Geospatial Evaluation of Niger Delta Coastal Susceptibility to Climate Change

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Key words: Geospatial, Inundation, Overlay, Sea level change, Susceptibility

ABSTRACT

Coastal topography is a result of complex interactions between anthropogenic activities and natural processes. The Niger Delta is not an exception. The region is currently under human unprecedented pressure and this is accentuated by climate change induced processes. In addition to the regional problems of rainfall/runoff induced erosion and flooding, anthropogenic induced land subsidence and global warming induced sea level rise, are additional imperatives. Quantifying spatial change in this dynamic environment is crucial for sustainable coastal management. This paper takes a look at the threats of inundation and erosion arising from sea level rise on the basis of existing tidal limits and indicative shore zone morphological susceptibility. Using geospatial analytical approach (ArcGis 8.3), the paper attempted an indicative delineation of habitats, conservation priority areas and shore zone morphology within at 50km from the shoreline through proximity and overlay analysis. Habits delineated and considered susceptible to future inundation and erosion/flooding include mangroves and mud flats, some cultivated and fallow land, and freshwater swamps. In addition, some areas designated as conservation priority zones by IUCN/WWF/NCF were identified as susceptible to inundation and increase salinity. Since the region has not been monitored for change detection, the paper recommended that detailed and locally-focused level of assessment should be carried out, accompanied by quantitative monitoring of actual geomorphic changes on the shore. This can be achieved by a combination of Real-Time Kinematic Global Positioning System (RTK-GPS), Light Detection and Ranging (LIDAR), and open-source Geographic Information System (GIS), which are the jurisdiction of the surveyor and regional planner.

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Introduction

The value of coastal environments cannot be overemphasized, being characterized by one of the most productive areas accessible to man (Beatley et al, 1994). The zone, which is an ecotone, lying between oceanic environments and terrestrial systems, is defined on the basis of inland limit of tidal influence to the outer extent of the continental shelf (Hansom, 1988, in Beatley et al, 1994). Some physical extent has been imposed to areas up to 100 km inland or offshore of a coastline (NAS, 1992).

The coastal region all over the world is under continuous human pressure and changing climate. Being a region of strong horizontal in-homogeneity, the interface between land, sea and air, the local climatic conditions are complex, while the global climatic influences are enormous. Such effects of climate change manifest in eustatic sea level rise, which can be compounded by local land subsidence. Thus the region is particularly sensitive and susceptible to alteration in sea level

Land subsidence, which contributes to relative sea level rise, is particularly common in areas of continuous subterranean fluid extraction, such as the Niger Delta, characterized by prolific oil exploitation. This implies that the Niger Delta is susceptible to both global changes in climatic trajectory and local environmental challenges such as land subsidence, which results in relative sea level rise. Areas under threat arising from different scenarios of sea level have not been clearly delineated even though studies have postulated the extent of land coverage at risk of lost to sea level increases of particular dimensions (Awosika, et al, 1992), while land subsidence has been reported in parts of the region.

Geographic information system proves valuable in delineating geomorphic units under threat as well as key biophysical and socio-economic attributes particularly susceptible, because of extent of exposure. This forms the basis of geospatial evaluation as used in this paper. It involves employing geospatial analysis, which concerns what happens where, and makes use of geographic information that links features and phenomena on the earth's surface to their location (Smith et al, 2007). This has been applied to highlight potential pressures and threats on biodiversity from oil and gas industry activities by UNEP/WCMC/NCF, while mapping environmental sensitivity index to oil spill has also been carried out by Fabiyi (2008). These have not been related to sea level rise (eustatic or relative).

This paper does not comprehensively delineate these areas, due to lack of spatially differentiated local scale digital geo-reference data at different time scales. This paper is based on this The paper examined the geomorphic units as well as coastal habitats and biodiversity conservation hotspots within 100km from the shoreline, which could be impacted by possible sea level change based on existing information on coastal morphology, tidal and salinity range inland. This is concomitant to effective coastal zone management.

In addition, although land subsidence exists, interest is on how climate induced sea level rise exacerbates the problems arising from such geologic alterations. The study is thus based on global projections of sea level, which provide scenarios of sea level rise mostly based on thermal expansion and ice melts discharges, while recognizing local factors of uplifts and subsidence. Thus the study holds others factors of sea level rise constant and focuses on climate change dimension of sea level rise.

Climate change, sea level rise and the Niger Delta: the underlying issues

The Intergovernmental Panel on Climate Change (IPCC) defines "climate change" as "a change in the state of the climate that can be identified by changes in the mean and / or the variability of its properties, and that persists for an extended period, typically decades or longer" (IPCC, 2007). One of consequences is sea level rise arising from thermal expansion of oceans and melting of ice. It is estimated that by 2100, in addition to the fact that the global average surface warming (surface air temperature change), will increase by 1.1 - 6.4 ^{o}C, the sea level will rise between 18 and 59 cm (IPCC, 2007).

Other projections are for a sea-level rise of between 9 and 88 cm between 1990 and 2100 (Church et al, 2005), about 18 cm by 2040. "Global average sea level rose at an average rate of 1.8 (1.3 to 2.3) mm per year over 1961 to 2003. The rate was faster over 1993 to 2003, about 3.1 (2.4 to 3.8) mm per year" (IPCC, 2007). Mid-line projections presented by the IPCC report for sea level rise over the next century range from 2.8 to 4.3 mm/yr for the 5 scenarios. There are therefore different sea level scenarios, depending on the model used. Whatever the overall global sea level rise rate turns out to be, it will be experienced differently by coastal communities around the world depending on the motion of the land upon which the communities are built. Local (or relative) changes in sea level depart from the global mean trend due to regional variations in oceanic level change and geological uplift/subsidence (Nicholls and Klein, 2005; Harvey, 2006 in Nicholls et al, 2007) and it is found that regional sea-level change will depart significantly from the global mean trends Meehl et al. (2007) in Nicholls et al (2007).

The most serious physical impacts of sea-level rise are: (1) inundation and displacement of wetlands and lowlands; (2) coastal erosion; (3) increased coastal storm flooding; and (4) salinization (Barth & Titus 1984 in Nicholls and Mimura, 1998). The impacts would vary from place to place and depend on the magnitude of relative sea-level rise, coastal morphology/topography and human modifications. The most threatened areas are deltas, low-lying coastal plains, coral islands, beaches, barrier islands, coastal wetlands, and estuaries (Tsyban et al. 1990, Bijlsma et al. 1996 in Nicholls and Mimura, 1998).

Deltas are widely recognized as highly vulnerable to the impacts of climate change, particularly sea-level rise (Nicholls, et al, 2007). Most deltas are already undergoing natural subsidence that results in accelerated rates of relative sea-level rise above the global average. Many are impacted by the effects of water extraction and diversion, as well as declining sediment input as a consequence of entrapment in dams (Nicholls, et al, 2007, Abam, 1999).

Analysis based on a coarse digital terrain model showed that much of the population of these 40 deltas is at risk through coastal erosion and land loss, primarily as a result of decreased sediment delivery by the rivers, and also through accentuated rates of sea-level rise (Ericson, et al, 2006). The Niger delta is considered to be under moderate vulnerability with indicative population potentially displaced by current sea level trends to 2050 (Ericson, et al, 2006; Nicholls, et al, 2007).

As noted by Professor Fubara in the Daily Trust Newspaper of December 24, 2007, “there may be an accelerated sea level rise of 30cm in the next three decades and about 110cm within the next century” in the Niger Delta. Using the situation in Lake Maraca Ibo in Venezuela, where oil platforms have subsided by 500cm in 50 years, as analogous, "If we superimpose the predicted subsided sea level rise on the gradually subsiding Niger Delta, the net effect is that within the next two decades, about 40 kilometers wide strip of the Niger Delta and their people would be submerged and rendered extinct." This, in addition to eustatic sea level rise, implies that a gargantuan part of the land in the Niger Delta would be submerged following an accelerated sea level rise as a result of global warming.

If sea level rises, inundation could occur along more than 70% of the Nigerian coastline, placing land at risk many kilometers inland (Awosika et al., 1992). Specifically, without consideration of oil wells in the Niger delta, the greatest value at risk is along the Barrier Coast-ranging from just over US$1.3 billion with a 0.2-m sea-level rise to almost US$14 billion with a 2-m rise (Awosika et al., 1992).

Ekanade et al (2008) using geospatial analysis, confirmed that sea level rise may occur with a consequence of submerging all coastal cities of the Niger delta area. The parts left un-submerged may face the risk of incessant flooding. These will also disrupt communications, damage vital infrastructures and affect urban settlements along the coast.

The above justifies the need for highlighting the morphology and ecosystems at risk. This is particularly for sustainable coastal zone management. As noted by Mitasova et al (2003), coastal topography is a result of complex interactions between anthropogenic activities and natural processes and the quantification of short-term spatial change in this dynamic environment is crucial for sustainable coastal management. This can be achieved by geospatial evaluation using appropriate surveying and geo-information tools.

The study setting

The Niger Delta is the southern most physiographic region of Nigeria protruding into the Gulf of Guinea extending over 450km from west to east (Awosika, et al, 1992). The part of the Delta under consideration constitutes about 60 per cent of the Nigerian coastline, extending from the Benin River in the west to the Imo River in the east (Abam, 1999).

NDES (1997), based on information from NEDECO (1959), Faniran and Jeje (1983) and so on, classifies the delta into three morphological units, namely: the Niger floodplain; the vegetated tidal flat; and the barrier island. Of particular interest for this paper are the last two. The barrier island and other coastal ridges fringe the sea, while the vegetated tidal flats fringe these other units inland. Interest on these areas is because of their proximity to the coastline and the low lying elevation. The tidal flat, which occupies approximately 13.7 percent of the delta, is found at elevations less 1m above mean sea level and characterized by continuous tidal influences (Abam, 1999; NDES, 1997).

The barrier island dominates the coastline and act as natural protection of the tidal flats. It is also of low elevation, with a maximum range of 2 to 4m above sea level. This area is equally vulnerable to denudation arising from sea level increase. This is because of the plethora of outer and inner sand bars, even though there are also outer barrier bar complexes and the absence of sand bars in some areas (NDES, 1997). Increased sea level would heighten the erosion of these areas and inland migration of the shoreline, hence susceptibility of the tidal flats to inundation and inland incursion of the salinity limits. At the present, the northward extension of the Niger delta is known to create tidal influences up to 30- 50 km from the shoreline (NDES, 1997) (see figures1, 2 and 3).

Baseline climatic conditions of one of the stations in the region (Port Harcourt) and future conditions have been provided by Ekanade et al (2008) and Nigeria's First National Communication on Climate Change (2003). All point to the fact that temperature regime in the region is likely to be on the increase, while rainfall would increase during the rainy season in the future.

While temperature would facilitate thermal expansion of the coastal sea, increasing rains imply increased dilution of the salinity of the tidal flats by runoff and further restriction of the high salinity boundary to the coastline during the rainy season. At the same time, the increased dry season conditions imply further inland movement of the high salinity boundary even beyond the current limits as established by the Niger Delta Environmental Survey during the same period.

The region is under investigation is characterized by two main vegetation zone viz:- mangrove swamp and freshwater swamp zone, which is fringed in the north by lowland rain forest zone (see fig. 1). Because of proximity and elevation, interest for this paper is in the first two ecozones. The delta's mangrove swamps spanning about 1900 square kilometers is the largest in Africa and is richest wetland in the world (Iyayi, 2004 in Akinro, et al, 2008). Its inundation would affect high degree of biodiversity, being the wetland ecosystem that is highly diverse and supportive of numerous species of terrestrial and aquatic flora and fauna.

Generally, the region has emerged as one of the most ecologically sensitive region in Nigeria, its sensitivity being greatly influenced by salinity and hydrological changes (SPDC, 1999; Raufu, 2000, in Fabiyi, 2008). Whereas changes in salinity and inundation of wetlands could compromise the integrity of the wetland ecosystems, saline incursion further inland into the freshwater zones could worsen the vulnerability of the zone not only to flooding and erosion but to biodiversity alteration and loss.

Already Abam (1999) points out that the delta has experienced shifts in the ecological equilibrium manifested as adjustments to the coastline geometry, lower flood water levels and upstream migration of tidal influences. This, associated with upstream damming, is expected to be exacerbated by the planned dredging of the River Niger and global sea level rise, while Oil exploitation provides additional risk of relative sea level rise.

Agbola and Olurin (2003) reported that the World Bank ranked coastal erosion as needing moderate priority attention in the Niger Delta, but coastal vegetation especially the mangroves have been lost to coastal erosion (Awosika, 1995). In some places, especially in Forcados, some oil wells have been lost to the ocean due to erosion (Okoh and Egbon, 1999, in Akinro, et al, 2008). Akinro et al (2008) see coastal erosion as the most important environmental problem facing the Niger Delta.

The above justify the vulnerability of the region to global and regional climate change particularly that associated with sea level change. Thus sea-level rise and repeated ocean surges will not only worsen the problems of coastal erosion that are already a menace in the Niger Delta, but would accelerate the associated inundation, increase problems of floods, intrusion of sea-water into fresh water sources and ecosystems and destroying such stabilizing system as mangrove, and affecting agriculture, fisheries and general livelihoods (Akinro, et al, 2008; NEST, 2004 in Akinro et al, 2008).

A mechanical analysis of available tide data has shown mean sea level rise to be 0.462m above zero level of the tide gauge (Udofa and Fajemirokun (1978). The Niger Delta could lose over 15000 square kilometers of land by the year 2100 with a one meter rise in sea level, while a 20cm rise in sea level will inundate 3400 km^2 of the Nigerian coastland (Onofeghara, 1990). It is estimated that with a sea level rise of 30cm, about 1 to 2 million people will be affected. In all this, it is predicted that Nigeria will lose about $9 billion as a result of the sea level rise while at least 80% of the people of the Niger Delta will be displaced due to the low elevation level of the region. The Niger Delta, home of Nigeria's oil and gas could lose well over 2846km^2 as a result of 0.2m sea level rise (Awosika et. al., 1992).

Other biophysical and socio-economic adverse effects of sea level rise in the Niger Delta abound (Ogba et al, 2008). These would be compounded by local subsidence and sediment starvation arising from upstream damming (French et al, 1995 in Nicholls & Mimura, 1998). 600 000 people living in the Niger delta might require relocation as conventional protection with sea walls would be impossible without a very large investment and the application of new technology (Nicholls & Mimura, 1998). This paper highlights the key environmental attributes that are particularly susceptible to sea level changes, given their proximity and physical characteristics.

Methodology

Geospatial evaluation of climate change effects as adopted in this paper addresses the key morphologic units that would be affected by sea level rise; hence the interest of this study was based on two of the components of the IPCC common methodology. The study therefore delineated the spatial extent of areas of interest and subsequent query (identification) of habitats and areas (attributes) highly susceptible on the basis of a inland shift/denudation of shoreline in event of further sea level rise.

The choice of these habitats is because of their proximity and low elevation as well as value. The barrier islands for instance serve as first line of defense against coastal storms and provide necessary enclosure to estuaries and marshes. Apart from this they are rich in biodiversity and provide recreational and aesthetic functions (Beatley, et al, 1994) hence their alteration is likely to have monumental consequences. Already as noted by Kaufman and Pilkey (1979) and Pilkey et al, (1980) in Beatley et al (1994), the barrier island system as a whole is continuing to retreat, largely in response to sea level rise. Estuaries on the other hand are very productive and important areas whose ecology depends on salinity gradient, with higher biodiversity in less saline areas (Thorne-Miller and Catena, 1991; Chabreck, 1988, in Beatley, et al 1994). Coastal marshes (vegetated tidal flats in this case) are equally classified into different types on the basis of salinity regimes. The inhabitants are dependent on their salinity tolerance level, while sea level represents their most serious threat (Beatley, et al, 1994).

The study attempted to develop a biophysical assessment for sea level rise in the region with emphasis on areas under the existing tidal and saline range/limits. These areas are not necessarily 100km from the coastline. This was achieved through the application of GIS techniques; hence the connotation geospatial analysis. The technique involved two types of geographic analysis – proximity and overlay analysis. The former aimed at determining the approximate distance of the salinity limit and inundation area from the coastline and within given sea level scenarios. Overlay was used to integrate different data layers, involving key habitats, geomorphic units and the saline range. The application of GIS techniques holds advantages for the derivation of regional strategies for the region, in the sense that spatial change detection analysis can be applied to time sequenced databases, to track environmental changes and trends in terms of land use, coastline geometry, river alignment, vegetation drift, water regimes, flood plain sizes, fisheries potential, pollution levels, etc (Abam, 2001).

Results and Discussion

The results of delineation and overlays are presented in figures 1 and 2. Figure 1 show the salinity limit overlaid on the coastal shoreline morphology. In this figure, it is clear that not all parts of the 100km from the coast, which is defined as the coastal area is under the influence of tides, hence the salinity limit has some spatial extent within the coast.

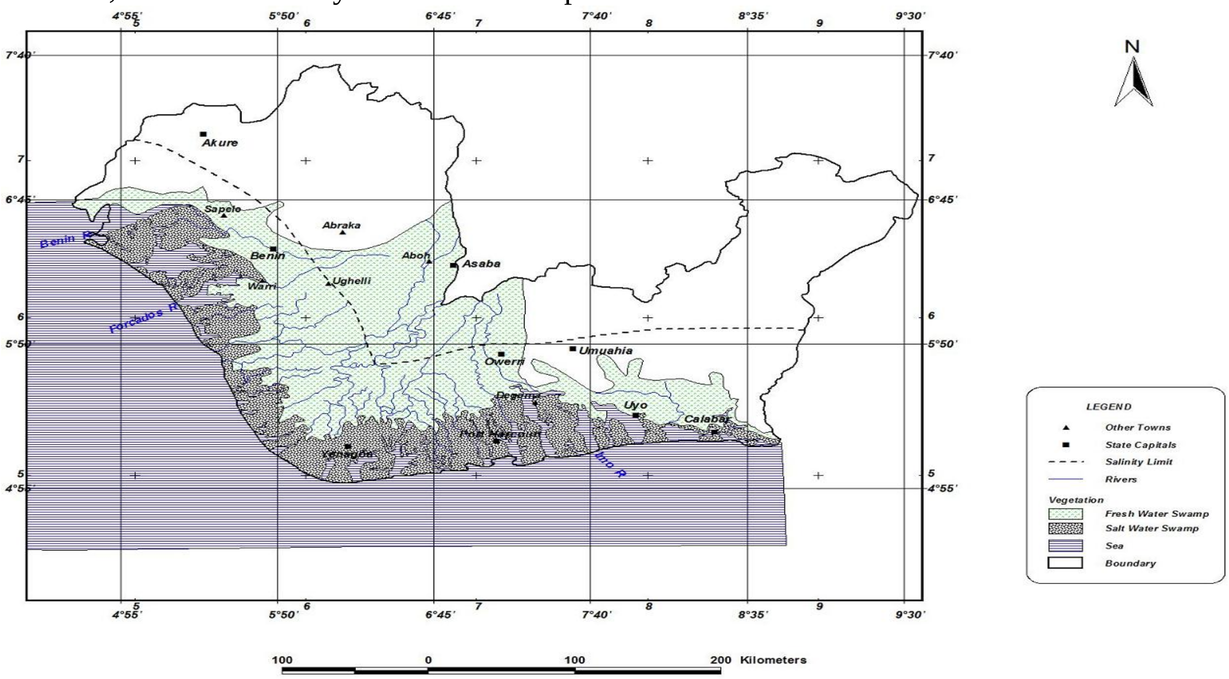

Fig. 1: Salinity limits including main vegetation of the coastal zone

This is in line with Abam (1993), who indicated the spatial extent of diurnal tidal range within the region. Abam notes that Semi-diurnal inundation is associated with tidal activity and its effects are most pronounced in the southern part of the delta. Tidal influences on inundation diminish inland and reduce to zero along the line joining Obete to Amassoma, implying that most major settlements such as Port Harcourt, Bonny, Brass, Forcados, Nembe, Opobo, Koko, Degema, Burutu and southern part of Warri are within this influence. The spring tidal range varies across the coastline with an average of 1.8 m (Abam, 1993).

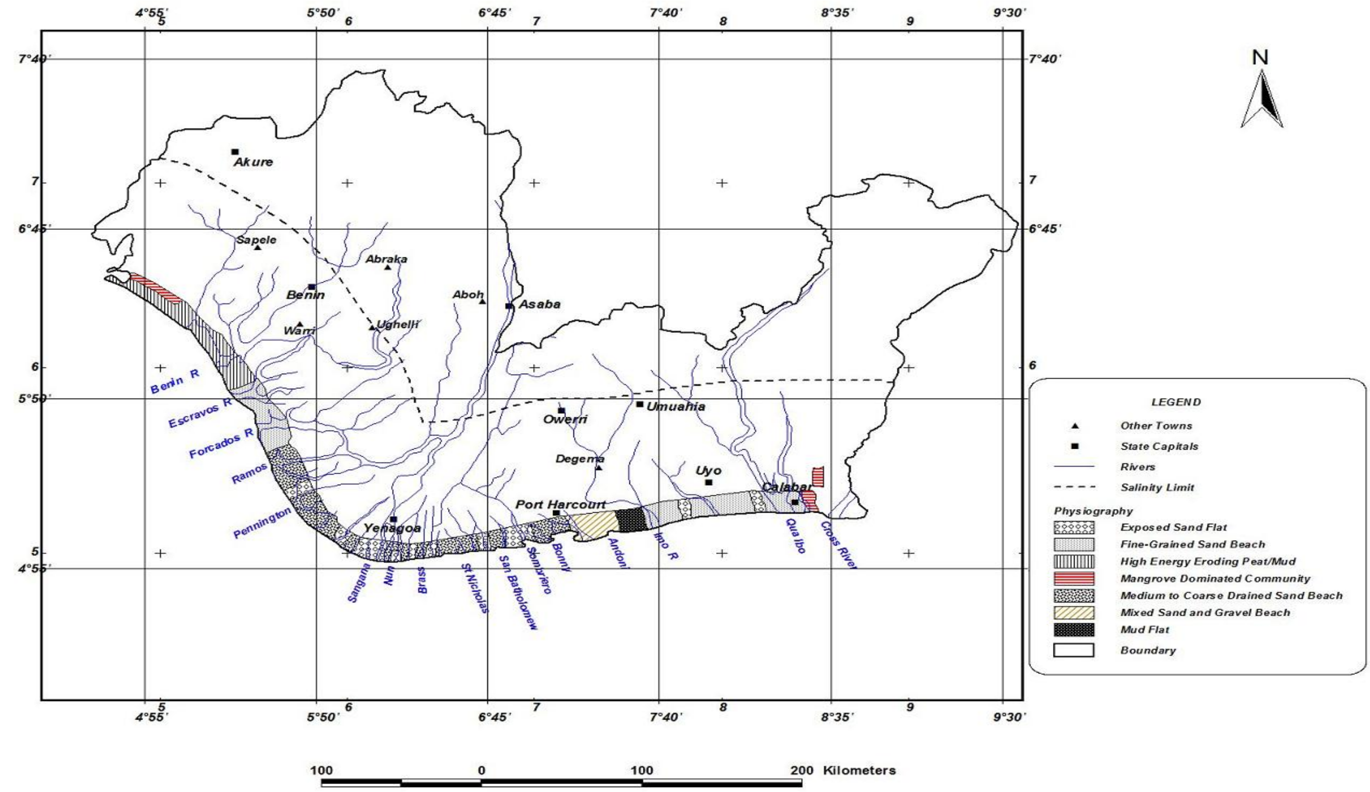

Fig 2: Shore line Morphology

Although the soil at the western flank made up of Dark and dark brownish organic and peaty clay of high plasticity (Abam, 1993), hence lower susceptibility to erosion, the eastern flank is more vulnerable, being in brown sandy clay soil. In addition, as shown in figure 2, the shoreline morphology is characterized by features dominated by sandy substrates. These are beach/ barrier ridges that protect the inland mudflats, rising some 4m above sea level. However there being characterized by white beach sand and sandy ridges (NDES (1997) makes them also vulnerable to erosion. Lowering of the area would expose the inner region and itself to inundation.

In figure 3, it is also indicated that most areas designated as conservation priority zones are within tidal influence and saline limit. The possible erosion and inland migration of shoreline as a result of the reduction of the barrier and beach ridges, arising from sea level rise, would further compromise the sustainability of these protected areas. Apart from the migration and possible extinction of species in the beach and barrier ridges, organisms not adapted to inundation of the tidal flats would be adversely affected. As can be observed, many birdlife sanctuaries as well as some primates and other mammals (such as elephants) protected areas are designated priority areas in the shoreline beaches and barrier islands and in the mangrove/ tidal flats. Changing environmental conditions arising from sea level rise could comprise the efforts at protecting these biodiversity species, since there natural ecosystems would be altered.

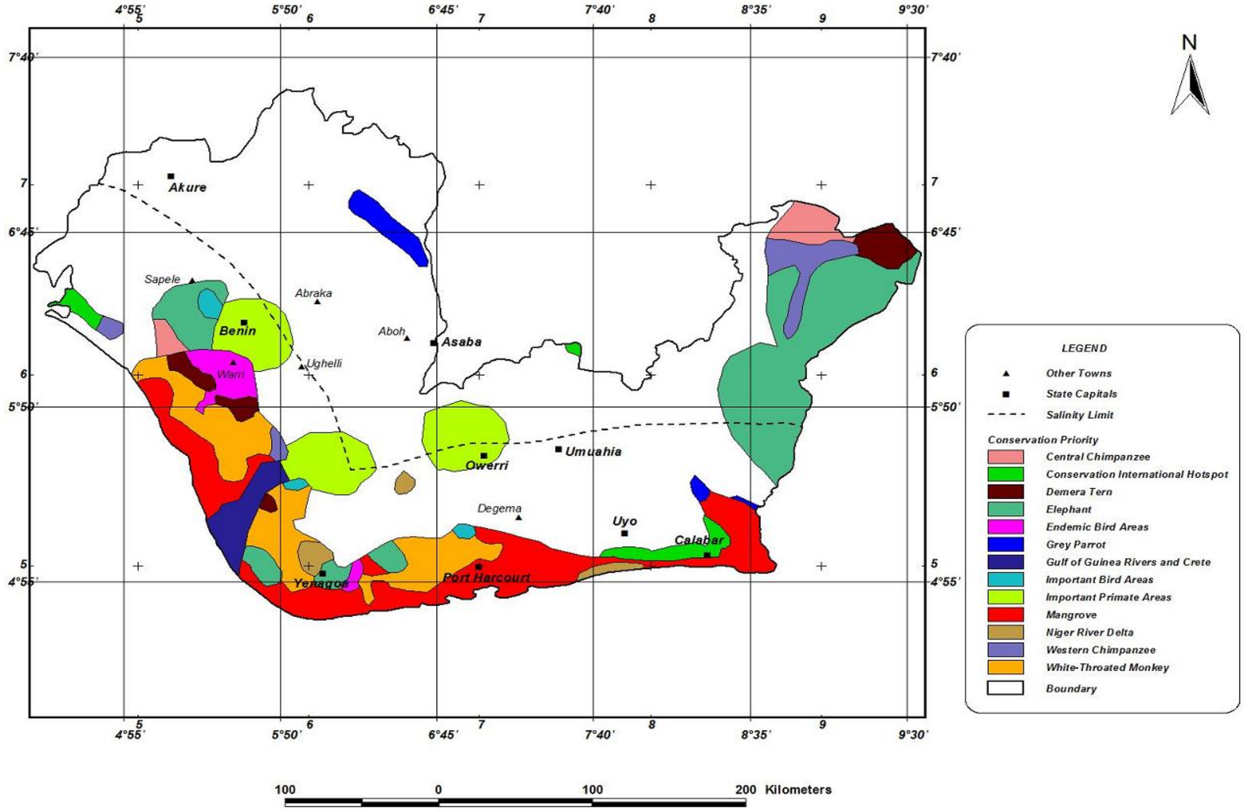

Fig. 3: Conservation Priority areas

The way forward

There is little doubt that the areas most at risk are low-lying areas and the shoreline ridges. However these are generally not mapped adequately at scales that are relevant for projected sea-level rise. Results presented above are mere approximations and may not represent the situation at the present or the changes that have occurred over time.

Sharples (2004) outlined techniques for indicative mapping, which combines available digital elevation models (DEM) with information on tidal and extreme water levels. This approach was considered valuable for this study. He however proposed that the vulnerability of coastal landforms to the physical impacts of coastal hazards including wave erosion and storm surge flooding – both at the present day and as a future result of ongoing climate change and sea-level rise - can be assessed at three broadly-defined levels of detail and confidence. These include: -identification of shores whose basic geological and geomorphic characteristics or types make them potentially vulnerable, in principle, to coastal hazard impacts. This has been partially achieved in this paper. For instance the fundamental vulnerability factors in the

Niger Delta shore is the vulnerability to sandy coast erosion and horizontal recession, being a sandy shore in most places, exposed to storm wave and associated by low-lying sand sediments deposits. The damming and dredging of the River Niger are culpable indicators of increasing vulnerability.

The paper does not give indication of relative differences in the patterns, rates or magnitudes of potential impacts at different sites, but attempts a Second Pass or Regional Assessment as proposed by Sharples (2006), which integrates the coastal geomorphic types with a range of regionally variable vulnerability factor, particularly salinity limits, tidal range and vertical tectonic movement (land subsidence arising from oil and gas extraction).

These vulnerability factors yield differing degrees of vulnerability along large stretches of the coast. This level of assessment has been applied in places such as the USA to yield a coastal vulnerability Index or CVI (e.g., Gornitz & Kanciruk 1989, Thieler 2000, in Sharples, 2006). Such mapping at national or state level is useful to map those parts of the coast that are most vulnerable. This is highly advocated for the region.
Sharples' (2006) third level is a detailed or Site-Specific Assessment (ideally) identifies all relevant geological, geomorphic, topographical, oceanographic and climatic factors (fundamental, regionally and locally variable vulnerability factors) influencing a particular local coastal system, and integrates these to produce a model of likely geomorphic behaviour for that particular shore. This was not part of the issues addressed in this paper. Access to data on local
variables that can be taken into account at this level of assessment, including local bathymetry, bedrock surface topography, dune height, sediment budget, exposure to wave energy, and others was not possible due to unavailability of such data.

In line with Sharples proposition detailed and locally-focused level of assessment should be accompanied by quantitative monitoring of actual geomorphic changes on the shore, so as to allow testing and refinement of coastal behaviour models for that site. The Niger Delta has not been monitored for sufficiently long periods as to provide useful data to support detailed coastal behaviour modeling. This is a task that needs to be emphasized and taken seriously by relevant governmental institutions as it would facilitate sustainable coastal zone management.

The surveyor plays very significant role in this direction. By assisting in mapping (topographic), he facilitates the provision of local indicators in digital format and the geospatial analysis of the changing conditions. The use and analysis of aerial photographs and satellite data are within the domain of the surveyor. Both traditional monitoring methods, which have relied on survey transects and aerial photography and modern mapping technologies such as laser altimetry (LIDAR), Real Time Kinematic GPS (RTK−GPS), digital photogrammetry, and interferometric sonar, which greatly enhance the capabilities to gather 3D geo-referenced data at spatial and temporal resolutions, and have been used in some advanced economies (Morton et al. 1999; Bernstein et al. 2003), are within the ambit of the surveyor's jurisdiction.

This has been achieved elsewhere. For instance, Yong Suk, et al (2008) used aerial photographs, satellite image data and GPS survey data with certain intervals to monitor the change in coastal areas of Songjeong, Haeundae, Kwanganri, Songdo and Dadaepo, while

Morton et al. (1999) have used GPS surveying techniques in monitoring beach changes. In addition, Mitasova et al (2004) have used innovative methodology based on a combination of Real-Time Kinematic Global Positioning System (RTK-GPS), Light Detection and Ranging (LIDAR), and open-source Geographic Information System (GIS) to gain a better understanding of rapid changes in coastal topography. These can be applied for the coastal areas of the Niger Delta.

Conclusion

It is recognized that the Niger Delta region is currently under human unprecedented pressure and climate induced processes and widespread. In addition to the regional problems of rainfall/runoff induced erosion and flooding, anthropogenic induced land subsidence and global warming induced sea level rise, are additional imperatives. Low-lying areas of the Niger Delta coast, particularly barrier islands, tidal flat wetlands and estuaries appear the most vulnerable to climate change, particularly eustatic sea level rise. The growing oil and gas extraction activities are additional push factors.

This paper identified the threats of inundation and erosion arising from sea level rise on the basis of existing tidal limits and indicative shore zone morphological susceptibility as some of the problems that would be aggravated by scenarios of sea level rise. An indicative delineation of habitats, conservation priority areas and shore zone morphology within at 50km from the shoreline through proximity and overlay analysis, indicated that habits susceptible to future inundation and erosion/flooding include mangroves and mud flats, some cultivated and fallow land, and freshwater swamps. These are likely to be converted to saline wetlands by the year 2100, given the global climate change and sea level rise scenario and the current hydrocarbon activities. In addition, some areas designated as conservation priority zones by IUCN/WWF/NCF are susceptible to inundation and increase salinity and this threatens biodiversity conservation efforts.

This study was however descriptive and qualitative. Quantifying spatial change in this dynamic environment is currently lacking but is crucial for sustainable coastal management. Monitoring the changing coastline using satellite remote sensing data and aerial surveys in conjunction with ground surveys at local scale would provide concrete data on the susceptibility of the region to human and natural changes. There is urgent need for a more systematic integration of high resolution topographic and bathymetric datasets with tidal and storm surge extreme water levels. These are some of the hindrances that need to be addressed.

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