GIS Modeling of Flooding Exposure in Nigerian Coastal Areas from Sea Level Rise

John Onwuteaka Ph.D
Department of Environmental and Applied Biology, Rivers State University of Science and Technology, Port Harcourt, Rivers State. Nigeria

Abstract
An SRTM elevation dataset and GIS grid analysis was used to analyze the number of local government areas that would be affected by severe flooding from sea level rise (SLR) of 1meter, 2meter, 3meter, 4meter, 5meter and an extreme 13meters. The GIS overlay of the Political boundaries of the Rivers State in the Niger Delta showed a minimum of 10 LGAs for a 1meter rise in SL and a maximum of 22 out of the 23 local government areas for 13 meter SLR. In all the scenarios developed only Omuma local government was not affected by model output. The relative proportion of land space to be displaced is highest in Degema local government area ranging from 392 sq km at 1meter SLR to 1154 sqkm at 13meter SLR. A number of strategic options including further scientific studies, legal and policy developments are presented as essential steps to actions that will facilitate varying layers of protection, adaptation and contingency planning in worse-case scenarios.
Key words: GIS Modeling, Flooding, Sea Level Rise

Introduction

The climate of coastal areas in the Niger Delta is influenced by large ocean-atmosphere interactions such as trade winds as well as sea-level rise. These climate characteristics, combined with their particular socioeconomic situations, make the coastal areas of the Niger Delta some of the most vulnerable areas to climate change in the world. One anticipated impact of climate change is sea level rise resulting from melting of the world's major ice sheets and temperate glaciers. Various estimates have projected the severity and pace of sea level rise around the globe. For example, the recently released Intergovernmental Panel on Climate Change (IPCC) report (IPCC 2007) provided an upper-level estimate of 26-59 cm of sea level rise over the next century. The U.S. Geological Survey (2000) has projected future sea level rise of approximately 80 meters if the entirety of the Greenland and Antarctic ice sheets were to melt. Sea level rise has the potential to displace large populations that currently live in proximity to the coast. According to one estimate, 10% of the world's population lives in coastal areas 10 meters or less above sea level (McGranahan, Balk, and Anderson 2007).

The various threats on the coastal areas from increasing sea level rise (SLR) include coastal flooding and erosion (French et al 1995). These physical threats are expected to be more common because structurally, the Niger Delta is characterized by lowlands. Except in the Northeast, where it rises to 10-15 m, most of the delta is less than 6 m above sea level (Ashton-Jones, 1998). Therefore, the Niger Delta is potentially vulnerable to any rise in sea level. This submission is strengthened by two major factors: the region's lowlands, and the fact that the delta is literally dissected by estuaries, rivers, creeks, creeklets and streams. The myriad of inland surface waters and the boundary coastal shelf means multiple flooding sources to the surrounding low-level flatlands. Other physical impacts of SLR include increase of salinity and estuaries and aquifers, alteration of tidal ranges in rivers, change of location where rivers deposit sediment, increase of height of waves and decrease in amount of sunlight reaching the bottom. The ecological consequences would include loss of wetlands, coastal vegetation and habitats, salt intrusion into groundwater systems, loss of cultivatable land, socioeconomic and legal implications for coastal area development.

In the present study, Rivers State, one of the coastal states in the Niger Delta was used as a case study to map and provide visualizations depicting projected sea level rise on the coastal landscape. Geographic Information System, an earth process modeling and data visualization tool critical to understanding the processes associated with climate change, was utilized to analyze climate modeling results in conjunction with land use datasets in order to assess the impacts of climate change on political and land use components of the State. This study provides an initial assessment of vulnerability of coastal states to sea-level rise. The scenarios developed are to help decision-makers, and other concerned stakeholders to develop appropriate public policies and land-use planning measures.

Study Area

The study area is Rivers State, a coastal state situated in the southern part of Nigeria(Fig 3.1). The Atlantic Ocean runs along the southern area of the State. The state has twenty three local government areas (LGAs). Many of the local government areas are connected by rivers and creeks that originate from the Bonny and New

Calabar Rivers within the central area of the state; the Orashi and the Sombriero Rivers to the West and Imo River at the eastern portion of the State.

Fig 3.1 Rivers State showing the 23 Local Governemt Areas

Methodology

A GIS framework was setup in ESRI Arc GIS as the primary analysis software. The sea level rise model was developed using elevation of the coastal area relative to mean sea level and connectivity to the ocean of the existing estuaries. The model used a digital elevation model (DEM) acquired by the shuttle radar topography mission (SRTM) to identify the extent and distribution of the high to low-risk areas relative to elevation. An equal grid of elevation values was used to identify all grid cells that would become inundated based on alternative sea level rise scenarios of 1 2,3, 4, 5, and 13 meters.

To be able to calculate the surface area potentially capable of receiving flooding impact, each local government area was converted into a grid surface (Fig 3.2) made up of 1 km x 1km grid. Each 1km^2 surface was overlaid over the inundation zones and the spatial exposure of land areas and local government area affected was calculated under different sea rise scenarios.

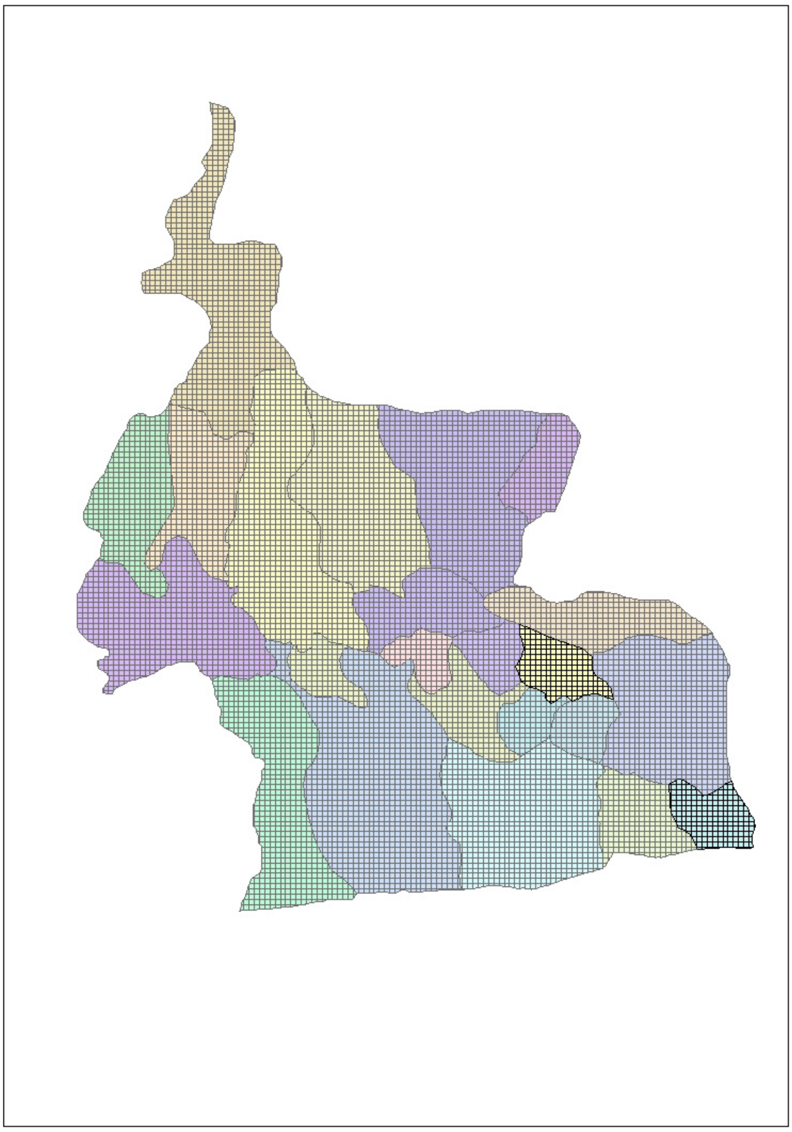

Fig 3.2 Rivers State showing 1kmx1km grid for each local government area

A one way ANOVA was used to measure the variability of the potentially flooded area among the local government areas. A Mann-Whitney U test was applied to analyze the data in order to ignore the normality assumptions. A categorical map analysis of incidence relationship between potentially flooded area and total area of each local government was used to illustrate deviations of area impact of flooding for each sea level rise value per local government area designated as:

Potentially Flooding Area (PFA =Grid no of 1 kmx1km)/Total Area (TA) of the Local Government *100%

A GIS categorical reclassification procedure of the value of the PFA/TA for each local government was used to provide a weighted ranking of priority local governments.

Results

Local Governments and Sea Level Rise

The graphical analyses of local government areas potentially susceptible to flooding impact from different sea level rise scenarios is shown in Fig. 3.3 while the spatial analysis is illustrated in figs. 3.4 -3.5.

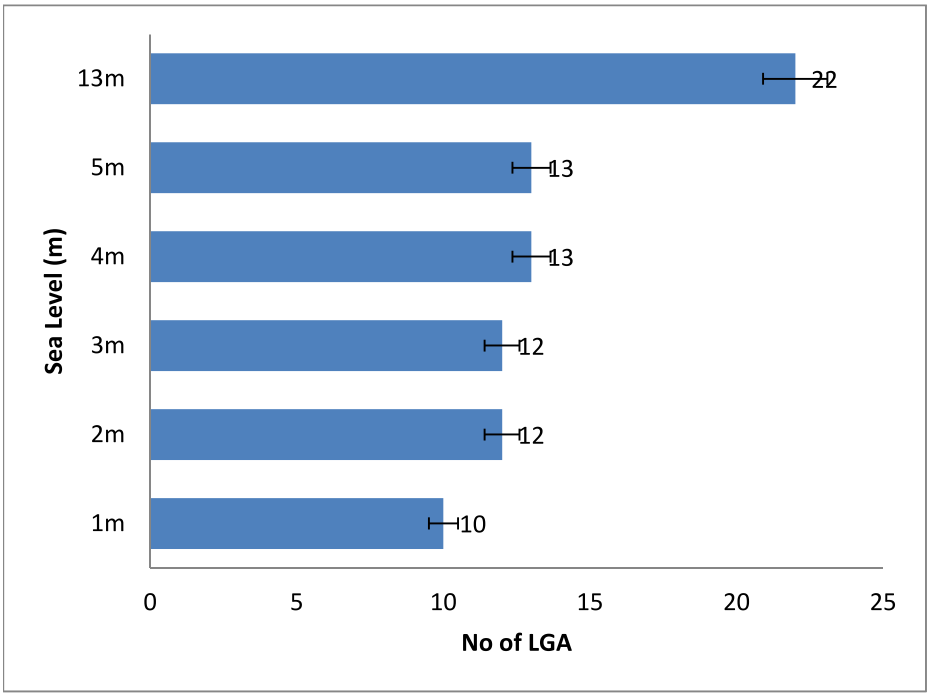

Fig 3.3 Number of local government areas potentially susceptible to different levels of sea rise

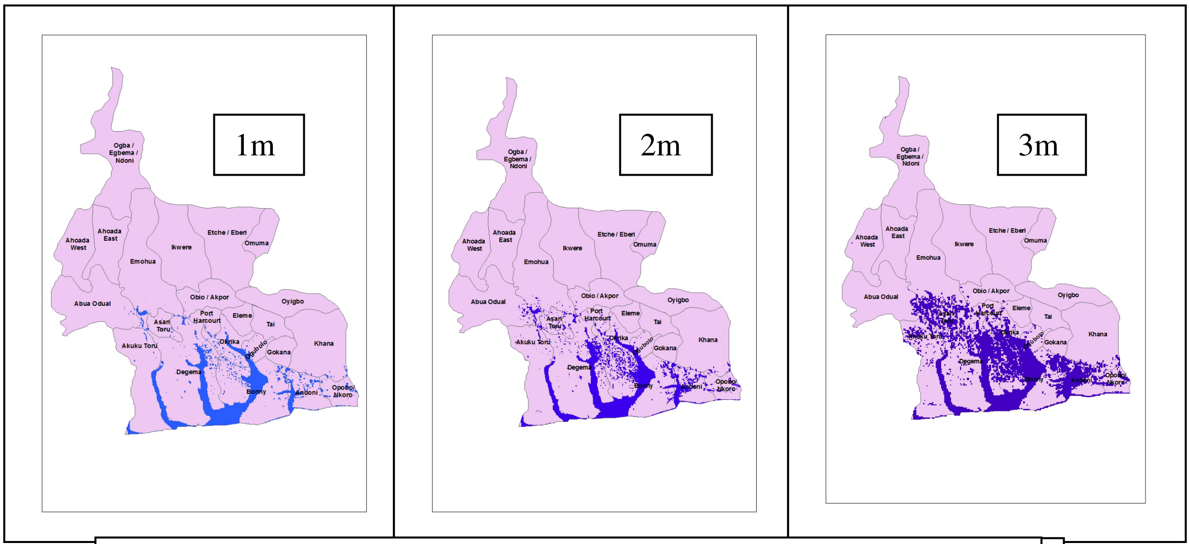

Fig 3.4. Potential LGA areas of Flooding for 1m, 2m and 3m Sea rise

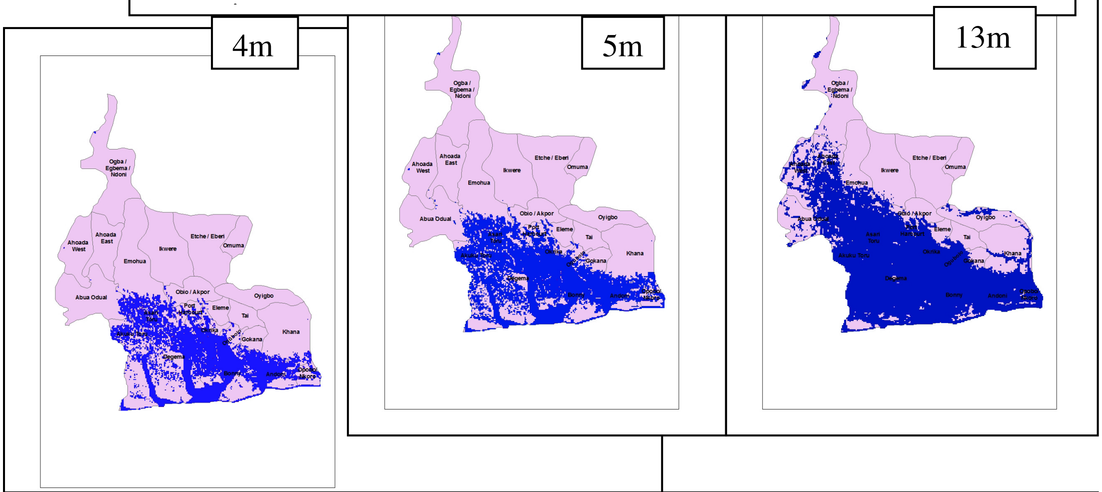

Fig 3.5 Potential LGA areas of flooding for 4m, 5m and 13m sea rise scenarios

The results indicate that out of a total of 23 LGAs, a significant number of ten (10) local government areas are likely to be affected by flood at 1m sea level rise. These are Akuku-Toru, Andoni, Asari-Toru, Bonny, Degema, Emohua, Ogu-Bolo, Okirika, Opobo-Nkoro and Port Harcourt. Five of these Local Government Areas namely Bonny, Andoni, Akuku Toru, Degema, and Opobo-Nkoro are coastal communities sharing a common boundary with the oceanic waters of the Gulf of Guinea. The five remaining local governments are located from the coast variously at 26 km for Ogu-Bolo, 27 km for Okirika, 38km for Asari-Toru, 44km for Port Harcourt and 53 km for Emohua.

In Figs 3.4, the potentially flood affected local government areas at 2m sea level rise scenario were observed to increase to 12 from 10 with the addition of Abua-Odual which is approximately 45km from the coast; and Obio-Akpor approximately 50 km from the coast. At 3m sea level rise scenario, the potential number of local government areas affected remains at twelve as observed for the 2m sea level rise scenario.

In Figs 3.5, the 4m and 5m sea level rise scenarios show the potential number of local government areas likely to be flooded to have increased from twelve to thirteen (13) with the addition of the Khana LGA located on the eastern flank, approximately 11 km from the coast.

At the extreme scenario of 13m sea level rise, the results indicate potential flooding in 22 out of 23 local government areas. The additional nine local government areas are located from the coast variously at 20km for Gokana; 34km for Tai; 37km for Eleme; 40km for Oyigbo; 59km for Etche; 62 km for Ikwerre; 65km for Ahoada West and 66km for Ahoada East.

Frequency of Impact

Figure 3.6 shows the chart of observations of the number of occurrences of potential flooding for the various scenarios for each local government area. Out of twenty-three local government areas, ten LGAs would receive flooding six times for all possible scenarios in this study. Four of these local government areas such as Bonny, Opobo-Nkoro, Degema, and Akuku-Toru are in close proximity to the ocean. The remaining six LGAs are those dispersed between twenty-six kilometers (26km) and fifty-five kilometers (55km) from the coastal area.

For all possible scenarios in this study, two local government areas namely Abua-Odual and Obio-Akpor would experience recurrent potential flooding five times. Khana local government area would experience potential flooding only three times for all possible scenarios modeled in this study. For the remaining nine local government areas of Ahoada East, Ahoada West, Eleme, Etche-Eberi, Gokana, Ikwerre, Ogba-Egbema, Oyigbo and Tai, flooding would occur once for all the scenarios in this study. No flooding is observed for Omuma local government area for all the scenarios generated in this study.

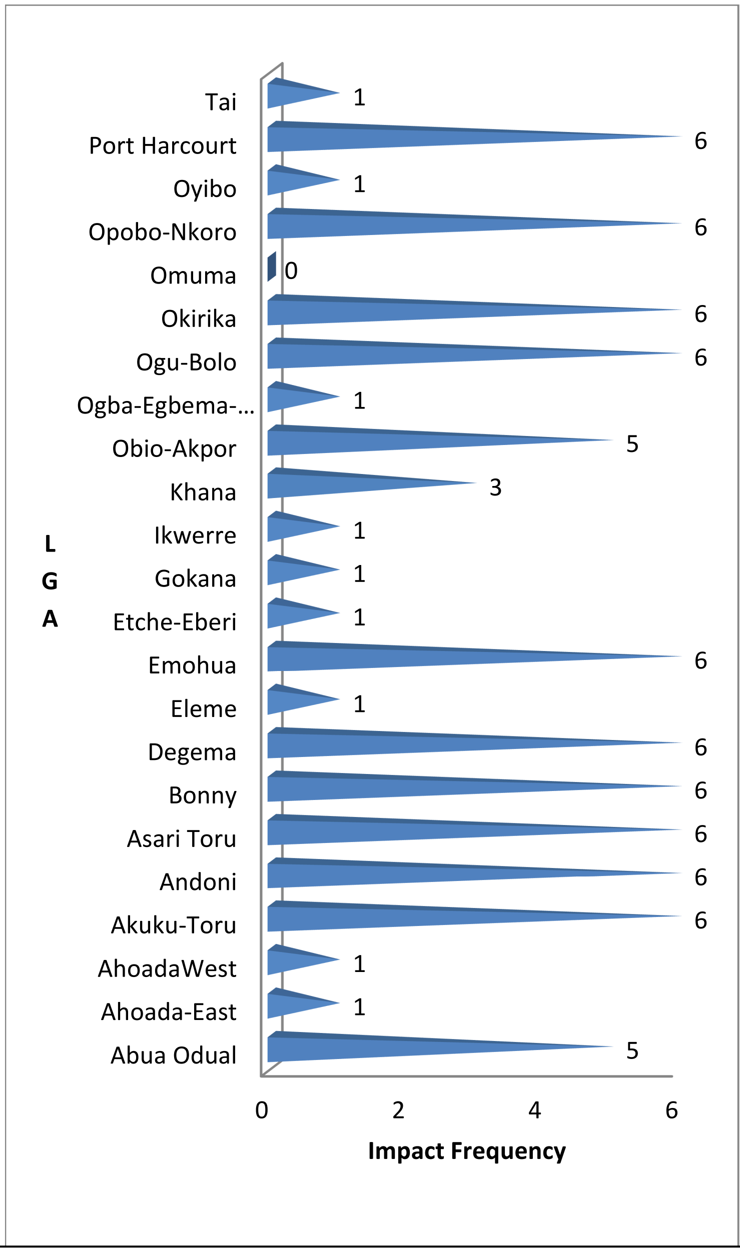

Fig 3.6 Frequency of Potential Flooding Impact on local government areas from sea level rise scenarios of 1m, 2m, 3m, 4m, 5m and 13m

Total Flooded Area

Figure 3.7shows the land area to be displaced for each local government area and for each SLR scenario. The chart shows the highest land areas above 200 sq km to be flooded in decreasing order are in Degema, Bonny and Akuku-Toru and Andoni local government areas. These are four LGAs that are in direct contact with the sea. For all the other LGAs only in the 13 m scenario are lands above 200sq km displaced in Abua-Odual, Ahoada-East and Ahoada-West, Emuoha, Khana and Okirika local government areas. The total area to be flooded would displace 1283 km^2 in SLR of 1 meter, 1767 km^2 in 2 meters of SLR scenario; 2351 km^2in SLR of 3meters scenario; 2990km^2in 4meters of SLR scenario ; 3483km^2 in 5m SLR scenario and 5893km^2in 13meters scenario.

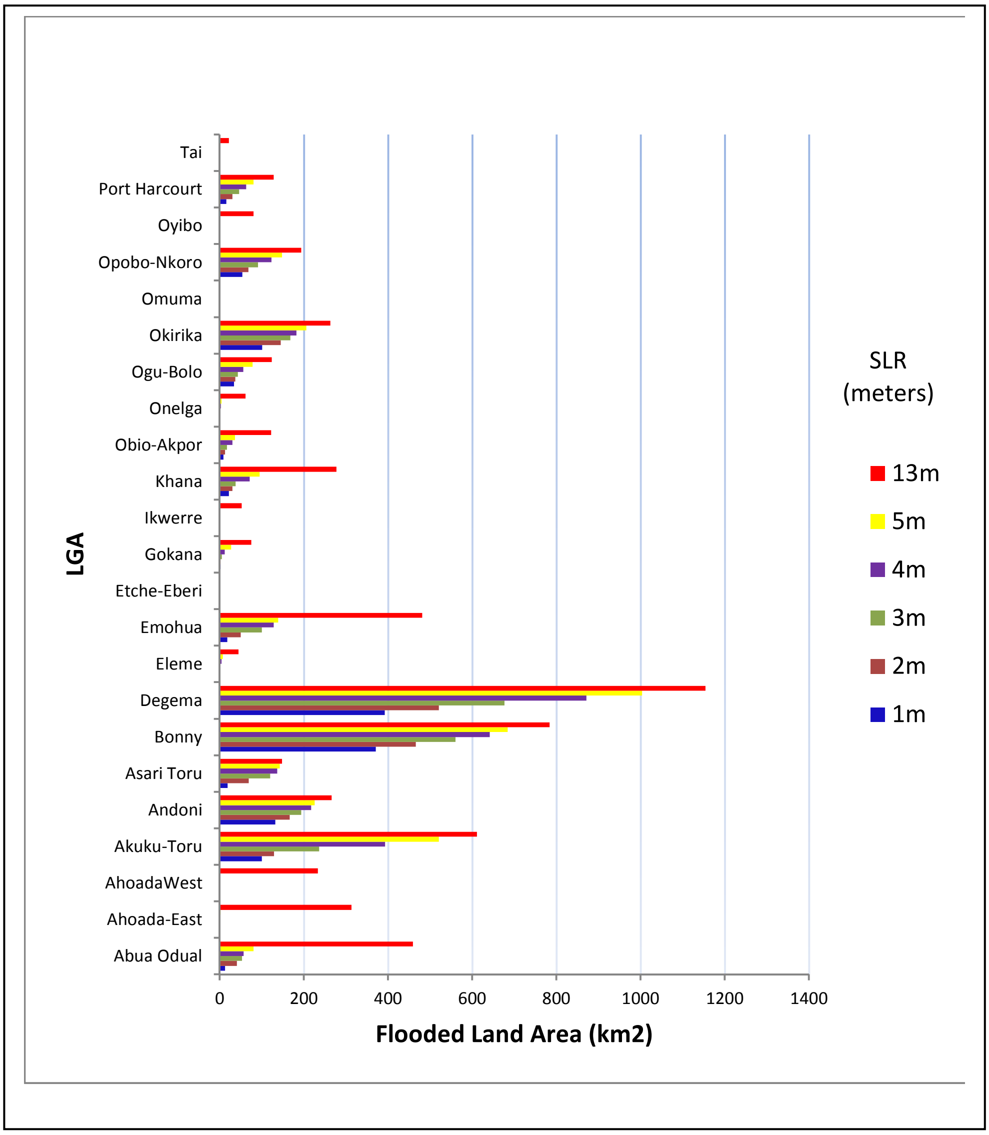

Fig.3.7 Total Land to be flooded in km^2 by SLR scenarios of 1m, 2m, 3m, 4m, 5m, and 13m for 22 local government areas of Rivers State

Relative Flooded Land Area

Figures3.8-3.13shows the proportion of the land area potentially flooded in relation to the total land area of each local government area for each scenario of sea level rise. In fig 3.8, the highest proportion of land area likely to be flooded in the 1m sea level rise is observed in two local governments namely Andoni (48%) and Bonny (46%). These are followed in decreasing order by Okirika (37%), Degema (33%), Opobo-Nkoro(27.27%); Ogu-Bolo (25.56%); Akuku-Toru(14.99%); Asari-Toru(12.58%); Port Harcourt(11.85%). Five local government areas have below 5% of land area likely to be flooded and they are Khana (3.15%); Obio-Akpor (2.80%); Emuoha (2.83%); Abua-Odual(1.76%); and Gokana (1.34%).

In Fig 3.9,the highest proportion of land area likely to be flooded in the event of a 2m sea level rise has the highest occurrence in Andoni (60.14%); Bonny (58.54%); Okirika(54.3%). These are followed in decreasing order by Asari-Toru(45.70%); Degema(44.53%); Opobo(34.34%); Ogu-Bolo(27.825), Port Harcourt(22.22%)andAkuku-Toru (19.34%). Five local government areas have below 10% of land area likely to be flooded and they are Emuoha (5.63%); Abua-Odual(5.56%); Khana (4.30%); Obio-Akpor(4.05%) and Gokana (1.34%).

In Fig 3.10, the highest proportion of land area likely to be flooded in the event of a 3m sea level rise has the highest occurrence in Asari-Toru (79.475); Bonny (70.35%); Andoni (70.29%), Okirika (62.92%) and Degema (57.86%). These are followed in decreasing order by Opobo (45.96%); Akuku-Toru(35.38%); Port Harcourt (34,07%); Ogu-Bolo (32.33%) and Emuoha (11.26%). Eight Local Government areas with less than 10% of land area likely to be flooded are Abua-Odual(7.19%); Khana (5.44%); Obio-Akpor (5.30%); Gokana 93.36%); Ahoada –West (0.23%); Eleme (0.65%) and Onelga (0.12%).

In Fig 3.11, the highest proportion of relative land area likely to be flooded in the event of a 4m sea level rise have the highest occurrence in Asari-Toru (90.73%); Bonny (80.65%); Andoni (78.62%); degema (74.44%); Okirika (68.16%) Opobo (62.12%); Akuku-Toru (58.92%). These are followed in decreasing order by Port Harcourt (46.67%); Ogu-Bolo (42.11%); and Emuoha(14.41%). Six Local Government areas with equal to or less than 10% of land area likely to be flooded are khana(10.17%); Obio-Akpor (9.35%); Gokana (8.05%); Abua-Odual (7.73%); Onelga (0.35%); and Ahoada (0.23%).

In Fig 3.12the highest proportion of relative land area likely to be flooded in the event of a 5m sea level rise have the highest occurrence in Asari-Toru (94.70%); Bonny (85.93%); Degema (85.81%); Andoni (81.88%); Akuku-Toru(78.11%); Okirika (77.15%); Opobo (74.75%); Port Harcourt (59.26%); and Ogu-Bolo (58.65%). These are followed in decreasing order by Gokana(18.13%); Emuoha (15.65%); Khana (13.61%); Obio-Akpor (11.21%) and Abua (10.85%). Six Local Government areas with less than 10% of land area likely to be flooded are Eleme(4.58%); Tai(0.51%); Onelga(0.46%); Ahoada East(0.46%); Ahoada West (0.23%) and Ikwerre (0.14%).

In Fig 3.13the highest proportion of relative land area likely to be flooded in the event of a 13m sea level rise have the highest occurrence in decreasing order in Degema (98.63%); Okirika (98.50%); Bonny(98.49%); Asari-Toru(98.01%); Opobo (97.98%); Andoni(96.38%); Port Harcourt(94.81%); Ogu-Bolo (93.23%); Akuku-Toru(91.60%); Ahoada East (72.29%); Abua-Odual (62.28%); Emuoha (54.17%); Ahoada West (53.20%); and Gokana (50.34%). These are followed in decreasing order by Khana(39.68%); Obio-Akpor (38.01%); Eleme (29.41%); Oyibo (20.83%) and Tai (11.17%).Three Local Government areas with less than 10% of land area likely to be flooded are Ikwerre (7.12%); Onelga (7.08%) and Etche-Eberi(0.13%).

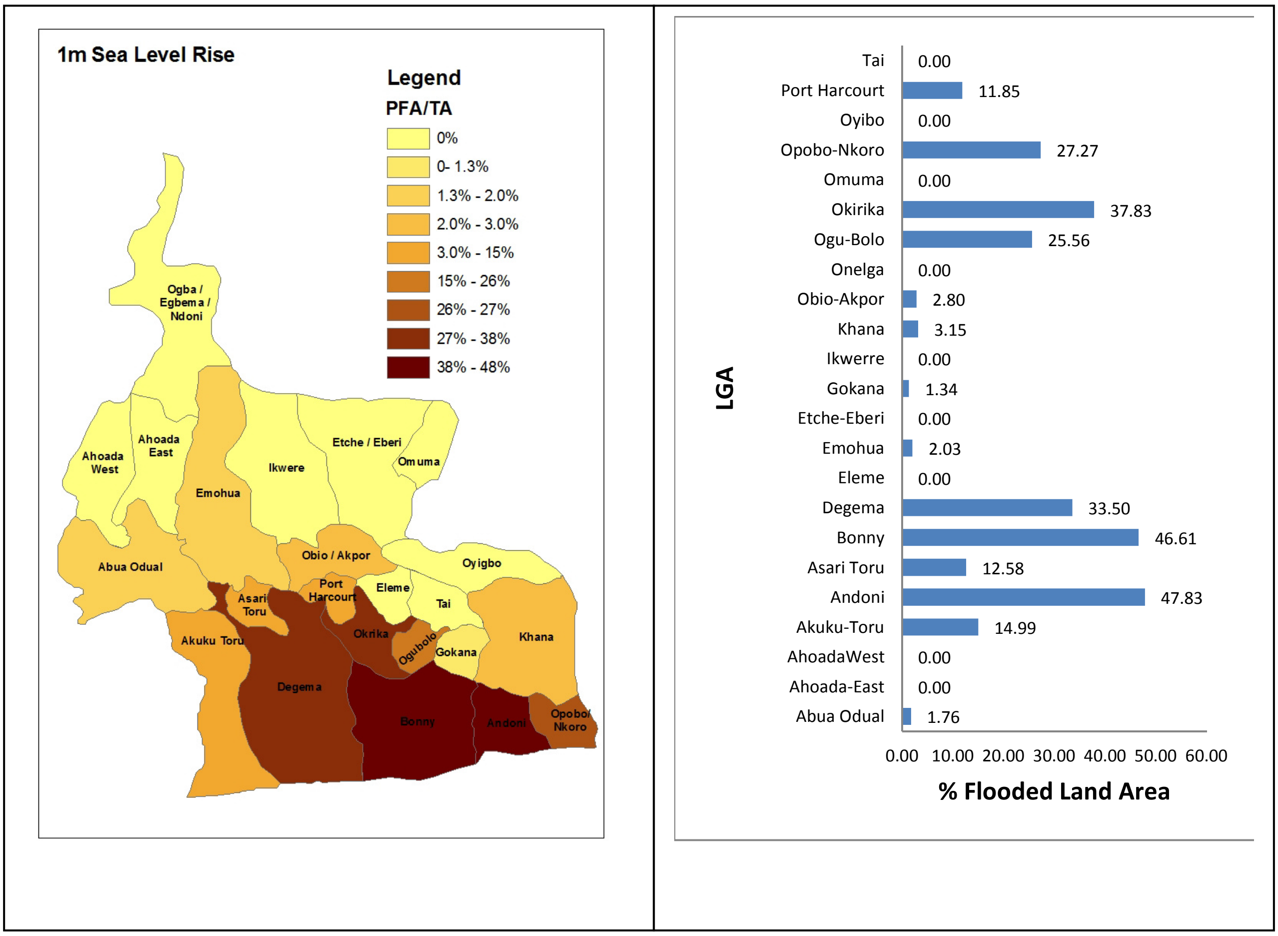

Fig 3.8. Relative Land Area Flooded as a result of 1m Sea Level Rise (Relative land Area = Flooded Area/Total Area of LGA)

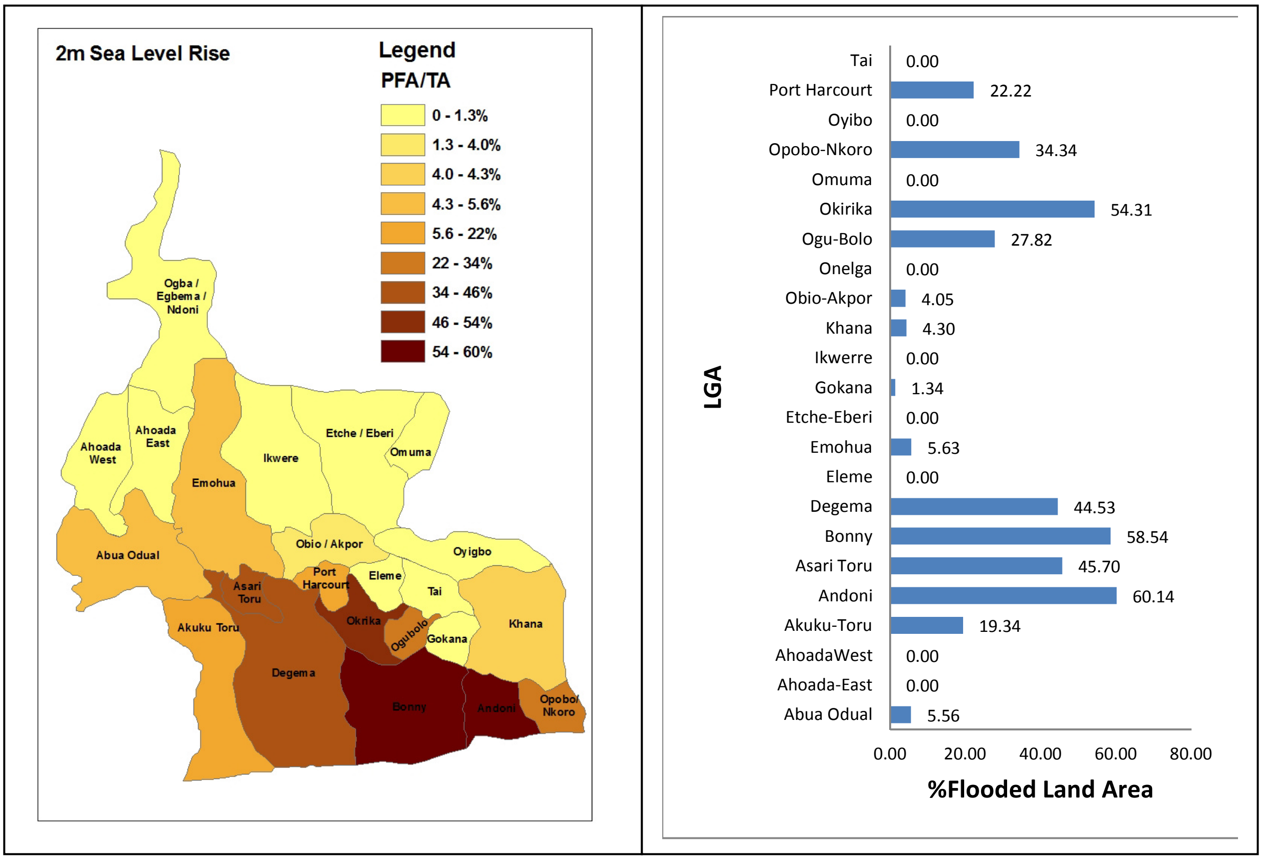

Fig 3.9 Relative Land Area Flooded as a result of 2m Sea Level Rise (Relative land Area = Flooded Area/Total Area of LGA)

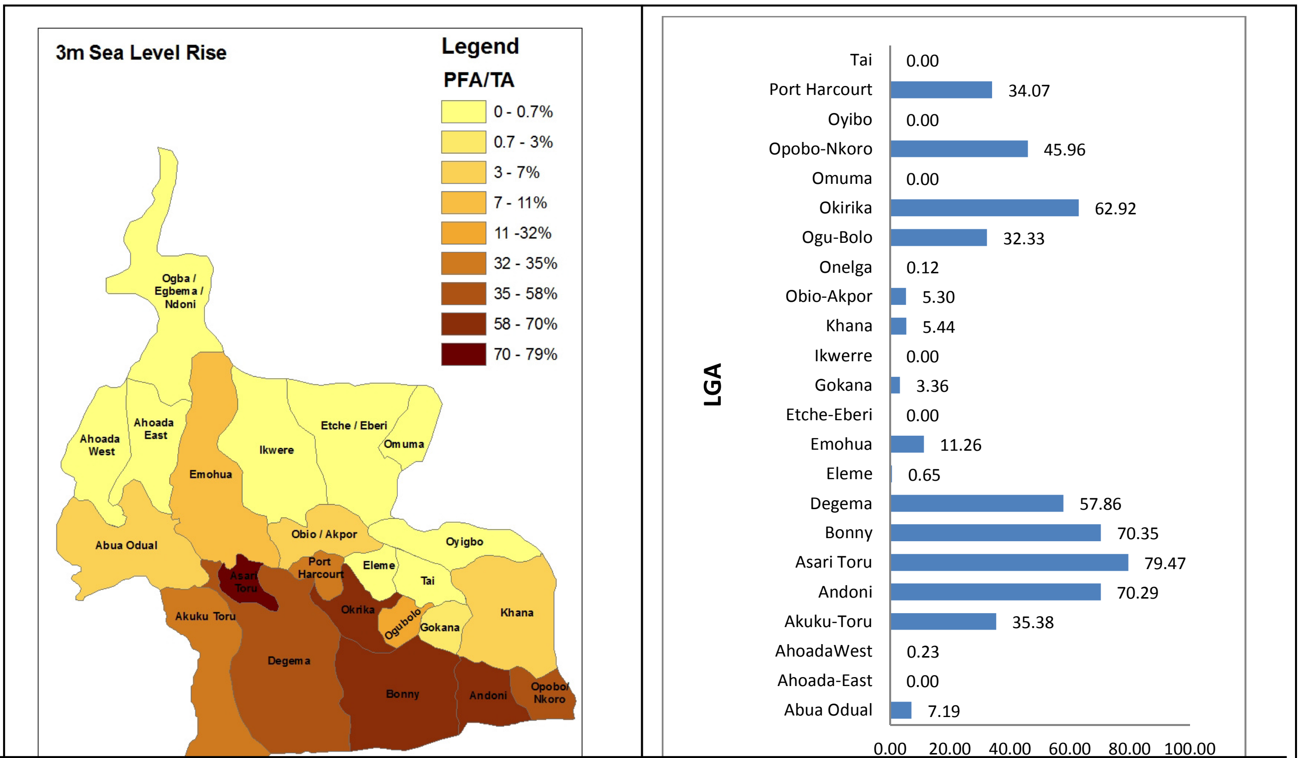

Fig 3.10. Relative Land Area Flooded as a result of 3m Sea Level Rise (Relative land Area = Flooded Area/Total Area of LGA)

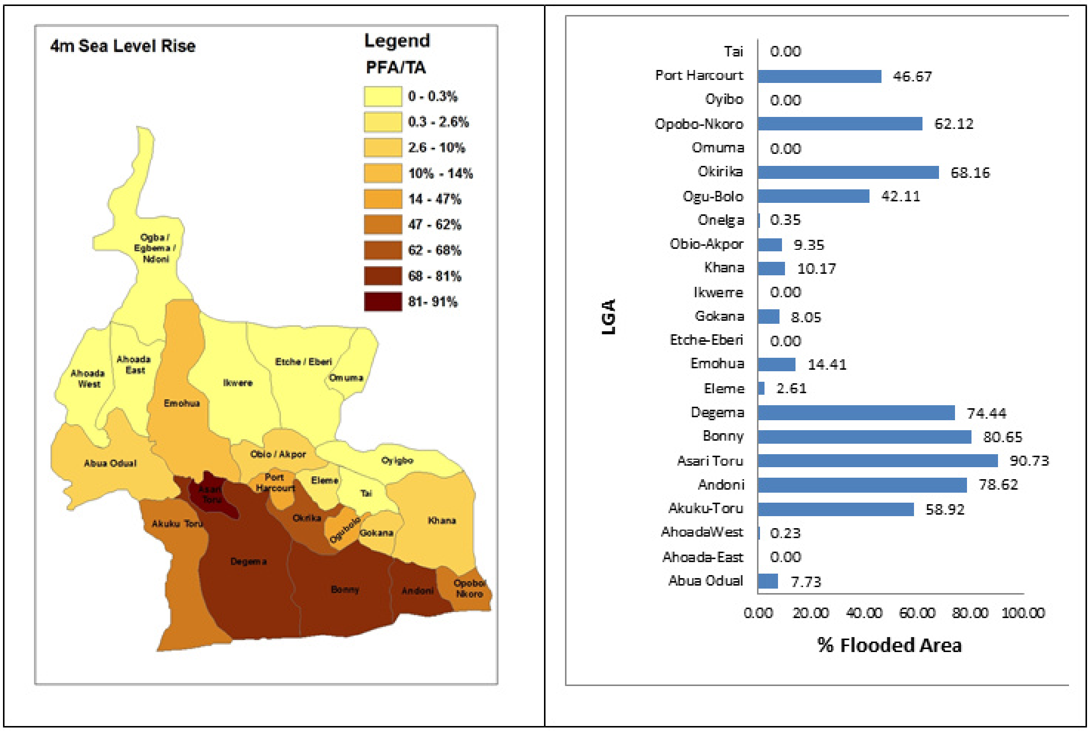

Fig 3.11. Relative Land Area Flooded as a result of 4m Sea Level Rise (Relative land Area = Flooded Area/Total Area of LGA)

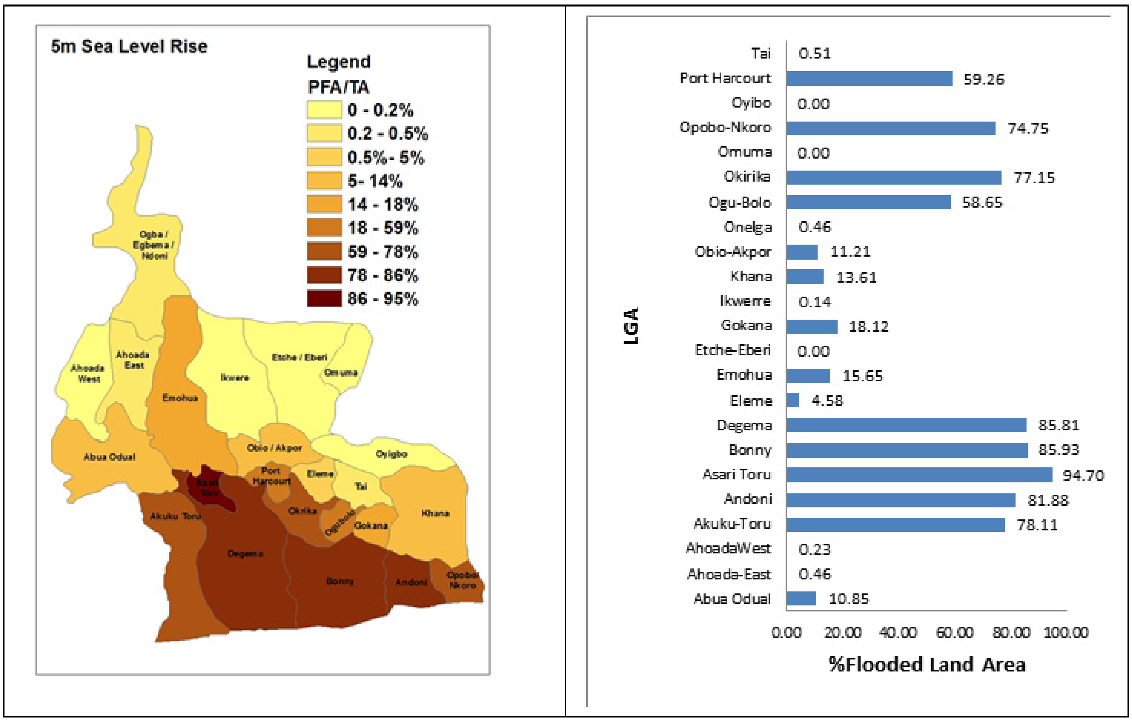

Fig 3.12. Relative Land Area Flooded as a result of 5m Sea Level Rise (Relative land Area = Flooded Area/Total Area of LGA)

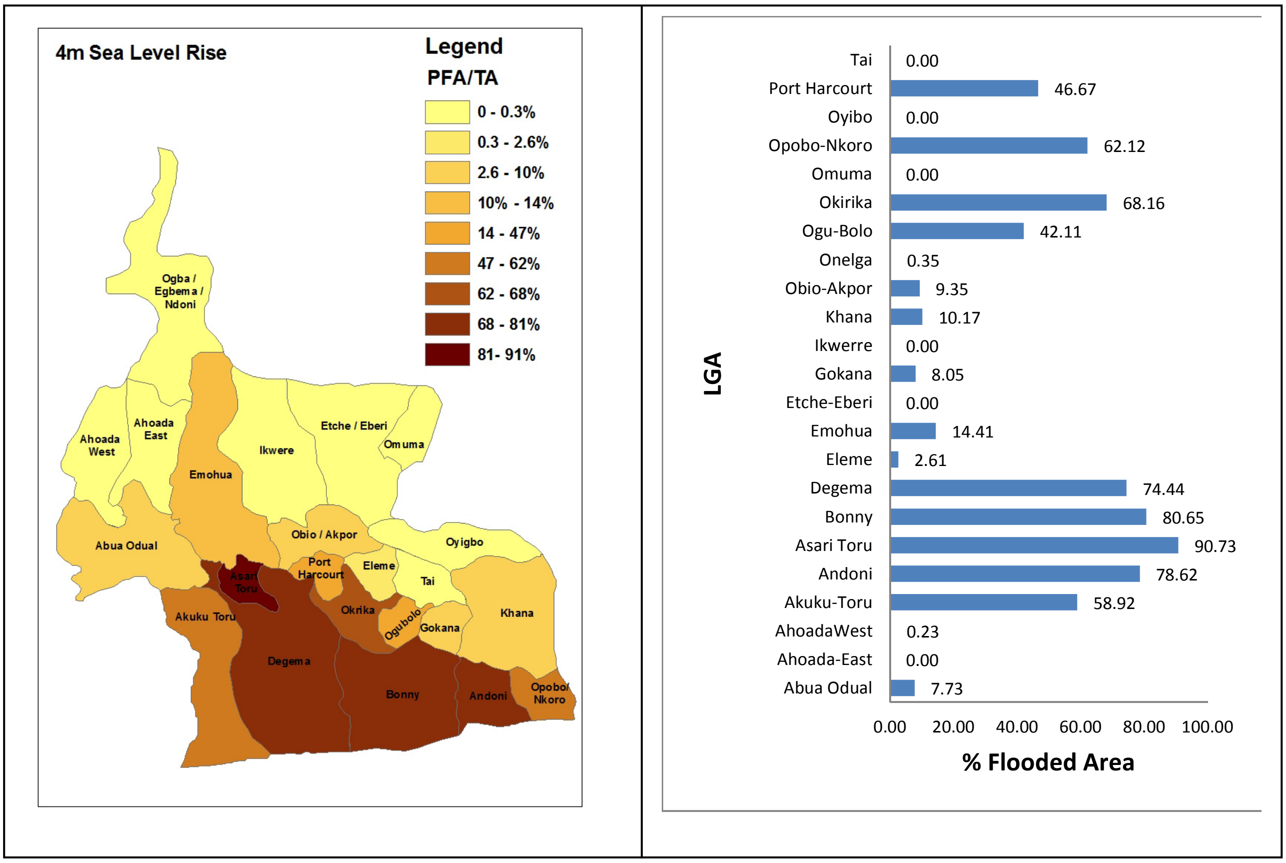

Fig 3.13. Relative Land Area Flooded as a result of 13m Sea Level Rise (Relative land Area = Flooded Area/Total Area of LGA)

4.0 Discussion

The study provides modeling evidence that a range of ten(10) to thirteen (13) local government areas would likely be affected by flooding and its associated impacts from SLR of between 1meters and 5meters respectively. In the extreme case of SLR of 13meters twenty two (22) out of the 23 local governments would be affected by flooding with the exception of Omuma local government. In these LGAs, significant differences are observed in the spatial area in square kilometres that will experience flooding in relation to the scenarios in this paper as shown in fig 4.1. These significant differences are observed between local government areas in direct proximity with the sea such as Bonny, Degema, and Akuku-Toru. There are however no significant differences between local governments such as Akuku-Toru, Andoni and Opobo that are also in direct proximity with the sea neither is there a significant difference with LGAs more than 30 kilometres from the coast such as Asari-Toru, Okirika Emouha, Ahoada-East, Ahoada-West, Gokana, Obio-Apkor, and Ogu-Bolo. These observations provide the basis for developing a variety of responses for each local government area based on the peculiar land use features one of which is the relative land available to flooding. The relative land available (fig. 4.2) to flooding in contrast to total land flooded indicates the component of response planning that is critical which is divided into two. The first category of local government areas whose means are not significantly different have greater than 30% of land displaced by flooding in the SLR model. These are Akuku-Toru, Andoni, Asari-Toru, Bonny, Degema, Ogu-Bolo, Okirika, Opobo-Nkoro, and Port Harcourt. The second category of local government areas whose means are also not statistically different are local government areas who have less than 30% land displaced by flooding in the SLR model. These are Abua-Odual, Ahoada east, Ahoada west, Eleme, Emuoha, Gokana, Khana, Obio-Akpor, Oyibo, and Tai.

These findings provide the basis for the state and local governments to start discussions of potential responses to accelerated sea level rise. A strategy of portfolios are available for adoption beginning with state-wide scientific studies on sea level rise including shoreline initiatives; land use amendments for very low lying areas including areas experiencing subsidence. Additional options include the adoption of legal and policy perspectives that promote broad comprehensive plans to accommodate and address all aspects of SLR. This which include coastal zones, inland zones, public health, water resources, transportation and communications infrastructure, oil and gas, agriculture, ecosystems, energy and related infrastructure. The fast and emerging scenarios of the consequences of a sudden SLR of 5meters to 6meters if the stability of the West Antarctic ice sheet (WAIS) were to collapse(Mercer 1978, Vaughan and Spouge, 2002, Tol et al., 2006).support the call for immediate attention. The state and local governments should begin the development for adoption of sea level rise benchmarks that will include informed land use planning and development, adaptation strategies and appropriate management responses through public advocacy.

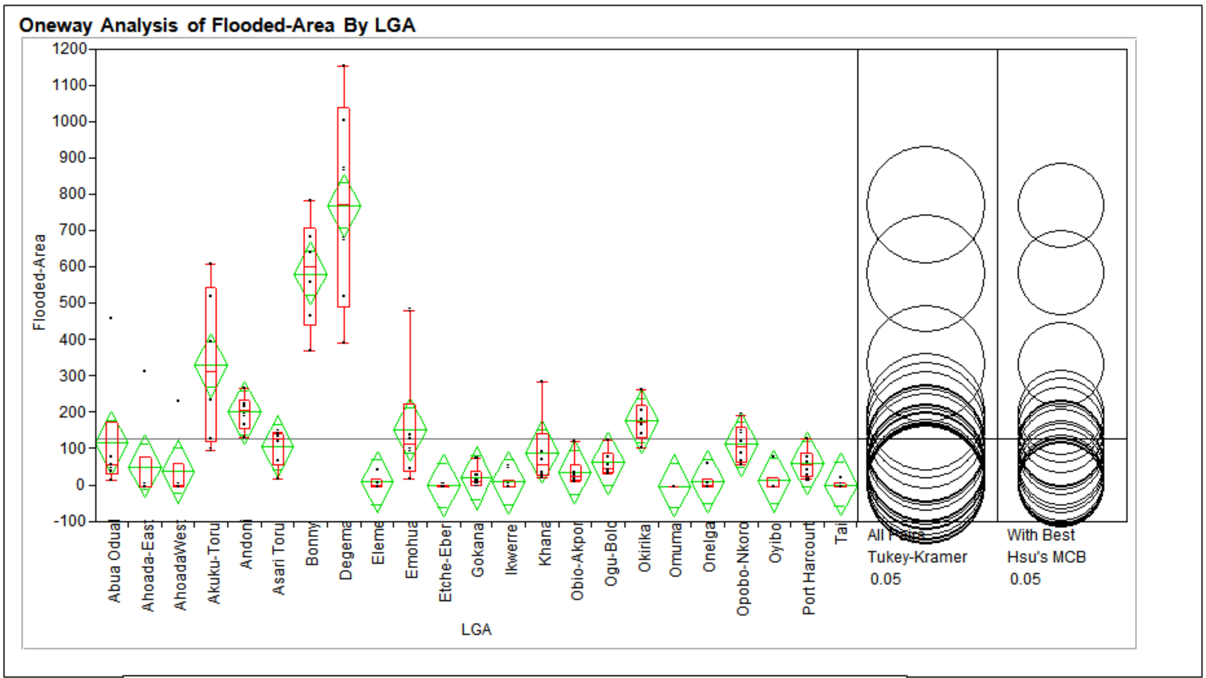

Fig 4.1 Oneway Analysis of Variance of flooded land area in Km²

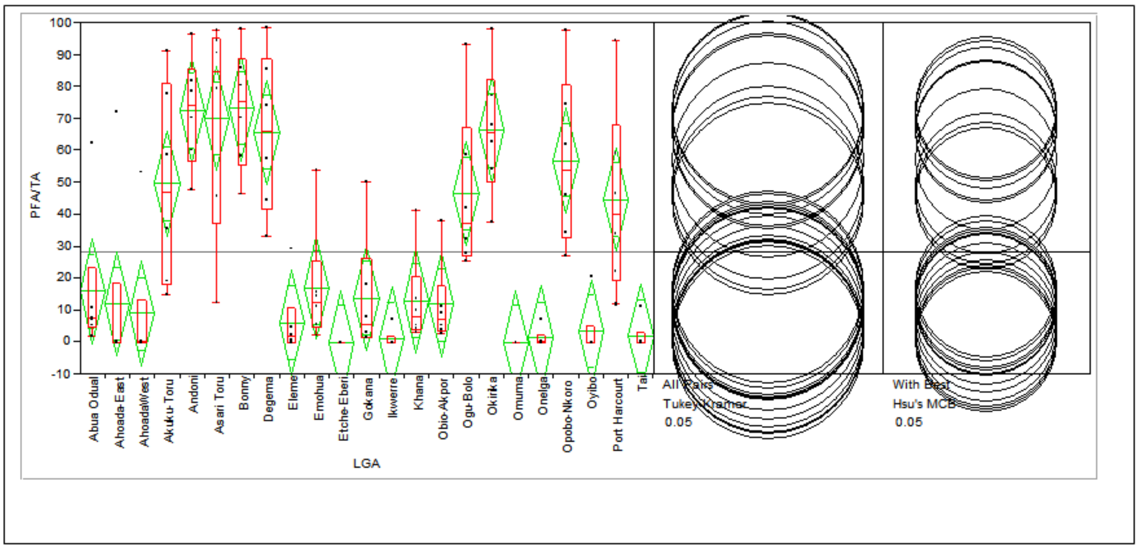

Fig 4.2 Oneway Analysis of Variance of Relative proportion of land area affected by Flooding in the SLR model (Potential Flooded Area/ Total Area)

Reference

Ashton-Jones, N. (1998). The human ecosystems of the Niger Delta-ERA handbook. Kraft books limited, Ibadan.

French G. T., Awosika, L. F. and Ibe, C. E. Sea Level rise and Nigeria (1995): Potential impacts and consequences. Journal of Coastal Research Special issue No. 14. p.224-242.

Inter-governmental Panel on Climate Change (IPCC). 2007. Climate Change 2007, the Physical Science Basis; Summary for Policymakers. Geneva: IPCC.

McGranahan, G., D. Balk, and B. Anderson. 2007. The rising tide: Assessing the risks of climate change and human settlements in low elevation coastal zones. Environment and Urbanization 19(1): 17-37.

Mercer, J.H., 1978: West Antarctic ice sheet and CO2 greenhouse effect: A threat of disaster, *Nature*, 271, 321-325.

Tol, R.S.J., Bohn, M., Downing, T.E., Guillerminet, M-L., Hiznyik, E., Kasperson, R.,Lonsdale, K., Mays, C., Nicholls, R.J., Olsthoorn, A.A., Pfeifle, G., Poumadere, M.,Toth, F.L. Vafeidis, N., wan der Werff, P.E., and I.H. Yetkiner, 2005: *Adaptation toFive Meters Sea Level Rise*, mimeo.

United States. Geological Survey (USGS). 2000. Sea Level and Climate, Fact Sheet No. 2. Washington DC: USGS. Available online.

Vaughan, D.G., and J.R. Spouge, 2002: Risk estimation of collapse of the West Antarctic ice sheet, *Climatic Change*, 52, 65-91.