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Modeling The Effects Sea Level Rise On Flooding In The Lower Niger River

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MODELING THE EFFECTS SEA LEVEL RISE ON FLOODING IN THE LOWER NIGER RIVER

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The Niger River bifurcates into the Nun and Forcados rivers as it flows through the Lower Niger delta; with the Forcados River taking 46% of the discharge and the Nun River taking 54%. Within the last fifteen years the Niger delta coastal zone has experienced peak floods between September and October due to intense rains from upstream. Many studies including the United Nations Framework on Convention on Climate Change (UNFCCC) reports, indicate that the Niger delta region could be inundated with water due to the effects of climate change. According to local experts, the Niger delta is subsiding at over 25mm/annum; a situation that can exacerbate the effects of flooding and inundation in the area. 1D and 1D/2D hydrodynamic Sobek models of flooding in the Niger River were set up with discharge data as upstream boundary conditions and tidal water level data as downstream boundary conditions. The models were run for the years 1998, 2005, 2006, and 2007. The data for 1998, 2006 and 2007 were flooding data while 2005 data was normal flow data. The boundary conditions were varied downstream at the mouths of rivers Forcados and Nun using sea level rise (SLR) values adopted from Rhamstorf predicted values. The simulations were projected for the years 2030 and 2050. Five scenarios were set up to check for increase in flooding extent, extension of flooding time and change in water depth. The results showed that SLR will not increase the lateral extent of flooded areas from both Nun and Forcados rivers, but will cause more areas to be flooded upstream. There will also be increase in water depth in areas downstream of the Forcados River which will be further increased by land subsidence.

1 INTRODUCTION

Coastal areas are exposed to many types of flooding including: river flooding, urban flooding, flooding due to rise of the groundwater table and coastal flooding. Coastal flooding is caused by storms coinciding with high tides, by ocean surge, by high river flooding due to precipitation upstream (and locally), and sometimes by under ocean earth quakes known as tsunamis. Coastal flooding resulting from high river flood might occur as flash floods, or when high sea levels impede the draining of river waters into the ocean.

Flooding has many consequences such as destruction of properties/farmland, loss of human/animal life, inundation of dry land, contamination of surface water, etc. For most coastal areas the possibility of coastal flooding in a year are quite high. Rise in sea levels will increase the frequency of coastal floods and expose the population to storm waves which will be carried deeper inland (Brooks, Nicholls, Hall J, 2006).

High sea levels can cause inundation of coastal areas; e.g. parts of the Mississippi delta and Black River marshes in the US have already been submerged by rising sea levels (Titus et al, 2009). Inundation due to sea level rise (SLR) will have a great effect if areas under fresh water regimes are turned into salt water swamps or wetlands. Deltas are the most susceptible coastal areas to inundation due to their natural tendency to subside in response to reduced sediment supply from upstream. Deltas are coastal areas where sediments from rivers are delivered to the sea or ocean. They therefore expand with increased activity upstream like agriculture and land clearing which loosen the soil adding to amount of sediment transported downstream (McManus, 2002). Due to different levels of land subsidence, deltas record different and higher relative sea level rise than the global average value of 2.9mm/yr. Relative sea level rise includes land vertical movement in addition to global sea level rise values. In the US, the Gulf of Mexico records a relative sea level rise between 2-10mm/yr, and the Atlantic coast records between 2-4mm/yr (Titus et al 2009).

To model river dynamics and the effects of floods, it is important to simulate the flow process and to represent the routes used by the river, rainfall and runoff. Consequently measurements of flow discharge/water levels and topographic information are important for flood modeling. Hydrodynamic modeling of flooding in river channels and floodplains is based on the principles of continuity (which is concerned with the mass balance of the system) and momentum (which is concerned with the balancing of forces that act on the water). Depending on the flow channel properties, averaging of the flow equations is done to enable modeling in one dimension (1D, e.g. flow in a pipe, stream), two dimensions (2D, e.g. flow in a shallow lake, coastal waters), and three dimensions (3D, e.g. wind driven currents on open water). SOBEK hydrodynamic model is used in this study to model the effect of sea level rise (SLR) on flooding in the lower Niger River.

2 CASE STUDY

The Niger River is 4,184km long, with a drainage area of 2.2million km^2. It is the second largest river in Africa by discharge volume (Grijsen et al, 2013) with a basin that covers nine African countries where it supports a population of over 100million people (UNEP, 2010). At its lower end the Niger River bifurcates into the Forcados and Nun Rivers in the Niger delta; which split into a network of distributaries that flow into the Atlantic Ocean (figure 1).

For most of the lower Niger River basin, the rainy season starts in late May. As shown in figure 2, river levels in the lower Niger delta show low flow periods from December to April, a high flow period from April to October and a gradually declining flow period between October and December (NDRMP, 2004). This lower Niger delta is made of two zones which undergo different types of flooding as summarized below:

"*The coastal zone, dominated by tidal activities, extends inland to about 50km in some places and comprises largely mangrove swamps and beach ridges. This zone is subjected to diurnal inundations, strong tidal currents, waves and floods, especially during high tides. The fresh water zone on the other hand is inundated annually and exposed to strong/hydraulic currents, which erode and cause the rivers to modify and sometimes abandon their course*" (NDRMP, 2004).

The Niger delta has over 500 oil fields onshore and is thus estimated to subside by at least 25mm/yr due to oil and gas extraction (Nwilo, 1997). Subsidence naturally occurs in deltas but is further increased by oil extraction from underground sources (Ericson et al, 2006).

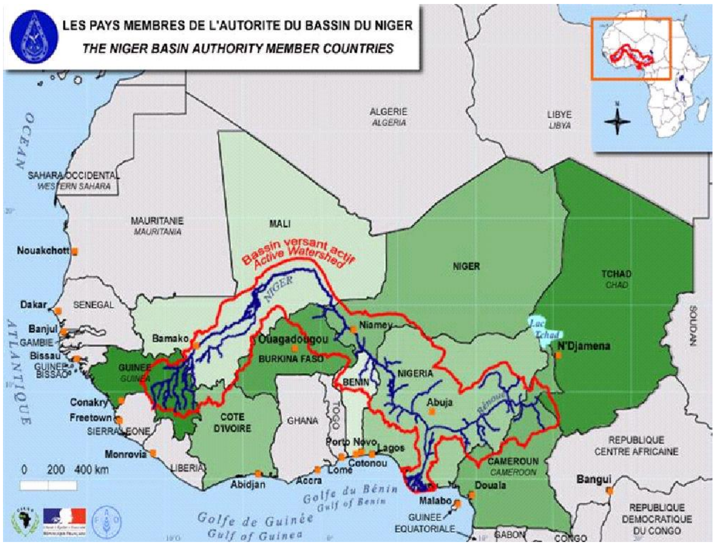

Figure 1: The Niger River basin showing the tributaries and the member countries. Retrieved on 04-02-2014, from: http://www.whycos.org/cms/sites/default/files/images/projects/Niger_basin.jpg

Within the last fifteen years, the Niger delta coastal zone has experienced peak floods between September and October every year, with the lowest lying communities having diurnal floods.This paper studies the interaction between the strong hydraulic currents flowing through the fresh water zone and the flooding in the coastal zone with future sea level rise.

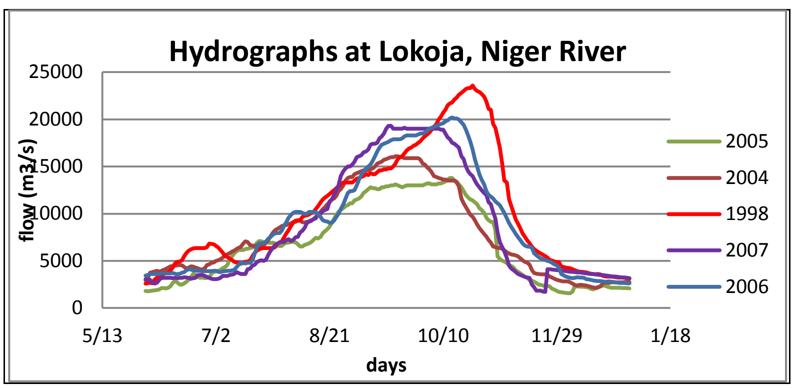

Figure 2: Hydrographs of flow at Lokoja gauging station, Nigeria.

3 METHODOLOGY

3.1 Data

SLR values are interpolated for the years 2030 and 2050 from Rhamstorf (2007) predicted values of 5.4 to 15.05mm/yr to obtain 0.12m -0.41m by 2030, and 0.23m - 0.65m by 2050. Land subsidence values of 0.75m by 2030 and 1.25m by 2050 are interpolated from Nwilo (1997) estimated subsidence level of 25mm/yr for the Niger delta.

Measured flow values at Lokoja gauging station for 1998, 2005, 2006 and 2007 are used for the upstream boundary conditions; where data for 1998, 2006 and 2007 are flood year data, and 2005 data is normal flow data (figure2). The downstream tidal boundary utilizes tidal data generated using wXtide[1] modeling software (for each year).

For the overland flow modeling, 2D grids are generated for the floodplain from the Shuttle Radar Topography Mission (SRTM) DEM. We resample the 90x 90m DEM data to a grid of 100x100m to reduce simulation time.

3.2 Model Setup

The sobek1D flow model was set up to run from June to November of each year with a simulation time step of 1 hour and initial water level of 0.1m (from readings obtained for the river Niger). The network has 48 flow cross sections with frictional values set at 0.035 for the main flow channel and 0.045 for the channel sides and calculation points[2] set for every 150m along the reach.

The 1D/2D overland flow couples the 1D flow model with a 2D grid such that there is exchange of data between the 1D channel and the 2D grid. The 2D grid represents the floodplain and overlays the 1D channel. The models were run with the boundary conditions and measured data to get the results for each event. The downstream boundary conditions are then varied to simulate the following scenarios: Sea level rise with normal year flow from upstream; Sea level rise with a flooding year flow from upstream; Sea level rise with flash flooding during high flow period; Sea level rise with subsidence and flooding year flow from upstream; Sea level rise with subsidence, and flooding year flow with flash flooding from upstream.

The scenarios are simulated using different datasets. 2006 and 2007 flood events resulted from high amounts of rainfall in the basin between July and September, therefore the data are used to simulate flooding due to rainfall/runoff. On the other hand, the 1998 flood was due to heavy rainfall modified by a dam break from upstream which caused flash flooding in the channel in October (NDRMP, 2004), therefore the data is used to simulate flash flooding during high flow. The models were calibrated using Manning's roughness coefficient (from 0.03-0.05) and verified based on flood map of 2007 from Dartmouth flood observatory (2013).

4 RESULTS AND DISCUSSION

a. 1D Flow Modeling

The 1D simulation results were used to determine the possible effect of SLR on the flood events (in the Niger River) through extension in flooding time and increase in flooding extent. It also provided the location information for 2D grids and the simulation period for the 1D/2D overland flow simulation. The simulation results of the different scenarios showed differences in flood reach and change in flood arrival time. Table1 compares the results of the 1D simulation for 2005, 2006 and 1998 for the different scenarios.

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[1]wXtide software predicts tides based on an algorithm used by the National Oceanic Service of the U.S.; it is uses 9500 stations located worldwide, a main reference station with subordinate stations whose values can be adjusted from the readings of the reference station. For the Nigerian coast, it has 21 subordinate stations and uses Takoradi Ghana station as the reference station (wXtide32, 2013).

[2] Calculations are done at each calculation point in the Sobek network. Calculation points are the numerical grids used for simulation. At these grids the continuity and momentum equations are solved using the staggered grid convention by which the water levels are defined at the calculation points and nodes and the discharges are calculated at the reaches (Sobek , 2013).

Table 1: Analysis of 1D simulation results

YEAR/ TYPE OF FLOW	DIFFERENCES IN SIMULATION RESULTS	
	NO SLR vs SLR	NO SLR vs SLR +SUBSIDENCE
2005/ normal year flow	Forcados: with SLR, flooding occurs one month earlier (July 15th instead of 20th August). Nun: flooding of coastal areas comes one month earlier (June instead of July) and upstream areas are flooded.	With SLR + subsidence, floods occur much earlier (first week of July) in both Forcados and Nun rivers.
2006/ flood year flow	With SLR, flooding extends further upstream of the Forcados river past the bifurcation, up to 220km upstream in 2030 and 300km upstream in 2050. Floods also arrive one week earlier in 2050. Nun river: flood extends up to 250km upstream by 2030 and along the entire channel by 2050.	SLR+ subsidence by 2030 shows increase in flooded areas up to 350 km upstream for Forcados river and Nun river shows flooding along the entire channel. Floods also arrive 10 days earlier in the Nun river. The results for land subsidence value of 1.25 by 2050 shows no significant difference with that of 2030.
1998/ flood year flow + flash flood	SLR value of 0.65 by 2050 showed continued flooding in the channel from July 20 with no recession in water level in early August as was the case for no SLR.	With subsidence there is continues flooding in the channel from July to October.

b. 1D/2D Overland Flow Modeling

The1D/2D overland flow simulation (e.g. figure 5) indicates change in water depth, change in lateral flood extent and location of change for the downstream coastal areas (closest to mouths of rivers Forcados and Nun). The results of the scenarios were exported into ArcGIS and overlaid to visualize the differences in flooding extent and water depth. The simulation results are presented below. The results for river Nun showed no differences in lateral flooding extent or water depth in all scenarios.

1. **Sea level Rise with normal year flow:** data for the year 2005 was used for this scenario simulation. The result for the downstream areas around rivers Nun and Forcados showed no difference in flooding extent or water depth between the normal flow year and all ranges of SLR for years 2030 and 2050.
2. **Sea Level Rise with a flooding year flow from upstream:** data for the year 2007 was used for this scenario simulation. The results also showed no difference in lateral flooding extent between the 2007 flood and all ranges of SLR for 2030 and 2050, however water depth for downstream Forcados River showed the following differences:
    - Water depth in green pixel shown in figure 6(a) increased from 0m in the 2007 flood to 1m with an SLR value of 0.12m (i.e. lower limit 2030).
    - Water depth for two pixels shown in green in figure 6(b) increased from 0m in the 2007 flood simulation to 1m with SLR value of 0.41m. The values remained 1m with SLR value of 0.65m (i.e. upper limit 2050).

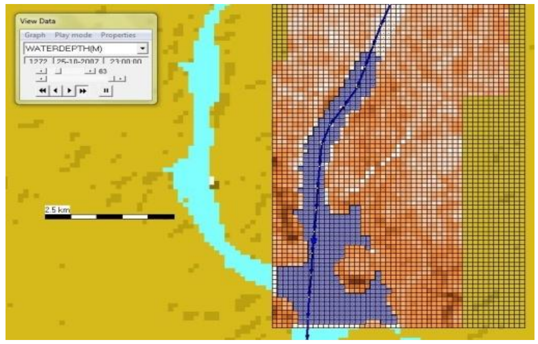


Figure 5: 2007 flooding downstream of River Nun

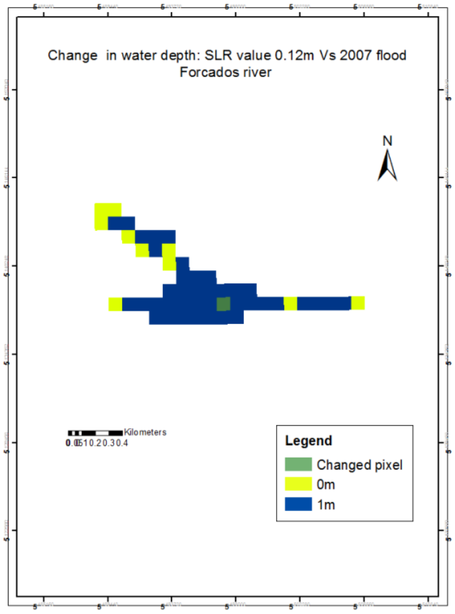
3. **Sea Level Rise with flash flooding during high flow**: data for 1998 was used in simulating this scenario. For Forcados river, with SLR value 0.65m (i.e. 2050 upper limit) water depth in all the pixels in green and purple (figure 6c) have increased in value : from 0 to 1m (green) and from 1 to 2m (purple). Pixels in blue have remained unchanged at 1m depth.
4. **Sea Level Rise with land subsidence and flooding year flow from upstream**: data for the year 2007 was used to simulate this scenario. For Forcados river there was no change in lateral flooding area between the 2007 flood and all levels of SLR +subsidence downstream, however there was a change in water depth from 0 to 1m for the brown pixels shown in figure 6(d) for all levels of SLR +subsidence (2030 and 2050).
5. **SLR with land subsidence, flooding year flow and flash flooding from upstream:** the data for 1998 flood was used in this simulation. Results for Forcados River showed increase in water depth in the downstream river grid (for all SLR + subsidence values) from 0 to1m and 1 to 2m for the years 2030 and 2050. In figure 6 (e), all the grids in yellow and blue have increased in value with the exception of the two green pixels which remained at 1m.

5 CONCLUSION

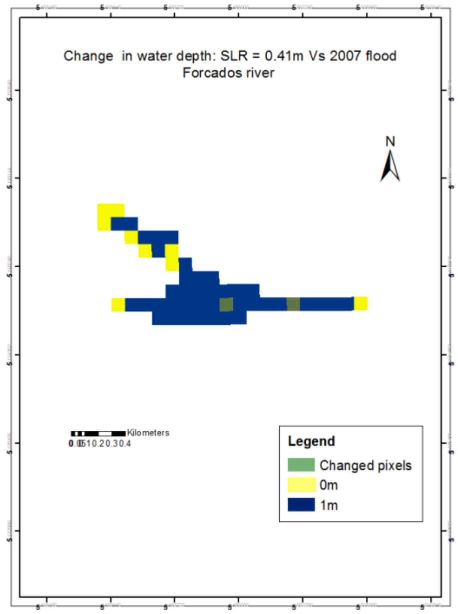
The modeling results show that flooding in the lower Niger River will be affected by rise in sea levels. The effects include earlier occurrences of downstream flooding, increase in water depth and flooding of areas further upstream (than would occur without SLR).

For areas nearest to the coast, the results for the Nun River indicate that the effects of flooding from upstream will not be further exacerbated by SLR. However, for river Forcados there will be increase in the water depth of flooded areas. The increase in water depth depends on the amount of rise in sea levels (which will be further exacerbated by land subsidence throughout the flooded areas). The simulation results further indicate that higher sea levels will cause flooding of more upstream areas. This is because high sea levels impede downward flow of flood waters which results in a backwater effect that floods more areas upstream; therefore lateral flooding extent might not expand in the downstream areas but flooded areas will increase upstream.

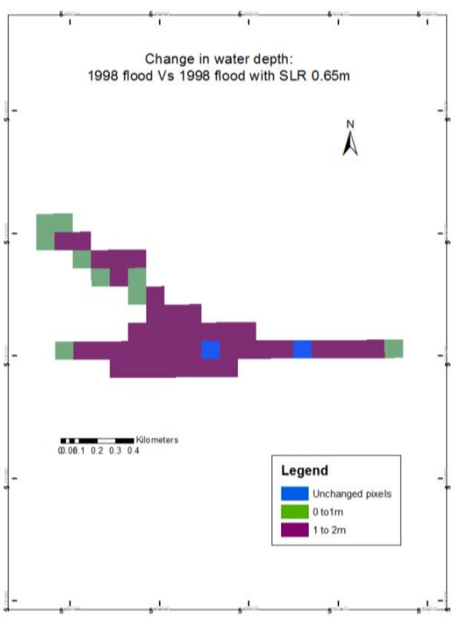
For years with no flooding from upstream, SLR will cause coastal areas to start flooding earlier than usual and this includes areas upstream of the Nun River which are not normally flooded during the year.


Change in water depth: SLR value 0.12m Vs 2007 flood
Forcados river
N
Kilometers
Legend
Changed pixel
0m
1m

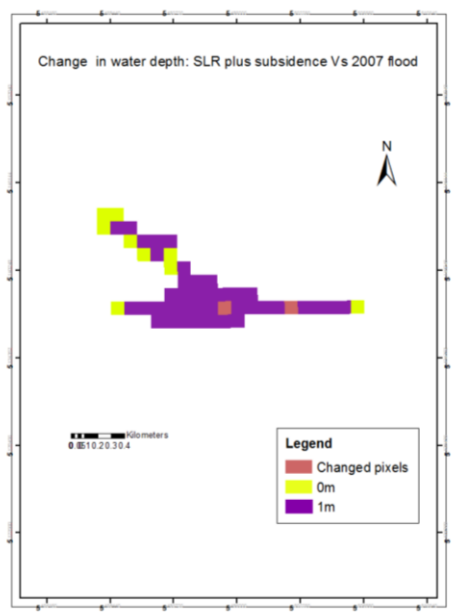
(a)


Change in water depth: SLR = 0.41m Vs 2007 flood
Forcados river
N
Kilometers
Legend
Changed pixels
0m
1m

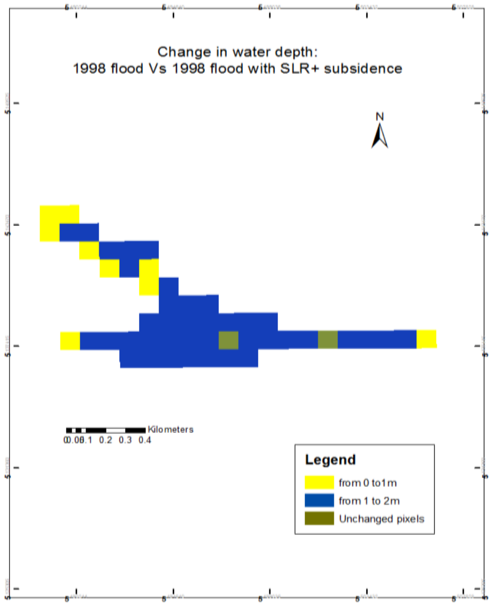
(b)


Change in water depth:
1998 flood Vs 1998 flood with SLR 0.65m
N
Kilometers
Legend
Unchanged pixels
0 to1m
1 to 2m

(c)


Change in water depth: SLR plus subsidence Vs 2007 flood
N
Kilometers
Legend
Changed pixels
0m
1m

(d)



(e)

Figure 6: Change in water depths: Forcados River flooding

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