To: Natural Hazards Earth Systems Discussion

Re:Niger's Delta vulnerability to river floods due to sea level rise
by Z. N. Musa et al.

Response to anonymous reviewer #3
(Note: *Reviewer comments are in italic*, authors' responses are in normal text)

Thank you for taking the time to read the discussion paper. Please find below, the answers to your questions and comments. We value the comments received as they point out the issues that need to be addressed in order to improve the paper.

Hera are the answers:

Comment 1: The authors assess the vulnerability of the Niger Delta to flooding with a GIS-based approach. Several variables influencing the delta are accounted for and ranked and an index of vulnerability calculated to identify the most vulnerable areas within the delta. The topic is of great interest due to the relevance of flooding issues to coastal areas which are often very densely populated and host important resources. The authors do a nice job in the introduction and acknowledge that healthy deltaic systems would be able to respond to sea level rise. The vulnerability of deltas is not only a function of sea level but of this factor combined with the capability of the system to respond to change, e.g. availability of sediment. The Niger is one of the largest deltas in the world and has been subject to anthropogenic disturbance due to oil extraction. The analysis of this system is thus important and of interest. The authors explain in the introduction why a simplified approach such as the one taken here, is necessary at times.

Authors' answer: Thank you reviewer for these comments which highlight the usefulness of simplified methodologies in studying the complex issue of vulnerability.

Comment 2: Clearly we cannot obtain field data everywhere in a system as large as the Niger and a preliminary analysis such as the one proposed in this paper represents a good first step. It cannot be the end of the analysis though; I think it can only highlight possible areas where to concentrate more detailed analyses through field work and numerical modelling. The assessment of a system's vulnerability cannot be based solely on an overall analysis based on spatial 2D maps.

Authors' answer: As rightly noted by the reviewer, the final proof of the vulnerability of an area will consist of several sources of information and as soon as identified is further analysed by using numerical models and data obtained via field work. The authors are not saying that such studies are the end of the analysis,on the contrary, they do consider that such studies are a preliminary step. Indicator based studied such as the examples written in the discussion paper (pages 5216 to 5218), and the particular example given in this paper use variables whose ability to change and respond to various effects of SLR (e.g. flooding) can be related to the systems susceptibility to that hazard. The results of such studies indeed highlight the areas that have certain characteristics that make them vulnerable to the effects of the particular hazard. Such results can be used by decision makers to identify focus areas that further need hydrodynamic modelling of flooding that will help in the process of mitigation and adaptation planning.

Comment 3: I also have some concern about the lack of acknowledgement, discussion and consideration of the uncertainty of the variables blended in the analysis. They come from different sources; can we trust these values? What is the uncertainty? How is the that reflected in the results presented?

Authors' answer: We will address the concerns of the reviewer one by one. A very important issue is the concern of the reviewer about the reliability of the data sources used in this study. In table 1 of the discussion paper, a list sources of the variables and the type of data obtained and used in the study is given. All listed sources are the official sources assigned by the governing authorities and decision makers in Nigeria and as such they are the most reliable data of the country. The sources include: Nigerian Institute for Oceanographic and Marine Research (NIOMR), Nigerian Emergency Management Agency (NEMA), Niger Delta Regional Master Plan reports (NDRMP), Nigerian Population Commission (NPC), Nigerian National Space Research and Development Agency (NASRDA). These are the official sources assigned by the governing authorities and the decision makers to provide the most reliable data.

Indeed any result based on data use is subject to uncertainties in the data type, data use, processing, and the deductions drawn from the data. Consequently, the 17 variables used here are extracted from documented and published measured data (via field work), where satellite remote sensing was used. Data was verified using measured historical data. The mapping of vulnerability as presented in the study is within the limited bounds of the data accuracy and the scale of the study. The influence of scale is such that some of the variables we used might not be applicable in a study of the vulnerability of the entire West African coast for example. At such a large scale several rivers will have to be taken into account in measuring the variable 'reduction in sediment supply', and the variable 'population growth rate' might not be included since the region is made up of several countries with varying data types and measurement techniques.
As per how the uncertainty in the data is reflected in the results, in the case of slope for example we used SRTM DEM in ArcGIS to generate slope in percentage rise. SRTM DEM data has a horizontal elevation of 90m and (for low lying coastal areas) a vertical accuracy of +-4m (Gorokhovich & Voustianiouk, 2006), however for data scarce areas SRTM is often the only source of elevation data. We delineated and classified the Niger delta coastline for slope ranges 0% -2.5%. To reduce the uncertainty in the slope generated we verified the ranges using the slope map of Nigeria shown in figure 1 below.

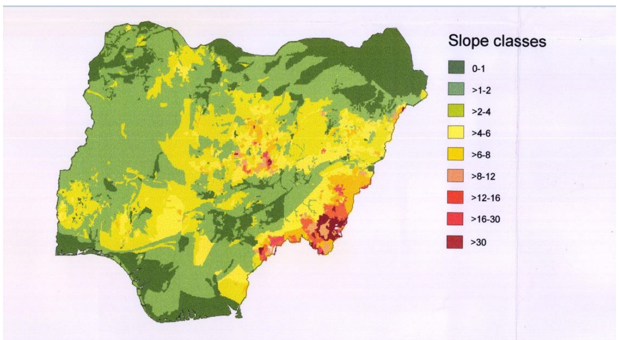

Figure 1. Soil map of Nigeria (source FAO 1997).

Cited reference in the explanation:

Gorokhovich, Y. and Voustianiouk, A. (2006) Accuracy assessment of the processed SRTM-based elevation data by CGIAR using field data from USA and Thailand and its relation to the terrain characteristics. Remote Sensing of Environment , 104 (2006) p.409–415.

We do appreciate the reviewer for highlighting this issue; we will include the limitations of this study (uncertainty in the data) in the revised version of the paper.

Comment 4: I also think the paper lacks a discussion on how the variables used are chosen and ranked. There are a few references listed and a good number of variables listed in Tables 2 through 4. Where are these coming from? The references cited refer to different systems than the one analyzed here. Are ranges and rankings the same across different systems? And why would that be the case?

Authors' answer: Thank you reviewer for raising a very important question in view of the fact that many factors do influence the vulnerability of coastal areas. In carrying out SLR vulnerability assessments using the CVI method, scientists have modified the number and type of variables used according to the study area and availability of data. In undertaking this study, authors were studying the indicators that have relevance to coastal erosion, inundation and intrusion of sea salt (with respect to groundwater). The option to use 17 of the variables is based on the data availability for these indicators on the Niger delta. The variables were chosen after a thorough study of recommendations given by similar studies, as shown in the table below.

Variable	Application area	Reference
Topography	Coastal areas	Yin et al (2012)
Coastal slope	Coastal areas	Gornitz, et al, (1991)
Geomorphology	Coastal areas	Gornitz, et al, (1991)
Relative slr rate	Coastal areas	Gornitz, et al, (1991)
Annual shoreline erosion rate	Coastal areas	Gornitz, White, & Cushman (1991)
Mean tidal range	Coastal areas	Gornitz, et al, (1991)
Mean wave height	Coastal areas	Gornitz, et al, (1991)
Type of aquifer	Deltas	Ozyurt & Ergin (2009)
Aquifer hydraulic conductivity	Deltas	Ozyurt & Ergin (2009)
Proximity to coast	Deltas	Ozyurt & Ergin (2009)
Population density	Coastal areas	Balica et al, (2009)
Reduction in sediment supply	Deltas	Ozyurt & Ergin (2009)
Population growth rate	Coastal areas	Balica et al, (2009)
Groundwater consumption	Deltas	Ozyurt & Ergin (2009)
Emergency services	Coastal areas	Balica et al, (2009)
Communication penetration	Coastal areas	Balica et al, (2009)
Availability of shelters	Coastal areas	Balica et al, (2009)

Rankings and ranges of the variables are not the same across different systems, but depend on the measured values. As per ranking of vulnerability, Kumar et al (2010), and Kumar and Kunte (2012) have used three classes (i.e. low, medium, high); Yin J. et al, (2010), used four (low, medium, high, very high) and Dinh et al, (2012), Pendelton et al (2010), Ozyurt & Ergin (2009), Thieler and Hammer-Kloss (1999) and Gornitz (1991), rank the measured ranges into five classes from very low to very high. The later approach is used in the present study of the Niger delta, considering that such a refined classification will reduce considerably the uncertainty of vulnerability.

Cited references in the explanation

Dinh, Q., Balica, S., Popescu, I., and Jonoski, A.: Climate change impact on flood hazard, 5 vulnerability and risk of the Long Xuyen Quadrangle in the Mekong Delta, International J. River Basin Manage., 10, 103–120, 2012

Gornitz, V., White, T., & Cushman, R. (1991). Vulnerability of the U.S. to future sea-level rise. Seventh Symposium on Coastal and Ocean Management, (pp. 2354-2368). Long Beach, CA(USA).

Kumar, T., Mahendra, R., Nayak, S., Radhakrishnan, K., & Sahu, K. (2010). Coastal Vulnerability Assessment for Orissa State, East Coast of India. Journal of Coastal Research, 26(3), 523-534

Kumar, T., & Kunte, P., 2012. Coastal Vulnerability Assessment for Chennai, East coast of India using Geospatial Techniques. Journal of Natural Hazards, 64, 853-872. doi: 10.1007/s11069-012-0276-4.

Ozyurt, G., & Ergin, A. (2009). Application of sea level rise Vulnerability Assessment Model to Selected Coastal Areas of Turkey. Journal of Coastal Research(56), 248-251.

Pendelton, E., Barras, J., Williams, S., & Twitchell, D., 2010. Coastal Vulnerability Assessment of the Northern Gulf of Mexico to Sea-Level Rise and Coastal Change. USGS. Retrieved from http://pubs.usgs.gov/of/2010/1146

Thieler, E., & Hammer-Kloss, E. (1999). National Assessment of Coastal Vulnerability to Future Sea-Level Rise: Preliminary Results for the U.S. Atlantic Coast. US Geological Survey.

Yin, J., Yin, Z., Wang, J., & Xu, S. (2012). National Assessment of Coastal Vulnerability to Sea-Level Rise for the Chinese coast. Journal of coastal Conservation, 16, 123-133. dOI 10.1007/s11852-012-0180-9

Comment 5: Also, how are the coastal segments identified? It seems to me that the spatial scale at which these parameters are computed is very important. So how to select those segments? What is the effect of this choice on the analysis results?

Authors' answer: The coastal segments were identified based on their physical properties of slope and topography, which are two very important properties for coastal flooding and inundation. While the elevation of an area above the mean sea level determines the lowest level of water that can flood it, the slope affects the flooding extent. On page 5229 of the discussion paper authors are stating that "The segment division is based primarily on three main elements; elevation, change in elevation and the presence of large estuaries". Both the elevation and slope data were generated using SRTM DEM and the segments have the same width of 4km inland. Each segment therefore defines an area whose slope/ topography makes it different from the neighbouring segments. The effect of the segment division on the analysis result is that it constrained the scale of CVI calculations and reduced the possibility of generalizing variable values along the Niger delta coastline. For example in the case of the variable 'population density', since the segments divide the coastline into smaller areas we were able to use data provided by local government in order to classify vulnerability of using state data (which is at a much larger scale).

Comment 6: Given that the paper does not propose a novel method but rather the application of two previously proposed approaches, some discussion of advantages, disadvantages and why a combined approach may be beneficial should be present in the paper.

Authors' answer: Thank you reviewer for this suggestion. It is indeed very important to include the advantages of this new combined method for vulnerability assessment of flooding. As suggested we will include the advantages and disadvantages of the proposed combined approach in the revised paper, as we are explaining them here bellow.

The advantages of the combined methodology are:

- It enables a ranking of vulnerability that acknowledges the importance of systems resilience;
- The resilience index shows the ability of the system (people) to cope and adapt to the disaster. Under resilience, we evaluated three variables: emergency services, communication

penetration, and availability of shelters. These are services directly provided by the decision maker, therefore our results can be useful in channelling such services to areas most in need.

- Its results differentiate the levels of intervention needed on coastal segments that might have the same physical properties but different social conditions. This explanation is exemplified in the revised 'Results and discussion ' section of the discussion paper
- It includes human modifications of the coastal environment in the vulnerability assessment. Human influences (e.g. construction of sea walls, groins, ports) add to the overall cost of impacts of coastal hazards, therefore there is need to capture them in a vulnerability assessment.

The main disadvantage of the method is the fact that it requires a wide range of data collection for the physical, social, and human influence factors which might not be readily available. Moreover different variables might be available in countries within the same region, making comparison difficult.

To better explain the choice to combine the two methods, a paragraph will be added (page 5220 line 17) to the discussion paper as follows:

- While equation 1 enables the simplified combination of variable rankings to calculate the CVI for exposure, susceptibility and resilience, equation 2 enables the combination of the three indices to allow a ranking of vulnerability that acknowledges the importance of systems resilience. Exposure and susceptibility variables increase the vulnerability of systems, while resilience variables enable systems to withstand and reduce the vulnerability to hazards. Therefore the methodology used in the present research combines the two methods into a composite index which multiplies the exposure index by the susceptibility index and divides the product by the resilience index.

Comment 7: In summary, a discussion of uncertainty, rationale on the approach taken and related limitations should be presented and discussed in this paper. I think this approach may help guide more detailed studies as I mentioned above, but the message of this paper is not along these lines, but rather that an approach like this one would be enough to identify mitigation practices. I do not believe this is the case.

Authors' answer: With this comment we noticed that our message was not clear and needs to be reformulated in order to make the scope of the study clearer. We are of the same opinion as the reviewer that such a study is not to be used alone but to be complemented by other detailed modelling studies.

We would also like to mention that in regard with the comments above, as per request of the other two reviewers we will add a new section in the paper and a new table. This new section might be helful to clarify some issues raised by reviewer 3, hence we are copying here the section as mentioned to be changed.

RESULTS AND DISCUSSION

(Remark: highlighted text is the new addition, Table 5 is new as compared with the discussion paper, hence shown at the end of this document.)

In order to calculate the $CV_{SLR}I$ for the 450km of the Niger delta coast, 54 coastal segments are considered. The segment division is based primarily on three main elements; elevation (fig. 2); change in slope (fig. 3); and the presence of large estuaries. The segments are represented in fig.4. The sizes of the segments differ from one another in length, however on average the segment width is 4km inland.

For each coastal segment, the exposure, susceptibility and resilience indicators are calculated and ranked. The range of results for the Niger delta coastal segments are normalized using equation 4 and classified into five vulnerability classes (very low, low, moderate, high and very high) based on percentile ranges. Accordingly, the calculated results for the Niger delta give the following ranges of vulnerability: 0.0-0.02 ('very low'), 0.02-0.04 ('low'), 0.04-0.09 ('medium'), 0.09-0.13 ('high'), and 0.13-1.0 ('very high'). As an example of the indicator ranking for the Niger delta coast segments 1-4, 52 and 54 are selected to be presented, as shown in table 5. The most vulnerable segment, number 52 has a low slope (<1%), low topography (3-5m), estuaries, very high hydraulic conductivity (>81m/day), very high population density (>800 people/km^2), and settlements within 100-200m of the coast. These attributes have thus made it highly vulnerable to SLR. On the other hand, the least vulnerable segment, number 1, has a high slope (>4%), a topography higher than 10m, is uninhabited with no coastal infrastructure, and a very low hydraulic conductivity (0-12m/day). These attributes give it a very low vulnerability to SLR. (Segment count is from left to right).

Figure 5 shows a plot of the calculated $CV_{SLR}I$ for the Niger delta coastal segments. Analysing the results it is seen that, 42.6% of the coastline has 'very low' to 'low' vulnerability, 18.5 % has 'moderate' vulnerability, while 40.8% have 'high' to 'very high' vulnerability; which is shown in figure 6.

In figure 6, that the eastern end of the Niger delta (from Bonny to the southern end of Opobo; made up of six coastal segments: 49-54), is the longest stretch with very high vulnerability to SLR. **As shown in the case of segment 52, such areas with 'high' to 'very high' vulnerability are characterized by: 'very low' to 'low' slopes, 'very low' to 'low' topography, 'high' to 'very high' mean wave heights, unconfined aquifers, presence of coastal infrastructure and 'high' population density, etc. These variables represent physical coastal properties, human influence, and social properties. The presence of human influence variables like coastal infrastructure and high population density, increase the probability of damage to lives and property when a disaster occurs. The combination of these properties has made the coastal segments highly vulnerable to SLR.** The coastal segments classified as highly vulnerable to SLR will require mitigation measures to be applied against SLR.

The advantages of using a method such as $CV_{SLR}I$ is the fact that it **takes into account existing social structures (in terms of favourable places to live/ invest in infrastructure) and shows the level of vulnerability of choice areas. For example the ranking of segments 1 and 2 for physical variables (1-7 in tables 2) are similar but their vulnerabilities are very different (see table 5), since in the $CV_{SLR}I$ method human influence variables differentiate between the vulnerabilities of the two segments. While segment 1 has a 'very low' vulnerability, segment 2 has a 'high' vulnerability due to its high population density and presence of many settlements along the coast. If the CVI calculation was based on physical factors only, both segments will have similar vulnerability and segment 2 will be given a 'very low' vulnerability ranking (consequently, it will not be included in any adaptation plan). The $CV_{SLR}I$ however, requires a wide range of data collection for the physical, social, and human influence factors which might not be readily available. Moreover different variables might be available in countries within the same region, making comparison difficult."**

Table 5: Ranking per indicator, and CVI results for the six segments.

SEGMENT NO	**1**	**2**	**3**	**4**	**52**	**54**
VARIABLE (FACTOR)			**RANKING**			
Topography (e)	1	1	2	1	4	2
Coastal slope (e)	1	1	4	4	4	5
Geomorphology	5	4	5	5	4	4
Relative sea-level rise rate (e)	5	5	5	5	5	5
Annual shoreline erosion rate (e)	5	5	5	5	4	4
Mean tide range (e)	4	4	4	4	3	3
Mean wave height. (e)	5	5	5	5	3	3
Population density(e)	1	4	4	4	5	5
Coastal infrastructure (e)	1	1	1	1	1	4
Hydraulic conductivity (e)	1	1	4	4	5	1
Proximity to coast(e)	1	4	1	4	5	5
Reduction in sediment supply (e)	5	5	5	5	5	5
Type of aquifer (e)	5	5	5	5	5	5
Population growth (s)	5	5	5	5	5	5
Groundwater consumption (s)	2	2	2	2	3	3
Emergency services (e)	1	1	3	3	1	5
Past experience (r)	5	5	5	5	5	5
Communication penetration (r)	1	1	4	4	1	5
Shelters (r)	1	1	1	1	1	1
$CVI_{exposure}$	5.56	19.88	31.43	44.44	60.00	47.14
$CVI_{susceptibility}$	2.64	2.63	5.27	5.27	7.23	6.45
$CVI_{resilience}$	0.56	0.56	1.94	1.94	0.56	2.8
CVIslr $= \frac{CV_E I * CV_S I}{CV_R I}$	**26.19**	**93.70**	**85.53**	**121**	**770**	**108.87**
Normalized result	**0.02**	**0.11**	**0.10**	**0.15**	**1.0**	**0.13**