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Sustainable Management of Muddy Coastlines

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1. Introduction

The Coastal Zone is home to many heavy oil and gas industries, and a significant proportion of the population and wealth generating infrastructure. The coastal zone therefore, provides economic, transport, residential and recreational functions, all of which depend upon its physical characteristics, pleasant landscape, cultural heritage, natural resources and rich marine and terrestrial biodiversity. The United Nations estimated that by 2004, more than 75 percent of the world's population would live within the coastal zone (Reeve *et al*., 2004). These regions are therefore of critical importance to a majority of humanity and affect an increasing percentage of our economic activities. The pressure on coastal environments is being exacerbated by rapid changes in global climate, overexploitation of fisheries, coastal and marine pollution, coastal erosion and flooding, physical modification and destruction of habitats, etc. For example, the Intergovernmental Panel on Climate Change (IPCC) has predicted a sea level rise of the order of 0.6m over the next century. For Nigeria, it is of the order of 0.83m (Nwaogazie & Ologhadien 2010)

The value of the coastal zone to humanity, and the enormous pressure on it, provides strong incentives for a greater scientific understanding which can ensure effective coastal engineering practice and efficient and sustainable management of coastlines.

2. Muddy coastline

Coastal classification generally falls into two main categories; namely, genetic (nature) and descriptive (based on morphology). Within the descriptive classification, a sub classification in terms of particle size of the beach material have: muddy coasts, sand coast, gavel/shingle coasts and rock coast. Another sub-classification based on typical coastal features have the following: barrier island coasts, delta coasts, dune coasts, cliff coasts, coral reef coasts, mangrove coasts, marsh grass coasts, etc.

While a vast majority of coastlines are made up of sediments ranging from coarse-grained fragments of rocks to fine-grained sand, only a few are muddy coasts. Sediment mixture with a fraction of clay particles ($d < 4\mu m$, AGU scale), larger than about 10% have cohesive properties. Mud may be defined as a fluid-sediment mixture consist of (salt) water, sands, silt, clays and organic materials. Muddy coasts fall within the descriptive category of coasts in which classification are based on particle size of the beach material. In a coastal environment, there is a continuous cycle of mud flocs which consists of erosion, settling, deposition, consolidation and erosion. Since mud particles are denser than water and unstable, the continuous agitation of the surf zone by breaking waves transport mud material cross-shore and equilibrium conditions are hardly attained. Thus muddy coastlines hardly form breaches, which offer natural coastal protection systems. Plate 1 shows the action of breaking waves on a muddy coastline.

Plate 1. Wave breaking on a muddy coast at Aiyetoro, Nigeria

3. Coastal processes

The hydraulic and morphological processes in the coastal zone are governed by two primary phenomena; namely, windwaves and astronomical tides. The wind stress on the water surface produces wind-generated waves which are of a relatively short period. The periodic rise and fall of water level is due to the astronomical tides produced by the gravitational field in the presence of the rotating earth, moon and sun. The timescale of tidal oscillations is very much larger than that of the wind-generated waves. Table 1 presents other free surface disturbances.

Phenomena	Generating force	Time scale (period)
Wind generated waves	Shear and wind pressure on sea surface	0-15s
Swell	Long-distance wind wave	0-30s
Surf beats	Grouping of breaking waves	1-5 min
Seiches	Variations of wind speed and atmospheric pressure	1-60 min
Basin resonance	Tsunami, surf beats	1-60 min
Tsunami	Undersea earthquakes	5-60 min
Tide	Moon-sun influences on earth	12-24 hr
Storm surge	Wind shear and atmospheric pressure on sea	1-30 days

Table 1. Free surface disturbances in the coast

The most important hydraulic process in coastal engineering is the wave motion; the understanding of wave motion and of its interaction with structures and coastal hydrography is vital in the estimation of erosion and accretion, sediment transport and coastal morphology. These processes are also important in formulating sustainable management plans.

3.1 Wave motion

The wave profile according to the linear wave theory is

$$\eta = a \cos\ (kx - \omega t) \tag{1}$$

where η is surface elevation, a is wave amplitude, ω is circular frequency, k is wave number, t is time, and x is positive direction of wave travel. The solution of the velocity potential (ϕ) for the wave profile of Equation 1, must satisfy the Laplace equation, boundary conditions at the sea bed and on the water surface. The resulting solution for ϕ is given by:

$$\phi = -gH\left(\frac{T}{4\pi}\right) \frac{\cosh k(d+z)}{\cosh kd} \sin\ (kx - \omega t) \tag{2}$$

where g is acceleration due to gravity, H is wave height, T is wave period, k and ω are as previously defined.
The wave celerity (c) and wave dispersion equations are :

$$c = g\omega^{-1}\ \tanh kd \tag{3}$$

and

$$\omega^2 = gk \tanh kd \tag{4}$$

where $k = \frac{2\pi}{L}$ and $\omega = \frac{2\pi}{T}$

The particle velocities are derived from Equation 2 using the definition of velocity potential:

$$u = \pi HT^{-1} \frac{\cosh\ (k(y+d)}{\sinh kd} \cos\ (kx - \omega t) \tag{5}$$

$$v = \pi HT^{-1} \frac{\sinh\ (k(y+d)}{\sinh kd} \sin\ (kx - \omega t) \tag{6}$$

where η is the height of the water surface above stillwater level, u is the horizontal water particle velocity, v is the vertical water particle velocity, d is the still water depth, H is the wave height, L is the wave length and T is the wave period.
For the computation of longshore sediment transport, coastline evolution, design of shore protection works and estimation of wave impact pressures on structures, historic wave data are required. The wave measurement facilities may be situated offshore in relatively deep water. By means of the wave dispersion equations (3 & 4), the wave conditions in the offshore station may be transferred to the coastal zone. Equations 5 and 6 are components of velocity used in estimating the wave forces exerted on structures.

3.2 Sediment transport

Coastal sediment transport consists of two aspects: sediment transport parallel to the shoreline (longshore) and sediment transport transverse to the shoreline (cross–shore). The imbalances in the longshore sediment transport are responsible for the long-term changes in the coastlines, whereas the cross-shore transport is responsible for the short-term variations.
The morphological consequences of shore protection works are assessed in terms of quantitative estimates of erosion and accretion. Waves and currents, along with the physical properties of the sediment materials, determine the rate of material transport in the coastal zone. The reliability of sediment transport predictions is strictly dependent upon the accuracy of the semi-empirical equations used to evaluate the sediment transport. Studies have been carried out to establish the validity and reliability of several solid transport formula (White et al. 1973; Gomez and Church 1989; Bathurst et al. 1987). These studies concluded that, there is no solid transport formula valid for all ranges of natural conditions and therefore, the more appropriate formula for each set of particular conditions can be chosen.
A number of longshore transport models have been developed for a number of natural conditions; namely,

3.2.1 Coastal erosion research council (CERC) formula (1963)

In the CERC formula,

$$\mathrm{S} = \mathrm{A}\, H_o^2 C_o K_{rbr}^2 \sin\phi_{br} \cos\phi_{br} \tag{7}$$

where S is longshore transport due to breaking waves, A is a constant, H_o is deepwater wave height, C_o is deepwater wave celerity, K_{rbr} is wave refraction coefficient at the breaker line, and ϕ_{br} is breaker angle.
The CERC formula does not account for differences in sediment materials often represented by d_{50} (mean size). The formula is often criticized for being only valid for relatively long and straight beaches, where the longshore differences in the breaking wave heights are small. Thirdly, the formula does not account for currents which are not generated by breaking waves, such as tidal currents. When tidal currents are important, another transport formula should be used.

3.2.2 Bijker formula (1967 & 1968)

The Bijker formula is:

$$S_b = b D_{50} \frac{\upsilon}{C} \sqrt{g}\, \exp\left[- \frac{0.27\, \Delta D_{50} C^2}{\pi \upsilon^2 \left\{ 1 + \frac{1}{2}\left(\xi \frac{u_b}{\upsilon} \right)^2 \right\}} \right] \tag{8}$$

where S_b is bed load transport, b is a constant ($\simeq$5), D_{50} is mean grain diameter, υ is current velocity, C is chezy coefficient = $18\log\left(\frac{12h}{\gamma}\right)$, h is water depth, r is bed roughness, g is acceleration due to gravity, Δ is specific density, $\xi = C\left(\frac{fw}{2g}\right)^{0.5}$ with f_w = exp $\left\{-6.0 + 5.2\left(\frac{a_o}{\gamma}\right)0.19\right\}$, a_o is the amplitude of orbital excursion at the bed, μ_b is amplitude of orbital velocity at the bed.

The Bijker longshore shore transport model takes into account the effect of tidal or other types of currents and may be coupled with other models. The Bijker model is unique, because it is adaptable to any current condition.

3.2.3 Kamphius equation (1991)

The Kamphius model was refined using a series of hydraulic model tests, giving

$$Q_k = 2.27\, H_{sb}{}^{2.0} Tp^{1.5}\, (\tan\beta)^{0.75}\, D_{50}^{-0.25}\, (\sin 2\theta_b)^{0.6} \quad (9)$$

where H_{sb} is breaker wave height, T_p is peak wave period, β is slope of the beach, D_{50} is medium sediment diameter, θ_b is wave breaker angle. The Kamphius model does not take tidal currents along the coast in account.

4. Coastal morphology

Morphological evolutions are a direct response to changes in sediment transport. The computation of longshore sediment transport rates preceeds prediction of coastal changes due to erosion and accretion. When the sediment transport rate reduces, accretion will occur; conversely, an increase in sediment transport will cause erosion. Consequently, morphological evolutions are indicative of changes in shoreline position, and these changes are often components of the decision making measures against coastal erosion.

In conclusion, the coastline is in a state of dynamic equilibrium, characterized by the local wave climate, currents, and other water level fluctuations summarized in Table 1. In order to manage coasts sustainably, a good data gathering programme comprising: bathymetry/ topography, seabed characteristics/bedform, waterlevels/ waves, etc. is recommended.

5. Data gathering and mathematical modelling

5.1 Mathematical modelling

Most coastal engineering models are non-linear equations, which do not have analytical solution. Therefore, they cannot be applied to problems involving complex boundaries and time-varying boundary conditions. Analytical solution of models of real world will be of little help and one has to resort to numerical techniques. Several types of numerical methods, such as finite differences, finite element, finite volume and boundary element methods have been widely used to coastal engineering problems. Such models are used in investigating coastal processes and the design of coastal engineering schemes.

Experiments using physical models can also be undertaken using controlled conditions, thus allowing investigation of each controlling parameter independently. Physical models are normally smaller scale versions of the real situation. This requires a theoretical framework to relate model measurements to the real (prototype) situation. Unfortunately, the result of this theoretical framework is that scaled physical models are unable to simultaneously replicate all of the physical processes present in the prototype in correct proportion. Thus, we return to nature, by way of field measurements. Such measurements obviously do contain all the real physics, if only we knew what to measure and the appropriate instruments to do so. Such measurement, as are possible, have to be taken in an often hostile environment, at considerable relative cost and under uncontrolled conditions.

5.2 Data gathering

Field investigations are often carried out for major specific coastal defense projects. Basically, measurements are made on waves, tidal currents, water levels and beach profiles. Such measurements are often used to derive the local wave climate, current circulation patterns, extreme still-water levels and beach evolution through the use of numerical models which are calibrated and take their boundary conditions from the measurement.

Mulder *et al.* (2000) described a set of measurement tools considered both comprehensive and informative, comprising descriptions of equipment to measure bathymetry/topography, seabed characteristics/bedforms, water levels/waves, velocities, suspended sediment concentrations, morphodynamics/sediment transport and instrument carrier/frames plat forms.

Table 2 contains some recent tools in measurement equipment taken from Dominic *et al.* (2004). Interested readers are referred to the above texts for guidelines on how to use the tools and examples of results.

In terms of the development of our understanding and the incorporation of that understanding in the management of coastlines, design process, field studies and physical model studies are required to improve both our knowledge of the physics and calibrate and verify our numerical models. These models are key component of the current state-of-the art tools.

5.3 Geographic information system (GIS) tools

Sustainable development and management of natural and economic resources depends on the ability to assess complex relationships between a variety of economic, environmental and social factors across space and time. Lack of Integrated data management tools among the Interrelated and Interwoven dimensions frequently Inhibit the quality of environmental and development planning. Consequently, information management systems are currently receiving growing attention. In this regard, GISs have emerged as a particularly promising approach, enabling users to collect, store, and analyze data that have been referenced to its geographic location.

A Geographic Information System is a system of computer hardware, software, and procedures designed to support the capture, management, manipulation, analysis, and display of spatially referenced data for solving complex planning and management problems.

The advantages of GIS capability can be categorized as long term or short term. The long-term category is where economic and environmental management on a national, regional or local level is called for , in other words, institutional or programmatic applications. The short-term category usually involve specific project situations, for example, Environmental Impact Assessment Studies.

S/No	Name of tool	Brief description
1	Total station leveling for bathymetry/topography	Method of surveying the coast and inter-tidal area, using laser leveling system.
2	Differential global positioning system (GPS)	Method for fixing absolute position (three coordinates), based on calculated distance from at least four geo-stationary satellites.
3	Echo Sounder surveys	Method of surveying the seabed using a standard maritime echo sounder.
4	Van Veen grab for seabed characteristics/bed forms	A method of obtaining samples of subtidal seabed material either for visual analysis or for quantitative particle size distribution analysis.
5	Roxann system	An acoustic system used to produce a map of the near shore and offshore zones of the study area.
6	Digital side-scan sonar	An acoustic system designed to map the bedforms in the offshore and nearshore zones.
7	Pressure transducer (TP) for water levels/waves.	A device for measuring total pressure, when installed underwater, analysis of instantaneous pressures gives measure of wave height/period.
8	Wave pole	A pole or pile driven into the bed, and extending above the highest water level.
9	Directional wave Buoy	A surface buoy for measuring offshore wave conditions, including wave height, period and direction.
10	Wave recording system (WRS)	The wave recording system is an array of 6 pressure transducers used to derive the wave height, period and directional spectra in the nearshore zone.
11	Inshore Wave Climate Monitor (IWCM)	The 5 wave staffs are driven into the beach in a triangular array and are connected to a central data storage/ battery power unit.

Table 2. Names and brief description of measurement tools

The basic equipment, software and human resource skills required may be similar for both long-term and short-term, but the design, implementation and operation implications may be different.

GIS may be particularly useful in cross-sectoral and regional development, for example, in coastal zones, catchments, large urban areas, or multi-purpose development schemes within a given administrative region.

Determining a region's vulnerability to soil erosion for instance, requires the consideration of such factors as soil structure and chemistry, seasonal fluctuations in rainfall volume and intensity, geomorphology, and type of land management regime in practice. Assessing the feasibility of a soil conservation programme in an area requires additional information on the economic status of Inhabitants, the type of crops grown, and the responsiveness to incentives for soil conservation. Then, selecting the appropriate land rehabilitation models requires data on land capability and its suitability for different uses. GIS technologies handle both the spatial and non-spatial properties of data-sets, thus providing an extension to other statistical methods that disregard the spatial nature and variations of environmental data. The advantages of using GIS in environmental assessment include the following:

- It encourages a more systematic approach to environmental data collection;
- It can reduce the overall costs and institutional overlap of environmental data collection and management;
- It increases comparability and compatibility of diverse data sets;
- It makes data used in environmental assessment accessible to a wider range of decision-makers; and,
- It encourages the spatial analysis of environmental impacts that would otherwise be more easily ignored because of analytical difficulty or cost.

Besides Environmental Assessment, GIS provides a powerful set of tools for:

- Supporting Resources Inventories and Baseline Surveys and land-use mapping;
- Impact Assessment and Analysis of Alternatives;

GIS modeling techniques allow complex interrelationships to be evaluated within comprehensive spatially referenced databases. Techniques such as network analysis, digital terrain modeling are routinely applied in coastal engineering to assess the vulnerability of climate change sea-level rise to coastal communities.

Decisions made in GIS application will be useful in designing mitigation measures. Risk assessment applications such as hazard identification, and risk minimization planning are other examples where GIS has been effective.

Environmental Monitoring

When monitoring environmental impacts during and after project completion, databases with multiple attributes must be integrated. GIS can help structure and integrate this diverse information ranging from water quality to soil productivity to habitat data. Specific GIS technologies that are useful in monitoring include remote sensing, which can be applied to monitor, for example, sewage disposal sites, effluent discharges and coastal areas for example.

5.3.1 Available GIS

Geographic information systems are available both in PC/micro computers and mini and main frame computers. Table 3 lists a summary of some commercially available geographic information systems.

5.4 Salt intrusion/gravitational circulation

Sediment-laden flowing water, other natural substances or pollutants move with the water, and therefore are transported by the flow. The flowing water is affected by density differences, causing density induced currents. These currents affect the direction of flow and transport, and may vary over the depth of water. Consequently, density currents are a factor to be considered when studying the sedimentation in estuaries, coast or the transport of pollutants through these systems. Another negative effect of gravitational circulation is the creation of "null points" causing shoaling and sedimentation which interferes with navigation.

System name	Hardware	Geometric Storage	Attribute storage
ARC/INFO	VAX, PRIME IBM, DG	Vector	Relational
DELTAMAP	HP, SUN	Vector	Relational
INFORMAP	VAX	Vector	Relational
INTEGRAPH	VAX	Vector	Network
MAPS	VAX, PRIME	Vector	Relational
SICAD	SIEMENS	Vector	Relational
SYSSCAN	VAX	Vector	Relational
GEOBASED	VAX	Vector	Relational
SYSTEM 600	VAX	Vector	Relational
ARC/INFO	IBM PC/AT SYSTEM 2	Vector	Relational
SPANS	IBM PC/AT SYSTEM 2	Quadtree vector	Relational
INFORMAP II	IBM/AT	Vector	Relational
ERDAS	IBM/AT	Vector	Relational
ILWIS	IBM/AT	Raster vector	Relational
PAMAP	IBM/AT	Raster	Relational
IDRISI	IBM/AT	Raster	Relational

Table 3. GIS in mini and main-frame computers

Management concerns frequently center on the concentration of waterborne indicators, including pollutants and plaktonic organisms. The need to consider the environmental and economic sustainability of present and future coastal management schemes on muddy coasts requires a good understanding of density currents and morpho-dynamics. Aquatic ecosystem sustainability is highly dependent on salinity concentration dynamics and must be studied for the particular environment. Both analytical and mathematical models are currently used to simulate salt intrusion. The models constitute a powerful tool for evaluation of salinity intrusion patterns and as supportive instruments for decision making in coast management. Table 4 contains some widely used coastal engineering models:

Designs	Name	Purpose
1	Genesis	Simulation of coastal processes
2	SBEACH	Coastal Engineering design
3	MODIFIED KRIEBEL	Cross-shore simulation for berm dimensions and hurricane storm events.
4	CEQUALW2	Salinity Intrusion

Table 4. Widely Used Coastal Engineering Models

6. Sustainable management of coastlines

Coastal management plans are designed to provide coastal zone resource development within the framework of:

a. Technical: coastal processes and defense, etc
b. Socio-economic: economic demography, regional planning and
c. Environmental: water quality, biodiversity, etc.

i. Coastal management is continually confronted with conflicting challenges. There are problems of jurisdiction involved in whether the responsibility for running the operation lies with the federal governments, a local government or some regulatory commission, and always there is application of priorities supposedly set by society as a whole. The basic tool is a legal framework to regulate the conflicting activities on the coast. These may include national laws made to meet specific requirements, e.g. National Environmental Policy Acts of 1969 which provides preparation of environmental impact statement, the Water Quality Act of 1970 which addresses oil pollution; international covenants and jurisdictional responsibility.
ii. There is a problem of political process. The political process is such that technical standards will almost always yield to such things as austerity cases, emergency situations, or strong public sentiments. Consequently, decision on coastal environment must have a public input or else the decision will probably not be effective. The manager must be prepared to strike a compromise between the emotional public, individual agencies, both state and federal, often working at cross-purposes.
iii. Arising from (ii), is the need for coordinated approach such that environmental protection, fish and wildlife services, etc, may work together and adopt a consistent approach to survey, mitigation and monitoring. The coordinated approach achieves better results for the environment in terms of a more consolidated, integrated approach and saves on resources and repetition by stakeholders.
iv. The physical characteristics of coastal environment is dictated by the actions of breaking waves and currents on sediment materials. There is need for quality data gathering, both comprehensive and information, comprising bathymethry/topography, seabed characteristics/bedforms, water levels/waves, velocities, suspended sediment concentration.
v. There is need to broaden the emphasis from assessment of physical environment aspects, to assessment of impacts on marine ecological resources, in particular benthic and epibenthic species, habitats.

vi. Application of Hydroinformatics systems: Hydroinforamtics, the use of information and communication technology in hydraulics, encapsulates and integrates engineering methods in software systems. It provides powerful methods to engineers and rational solutions to policy makers. The application of hydroinformatics systems to problem solving in coastal environments requires the availability of databases for calibration and verification of engineered systems. It also calls for adequate instrumentation and experimental methods, and international cooperation for the acquisition and exchange of data. Hydroinformatics systems will have to be built up from proprietary codes and modeling systems that have been constructed, in most cases, for quite other purposes than those of hydroinformatics. Interested readers are referred to Abbot et al., (1988) for full description of hydroinformatics systems.

vii. The need for integrated coastal zone management (ICZM). Integrated coastal zone management has been widely accepted as an effective mechanism for addressing and resolving these types of issues throughout the developed and developing world. ICZM will enable the integration of all issues and emphasize the involvement of all key players in the planning process, coordination between sectoral agencies, and application of cooperative management strategies involving stakeholders.

7. Environmental aspects of coastlines

As a case study, the Nigerian coast and marine areas have been chosen under this heading:

7.1 Wave and tidal characteristics

The Nigerian coast and marine areas are under the influence of moderate oceanographic forcing consisting of semi-diurnal tidal with spring tide ranging between 0.95m in the West to 3.25m in the East. The prevailing South-Westerly waves vary from spilling breaker to plunging waves. The persistence of significant wave height (hs) are in the order of 1.4m – 2.5m. Long shore currents and prevalent in the near shore while the West-East Guinea currents constitute the major ocean current.

The relative importance of diurnal and semidiurnal harmonics can be determined from the ratio, F, given by

$$F = K_1 + O_1 / M_2 + S_2 \tag{10}$$

where K_1, O_1, M_2 and S_2 denote the amplitudes of the respective tidal constituents. The form of tide (F) found in the Nigerian Atlantic Coast was calculated by substituting the amplitudes for K_1, O_1, M_2 and S_2 into Equation (10). The value of F calculated is 0.1601. Consequently, the tidal behaviour found along the Nigerian Atlantic coast is semi-diurnal, with two high and two low waters of approximately the same height.

7.2 Assessment of climate change

The possible impacts of climate change include higher sea levels altered pattern of rainfall and air temperatures, and increased frequency and intensity of severe storms. Some industries could be directly affected by adverse impacts of climate change. The coastal tourism industry, for example, is vulnerable to both sea-level rise and greater weather extremes. Table 5 shows a comparison of sea-level rise indicator parameters with others (Nwaogazie and Ologhadien 2010).

Parameter	Nigerian Coast	IPCC	Ghana	England	Remarks
Temperature	1.8^{o}C	1.5 – 4.5^{o}C	0.11^{o}C	NA	Per decade
Rainfall	55.2mm	NA	13mm	NA	Per decade
Mean Sea Level	8.3cm	6cm	2.2cm	4cm-6cm	Per decade

NA - Not Available; IPCC – Intergovernmental Panel on Climatic Change

Table 5. Comparison with IPCC and other Predictions

7.3 Sea-break-through inlets

The major environmental concern of the Ondo Coastline in Nigeria is its susceptibility to sea-break through inlets (Odi-Owei and Ologhadien, 2009). The first sea break-through inlet occurred in 1983, when a canal was dredged oblique to the coastline, leaving a vertical head cut. The overhang, coupled with the poor geotechnical characteristics and mechanisms of sediment transport downstream in the channel, initiated an upstream migration at the head cut towards the sea. Over time, the combined actions of the breaking waves, tidal currents and sea wind migration of the head cut eventually opened up the inlet, discharging saline water into the fresh water forest. Consequently, over 20 hectares of fresh water forest resources were destroyed (Plate 2), impacting negatively on the local economy. It also reduced the volume of saw-logs supply to the timber markets in Lagos, Benin, etc. Freshwater resources are extensively exploited for cash or subsistence. The Ondo State coastline is fairly stable except in areas that are exposed to breaking waves.

7.4 Coastal erosion and flooding

The coastline has been subjected to erosion over the years in Nigeria. Scientist from the Nigerian Institute for Oceanography and Marine Research (NIOMR) have reported widespread erosion and flooding of the Barrier Islands and the Niger Delta (Ibe *et al*., 1984, Awosike 1993) created erosion resulting from deficit of sand due to natural and anthropogenic activities varies. Notable among the natural causes of coastal erosion are vulnerable soil characteristics, topography and occurrence of off-shore canyons. Anthropogenic causes include destruction of coastline dredging and river dams.

The Victoria beach is fastest eroding beach in Nigeria with arrange erosion rate of 20 -30m yearly. Erosion rates range between 18-24m annually at Ugborodo/Escravos; Forcados, 20-22m; 16-19m at Brass; Karamo, 15-20m; Bonny, 20-24m; and Opobo; 10-14m; as reported by Ibe in 1989. Coastal erosion with serious flooding has done widespread damage in many areas along the coastal zone. The beaches along the Nigerian coastline are very susceptible to flooding due to their very low topography. Flooding of the Victoria Island in Lagos State and other low-lying areas of the state are common during the rainy season (June-August). High rainfall in the Niger Delta coupled with poor drainage allow storm waters to collect in the hallows and eventually flood large areas within the Delta.

Plate 2. Dead vegetation around Awoye inlets

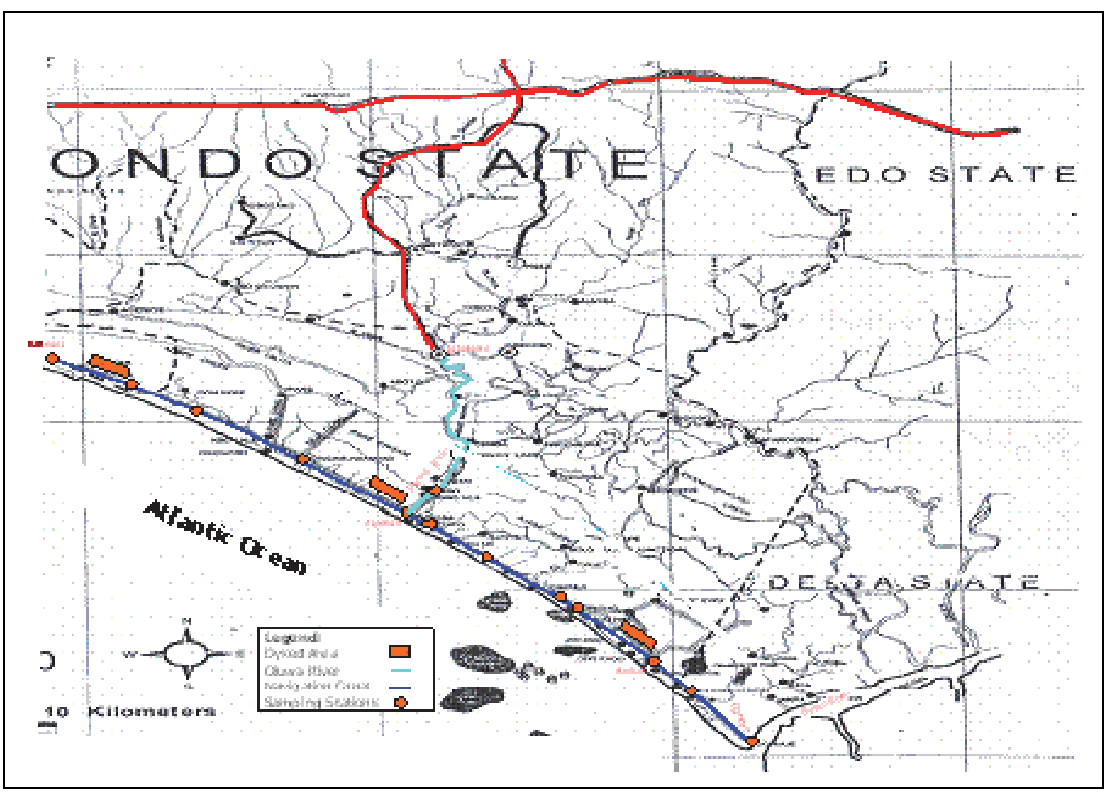

Fig. 1. Map showing Canal and Sampling Stations

7.5 Physical modification and festruction of habitats

The coastal zones have undergone wide modifications in the last thirty years. Due to high pressures on coastal resources conflicting exploitation techniques and increasing population leading to loss of biodiversity, in the ecosystem, the value of coastlines has been diminished. The destruction of mangrove ecosystems has been on the increase since exploitation of oil and gas started in the Niger Delta resulting in replacement of mangrove vegetation by new vegetation species like nympa palms.

The Kwale game reserve in the 1950s was rich in biodiversity but due to oil exploration, gas production and poaching elephants and many flora and fauna have disapproved in the Reserve several animal species of conservation interest including Scalter's Guenon, Delta Red Columbus, the Crested Genet, the Pygmy Hippo, Chimpanzee and African Leopard have almost disappeared in the Niger Delta, many plants of medicinal, economic and cultural values such as *Thaumatiococcus daniel* (sweetener) *Fegara sp.* (for sickle cell anemia) and *Rauvolfia vomitoria* (for treatment of high blood pressure and now rare in the Niger Delta).

The major socio-economic problems result from poverty ecosystem modification in the coastal zones include unemployment because the people depend on their tradition mean of livelihood.

7.6 Environmental management plan for coastal communities

The key to effective environmental management plan is adequate monitoring of the projects implementation, predicted impacts and monitoring or implementation of predicted mitigation measures. The environmental issues that will be addressed are;

i. Over exploitation of Fisheries resources,
ii. Costal and Marine Pollution
iii. Oil spills
iv. Coastal Erosion and Flooding
v. Physical modification and destruction of habitats
vi. Climate change and sea-level rise
vii. Invasive species (exotic species)
viii. Storm surges.

8. Conclusion

In order to implement the Environmental Management Plan for Coastal Communities, guidelines for dealing with specific environmental issues identified should be developed. As part of the management plan, continuous data collection for bathymetry, topography, waves, tides, surges, wind and salinity need to be carried out.

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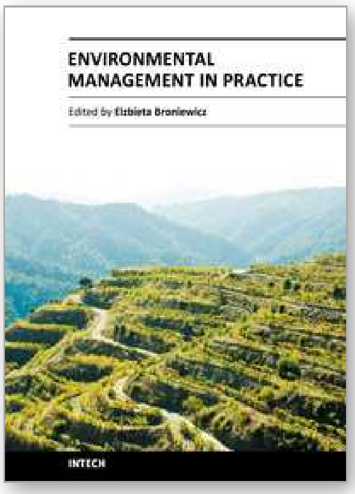

Environmental Management in Practice
Edited by Dr. Elzbieta Broniewicz

ISBN 978-953-307-358-3
Hard cover, 448 pages
Publisher InTech
Published online 21, June, 2011
Published in print edition June, 2011

In recent years the topic of environmental management has become very common. In sustainable development conditions, central and local governments much more often notice the need of acting in ways that diminish negative impact on environment. Environmental management may take place on many different levels - starting from global level, e.g. climate changes, through national and regional level (environmental policy) and ending on micro level. This publication shows many examples of environmental management. The diversity of presented aspects within environmental management and approaching the subject from the perspective of various countries contributes greatly to the development of environmental management field of research.