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ON

EFFECTIVE WATERSHED MANAGEMENT FOR ENVIRONMENTAL HAZARD CONTROL/ MITIGATION IN NIGERIA

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LEAD PAPER 1:

THE IMPACT OF LAND USE MANAGEMENT PRACTICES ON FLOOD AND EROSION IN A MULTI-WATERSHED SYSTEM: THE CASE OF THE FRESHWATER HYDROMETEOROLOGICAL ZONE OF THE NIGERIAN NIGER DELTA.

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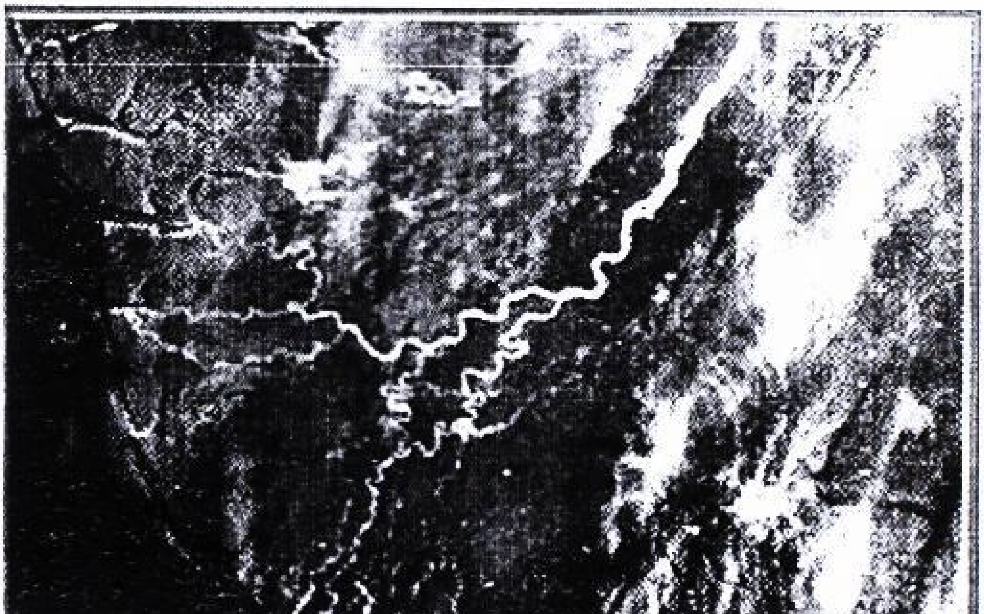
ABSTRACT

Land-use management practices in a sensitive environment such as the Nigerian Niger Delta calls for careful planning, especially, within watershed areas in the upper reaches of the Rivers and Creeks that criss-cross these fragile environments. The peculiar soil types such as deep clayey-silts and occasional sandy-clays, silty-sands and lateritic sands need careful management during project executions in these areas. Farming practices, lumbering practices, grazing practices and urban developments within the Freshwater hydro-meteorological zone of the Niger Delta are factors that may impact negatively when subjected to the twin-problems of annual flooding and erosion that are very common place in this zone. The general morphology of the several inter-river systems and watersheds that abound in the freshwater zone of the Nigerian Niger Delta also demands that farming systems such as contour ploughing, orientations of building positions with respect to slope positions and geometries, River bank landing steps during dry seasons and slope protection measures be scientifically designed to reduce the impacts of erosion. Water generally is a limiting factor for crop production where irrigation is not available. It can be limiting even in humid and sub-humid regions where there is a theoretical need to dispose of excess water. Dry periods with water deficit frequently occur in these regions and positive responses to moisture conservation techniques are commonly obtained. Over 80% of the agricultural land of the world is not irrigated. In Africa, where a little over 0.3% of the land is under irrigation (FAO 1987), rain-fed agriculture prevails. In rain-fed systems the constraint is not only the erratic rainfall distribution but the amount of rainfall that can be stored in the root zone and its effective utilization. So the importance of watershed planning and establishment of *conservation authorities* whose functions are to promote water management on a watershed basis cannot be overemphasized. Although flooding and erosion issues had dominated water management for many decades in the world, it has now been recognized that water management has many other objectives such as *water quality, ecological health, terrestrial and aquatic resources*, etc. In order to manage our water resources effectively, we should apply an ecosystem approach in water management. The logical sequence of water management planning should be Watershed plans, Sub-watershed plans andSite plans that should be integrated with municipal land use planning process. Some Single-Watersheds and Multi-Watersheds within this zone have been identified, especially where these coincide with the locations of important towns and settlements. Mechanisms of Flooding and Erosion occurrences within this Freshwater Zone have also been proffered in this paper together with some proffered Control Measures for these twin problems of flooding and erosion.

1.0 INTRODUCTION

1.1 Definitions of the Niger Delta Sub-Region: The Niger Delta lies at the southern extremity of the entity referred to as ***NIGERIA***. It is an arcuate structure that lies between ***Latitudes 4° 15' 00''*** and ***6° 30' 00''*** North of the Equator and between ***Longitudes 6° 37' 47''*** and ***7° 30' 00''*** East of the Greenwich Meridian. Thus, ***sensu stricto[strictly speaking]*** the Niger Delta is defined geographically and geologically as that area extending from ***a northern apex situated at Aboh***, bound on the east by the ***Imo River***, on the west by the ***Benin River***and on the south by the ***Atlantic Ocean***. The Niger delta basin serves as the receptor of the water and sediments generated upstream of the Niger and Benue catchments. These excess water and sediments generated during the annual floods are released through an anastomosing network of rivers, creeks, rivulets and in some cases canals into the Atlantic ocean. The sediments upon reaching the mouths of the rivers are acted upon by both the waves and long shore drifts to form the various barrier beaches and islands such as ***Bonny, Brass, Akassa and Forcados***in the present day delta. In a general definition, (***Sensu Lato)***the Niger Delta extends beyond the boundaries defined above. To the east of the of the Niger Delta proper are the ***Eastern Lowlands*** which comprise the present day ***Akwa Ibom, Cross River and Imo states***.To the west of the Niger Delta proper are the Western Lowlands which comprise the present day Central and Western Edo, Ondo and even Lagos states. A Zonation based on ***hydro-meteorological factors*** has been made for the Niger Delta sub-region by the ***Institute of Geosciences and Space Technology (IGST,) formerly known as the Institute of Flood, Erosion, Reclamation and Transportation (IFERT)*** of the Rivers State University of Science and Technology, Port Harcourt ***(Fubara, Teme et al., 1988)***.
A relatively recent satellite image of the Niger Delta sub-region is shown in ***Figure 1***a below.

NigeriaSat-1 image of a part of the Niger Delta, Nigeria



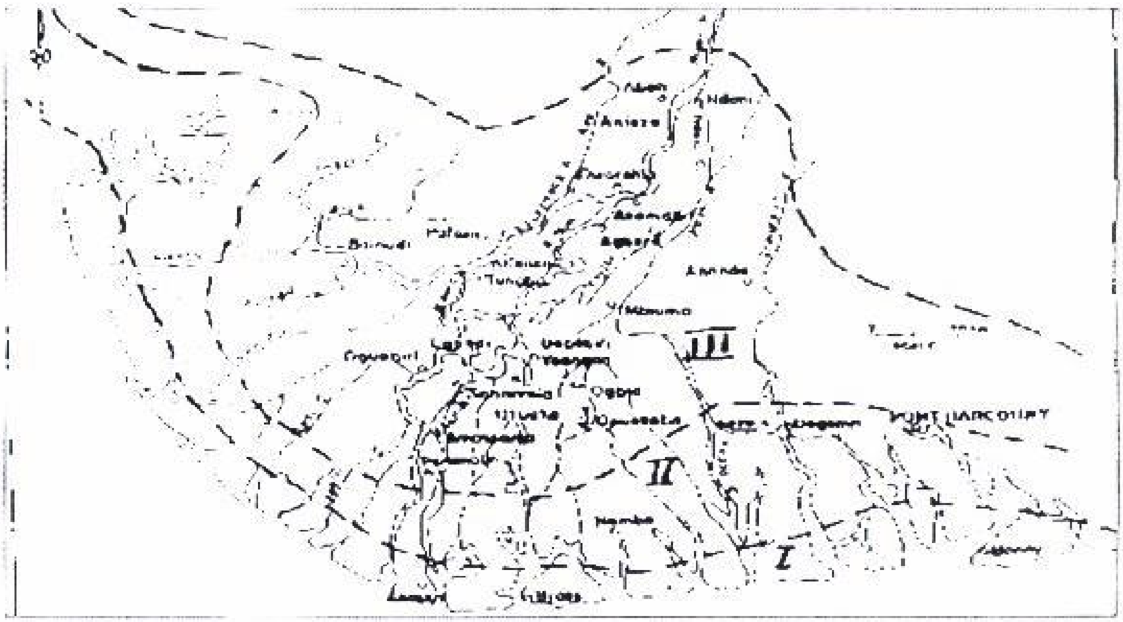
Source: NigeriaSat-1 (NASRDA, 2010)

Figure 1a: **Satellite Image of the present Niger Delta sub-region.**

Zonation of the Niger Delta Region.

The zones of the Niger Delta are namely:-

(a) Coastal or Lower Delta Zone
(b) Transition' or Mangrove Zone, and
(c) Freshwater Zone



LEGEND

I = Coastal Zone
II = 'Transition" or Mangrove Zone
III = Freshwater Zone

Figure 1b: **The Niger Delta sub-region showing the three hydro-meteorological zones.** ***(after Fubara, Teme et al, 1988)***

1.1.1 The Coastal Or Lower Delta Zone.

This zone consists mainly of **sand bars** and **ridges** and the water bodies here are saline in nature. The area is subjected to ***diurnal ebb*** and ***flow tides*** and thus not prone to the annual floods of the Freshwater zone. The sub-soils here consist of sand, silts and highly plastic clays in some inlet areas.

The vegetation of this zone is basically mangrove trees with a preponderance of ***nippa palms (a recent development in this zone)***. Some freshwater trees such as palm trees are also found within the few elevated beach ridges within this zone.

The ***climate of the zone*** is basically that of ***tropical monsoon with rainfall occurring almost all through the year except the months of December, January and February which are not completely free from rainfall in some years***. Rainfall within the zone reaches highs of ***over 4000mmm at Akassa Bonny and Forcados*** during the peak of the wet seasons (Institute of Geosciences and Space technology Meteorology division records 1988-2000). Some towns within this zone are ***Bonny***, ***Akassa***, ***Brass***, ***Bekinkiri***, ***Koluama I*** (wiped out by wave erosion), ***Koluama II***, ***Oyorokoto***

Figure 1c: Some River-basins and Water sheds in Rivers and Bayelsa States in Nigeria

1.1.2 'Transition' Or Mangrove (Middle Delta) Zone

This area coincides with the **Mangrove brackish water zone** with its numerous ***inter-tidal flats*** and ***mangrove vegetation***. Sub-soils here are characterized by a typical ***fibrous, pervious clayey mud that exhibits large values of compressibility and consolidation.*** Usually beneath these fibrous layers are ***silty sands which most often grade into poorly-graded sands and further downwards into well-graded sands and gravels. Lateritic clays also occur in certain 'old' residual deposits*** on which are usually located densely populated towns such as ***Bakana, Buguma and Abonnema*** in Rivers State. The vegetation within the ***'Transition' zone*** comprises basically ***"tall" mangrove trees*** especially within the saline swamps and along the banks of the numerous rivers, rivulets and creeks. Behind the river banks are usually ***"red" short mangrove trees***.

The climate of the zone is basically that of ***tropical monsoon with rainfall occurring almost all through the year except the months of December, January and February which are not completely free from rainfall in some years***. Rainfall within the zone reaches ***highs of over 600mm*** at **Port Harcourt, Opobo and Warri** during the peak of the wet seasons (***Institute of Geosciences and Space technology Meteorology division records 1988-2000)***

Just like the Coastal Zone, this zone experiences ***diurnal ebb-and-flow of the tides*** with maximum values obtained during the **once-a-year** ***Spring tides.***

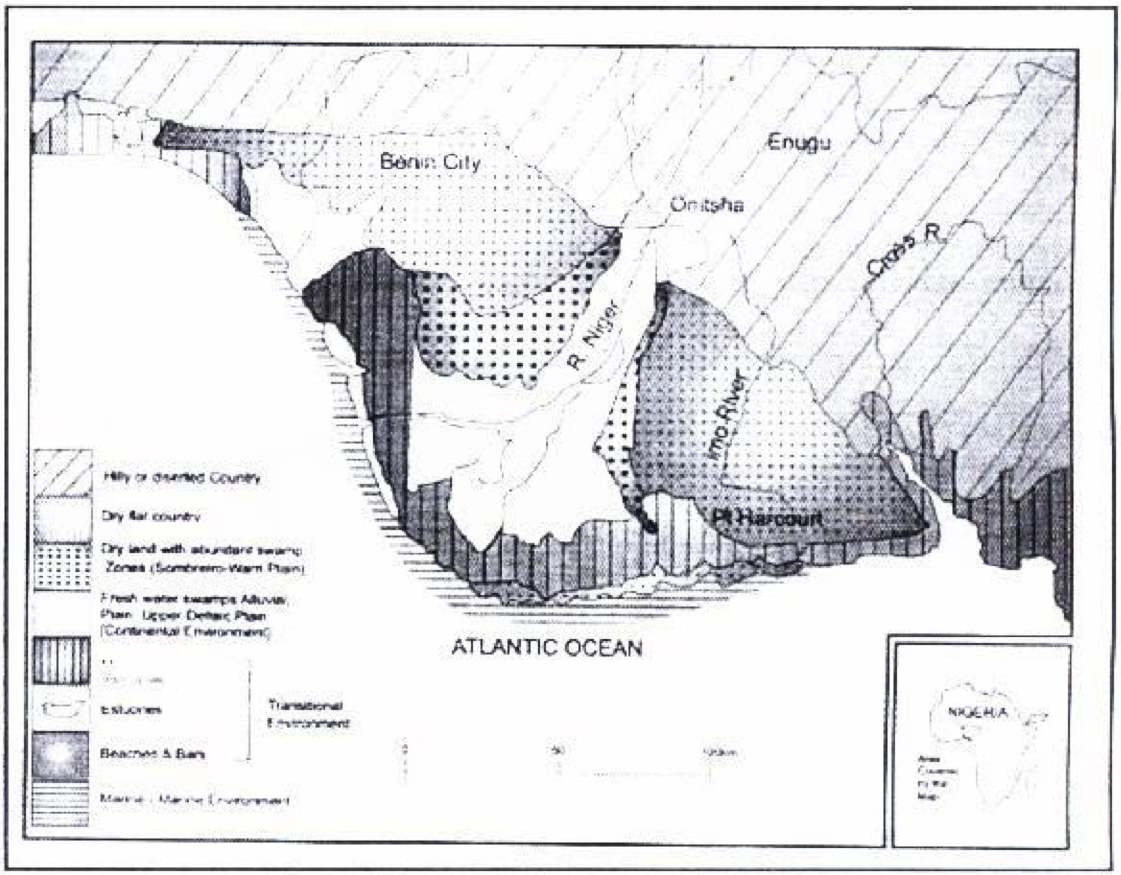


Figure 1d: Some subdivisions and River basins in the Niger Delta sub-region.

Notable settlements and towns within this zone comprise ***Port Harcourt, Opobo, Sapele, Buguma, Abonnema, Bakana and Warri.***

1.1.3 Freshwater Or Upper Delta Zone.

This zone comprises the ***remaining northern portion of the Niger Delta sub-region***. This covers the ***predominantly fresh water rivers, creeks and ephemeral depressions***. Generally, soil profiles within this zone comprise of a ***top lateritic clay layer usually underlain by silty clays and silty sands which are further underlain by poorly-graded sands and sands and gravels.*** Notable towns in this zone include ***Agbere, Odoni, Ndoni, Isampou, Patani, Asamabiri, Yenegoa and Amasoma.***

The vegetation within the Freshwater zone comprises***Palm trees, broad-leafed trees with very thick undergrowth characterized by creepers and climbing varieties. Tall grasses are not uncommon within the zone.***

Climatically, ***rainfall occurs in over nine months of the year***, especially during the ***annual flood periods of May through October*** and ranges in intensity ***between 200 and 600mm in towns*** such as ***Ahoada and Omoku in Rivers State***(*Institute of Geosciences and Space technology Meteorology division records 1988-2000*). ***Before the mid- 1970s the Annual floods were observed to start receding from the 15th of October each year but due the effects of CLIMATE CHANGE floods are presently being noticed as late as early-to mid-November of the year. Also, heavy rainfalls occurring on the First day or First week of January are no longer unusual occurrences!***

2.0 LANDUSE MANAGEMENT PRACTICES.

Land-use Management practices have been known to affect the impact of Flood and Erosion within the Niger Delta sub-region over the years.

2.1 General Practices within the Niger Delta Sub-region.

The general occupations of the inhabitants of the Niger Delta sub-region which to a large extent define the Land Use management practices of the area include (a) Farming, (b) Lumbering, (c) Grazing, (d) Urban development activities.

2.1.1 Farming. Farming within the Niger Delta sub-region, especially within the Freshwater Hydro-meteorological zone takes place during the rather short "Dry Season" period – usually between late November (at the onset of the Flood recession) and late May – late June (at the onset of the annual Flood season). This is usually carried out along the river banks (flood plains) for food crops such as yams, cassava, cocoyam and other vegetables. In the elevated areas within this sub-zone are usually planted some cash crops such as Cocoa trees, rubber plantations and fruit trees. The agricultural practices include the following:

(i) Planting crops on rows parallel to the slopes directions of the flood plains,

(ii) Strip farming o occasional fallow lands on aa annual or bi-annual rotational system,

(iii) Contour-Row farming.

2.1.2 Fishing and Hunting. Fishing which is carried out both in the rivers and streams also take place in the upper floodplains through creation of ponds which trap fishes during the annual floods and are harvested communally after the flood periods. The ponds become collector-centres for water which, when not properly managed can trigger erosion subsequently.

2.1.3 Lumbering. The processes of excessive lumbering lead to deforestation over long periods and these give rise to land erosion, if not properly managed over time.

2.1.4. Grazing. Though not significant at the moment, this has become a rather new phenomenon introduced by the Nomads from the northern sections of the country in search of pastures for their cattle. This is an indirect consequence of Climate Change which has brought about desertification in the Sahel regions of northern Nigeria. Over grazing will definitely lead to upland erosion (discussed in a later section of this paper).

2.1.5. Urban Developments within the Niger Delta.

Influx of persons, goods, industries etc due to the operations of the Oil and Gas firms and companies into the Niger Delta zone of the country has led to the opening up of new settlements, base camps, towns and villages within the Freshwater zone, as well as the other zones of the Niger Delta. This development calls for massive land clearing, which when not properly managed and unprotected, leads to severe overland erosion during the rainy seasons.

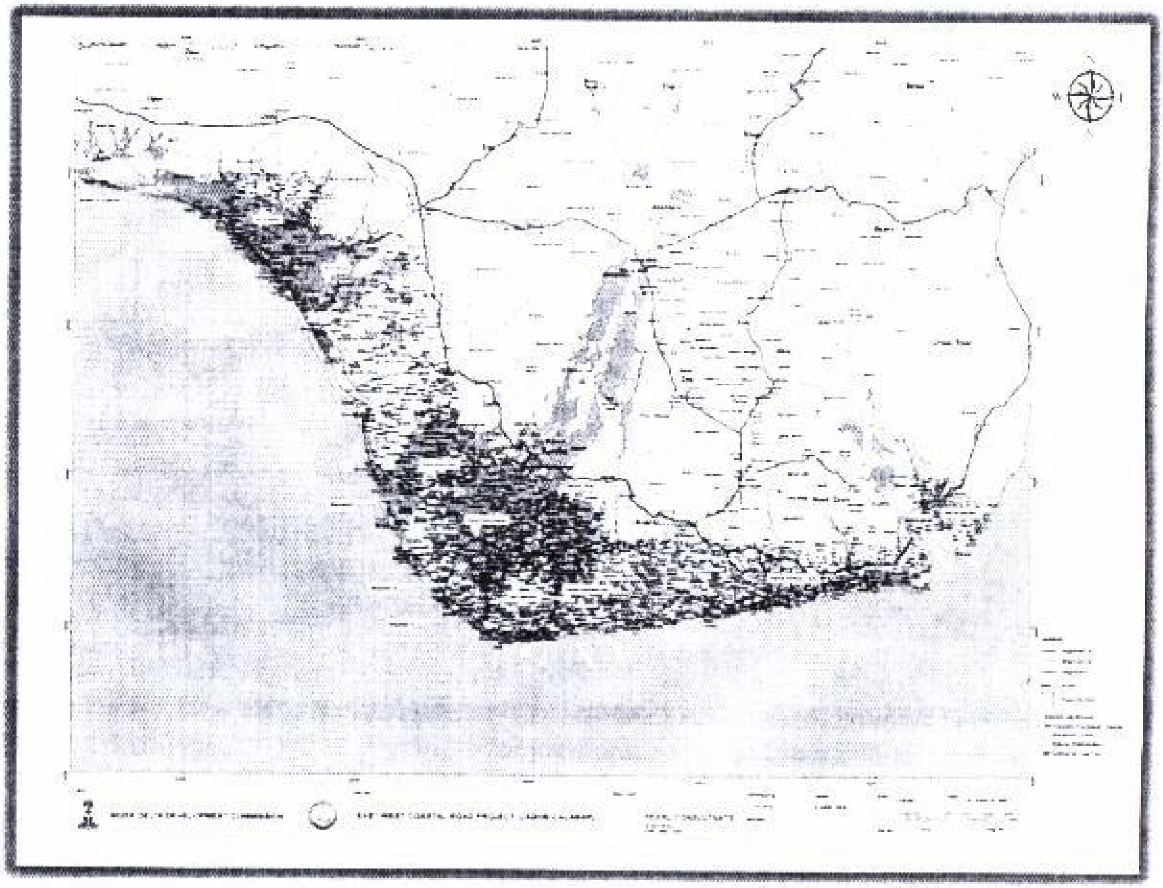


Figure 1e: **The Nigerian Niger Delta Sub-region** *(after the NDDC)*

2.1.5.1. Residential Development. This is one of the fallouts from urban developmental processes. It is also the commonest way in any urban development because the migrants to any developed area must have accommodations before any other occupational practice. The choice, locations, layouts, rapid growths and management of the estates determine their impacts on the environment.

2.1.5.2. Industrial Development. The need to diversify the Nigerian economy now that the main stay (petroleum crude oil) has taken a deep plunge in terms of costs, other manufacturing activities such as artisanal fisheries canning and vegetable production are springing up. The major set-back being the un-interrupted supply of electricity to the local factories.

2.1.5.3 Overland Erosion.

Urban development has brought about deforestation to make way for housing and other infrastructural constructions. Since the Niger Delta experiences a heavy annual rainfall throughout most of the year, overland erosion in the exposed land surface is common and this is aggravated by minor slopes which aid sheet erosion in particular.

2.1.5. 3.1 Industrial Pollution. With the development of industries within the Niger Delta comes the attendant Industrial pollution, if this is not properly managed and handled properly. However, with proper Environmental Impact Assessment (EIA) procedures before, during and after the construction of the industrial complexes, the issue of Industrial Pollution can be minimized, at least within the first 10-15 years of operation of such industries. Industrial Pollutions come in thee (3) different forms, namely: Water(aqueous pollution); Air pollution and Solid Wastes Pollution.

2.1.5.3.1.1 Water Pollution. Water is an important ingredient in virtually all industrial manufacturing processes. The effluents from these processes, if not properly treated before disposal pose a grave danger to the effluents points, especially rivers, creeks and other sumps that may form the receptacles for these effluents.

Since most effluent points are located into the water bodies,pollution of these water bodies become a function of the degree of treatment of the effluents prior to discharge into the water bodies.

2.1.5.3.1.2 Air Pollution. Most manufacturing and power generation plants discharge their waste products through gas emissions via elevated smoke-stacks. The degree of treatment of the gaseous wastes determines the quality of the wastes emitted into the atmosphere and their impacts on the environment is determined by the major wind directions during the periods of the gaseous emissions. The predominant wind directions within the Niger Delta sub-region are the South-Westerly winds during the Rainy Season months of June - October and the North-Easterly winds during the Dry, dusty Hammattan season months of Late November to Mid-March.

2.1.5.3.1.3. Solid Wastes Pollution. Next to Water Pollution is Solid Wastes which are generated by the inhabitants of the region. The major solid wastes generated within the Niger Delta sub-region are agricultural

2.2 Localized Management Practices.

In as much as the general management practices are discussed above, there are certain Land-use management practices peculiar to the various local river basins abound within the Niger Delta sub-region.

2.2.1 General Morphology of the Inter-River Systems within the Freshwater Hydro-meteorological Zone.

The general morphology and directions of the Rivers in the Niger Delta sub-region are mostly north-south trending starting from the northern freshwater zone through the middle "Transition" or Mangrove zone, through the Coastal zone and finally to the Atlantic Ocean.*(see Figure 1f).* Towards the Mangrove zone, owing to the relatively flat topography, the rivers tend to exhibit a high degree of meandering with several ox-bow lakes cut-off chutes.

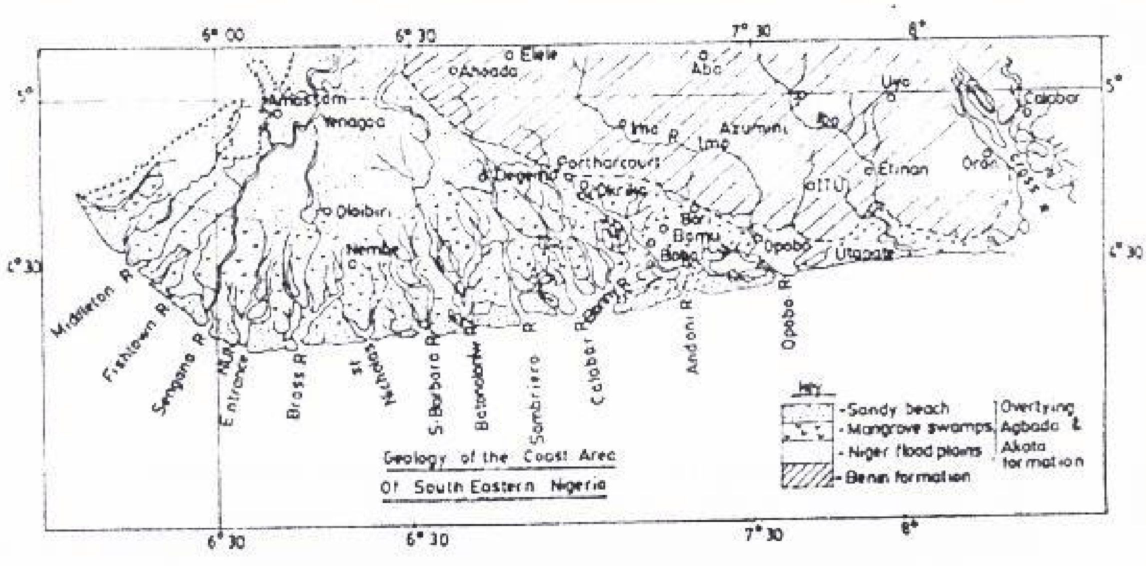


Fig.126 Geology of the Coastal Area of South Eastern Nigeria

Figure 1f: **The morphology of the River systems within the Niger Delta sub-region.**

2.2.2 Positions of Buildings Orientations with respect to Slope positions and Geometry.

Since the surface of the land slopes towards southwards generally, most overland runoffs follow this trend resulting in southerly erosional surfaces. Hence most buildings are located in an east-west direction to aid in slowing down the overland runoffs in between buildings.

2.2.3 River Bank Landing Steps.

The difference in height between the high flood water and the Low-Low water level at the peak of the dry season is usually very highin the order of between 6.0 and 10.00 meters in places and times. In order for the native inhabitants to fetch water from the rivers for both domestic and other uses during the low-low water periods, they used to climb down several meters to get tothe river. In order to do this, steps are usually constructed from the top to the river bottom during the low-low water periods

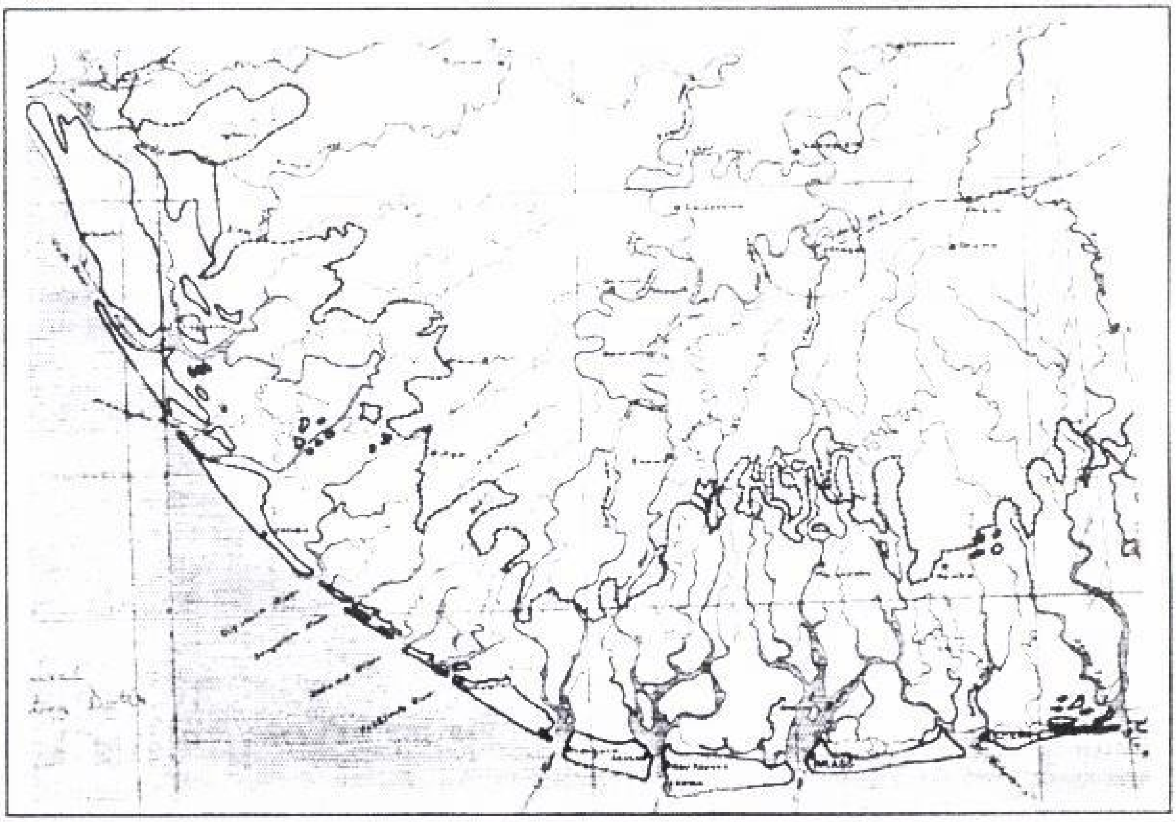


Figure 1g: **Some River Basins in the western segment of the Niger Delta sub-gion.**

3.0 WATER-SHED SYSTEMS.

Water-sheds by definition are the intervening areas between two rivers. There could be either single or multi-watersheds in a sub-region as shown in *Figures 1fand 1g* above

Water-sheds in the Niger River sub-basin form the foci of water management planning in the sub-region and this should therefore be integrated with municipal land-use planning processes.

3.1 Effects of Runoff on Erosion and Water Resources in a Multi-Watershed System

There is a pronounced relationship between rate of runoff and incidence of erosion. Runoff water has the energy to detach soil particles by scour and to transport entrained soil materials either in suspension or by pushing or rolling larger particles. In this way overland flow causes erosion that are watershed based. Erosion by scouring accounts for less than 10% of the erosion process, the rest being caused by raindrop impact. Secondary forms of erosion resulting from the transporting effects of runoff are more damaging and are usually classified as rill, gully and stream channel erosion according to increasing concentration of runoff and the degree of damage caused to land. Runoff erosive capacity is a function of its volume and velocity; as the volume and velocity increase, so do the energy to scour away soil particles and the load-carrying capacity or transportability. Doubling the velocity of runoff increases its scouring capacity and transportability ***(Shaxson et al. 1977).***

The consequences of runoff and erosion in a multi-watershed are the impairment of the quality and productivity of the land, both the eroded and the receiving soil material from upslope. Erosion results in the decline of soil fertility as a result of loss of topsoil and nutrients, loss of organic matter and clay and the consequent loss of the soil's capacity to retain nutrients and water. It can also result in the compaction and sealing of soil surface giving lower infiltration rates and increased runoff. There are many areas in the world where erosion has led to serious impoverishment of the land and rendered it unusable for crop production. Runoff, wherever it occurs, results in washing away of crops and fertilizer inputs, loss of soil moisture and recharge capacity, so consequently there is frequent drought stress in crop production. Runoff, as it increasingly concentrates in drainage lines, has always built up and caused severe physical damage down-slope including the washing away of roads, bridges, buildings and the development of dangerous gullies in many parts of South Eastern Nigeria. The effects of extreme runoff are usually visually emphasized by the development of gully systems along which the erosion is concentrated. Several examples of these are found in the Agullu-Nanka, Uyo and Calabar municipalities and other areas in the South Eastern part of Nigeria where greater part of the place has been rendered bad land. Deposition of particles carried by runoff causes channel sedimentation, silting up and pollution (by nutrients, pesticides and toxic chemicals) of dams and reservoirs and flooding and sedimentation of bottomlands.

Most arable systems, especially those involving complete tree clearances, mechanical tillage and continuous cultivation, disturb the surface soil and expose it to the weather, so making the land liable to serious runoff and erosion. Deforestation by mechanized systems followed by plough-based tillage, for example, causes severe runoff and erosion. Runoff and erosion under such systems can be very substantial and seriously limit crop production. Appropriate runoff management techniques that enhance water conservation and reduce erosion to acceptable rates will minimize these effects.

3.2. Watershed Runoff Management Techniques.

There are some management techniques that are discussed below to control Watershed Runoff, especially within the Freshwater zone of the Niger Delta sub-region.

3.2.1. Definition of Watershed Management

Watershed management is the process of creating and implementing plans, programs, and projects to sustain and enhance watershed functions that affect the *plant, animal, and human communities* within a watershed boundary.

Features of a watershed that any agency should seek to manage include the following: **(i)** ***water supply,*** **(ii)*****water quality,*** **(iii)** ***drainage,*** **(iii)** ***stormwater, (iv) runoff,*** **(v)** ***water rights,*** **(vi)*****erosion and the overall planning and utilization of watersheds***.

Improvements in soil conditions and soil-water regime to optimize crop production can be accomplished by runoff management techniques which may vary in situation, depending on existing conservation problems, on soil and on ecological region. The various types of run-off management in any multi-watershed may be classified as those which:

(i) **Increase water intake and storage and so reduce runoff**. The control of water movement over the soil surface, dispose safely of the excess rainfall as runoff or concentrate inadequate rainfall runoff.

Soil and water conservation are interrelated; methods that control and conserve water on hillsides also conserve the soil and control erosion.

In the arid and semi-arid regions, the choice of management is clear; all rainfall must be retained by techniques that reduce storm-water runoff, improve infiltration and increase the water storage capacity of the soil. In the humid area where we are concerned in this paper, a balance has to be struck between conservation of soil and water by runoff control and the avoidance of surface water logging, so the options are not as straightforward.

(ii) **Biological conservation techniques**: In general, runoff is best minimized by ensuring high infiltration of rainwater into the soil through biological conservation measures. Where this cannot be done to full effect, particularly in areas of high-intensity storms or where there are periods of poor crop cover, earth works (physical control measures) can provide surface protection by holding water to give it time to soak through the surface. Such physical conservation measures involve land shaping, the construction of contour bunds, terraces and ridges.

These require considerable technical design, supervision, proper construction and maintenance. In contrast, the biological methods include some soil management and agronomic cultural practices that are normally the companion of profitable agriculture such as appropriate land use and preparation, fertility maintenance, crop residue management, the use of cover crops and appropriate crop husbandry.

3.3Why Watershed Approach?

Watersheds are among the most basic units of natural organization in landscapes. The limits of watersheds are defined by topography and the resulting runoff patterns of rainwater. The entire area of any watershed is therefore physically linked by the flow of rainwater runoff.

Consequently, processes or activities occurring in one portion of the watershed will directly impact downstream areas (land or water).

(i) When detrimental activities like clear-cut deforestation occur, negative impacts are carried downstream in the form of eroded sediments or flooding.

(ii) Poor agricultural land management activities like excess fertilizer application convey negative impacts to downstream areas in the form of eutrophication and possible fish kills.

Water is the fundamental agent that links all components (living and non-living) in watersheds, and watershed management generally revolves around water as a central theme.

A significant portion of this discourse will be devoted to examining the pathways and mechanisms by which water moves from the atmosphere, to the watershed surface and subsurface, into and out of biological communities, and ultimately downstream to the ocean or subsequent river reach.

Water is the fundamental agent that links all components (living and non-living) in watersheds, and watershed management generally revolves around water as a central theme.

Recognizing that enhanced interactions between seemingly separate systems and organisms occur within watershed areas, both scientists and progressive-thinking resource managers have, in recent years, called for management programs to be organized at the watershed level.

By working in concert with nature in this way, we might manage resources in an integrative fashion that avoids some of the many past failures that were brought by not recognizing or considering the larger-scale impacts of any one management decision.

3.3.1 Watershed Management Strategies & Responses to Problems

Watershed management involves:

- Non-structural (vegetation management) practices
- Structural (engineering) practices
- Tools of Watershed Management
    - Soil conservation practices
    - Land use planning
    - Building dams
    - Agroforestry practices
    - Protected reserves
    - Timber harvesting
    - Construction regulation

Watershed Interactions

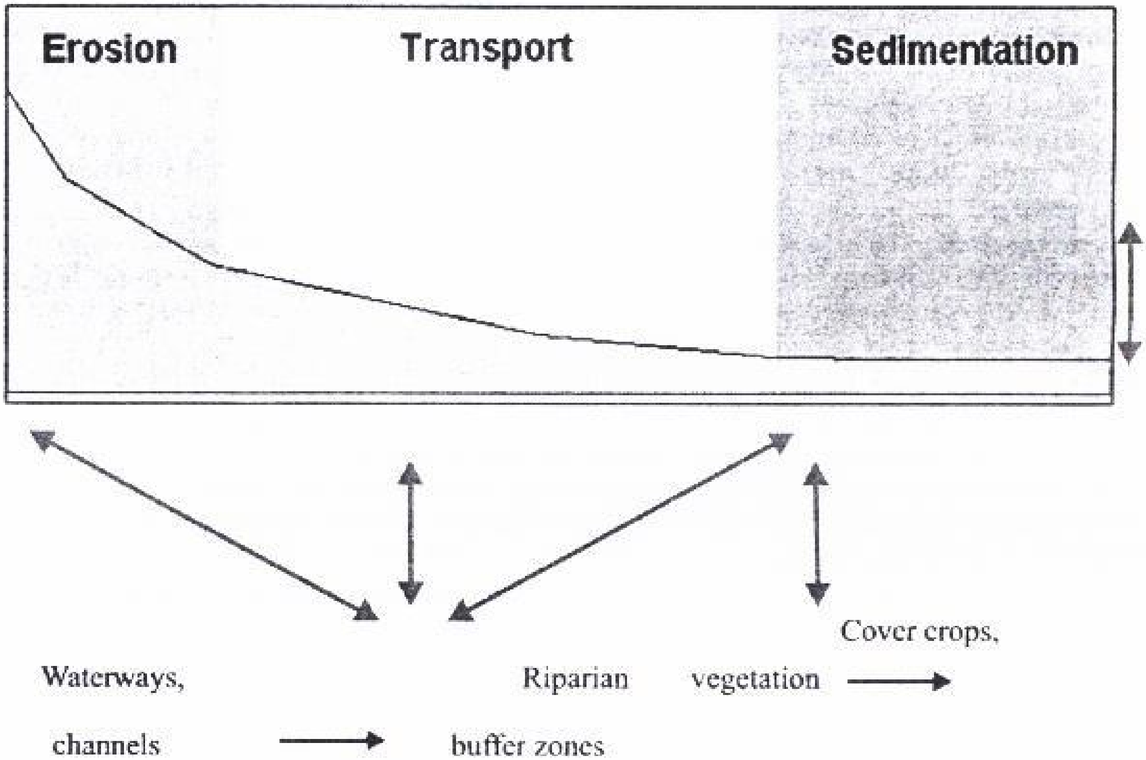


Figure 2: **Watershed Interactions in any Multi-Watershed system.**

3.3.2 Watershed Hydrology

The main process in a watershed is the "**Hydrologic cycle**" which summarizes the movement of water among surface water, air, land, and ground water. This process governs the physical, chemical, and biological characteristics of water ecosystems in a watershed.

Watershed management as a tool to assist land and water use decision makers has four phases:

a) issue identification and data gathering;
b) analysis and planning;
c) implementation; and,
d) monitoring.

It should be emphasized that monitoring does not conclude the process, but rather initiates the beginning of understanding of the sub-watershed, for which the plans should be updated over time.

3.3.3 Contemporary Practice of Watershed Management

In the world, the practice of watershed management has evolved over the last decade to become more comprehensive by integrating and addressing a broader range of resource and environmental protection issues and to more thoroughly evaluate the important linkages

- between land and water,
- between surface and groundwater and
- between water quality and water quantity.

3.3.4 The Need/Importance of Watershed Management

Watershed management projects are usually initiated in response to issues and concerns around existing environmental health, proposed land use practices, land use management or Redevelopment/restoration demands. These projects are usually initiated in one or any combination of the following six ways:

(i) by a conservation authority as input to official plans and resource management programs, or to protect particularly sensitive environments;

(ii) by a municipality or adjacent municipalities to address environmental protection components in official plans related to or because of proposed land use change;
by a developer landowner, or group of developers as a precursor to the subdivision approval process, commonly at the request of a commenting or approval agency;

(iii) by a provincial agency in fulfilling its mandate to protect resources and preserve the environment;

(iv) by a federal program for the designation of heritage rivers; and, in the future, through locally initiated, community driven activities.

Watershed management is necessary for the sustainable protection of natural resources and environmental health.

Watershed management, which recognizes the hydrologic (water) cycle as the pathway that integrates physical, chemical and biological processes, is an important approach to achieving the goal of a sustainable environment, and is the tool to implement an ecosystem-based management strategy.

3.4 Voluntary rather than Compulsory Mandate of Watershed Management

Generally, stakeholders and participants supported the voluntary initiation of watershed management studies by conservation authorities or municipalities rather than provincially mandated watershed management except in the following circumstances:

when development pressure was likely to degrade water quality/quantity or aquatic life;

when there was an urgent threat to water resource sustainability; and,

when there was existing environmental degradation and a pressing need for rehabilitation or restoration.

3.5.0 The Driver of Watershed and Sub-Watershed Management

Watershed and sub-watershed Management are generally driven by any or all of the following factors: (i) **Environmental resources** - a larger scale strategy emphasizing environmental protection and management, for instance;

(ii) **Land use changes** - input to designate new land uses or input to alternatives for management of already designated, but not yet developed.

(iii) **Land use management** - input to new management applications and practices of already present land use types.

(iv) **Redevelopment/restoration** - input to habitat restoration, pollution abatement or environmental enhancement options.

3.5.1 Objectives of Watershed Management

The overall objectives for the process are divided into two types:

3.5.2 Planning Objectives and Implementation Objectives.

3.5.2.1 Planning Objectives: These are distinct, specific, measurable statements that reflect and define each goal. They are designed to direct, track and measure progress over the next several years of preparing the Watershed Plan, but they do not necessarily guide implementing "on the ground" actions in the watershed. By definition, Planning Objectives will be one or several Implementation Objectives.

3.5.2.2 Implementation Objectives: These are also distinct, measurable statements that reflect the goals, but are meant to guide ongoing implementation actions in the watershed. The Implementation Objectives will become part of the Watershed Plan and can be used to measure long-term progress.

4.0 FLOOD AND EROSION IN THE FRESHWATER HYDRO-METEOROLOGICAL ZONE OF THE NIGER DELTA SUB-REGION.

4.1 Mechanisms of Flooding and Erosion.

By Definitions:Flood is by definition, any relatively high stream flow, which overtops the natural or artificial banks in any reach of a stream. Mainly, ***several types of floods and their corresponding types of Erosion*** that are very disturbing in the Nigerian coastal environment are:-

(i) the regular ***diurnal flooding*** associated with the tidal invasion of the about 10,000km^2 saline mangrove swamps lying immediately behind the island barriers, and

(ii) the ***annual floods*** related to annual discharge pattern of the Niger-Benue systems.

(iii) Urban Flooding caused mostly from excessive rainfall

(iv) Urban Erosion caused mostly from sheet-erosion arising rills and rivulets

(v) Upland Flooding caused mostly by the approach of floods from the rivers as well as from the back-swamps which are usually behind the settlements and communities

(vi) Upland Erosion occurs immediately after the Annual Floods from excessive pore-water build-up behind the slopes of the river banks

4.1.1Diurnal Floods: These are floods which affects the low-lying saline mangrove swamps and are associated with tidal activities. The tides in the delta are semi diurnal with two high and two low waters. These promote two upstream flowing currents and two downstream flowing currents within a 25 hour period. The tides approach the Niger Delta Coast from SSW and have vertical ranges increasing from the western to eastern delta. The range at Forcados is ***1-3m***, increasing to ***2-0m*** at the Bonny Town Reference Station (BTRF). High water currents attain velocities up to ***1.5m/s*** while the low water (ebb flow) is stronger with velocities up to ***2.8m/s(NEDECO, 1961; Allen, 1965)***. The limit of tidal incursion varies from one part of the coast to the other. Along the Forcados River for instance, it is in excess of ***50km***.

Along the **Ramos**, **Dodo** and **Pennington Rivers**, it is about ***30km,*** decreasing to about ***10km*** between **Digatoru** and **Sangana Rivers**, increasing thereafter to about ***55km*** along the **Sombreiro**, **New Calabar** and **Bonny Rivers**, reaching beyond Degema and Port Harcourt and thereafter decreasing again to less than ***10km*** along the **Andoni River** east of the **San Bartholomew River**. The tidal range increases when going upstream due to the resistance of the local ***'basins'*** to tidal inflow consequent on high mainland reflection and the insignificant upriver storage in the headwaters especially in the case of the Sombreiro and New Calabar Rivers. West of the **San Bartholomew River** and along the **Imo River**, tidal ranges decrease upstream, a phenomenon promoted by the vast inland swamp which can ***'absorb'*** the tides and the ample storage capacities of the headwaters. Each tidal cycle inundates the saline mangrove swamp with an estimated ***$50 x 10^9 m^3$*** of sea water. The most devastating floods are associated with ***spring flood tides*** whose range can be in excess of ***3m***. If these tides occur concurrently with high velocity South-Westerly winds or any local thunderstorms or squall line, the flooding effect can move upstream for a considerable distance to promote saline water invasion of the fresh water. At times such as these, saline water moves upstream as far as Yenagoa and to even submerge some inhabited natural levees. The general Niger Delta Region *(sensu lato)* is shown in ***Figure 1a****above*.

4.1.2Annual Floods: The occurrence and pattern of annual flooding have varied over time and space in the Niger delta. Several documentations have shown that annual floods in the delta relate mainly to the Niger River discharge at Aboh. The river discharge has experienced significant variation over time as a result of the large number of upstream dams built on it and its tributaries. Immediately after the construction of each of the dams, discharge was observed to reduce but on attaining optimal dam capacity, the discharge increased and on the event of any dam failure, flash floods are experienced.

The coastal region of the country is most of the time under the influence of the **inter-tropical convergence zone (ITCZ)** with its induced low pressure belt, thus bringing the region under the influence of SW winds during the rainy season. The monthly rainfalls which are characterized by two peaks rise from less than ***50mm*** in all stations in January, to above ***300mm in July***, declining slightly in August ***("August break" phenomenon)*** only to rise again relatively sharply. The ***Mean Annual Rainfall(MAR)*** varies from above ***4500mm at the mouth of Forcados*** to ***3000mm*** across to Yenagoa, to the middle of Sombrero –Abonnema Rivers. The other areas in the Niger Delta sub-region are covered by the ***2500mm isohyet.*** On the average these heavy rainfalls supply more than ***$88x10^9 m^3$*** of fresh water into the delta. With a very low rate of infiltration into the delta subsurface soils estimated at less than 1m/day, (due to saturation of most of the subsurface) this water supply from the local rain normally augments the Niger discharge to further intensify flooding all over the delta.

The coastal terrain, especially the delta region with its large asymmetrical depression with greater part in the saline mangrove swamps is a major contributing factor to the flooding of the region.

The elevation of delta at **Aboh** is 5m above mean sea level decreasing down south. Directly behind the coastal barrier bars the elevation declines to ***less than 1m or even dip below sea level*** and rises from ***2m to 5m*** on the barrier islands. The net effect is that ***the delta is a flat flood depression criss-crossed by a network of slow flowing braided, reticulate, anastomosing, meandering, deranged, efficiently draining the large volume of water introduced into it from the rainfall estimated*** at ***$182 x10^9 m^3$*** annually and the more than ***$50 x10^9 m^3$*** of sea water introduced during each diurnal tidal cycle***(NEDECO, 1961)***. The back swamps behind the barriers bars and in the Fresh Water Zone are permanently flooded because of the depressed nature of these regions.

The Niger Delta Coastline is undergoing some level of subsidence due to the enormous weight of sediment, estimated at ***$3.0x 10^{12} m^3$*** introduced into it. ***NEDECO (1959), Allen and Wells (1962)*** used a sequence of dead coralline banks in shallows off the Nigerian coast to show stages in subsidence for the past 4000 years. ***Burke (1972)*** observed a total subsidence of ***80m*** in the last ***15,000 years*** in the south-western delta, which works out at a mean rate of ***0.5cm/yr.*** It is no wonder therefore that delta coastline has been experiencing eustatic sea level rise (flooding) for some years now.

A projected sea level rise of ***1cm/yr for 100 years*** by the international panel on climate control shows that the entire saline mangrove swamps and part of the fresh water swamp will be completely inundated, the barrier islands at the coast will be partially drowned and floods will become

relatively permanent ***(Tobor, 1990).***
Within the context of the Niger Delta sub-region where very high rainfall (over 200 – 600mm in the coastal zone) occurs, there are ***three (3) basic types of flooding*** namely: ***Urban Floods, Upland floods*** and ***Coastal Floods.***

4.1.3Urban Flooding. Though floods occur in all parts of the Niger Delta, it is most noticed in the urban centres because of the human settlements and human activities. Contributions of humans to the blocking of drainage paths, where available, through dumping of domestic, commercial and industrial refuse have helped to accelerate the rate and quantities of flood in the human settlements such as ***Port Harcourt, Warri*** etc. In other areas there is virtual absence of drainages and water flow paths thus giving rise to rapid and uncontrollable urban floods. These can be ameliorated in places by filling of depressed areas with soils that have both friction and cohesion such as laterites.

4.1.4Upland Flooding. The Uplands in this context refer to the ***Freshwater zone of the Niger Delta***. Once every year these areas, as described above are subjected to floods as high as 2.5 meters above the normal ground levels. These constitute constraints to farming, commerce and industry. Solutions such as levee and dyke constructions are not only exorbitantly expensive but cumbersome to the local inhabitants. Besides, the permanent solutions to flooding such as **building of upstream dams** are elusive dreams to the people of the Niger Delta because of the lack of political will on the parts of both the state and Federal governments.

4.1.5Coastal flooding. Though floods occur in the Coastal Zone of the Niger Delta, their magnitudes are not as much as those of the Upland or Freshwater Zone due primarily to the influence of ***diurnal 'ebb and flow' mechanism*** that prevails within this zone. What is normally observed are the increase water levels during the spring tide flows. Land Reclamation and shore protection techniques have often been applied to advantage in the remediation of these flood hazards such as at Bonny, Buguma, Abonnema, Okrika etc.

4.2 Erosion: This is the twin brother to flooding and usually always occurs either during or to a great extent immediately after flooding due to the rapid build-up of pore water pressures behind river bank slopes which in most cases are clayey soils. Again, erosion occurs in urban, upland and coastal areas such as flooding.

4.2.1Urban Erosion. These occur mostly in form of sheet erosion and even then in areas with substantial inclines and can be easily ameliorated by construction of drains and other appurtenant structures.

4.2.2Upland Erosion. Where soils are non-cohesive, rivulets and gullies are formed usually after torrential rains or after the annual floods especially along the banks of rivers and creeks within the upland or freshwater zone. Sufficient protection measures such as river bank shore protection using flexible geotextiles can be taken to ameliorate this problem in most cases.

4.2.3 Coastal Erosion. Erosion along the coastline is usually caused by the impact of waves and currents especially long-shore drifts. In most sandy coastal settlements with low slope angles (= *10°-30°*) relatively inexpensive methods such as the ***URT Network System of Coastal erosion prevention (Teme, 1987, 1988)*** can be successfully applied in places such as Bekinkiri.

4.3 Control Measures For Flood And Coastal Erosion.

Control measures for Flood and Erosion depend on the Zone of the Niger Delta where the projects are situated but in general the following measures have been known to be applicable in some zones:-

4.3.1 ***Reclamation of adjoining areas to the rivers, creeks and coastlines***: These may include any of the following methods usually adopted ***in either the Coastal, Mangrove "Transition" or Freshwater Zones of the Niger Delta sub-region:-***

- Hydraulic Sand-filling (eg. Okrika, Buguma, Abonnema etc)
- Sand-filling with a mixture of sand and clays (Ido, near Buguma)
- Construction of bond-walls accompanied by the dewatering of the enclosed areas (process of polderization practiced in the Netherlands – not yet practiced in Nigeria or West Africa due to lack of appropriate technology to maintain the process and lack of political will by the governments)

4.3.2 ***Shore protection measures including but not limited to the following methods usually applicable to the Coastal and Mangrove "Transition" Zones:***

- Sheet pile shore protection measures with or without groynes, which can be pervious or impervious.
- Gabion shore protection measures. The gabions could be in the form of Steel wire mesh bags filled with stones or coated steel baskets filled with stones.

4.3.3 ***Shore Protection measures usually employed within the Freshwater Zone of theNiger Delta***: These include, but not limited to the Flexible Membranes such as

- Impermeable geomembranes and permeable geotextiles.
- Bio-technical shore protection of river banks involving the use of agro-forestry techniques.

For Urban Flooding, the following control measures are applicable:

- Proper physical Town and City planning.
- Proper drainage Planning and Construction. Dimensions of Drainage structures to take the following into consideration:-
    - Meteorological data such as rainfall intensity; rainfall duration and rainfall frequency
    - Gradients of Drainage structures should allow for efficient drainage of excess water within the urban areas, especially after heavy downpours.

The summary of the various control measures for flood and erosion control are given in **Table 1** below.

Table 1: **Control Measures for Flood and Erosion in the various zones and settings in the Niger Delta sub-region.**

S/No.Niger Delta ZoneControl Measures. Flood	Erosion	
1. Coastal Zone	*(a) Sand-filling and sheet pile shore protection.*	*(a) Erection of groynes combined with shore Protection measures.*
2. Mangrove or "Transition" Zone	***(a) Sand-filling and sheet pile shore protection.*** ***(b) Use of gabions***	***(a) Building of Bond Walls to prevent sur - face runoff.***
(a) Sand-filling, 3. Freshwater Zone.	***(b) Use of Flexible Membranes.*** ***(c) Bio-technical shore protection.***	***(a) Bio-technical shore protection.*** ***(b) Rapid dewatering of river bank slopes***
4. **Urban Centers** *manicured lawns and shoulders of roads etc.)*	***(a) Proper physical town planning,*** ***(b) Proper drainage design and construction.*** ***(c) Filling of depressions***	***(a) Proper physical town planning*** ***(b) properly designed drains.*** ***(c) Bio-technical erosion control measures, (well***

4.4 Coastal Zone Management and Conservation In Rivers State.

Management and conservation of the Coastal Zone of the states within the Niger Delta sub-region, especially Rivers State, depends to a large extent on Monitoring of Floods and Erosion within the State. Attempts made to find solutions to the Flood and Erosion problems in the Niger Delta those of ***Abam (1995), Democratic Republic of Korea(1980), NEDECO (1959,1961,1966,1980a & b, 1981)***. Also, ***Guidelines and Standards*** have recently been established for Environmental Pollution Control and Management in Rivers State ***(Report of the Rivers State Technical Committee on the production of Environmental Guidelines and Standards, November, 2002)***. The presentations under this Section of this "***Blue Print***" are taken from ***Chapter Two*** of these "Guidelines and Standards on Environmental Pollution Control and Management in Rivers State" authored by ***Teme (2002).***

4.4.1 Monitoring Guidelines:

4.4.1.1 Floods – Establishment of Flood gauges at selected sections of the following rivers and streams that traverse Rivers State, for purposes of Flood Monitoring and disaster warning.

Table 2: **Proposed Flood Gauges in parts of the Niger Delta sub-region, Nigeria.**

(i)	***Orashi River***	*(vi)*	***Imo River***
(ii)	***Sombreiro River***	*(vii)*	***Andoni River***
(iii)	***New Calabar River***	*(viii)*	***River Ogochie***
(iv)	***River Niger***	*(ix)*	***River Otamiri***
(v)	***Taylor Creek***	*(x)*	***Bonny River***

4.4.1.2 Erosion: Establishment of Landmarks and / or bench marks within selected urban areas, river banks and coastal areas that are considered prone to flooding and subsequently erosion. These landmarks and / or bench marks are to be used for periodic monitoring of either erosion or accretion of these particular areas and in cases of excessive erosion, notify the appropriate authorities accordingly.

4.4.1.3 Reclamation – Establishment of the desirability or otherwise for reclamation of given areas for purposes of urban and / or resources development.

4.4.1.4 Canalization – Establishment of the desirability or need for canalization of given areas between creeks and rivers for purposes of navigation of crafts and mobility of goods and services.

Table3: **Flood Monitoring Standards in Rivers State.**

S/No.	River / Stream / Creek	Position of Gauge Stations	Flood Disaster Reading Above H-H-W Level (Cm)
1.	Orashi River	Bridge Head, Mbiama	30.00
2.	Sombreiro River	Bridge Head, Ahoada	30.00
3.	New Calabar River	Flow Station at Cawthorne Channel	30.00
4.	River Niger	Shoreline at Ndoni	30.00
5.	Bonny River	Shell Jetty, Bonny	30.00
6.	Imo River	Bridge Head, Oyigbo	30.00
7.	Taylor Creek	Estuary at Mbiama	30.00
8.	Ntawoba Creek	Culvert Head at Okija Street	25.00
9.	River Ogochie	River Crossing at Nihi Odufor	30.00
10.	River Otamiri	Chokocho	30.00
11.	Andoni River	Shoreline at Ngo	30.00

4.5 Control Measures.

4.5.1 Erosion Control – Upon establishment of Landmarks at particular sites in the following towns, villages, rivers, streams and creeks within the territorial boundary of Rivers State, erosion and accretion shall be deemed to have occurred if the readings on these landmarks fall below or exceed those established ***status quo ante*** at these stations. In the case of excessive erosion, the relevant authorities should be notified immediately of impending danger if, the readings in centimetres (cm) exceed these amounts indicated below in **Table 4**:

4.6 Reclamation.

Within the territorial area of Rivers State of Nigeria, Land Reclamation is known to becommon and therefore practiced extensively within the *Freshwater, Mangrove and Coastal Zones*. Within the *Freshwater zone*, Reclamation is primarily carried out mostly at the back-swamps of settlements. On the other hand, *Reclamation is carried out mainly on the foreshores of Towns and Villages within the Mangrove and Coastal Zones*. The Minimum heights of reclaimed sites (in the case of hydraulic sand-fill) assuming *an average of 15% consolidation over a 10-year period* is as given in Table D below:

Table 4: **Erosion Monitoring Stations in Rivers State.**

S/No.	EROSION MONITORING STATION	POSITION OF EROSION LANDMARK	EROSION DISASTER READING BELOW ORIGINAL VALUE (cm)
1.	Port Harcourt	Abonnema Wharf Road Slope	30.00
2.	Omoku	Sancta Maria College grounds	50.00
3.	Ahoada	Town Market	30.00
4.	Akinima	Shoreline at the Old St. Peters Church Compound	30.00
5.	Orashi River	Shoreline at Baptist Hospital Joinkrama	30.00
6.	Sombreiro River	Shoreline at Bridge Head Ahoada	30.00
7.	New Calabar River	Shoreline at Elem Bekinkiri	25.00
8.	River Niger	Shoreline at Ndoni	30.00
9.	Bonny River	Shoreline at Beach Head, Bonny	45.00
10.	Imo River	Shoreline at Oyigbo	30.00
11.	River Ogochie	Shoreline at Nihi Odufor	50.00
12.	River Otamiri	Shoreline at Chokocho	50.00
13.	Andoni River	Shoreline at Ngo	30.00

Table 5: **Minimum Heights Of Reclaimed Sites in Nigeria.**

S/No.	*ZONE OF SANDFILL (m)*	*AREA OF RECLAMATION*	*MINIMUM HEIGHT*
1.	*FRESHWATER*	*Mainly Back swamps of Settlements*	*1.00 m above height of Settlement*
2.	*MANGROVE*	*Mainly Foreshores of Settlements*	*0.50m above height of Settlement.*
3.	*COASTAL*	*Mainly Foreshores of settlements*	*0.50m above height of Settlement*
4.	*OTHERS*	*Minor Reclamations*	*Same height as that of Settlement.*

4.7Canalization:

Within the territorial area of Rivers State of Nigeria, Canalization is known to bepresent within the Mangrove, Coastal and even Freshwater Zones. Within the Mangrove and Coastal Zones, Canalization has been primarily carried out at certain locations to shorten navigational routes between towns and villages. Whereas there is the need to carry out canalization of more areas between identifiable creeks and rivers within the three hydro-meteorological zones of the state namely, Coastal, Mangrove and Freshwater zones; a Preliminary Subsurface Investigation (PSI) along the proposed route of the canal alignment must be carried out to assess the stability and strength of the subsurface materials prior to commencement of the canalization process.

The following criteria must be met during the process of surveying, alignment, clearing, stumping, dredging, placement of dredge-spoils, placement of navigational traffic signals, de-mobilization and commissioning. The Standards are as given in the Table 6.

The overall management and conservation of the Coastal Zone in RiversState should take into consideration the following strategies namely:

(i) Short-Term

(ii) Medium-Term, and

(iii) Long-Term.

4.7.1 Short Term Strategies:

At this level, both the Local and State Governments should actively participate in the management of Flood and Erosion Control.

First the Local Governments should be involved through the following interventions:-

- Maintenance of drains by keeping them free from clogging materials
- Awareness campaigns and environmental education at the local government levels

The State Government should be involved through the following intervention strategies:

- Construction of drainages.
- Placement of biotechnical erosion control elements on river bank slopes

4.7.2 Medium Term Strategies:

At this level, the State Government should be involved in the following intervention strategies:

- Reclamation of flood-prone sites
- Construction of shore protection structures and their maintenance
- Setting up of Flood Gauges along identified stations
- Regular monitoring of Flood Gauges and their interpretations

4.7.3 Long Term Strategies:

At this level, the State Government, ably assisted by the Federal Government through either the Ecological Funds or the Niger Delta Development Commission (NDDC), should undertake the following upstream Flood Control Measures:

- Periodic River Channel dredging to increase the volume of storage and hence reduce incidences of annual flooding episodes.
- Construction of dams upstream and monitor and control periodic discharges from all upstream dams.

Above all, the use of **Space Science applications** to remotely monitor and / or forecast floods especially coastal floods and urban floods has become mandatory in the light of the fact that Nigeria has joined the Space Science League with her launching of the **NigeriaSat-1**.

It therefore naturally follows that there should be continuous education of the scientists and engineers in both basic and applied Space Science in order to successfully utilize more of Space applications in the monitoring, analyses and control of Flooding and consequently Erosion within the Coastal Zone of Rivers State as well as the entire Niger Delta sub-region.

S/No	Zone	Min. Width of ROW (m)	Max Curvature of alignment (degrees), *(°)*	Max Length of Stumps prior to dredging *(m)*	Min. Depth of Dredging *(m)*	Max. Slope angle of canal banks *(°)*	Min. distance of dredge Spoil from bank of canal *(m)*	Max. Height of Dredge Spoils *(m)*	Max. Slope Angle of Dredge Spoils (°)***	Point of Placement of Navigational traffic signal
I	**COASTAL**	30.00	2.00	1.00	3.05	80.00 **	2.50	2.00		-Entry point -Mid-point -Exit point
II	**MANGROVE**	30.00	2.00	1.00	3.05	80.00 **	2.50	2.00	45 - 80	-Entry point -Mid-point -Exit point
III	**FRESHWATER**	25.00	2.00	1.00	2.50*	70.00 **	3.50	3.00	45 - 80	-Entry point -Mid-point -Exit point

ROW = Right of Way

* = ***Minimum Depth during Low – Low Water Level (LLW) at peak of Dry Season (December through February)***

** = ***Slope angles may vary along the course of the canal depending on the characteristics of soils along the canal route***

*** = ***Depends on the characteristics of sub-soils at the project site***

5.0 SUMMARY AND CONCLUSIONS.

5.1 Summary.

The Niger Delta sub-region has been defined sensu stricto as well as sensu lato and the three hydro-meteorological zones in the sub-region have been delineated and adequately described. Some of the general as well as localized land-use management practices within the subject matter area [Freshwater Hydro-meteorological zone] have been outlined and described.

The concept of Multi-Watershed systems within the actual Freshwater zonewithin the Niger Delta sub-region, as well as some adjoining zones, has been defined in terms of their Land-use management techniques.

Occurrence and Control of Flood and Erosion in the Niger Delta sub-region in terms of their modes and mechanisms of occurrence and identified Control measures, with special reference to the Rivers State, have been given and described in this paper.

Basically, runoff management is based on the principles of minimizing the concentrations of runoff volume, slowing the runoff velocity so diminishing its capacity to cause scour erosion. It aims to enhance surface detention storage, thus allowing the water more time to soak into the soil, and to conduct away unavoidable runoff. Since the choice of appropriate measures of runoff management depends on soil, topography, climatic and socio-economic considerations, generalization about their applicability is difficult. The techniques are broadly grouped into biological and physical protection measures.

Biological control measures combining good agronomic and soil management practices are directed at selecting land uses that provide good protection of the soil from raindrop impact, increase surface depression storage and infiltration capacity of the soil to reduce the volume of runoff, improve soil aggregate stability to increase its resistance to erosion and increase the roughness of the soil surface to reduce the velocity of runoff. Mulch farming appears to be an effective conservation measure in all ecological regions especially when used with planted cover crops. Mulch farming in combination with a no-tillage system has a wide application and is an effective conservation technique for grain crop production on a range of soils in the humid and sub-humid regions. Ridging is widely practiced and is effective in soil and water conservation, especially contour ridging in the more humid regions. As shown by ***Temple (1972)***, biological measures are easily incorporated into existing farming systems.

Physical conservation measures such as terraces and contour bunds are considered of secondary importance in runoff management for small-scale farmers but it may be necessary for large-scale mechanized farming to cope with larger exceptional runoff on steep cultivated lands. The use of terraices and contour bunds as physical protection measures is limited by the poor socio-economic conditions of farmers in this poor region of Nigeria. Because of prohibitive costs of construction of terraces, other methods such as contour hedges, straw barriers and buffer strips of grass or alley cropping are often suggested for use on steep cultivated lands. Where a risk of runoff remains, an artificial drainage or waterway (sodded) system is constructed to dispose of it non-erosively.

The most appropriate strategy for runoff management depends upon identifying the key factors influencing runoff and applying appropriate techniques based on acquired knowledge.

5.2 Recommendations.

(1) Taking the Freshwater Zone of the Niger Delta Sub-region of Nigeria we are discussing as an example, there is the need for more studies of Water-sheds with respect to the impacts on them of the effects of erosion, flooding and other environmental hazards such as wind erosion leading to desertification etc.

(2) There is the need for studies of Water Budgets of identified Watersheds in the various geographical as well as political zones of the country.

(3) Observations during the course of this study reveals that there is a paucity of data on the hydrographical cross-sections of most of the rivers within the Freshwater zone of the Niger Delta sub-region. This can be taken further to other geographic and geologic zones of the country.

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