global climate model projections produced by a wide variety of modeling groups for the IPCC-Ar4 and Ar5 show little consent over West Africa [4] This deficiency of consent results partially from the incapacity of climate models to apprehend the basic features of the present-day climate variability in the region, most especially precipitation figure 1(b). Though, model discrepancy about precipitation is large, precisely on a regional scale. While climate models are getting continuously more complex, explicit statements about future changes in precipitation patterns are still difficult to provide [13, 14].

Figure 1: Plots a and b above shows temperature increase in the future and the annual average rainfall climatology from 2050-2080 for 30 years, based on IPCC Ar4 and Ar5 Models.
The aim of this paper is to quantify the present and future changes in SL in the Niger Delta Region of Nigeria so as to understand the implications of SLR on flooding of the Niger Delta. The paper first examines changes in T and P to understand the implications of increase in T and rainfall over the Niger Delta catchment area on delta flooding. Datasets from IPCC-AR4 and AR5 were used for the simulation. The crucial elements of our discussion are, however, coherent with the broad scientific consensus reflected in IPCC AR4, particularly regarding T and P over the region.

**Study Area**

The Niger Delta region of Nigeria is situated in the Atlantic coast of Southern Nigeria where River Niger divides into numerous tributaries which drains into Atlantic Ocean [15]. The importance of the Niger Delta wetlands cannot be overemphasised as it transcends national to global importance. This region has the largest mangrove swamp and wetland in Africa, and it is the third largest wetland in the world [16, 17]. Also this region is the richest part in Nigeria in terms of petroleum resources and diverse natural ecosystems supportive of numerous species of terrestrial and aquatic fauna. As a low-lying area the region is close to the equator, hence cloud cover is very high, sunshine hours are low and the air is clammy for most of the year [15]. This is as a result of very high relative humidity of the air. Politically, Niger Delta region consists of 9 oil-producing states (Abia, Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Ondo, Imo and Rivers).

The rich oil and gas exploration for several decades in the region have placed much demand on the ecosystem. Since 70% of its population and infrastructure are situated in low-lying coastal areas, this would threaten the livelihood and development options of the Niger Delta and the country at large [18]. The influences of environmental pressures experienced in this region may be transmitted several hundred kilometres to regional and even a global scale [18]. Research has it that the unceasing stress on the coastal environment has consistently been harmful which has been attributed to human influences connected with global climate change Cummins et al. [19], Popoola et al. [20] and if not properly maintained would produce serious environmental consequences. As the population increases the risks of the populace being exposed to natural hazards is a major concern. Figure 3

It is projected that the coastal communities will be more vulnerable to SLR as a result of climate change and consequent to increase in frequency and intensity of flood. It is projected that increases in T will also increase P and these would intensify the exposure of coastal regions to natural hazards [21, 22].

This evidence is experienced in the Niger Delta region of Nigeria. Sonia Sharmin [23] argues that Man made global climate change and associated SLR can have
Figure 2: Map of Nigeria showing the position of the Niger Delta Region

Figure 3: Niger Delta showing the drainage pattern, Ecological areas and boundaries in the Niger Delta

major adverse effect for coastal increase. As the global climate changes, the regional climate of the Niger Delta will change as well. Some of the ways in which it will change are fairly certain. Recent research argues that while the destruction of traditional means of livelihood in the Niger Delta has forced peoples into an environment-related poverty, worsening living conditions, and enormous underdevelopment, environmental change in the area has prompted this research. Considering factors threatening Niger Delta region, such as coastal erosion, flooding and destruction of the ecosystem may be ascribed to SLR as a result of global warming and intense human activities respectively. Given these challenges the study emphasizes on the vulnerabilities to climate change and the possibilities for adaptation in the Niger Delta region.
Data and Method

To sub sample the outputs from a suite of climate General Circulation Models (GCMs) submitted to CMIP3 and CMIP5 Ruiter, [24] to simulate possible present and future SL risk for the Niger Delta region. The study used data collected from IPCC Ar4 and Ar5 models to carry out the simulation of T, P and SL in the region.

IPCC Ar4 and Ar5 Global Climate Models

The paper assesses the SL in the region through the use of climate change scenarios generated by IPCC Ar4 and Ar5 GCM to explain the implicit climate change into the changing planet responses. GCM is a complex mathematical representation of the major climate system components (atmosphere, land surface, ocean, and sea ice), and their interaction. Also it predicts the effects of changes in the given region [25]. The significant of GCM has been recognized especially when carrying out analyses of extreme events. These portray the importance of GCM in assessing effects of climate change. It is expected that the SLR will exacerbate coastal erosion, extreme marine flooding, or saltwater intrusion in coastal aquifers Nicholls and Tol [26], Nicholls et al. [27], Nicholls and Cazenave [28], Cazenave and Le Cozannet [29]. Although for each type of impact, the dynamic response of coastal systems remains highly uncertain.

The investigation of climate change analysis is based on simulations derived from large-scale GCMs which model atmospheric processes, both for historical and future periods. IPCC Ar4 and Ar5 models were used to examine T and P including SLR over the Niger Delta region. The study is carried out using ingv_echam4, csiro_mk3_0 climate models for Ar4 while the following models were for Ar5 CNRM_CM5, FGOALS_s2, MPI-ESM-LR, IPSL-CM5A and inmcm4. The study used SRES emission scenarios developed by IPCC. The SRES emission scenario represents inadequate knowledge of external factors influencing the climate system, including future courses of anthropogenic emissions of GHGs, stratospheric ozone concentrations and land use change Deser et al. [30].

Analyses

The simulations were based on the SRES-A2 over the reference period (1960 to 2000) and for the 21°C (2020–50, 2050-80) for T, P and SLR. The analyses were based on output provided by IPCC Ar4 and Ar5 models. The data were analyzed using Microsoft Excel, KNMI Climate Explorer Exceed onDemand, and Climate Data Operators (CDO) software. To visualize the climate data the results were shown in Linux based software, including the Grid Analysis and Display System (GrADS). The analyses started by extracting T and P data over the Niger Delta region for the study period to calculate present day climate data from (1960-2000) and multiple future (2020-50, 2050-80) across Niger Delta over 20th-21st century; figure 4. This is to understand the implication of changes in T and P has over the Delta flooding. Again, to explore the potential to quantify the influence of increase in T on additional variables beyond T and P, the study also analyse the present and future SL (Figure 6) to understand the vulnerability of the Niger Delta to SLR in future. The paper used the ‘SRES A2’ scenario from seven GCM model to obtained mean changes in T figure 4(a, b, c, d and e), and maximum daily average P figure 4(f, g, h, I and j) for grid cells in Niger Delta region from the IPCC Data Distribution Center reflecting climatic projections for the period around 1970-2080. The A2 scenario represents the annual T and P destitutions over the region. Figure 1(a, b) shows estimates of mean average T and P in the future over the Niger Delta.

Figure 4: Plot shows climatology from the five GCM for T (a,b,c,d and e) and P (f,g,h,l,j) from 1970-2080 for Niger Delta.
Results
Projected Temperature and Precipitation in the Niger Delta

The simulation of T and P over the Niger Delta shows differences in the behavior of the different GCM regarding the reference period. When comparing the GCM for the three-term period for T and P simulated, all models show an increased in the simulations. As noted among the model results for the historical period, the coupled models exhibit large differences in the twenty-first century. The growth rate becomes very worrisome around 2050-2080, which the IPCC report indicates. That is to say, all models have a positive feedback, which indicate warming trends over the region. This has confirmed the initial findings of Cox et al. [31] and Friedlingstein et al. [32]. The results suggest that SL will rise with the concomitant rise in mean global T, with the indication that the warmer it gets the faster SLRs. It also implies that coastal flooding from storm surges will become more frequent with SLR over the Niger Delta [33]. These projected changes in T display a substantial hazard to different economic activities and environment of the coastal area.

Percentage change in T and P in the Niger Delta

Figure 5 (a, b, c, d) shows the changes in the mean annual T and P projected from Seven GCMs for the two-time periods in the 21°C (2050-2080) over the Niger Delta. Overall, the 31 years projections manage to discern the phase of the major variations of the models in representing Niger Delta T and P quite well. The result demonstrates a significant increasing in T and P trend across the Niger Delta region under A2 scenarios. The magnitude of the projected changes varied somewhat among the GCMs (Table 1) but it is comparatively robust. Nevertheless despite the differences in the GCMs the majority of the models show entirely increasing T and P trend over the 21°C in the Niger Delta. The maximum change in mean annual P value recorded is 27.42% mm/year with 3.06 degree Celsius change in T during 2050-80 from FGOALS Ar5. The projected changes in T and P indicate warming trends in the Niger Delta over the 21°C, which correlate with [34].

The results from T have shown that it is likely that rainfall pattern across the Niger Delta will increase as Wilby and Kneenan [35] highlighted though rather uncertain. Thus the changes might result to increase the risks of flooding, accelerate SLR, storm period, storm intensity; all these constitute a serious threat to the livelihood of people in Niger Delta. The results confirmed the projection of AR4 IPCC report [36] concerning the implication of climate change on the coastal region. The situation is not encouraging for agricultural production in the Niger Delta, which may lead to food insecurity in this region since the communities depend on agriculture production for their livelihood [34]. These suggest that the Niger Delta low land is likely to be vulnerable to SLR in the future due to the projected increase in T and P across the region, which correlates with IPCC report Solomon et al. [36]. This suggests significant consequences for adaptation methods for management of flood risks in the area [37].

Figure 5: Projected change in the mean annual T and P between the 21°C and historical period across the Niger Delta. The study used Seven GCM from AR4 and AR5 for the simulation. The scatter plot appears to be nonlinear on the Ar5 models but appear to be linear on Ar4 models. The domain includes both positive and negative values; the range is greater than zero. Note: y-axis is ∆P mm/year and x-axis is ∆T Degree Celsius.
Sea Level Rise

Past and future climate change drives numerous reactions in the oceans. One such response is variation in SL as the oceans warm or cools [38]. The study quantifies the SL to ascertain the projected increase in SLR by IPCC Ar4 over the coastal area in the 21st C. A recent by study Ogba and Utang [39] has investigated that the Niger Delta could lose over 15000 km² of land by 2100 with 1m rise in SL. Figure 6 (a, b, c) displays the simulated mean annual SL for the 21°C runs and historical period. Projections of SL indicate a statistically significant increase in mean SL along the entire Niger Delta coastline. The results show substantial disparity in the degree among the GCMs. It is more likely that the changes shown between the models represent an increase in SLR in the region rather than acceleration of land subsidence or compaction reflecting that the low-lying Niger Delta region is vulnerable. The results confirm IPCC Ar4 report [40]. HadGEM2-ES model tends to overstress the SL with the magnitude value of 1.5741 m during 2050-80. Though if the result is interpreted with the relevant assumptions as reported by IPCC in Klein et al. [41], Nicholls [42] these studies provide significant insights into the likely effects of SLR in the Niger Delta region which French et al. [43], Nicholls and Mimura [44] notice. It is obvious to state that some of the models are underestimating the SL in the Niger Delta; particularly IPSL-cm5A-LR, which shows a decreasing trend. This experience suggests that there are high degrees of uncertainty in the assessment of comprehensive impacts of SLR among climate models. Overall, model agreement is strong for the mean SL projections over the region. Tebaldi et al. [33] pointed out that, increase in SLR will lead to coastal flooding from storm surges becoming more frequent meaning that Niger Delta lowland is at risk.

Table 1: The summaries of percentage changes in GCMs projection of mean annual T and P over Niger Delta between the future and historical for the period of (1970-2000) and for two time in the 21°C

<table>
<thead>
<tr>
<th>AR5 MODELS</th>
<th>2020-50</th>
<th>2050-80</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNRM</td>
<td>0.97</td>
<td>3.93</td>
</tr>
<tr>
<td>IPSL</td>
<td>1.65</td>
<td>0.17</td>
</tr>
<tr>
<td>INMCM4</td>
<td>0.79</td>
<td>-74.66</td>
</tr>
<tr>
<td>MPI</td>
<td>1.27</td>
<td>2.59</td>
</tr>
<tr>
<td>FGOALS</td>
<td>1.50</td>
<td>9.60</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>AR4 MODELS</th>
<th>ΔT</th>
<th>ΔP</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNRM</td>
<td>0.97</td>
<td>3.93</td>
</tr>
<tr>
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Figure 6: Projection of SL from 1960 to 2080 in the Niger Delta based on IPCC emission scenario (A2)
Changes in the Sea Level between the Historical and the 21°C

Having analyzed the mean annual SL and its likely effects, it is important to examine precisely the changes that have taken place in order to understand how vulnerable the Niger Delta region is with regard to SLR in the future. The study calculated the differences in mean annual SL between the 21°C runs and the historical period (Figure 7). The results show an overall increase in SLR intensities for the two time periods.

The changes came to be more noticeable with HadGEM2-ES models having greater increase when compared with the other GCMs. PSL-CM5A-LR model underestimates the SLR in the Niger Delta, the result
indicating a decreasing trend over the delta for the two time periods. The differences noticed between the GCMs might be as a result of uncertainty associated with climate models. Overall the results obtained from the changes show that the Niger Delta is likely to be vulnerable to SLR as Ogba and Utang [39] noticed. The implication of the projected SLR will have a substantial impact on the Niger Delta coast because of the concentration of poor population in possibly dangerous area as reported by [40-42]. This result confirms IPCC report on impacts, adaptation and vulnerability; the report emphasis is on the great socio-economic and physical vulnerability of the coastal areas.

**Discussion**

**Implications of the results for the future climate change in the Niger Delta**

Figures 1, 4 to 7 respectively provide a continental overview of simulated changes in T, P and SL frequencies for Niger Delta region. The results are based on IPCC Ar4 and Ar5 GCMs, employing model outputs of the seven GCMs and the baseline use scenario for the time slices of the 1960-2080. Based on the projected value of climatic

![Graph showing sea level changes](image-url)
variables simulated in the study over the Niger Delta and its predicted implications, it is obvious that the future picture for the Niger Delta’s climate is increasingly clear. The projected increase of this climate variable confirms the report of IPCC, [4] and Ike and Emaziye, [34] in this region. This will cause the Niger Delta coastal zone, water resources, water quality, agricultural land, livestock and fisheries to be possibly exposed to vulnerability Bariweni, [45] also highlighted. This is possible that the region might experience more extreme floods. Based on this, Nigeria’s GDP might be impacted significantly since the main sources of revenue for the Nigerian state are the oil and gas from the region. The projected increase in SLR is disturbing as recent study by Nicholls and Mimura [44] highlights the implication of a 1m rise in SLR in this region. Reflecting that most of the land in the Niger Delta might be lost along with economic activities especially infrastructure connected to the oil industry. All these would threaten the livelihood and development options of the Niger Delta and the country as a whole as reflected by Boko et al. [40] on the implication of SLR in low land areas, although these study primarily show the hydrological sensitivity to climate change within a reasonable interval.

Socio-Economic Implications

Based on the projected increase in SLs above, it is worth noting that the present and future climate of Niger Delta coast constitutes a serious danger. The effects would be expected to have numerous influences, particularly on coastal systems such as increase flood risk and potential loss of lives, increased coastal erosion, changes in surface water quality and ground water characteristics and many others. Their well-being and resilience depends on the efficiency of natural and anthropogenic shoreline flood defense, i.e., the ability of the coastal region to act as a buffer and absorb ocean energy through multifaceted wave shoaling and breaking processes [45, 46]. Economically, the livelihood of the Niger Delta population spins around fisheries, trading including farming. The percentage of persons effectively engaged in fishery activities ranged from 45-50%, although inhabitants of some of the coastal communities are 100% into fisheries as reported in Ojile et al. [47]. Hence, going by the scientific information display by the GCMs in the paper (figure 7) it is most likely that the communities living in the Niger Delta region are at risk of being vulnerable to SLR [30, 47-52]. Thus, the simulations testify that the present and the future population of the Delta are vulnerable to SLR. The consequence of this might contribute in rendering a large part of Niger Delta coastal region exposed to recurrent flood hazard. These findings emphasis the need to timely develop and implement appropriate adaptation measures in this region.

Conclusion

Studies have shown that atmospheric forcing resolution is analytical for the predictive skill of ocean models Michalis et al. [46]. The present study is based on GCMs from IPCC Ar4 and Ar5 under A2 emission scenario. The models have displayed a wide range of performance skills in reproducing the current (1960–2080) observed the presents and the future changes in T, P and SL over the Niger Delta region. The results have exhibited that not all GCMs are able to provide an equally accurate description of the present climate [53]. The use of different GCM data give confidence to the user to obtain better results and to assess the uncertainties linked with different GCMs [54, 55]. Although, the results revealed that projected climate change effects include an increase in T, P and SL over the region, in some of the models decreases were observed. The results presented here are subject to uncertainties inherent in any scenario-based analysis. However, besides the limitations and assumptions, the results of this study provide relevant and useful information for investigating the combined effects of climate change over the Niger Delta region. Considering these limitations, it is established that observing separate and combined effects of climate change is useful for decision makers in order to prepare and adopt strategies to mitigate the negative effects of climate change in the Niger Delta region of Nigeria.

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