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 #2
(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 paper under discussion is about the vulnerability to sea level rise for the case of the Niger delta. The paper presents an interesting approach in the area of vulnerability indexes due to river floods. Moreover I found the authors' approaches to the vulnerability an interesting one, combining two approaches.*
The introduction presents a state of the art review which is up to date and well presented. The methodology is well explained, however when it comes to the application of it I found that definitions are well extended while results are only presented in figures based on the defined ranges in tables. The 54 segments, which are evaluated for vulnerability, do not have specific values presented, which can be assessed with respect to the ranges (that are previously defined in tables). It is well understood that results cannot be shown for all 54 segments, but an example result for example for the most vulnerable segment, values on how the vulnerability is computed for the particular segment would be good. A similar approach for the least vulnerable would be appreciated.

Authors' answer: Thank you for the appreciations on the paper. Indeed, the results and discussion section of the submitted manuscript did not describe the application of the methodology. As suggested, we have revised the section by adding more detailed descriptions and also included examples of the most vulnerable and least vulnerable segments. The revised results and discussion section will thus read as follows:
(Remark: highlighted text is the new added one, Table 5 is new as comapred 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 gives 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. "**

Comment 2: • *I am also missing a few words on why only 17 indicators, why other indicators were not relevant and as such left out, or maybe there is no data available for them.*

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 salts (into underground water). The option to use 17 of the variables is based on the data availability for these indicators on the Niger delta. The variables as chosen represent the three indices of exposure, susceptibility and resilience. These indicators are documented in studies by Gornitz, White, & Cushman (1991) for general coastal areas; and Ozyurt & Ergin (2009) for deltas. Similarly Balica, Douben & Wright, (2009) and Ozyurt & Ergin (2009) documented social and human influence variables that are important for determining the vulnerability of coastal areas. In the final version of the paper we will mention all details on data availability and their sources as per references bellow.

Cited references in the explanation:

Balica, S., Dinh, Q., Popescu, I., Vo, T. Q., and Pham, D. Q.: Flood impact in the Mekong Delta, Vietnam, J. Maps, 10, 257–268, 2014.

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).

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.

Comment 3: In the conclusion part I am missing just a few words on how the decision makers can make use of such result. In the day to day work of a decision maker it is not straight forward that they can make use of such results directly. How do the authors see the use of such results: will they be used at the moment of flood events occurring or before flood events?.

Authors' answer We agree with the reviewer that the study will only be useful if it can be applied on the Niger delta. As we mentioned in the manuscripts (lines 6-8, page 5231), this study can serve as a complementary source of data for the decision makers in planning adaptation strategies for the Niger delta. Before a flood occurs, the following outputs of this study can be used:

- The map of the Niger delta coast showing the level of vulnerability of each coastal segment (figure 6). This map can be used alongside other data to identify those areas that are most likely to be affected by flooding from the Niger River. With the Niger River flooding frequently in recent times, the decision makers can plan mitigation/ adaptation strategies for such areas and not for the entire geographical region all at once.
- The evaluation of resilience for the coastal segments which 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 those areas most in need.

In line with this point raised by the reviewer, we will revise the conclusion section of the manuscript to include above suggestions.

Comment 4: • *Will such indices be used in connection with physically based models or not? Are there ranges of uncertainty in the mapping of the vulnerability?*

Authors' answer: Thank you the reviewer for these two important questions. Indeed a combination of this study results with physical models of flooding in the Niger delta will provide a much better picture of the effects of sea level rise for the decision makers. As a result, we carried out hydrodynamic modelling of flooding on the Niger River with downstream sea level rise, and our results have indicated effects such as: increase in water depth, increase in upstream flooding reach and extension of flooding time (Musa, Popescu and Mynett, 2014). Although our results are only limited to the two estuaries (mouths of river Forcados and Nun), they have shown that those areas are vulnerable.

With respect to uncertainty issue we can mention that the mapping of vulnerability as presented in the study is within limited bounds of the data accuracy and the scale of the study. Consequently, some of the variables used might not be applicable at a larger scale. In a study of the vulnerability of the entire West African coast for example, several rivers will have to be taken into account in measuring the variable 'reduction in sediment supply'; and 'population growth rate' might also not be included as a variable since the region is made up of several countries with varying data types and measurement techniques. In tables 2&3 of the paper variable rankings are in line with those found in similar studies (e.g. Thieler & Hammer-Kloss, 1999; Ozyurt and Ergin 2009; Pendelton et al. 2010; Kumar and Kunte 2012), while the ranking of resilience variables in table 4 is based on the Nigerian management of disasters and consequently localized for the Niger delta. We do appreciate the reviewer for highlighting this issue; therefore we will include the limitations of this study (uncertainty of the results) in the revised version of the manuscript.

Cited reference in the explanation:

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.

Musa, Z. N., Popescu, I., & Mynett, A. (2014). Modelling the effects of sea level rise on flooding in the lower Niger River. *11th International conference on Hydro-informatics, HIC 2014.* New York: HIC, 2014. Retrieved from https://www.conftool.pro/hic2014/index.php?page=browseSessions&form_session=90

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.

Table 5: Ranking per indicator and CVI results for the first four 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
CVIexposure	5.56	19.88	31.43	44.44	60.00	47.14
CVIsusceptibility	2.64	2.63	5.27	5.27	7.23	6.45
CVIresilience	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**