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Analysis of Hydrological Characteristics: A Case Review of the Niger Delta

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Abstract

This paper reviews the significant contribution of hydrologic continuity in the development, evolution and fate of the Niger Delta. Formed from the aggregation of sediments from a drainage catchment area of over 2 million km^2, the Niger Delta has evolved into a prolific sedimentary basin with a dense network of rivers and creeks. The ecological system is in a fragile state with fresh and saline water ecosystems maintaining a dynamic equilibrium. Rainfall typically varies from 2500 - 4000 mm per year compared to average annual evaporation of about 1500 mm, resulting in net antecedent moisture. Over 70% of the rainfall occurs in 4 months between May and September, creating a potential for flooding. Water level varies from less than 1.5 m in the estuaries to about 8 m at the apex of the delta, with Nun River having a slightly higher elevation compared to Forcados River, implying that canals connecting both rivers at the same reach would experience water movements from Nun to Forcados River. Similarly, water level gradients vary across the stretch of the rivers from 8.6 to 9.5 × 10^{-5} (cm/km) between Onitsha and Asamabiri, 7.5 to 7.7 × 10^{-5} (cm/km) on the Forcados River downstream of Asamabiri, and from 7.4 to 7.6 × 10^{-5} (cm/km) on the Nun River. At peak flood, about 23 × 10^3 m^3/sec of runoff enters the Niger Delta. At the same time, about 16 × 10^3 m^3/sec discharges from the estuaries into the ocean in a semi-diurnal tidal flow leaving a surplus that accumulates to cause flooding. The delta thus acts like a sponge, absorbing the shear amount of flow and releasing slowly stored water through at least twenty-one outlet estuaries into the Atlantic Ocean. The shear amount of discharge overwhelms the capacity of the network of distributaries and predisposes the delta to flooding. Assessment of the capacity of the rivers to evacuate pollutants showed that rivers to the west of Brass which are fed by Forcados River exhibited relatively stronger flux efficiencies prior to 1998 but are presently weaker compared to rivers fed by Nun. The rivers to the east between New Calabar and Imo Rivers exhibited very weak ebb tide asymmetry or net upstream flow largely because

these rivers receive little or no freshwater influx from upstream sources. Flood and erosion are the major hydrological hazards in the region.

Keywords

Hydrology, Niger Delta, Nun, Forcados, Water Level, Flood

1. Introduction

The geographical area of the Niger Delta covering some 38 km^2 is the receptacle of water and sediments from the vast catchment area of approximately 2 million km^2 of the Niger River system (**Figure 1**). The continuous deposition of sediments for several million years together with other delta development processes have resulted in the formation of a gently sloping prolific sedimentary basin characterized by a crisscrossing river and creek network (**Figure 1**). The fresh and saline water ecosystems which inhabit the channels maintain a dynamic equilibrium thus making the ecosystem which is rich in biodiversity relatively fragile. At the same time, the interaction of the hydro-ecological processes with the environment has resulted in the development of different ecological zones (**Figure 2**) whose boundaries are constantly adjusting to the balance of upstream discharge and tidal flows.

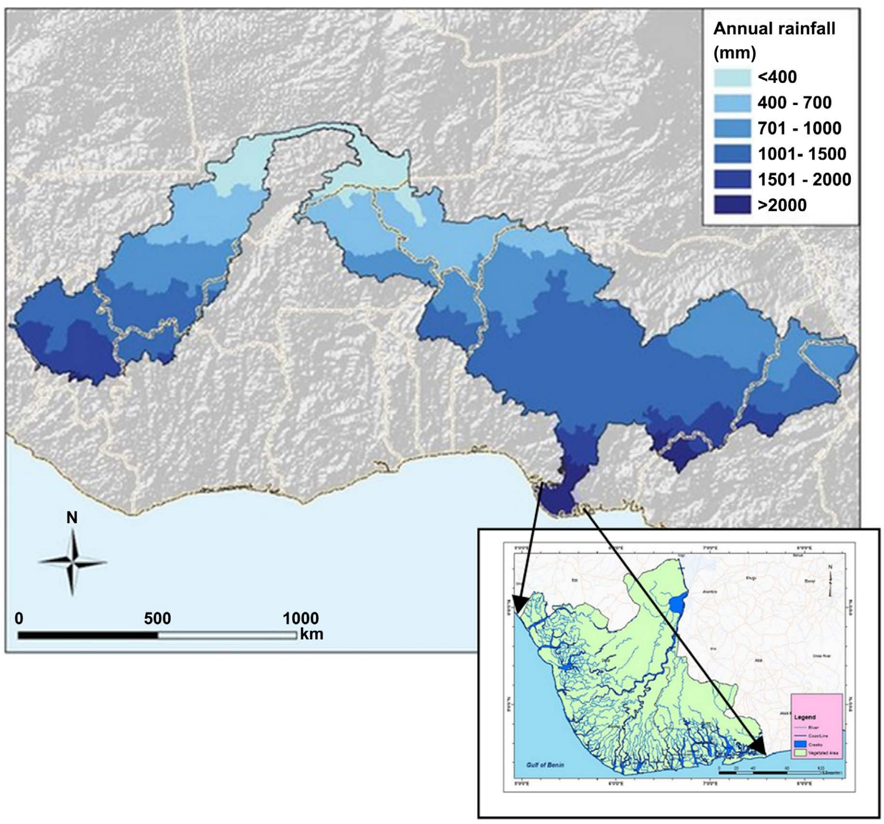

Figure 1. Drainage catchment area of the Niger Delta.

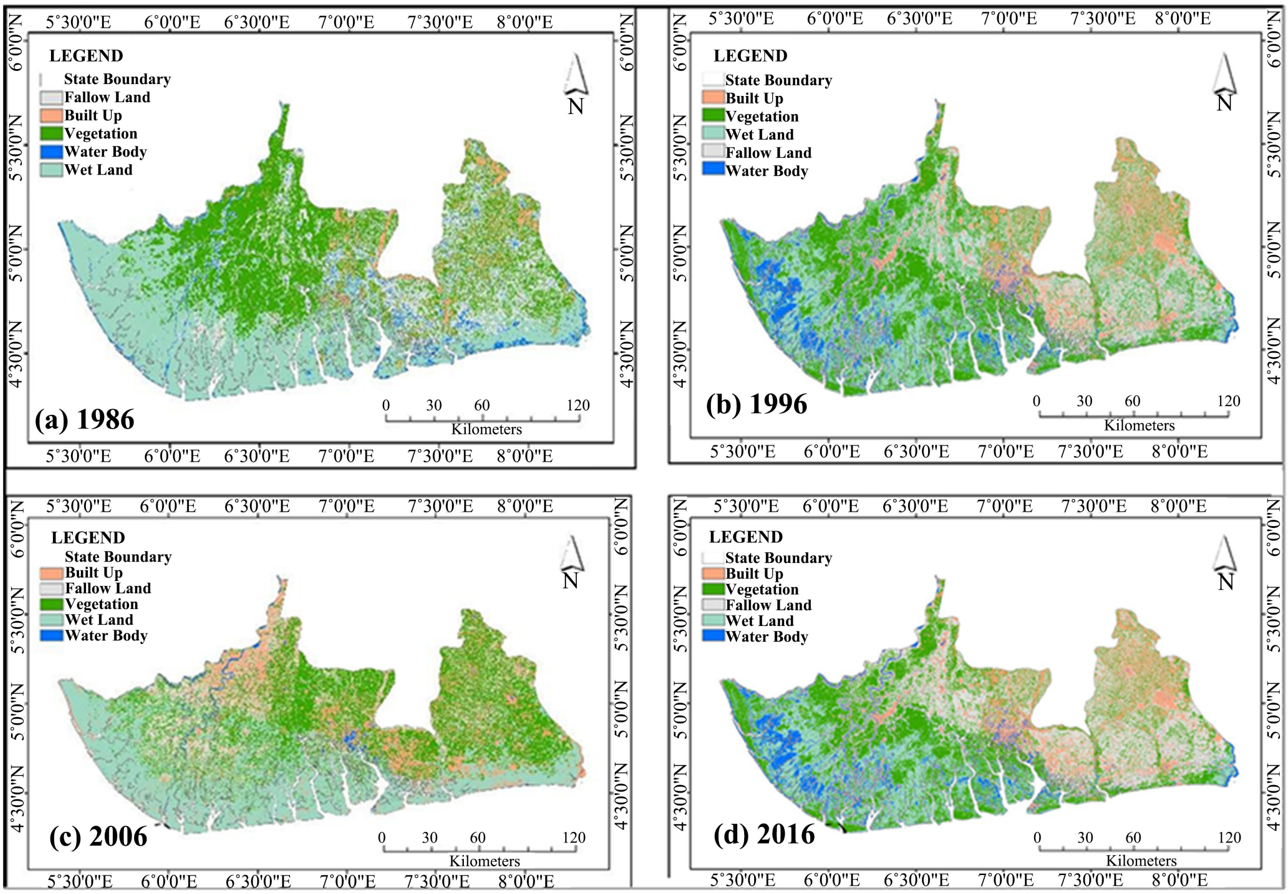

Figure 2. Spatiotemporal changes in ecosystem in the Niger Delta Region [2].

As the flow progresses towards the ocean, the ecological zones are further dissected by a dense network of rivers and creeks that convey water and sediments through the numerous estuaries to support the dynamic equilibrium of the coastal hydrological processes. Due to estuarine processes and the combined influence of tides and ocean currents on the sediments, the original river outlets may frequently be blocked, forcing the creation of new outlets. Consequently, the form, shape and size of the chain of coastal islands bordering the shoreline continue to change over time. Recent changes in the shoreline during the last 100 years against the background of conflict between forces of Nature and Humans were described by Dada *et al.* [1].

The change from one geomorphic zone to the other can be imperceptible in the field since in actuality, there exists in the field, a transitional zone of variable width, characterized by mixed attributes [3]. The extent of the variation is usually heavily influenced by topography, soil type and discharge. Any alteration in these factors has the potential of changing the geo-ecological equilibrium and boundaries. The present study attempts to explain the changes in riverine ecological conditions that are occurring and predict possible impacts of climate change in the Niger Delta with the overall aim of improving the management of the Niger Delta environment.

2. Characterization of Drainage Basin

This section describes the physical characteristics of the Niger River drainage basin, its catchment structure, rainfall distribution, discharge patterns and seasonal/annual variations. This understanding is important to appreciate the role of the various hydrological and morphological processes in the shaping of the delta and in its vulnerability to flooding, including its ecological zonation, discharge distribution (water and sediments).

The River Niger follows a relatively straight southwesterly trajectory after Onitsha. The main course of the Niger bifurcates into two (2) major courses at Asamabiri, namely; Forcados River and Nun River as it enters the lower Niger Delta and discharges into the Gulf of Guinea. From this point of bifurcation, the dry season riverbeds for both Nun and Forcados Rivers are generally straight, but the rivers follow a strongly braided pattern. Along this stretch the River Niger has a well-defined flood plain boundary due to the absence of backswamps. Further downstream of the Nun-Forcados bifurcation, the braided character of the river changes gradually into distinct meanders. Many towns and settlements in this part of the delta are located along the riverbanks at the natural levees due to their relatively higher elevation. Unfortunately, these concave sides of the bends in the river are also exposed to stronger currents and are therefore often more easily erodible. The Forcados and Nun Rivers split into several distributaries and at 50 - 100 km from the coast into a braided network of rivers and creeks.

The range in water level varies less than 1.5 m in the estuaries to about 8m in the Niger River between Asamabiri and Onitsha. Below Asamabiri, water levels are generally higher in the Nun River by as much as 1m compared to Forcados River. This means that canals connecting both rivers at the same reach would experience water movements from Nun to Forcados River. Water level gradients similarly vary across the stretch the rivers. It ranges from 8.6 to 9.5×10^{-5} (cm/km) between Onitsha and Asamabiri, and between 7.5 and 7.7×10^{-5} (cm/km) on the Forcados River downstream of Asamabiri, between 7.4 and 7.6 $\times 10^{-5}$ (cm/km) on the Nun River. The water level gradients become significant reduced towards the sea to the extent that the impact of the semi-diurnal tide is easily observed.

3. Metocean Characteristics

The Metocean characteristics are defined by rainfall, wind, evaporation, temperature and relative humidity and others. Rainfall Distribution in the Niger River Basin varies from as low as 300 mm in the extreme north to 4000 mm in the Niger Delta. Rainfall in the Niger Delta (**Figure 3**) typically varies from 2700 - 4000 mm per year as against an annual evaporation of about 1500 mm. By far the rainiest part of the Basin is the coastal segment of Niger delta, where rainfall exhibits a bi-normal distribution and reaches about twice the amount of evaporation. Over 70% of the rainfall occurs between May and September. Baring

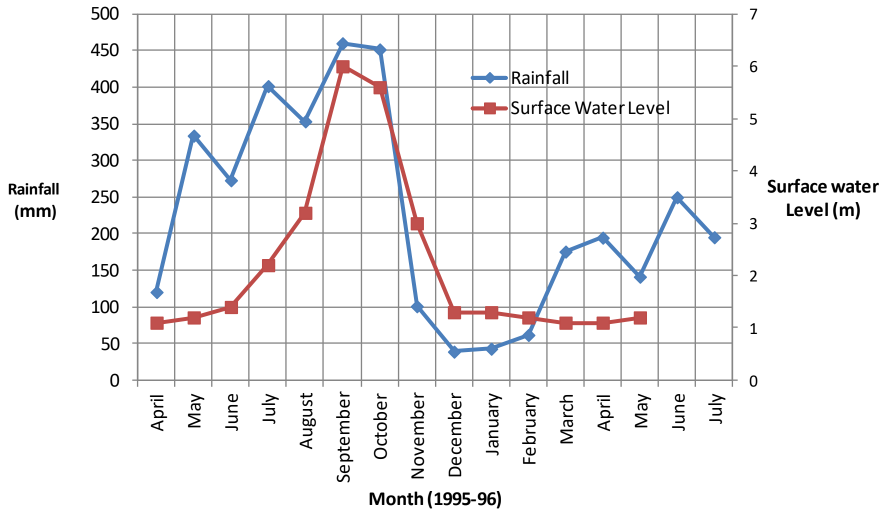

Figure 3. Rainfall and surface water level distribution in the Niger Delta.

infiltration through the soil, there exist a tendency for rainfall in the region to generate runoff, which follows a somewhat similar pattern (**Figure 3**). The peak of the rains coincides with peak flood which is also associated with significant levels of sediment transport and riverbank erosion.

Analysis based on the water balance of the area indicates that a total precipitation of between 1200 - 2500 millimeters over an area of about 37,000 square kilometers should generate an additional runoff/flow of 5 cubic kilometers. Added to the regular discharge from the Niger-Benue River system through Onitsha, a total of 250 cubic kilometers per year discharges into the Gulf of Guinea.

4. Infiltration and Recharge

The annual rains recharge the aquifers, causing groundwater levels to rise as much as 6.5 m as is in Port Harcourt (**Figure 4**). Average infiltration rate is between 6 and 22 cm/hour [4]. The process of infiltration increases the antecedent moisture level in the soil and consequently reduces the available storage capacity for infiltrating water, thereby increasing the vulnerability to flooding. As a results, even relatively elevated areas such as Port Harcourt, become vulnerable to flash flood during the wet season.

Gobo and Abam [6] examined records of daily/monthly/annual rainfall spanning over 30 years as part of a return period analysis intended for flood prediction in urban areas. Return period analysis enables us to determine when a rainfall event is expected to occur, be equaled, or be exceeded. The results indicated that flash floods were governed by a return period of 10.3 years for a maximum 1-month rainfall of 804 mm with a maximum 1-year rainfall of 2544 mm for same return period.

5. Surface Water Levels

Three types of flow are observable in the Niger Delta, namely, a unidirectional

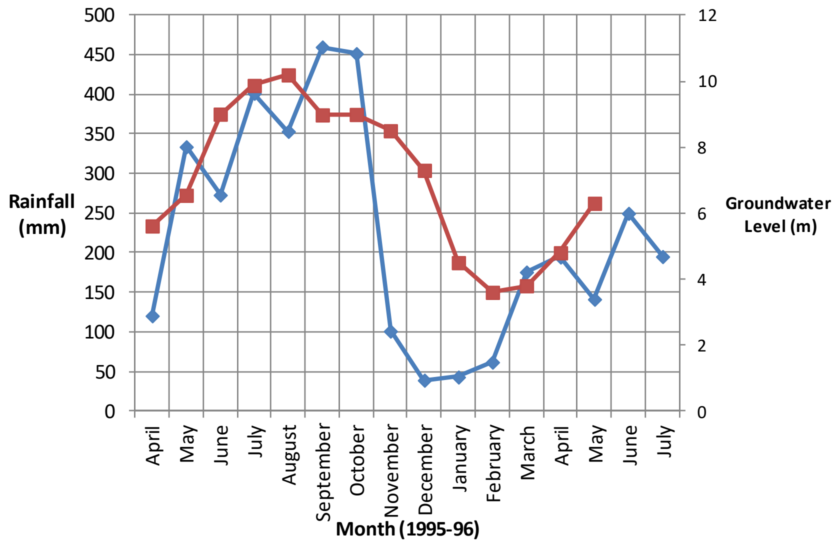

Figure 4. Relation between rainfall and groundwater in PortHarcourt [5].

flow in the upstream sections of the Niger delta, a bidirectional tidal flow in the downstream and coastal areas and estuaries, and in between these, a mixed flow, in which the unidiretional and bidirectional attributes are combined. The boundaries of these flow types depend largely on the relative strength of freshwater flux into the delta. Hydrographs for both upper and lower sections of the Niger Delta (**Figures 5-8**) show annual variations in peak water levels across the region. Each hydrograph in the upper section of the delta with unidirectional flow (**Figure 5** to **Figure 6**) is characterized by a dry season period from December to April followed by a gradual rise in water level, reaching a peak around September/October followed by rapid recession of flood water. **Figure 7** typifies the mixed flow with strong tidal influences at low water during the dry season and becoming predominantly unidirectional during the wet season characterized by heavy water influx into the delta. The rising limb of the hydrographs reflects the water level response to increased rainfall in the lower basin while the rapidly receding limb indicates cessation of rains. They also show the flood peaks which vary in elevation, depending on the return period of a particular magnitude of flood. Sometimes, occasional peaks occur during the stage of rising water levels caused partly by local rains and partly by the climatic August break characterized by a lowering of the amount of rainfall.

The hydrographs in the upper section of the delta with unidirectional flow (**Figures 5-7**) show that immediately after the attainment of peak flood, the water level falls abruptly, reaching its dry season level in less than 45 days. As indicated by Abam [8] the rates of rise and fall of water level varies from river to river, with the higher rates in the upstream locations. The peak flood wave travels from Lokoja to the lower Niger Delta in approximately 10 days.

This flood usually peaks about the first week of September when the runoff from Niger-Benue catchment in Nigeria merges with the subdued White flood from the upper reaches of the Niger River as described in **Figure 9** by Okoli [9].

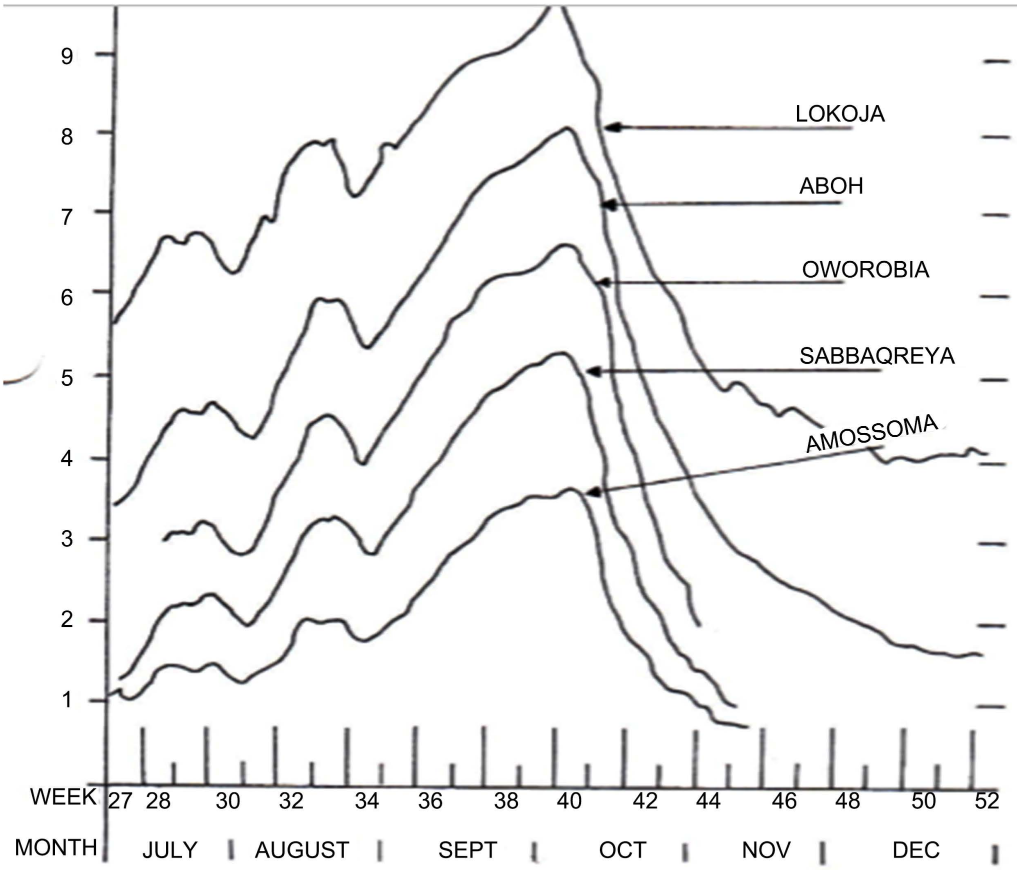

Figure 5. Hydrographs for Lokoja and some Niger Delta communities [7].

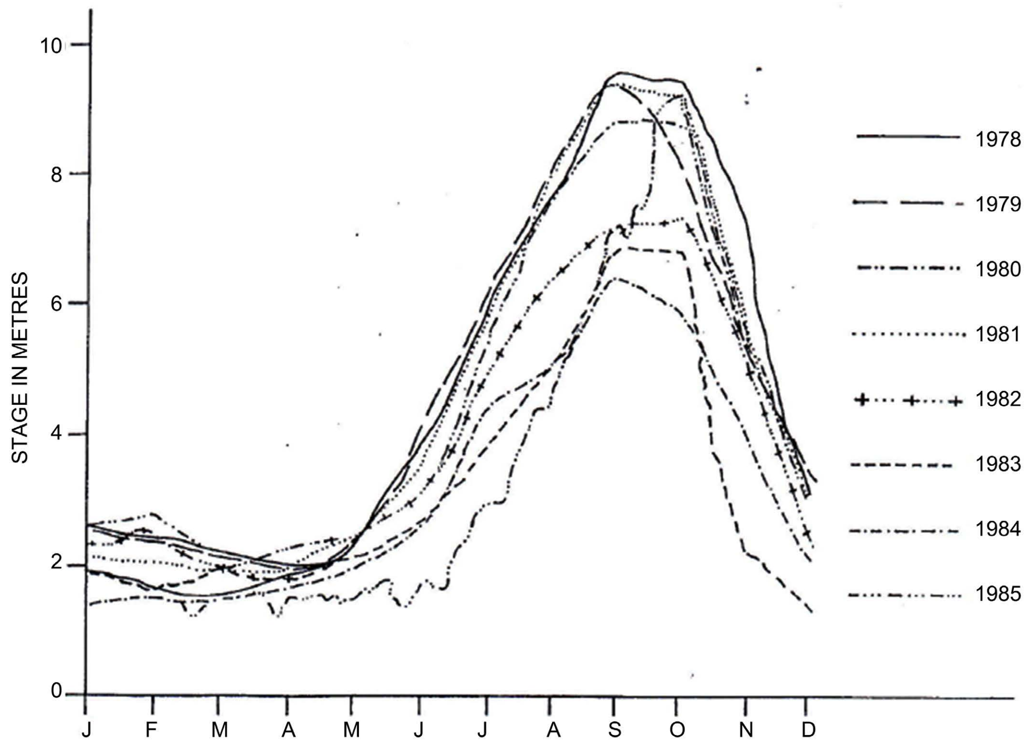

Figure 6. Assembly hydrograph for Lokoja [7].

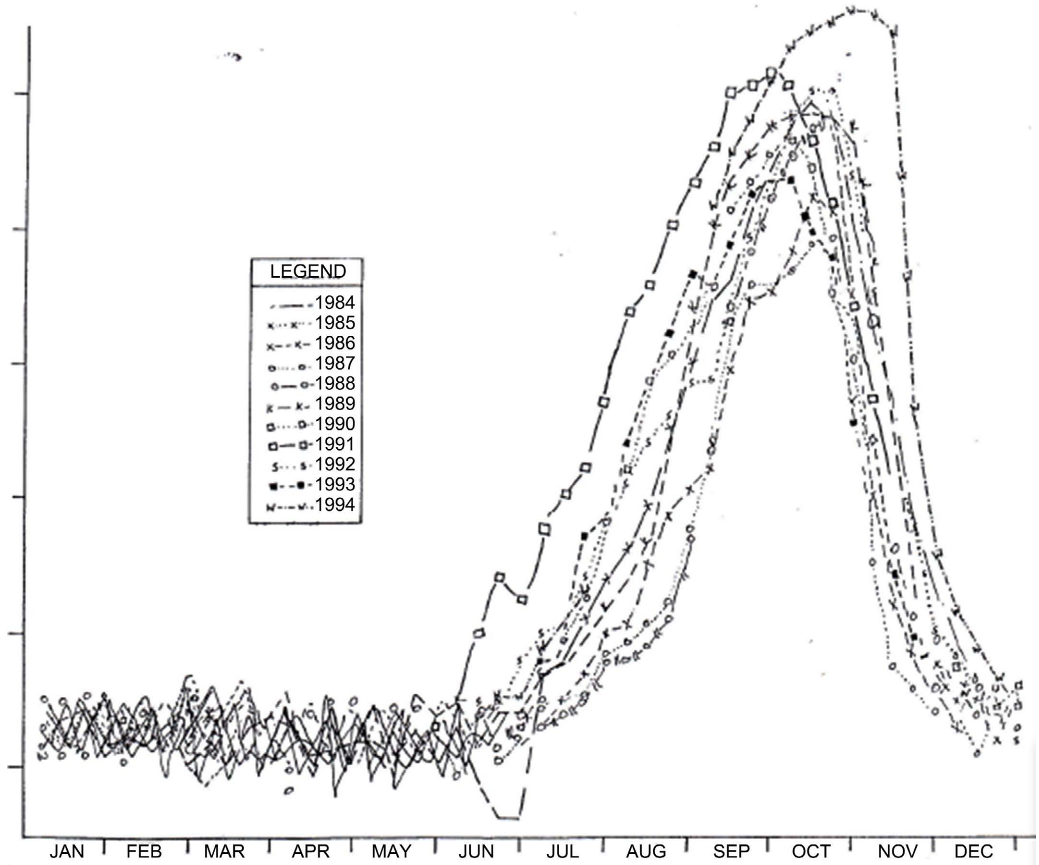

Figure 7. Hydrographs for Yenagoa [8].

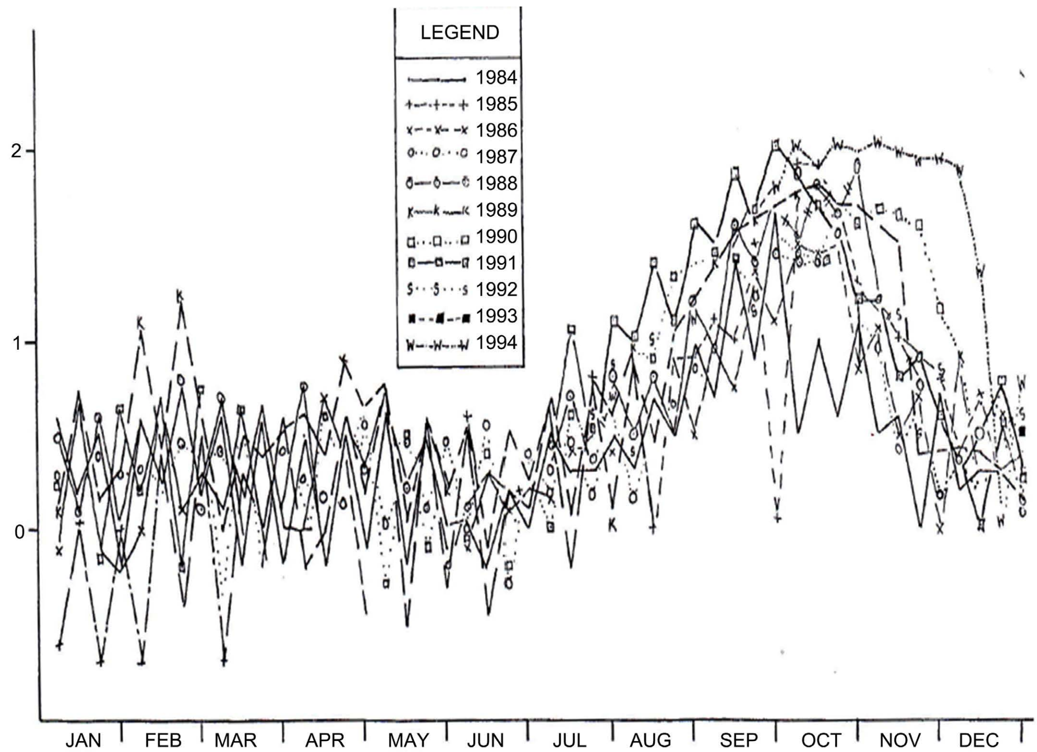

Figure 8. Hydrographs for Peremabiri [8].

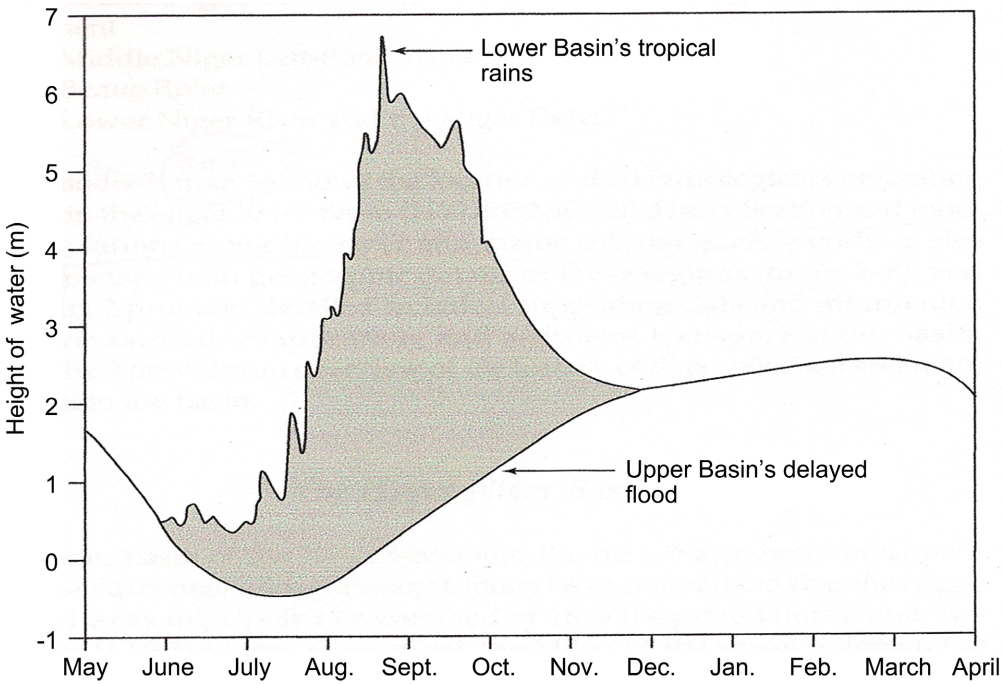

Figure 9. Example of the Hydrograph of the Niger River at Its Entry at the Niger Delta [9].

As the River Niger splits into several distributaries, the peak flood wave decreases and flattens considerably when passing through the delta. Since the delta is relatively flat and without well-defined flood plain boundaries; flooding is inadvertently extended to inter-channel areas which may be settlements. In this way, a considerable part of the river discharge occurs over land. The extent of land area covered by annual floods is estimated at 11,660 km^2 as depicted in **Figure 10**. Due to elevation differences, the interior backswamps start flooding before the attainment of the peak floods. There is often no outlet for the accumulated water in these backswamps because of the low permeability of the subsoil.

The coastal area of the delta is influenced by the Atlantic Ocean and experiences a diurnal tidal cycle with a tidal range from 1.8 to 2.75 m. While the tidal flow is bi-directional and periodically pushes inward, the fluvial flow from the drainage catchment area of the Niger River is uni-directional and discharges into the Atlantic Ocean. The flow in opposite directions of ocean water of equal density with the sediment laden fresh water creates a zone of mixed flow at the interface in which the tidal fluctuation is accompanied by a cyclic change in water quality. This change in quality is due to the lateral shift of the fresh/saline water interface and the mixing in continuously varying proportions of freshwater discharged from upstream areas with the sea water which flows upstream during rising tide. According to Abam [10] the zone of mixing migrates up and down the estuary and river with saline contamination extended furthest upstream at spring high tides during the period of low freshwater flush from upstream sources (January-May).

Figure 10. Land area of the Niger Delta impacted by annual floods.

6. Discharge Distribution

To fully appreciate the dynamic balance between fluvial and tidal discharges at the Niger Delta estuaries, it is important to understand the distribution of discharge from the Niger-Benue River system. Previous studies [10] [11] have shown that flow through the two main distributaries at the bifurcation largely determines annual flood distribution to downstream sections of the Niger delta. Historical flow through Forcados River and Nun River have consistently been in the ratio 55% for Forcados against 45% for Nun, until sometime in 1988-89 (**Table 1**), when some sand mining activities were undertaken around Agbere/Odoni just downstream of the bifurcation by the defunct Oil Mineral Producing Development Commission (OMPADEC) using cutter-suction dredgers. Flow distribution measurements carried out by Kariala Consult for NDES in 1998 [12] confirmed that 45% of the Niger discharge was now routed through Forcados River as against 55% through River Nun. Since then, the bifurcation area has undergone changes which are depicted in **Figure 11**.

The implication of the new flow regime is that River Nun and her distributaries now received much more water than it had done in the past, meaning that it would now experience not only a higher flood frequency but larger magnitudes and longer standing period for flood with the associated socio-economic consequences.

The large volume of water arriving in the Niger delta from the Niger and Benue Rivers is routed through a network of at least 21 no. distributaries (NEDECO, 1961) and creeks into the Atlantic Ocean. Rivers Forcados and Nun distributes the waters arriving the bifurcation in proportions that reflect the bathymetric configuration at Asamabiri (Abam 1999a), to the southwest and southeast of the lower Niger delta respectively. **Figure 12** is a schematic model to compare the discharge distributions pre-dam and post dredging of the bifurcation area. The effect of the alteration of the discharge proportions between Forcados and Nun Rivers was extended to the downstream of the distributary creeks as evidenced in **Table 2**. The trajectory of flood water at peak discharge indicates a spillover

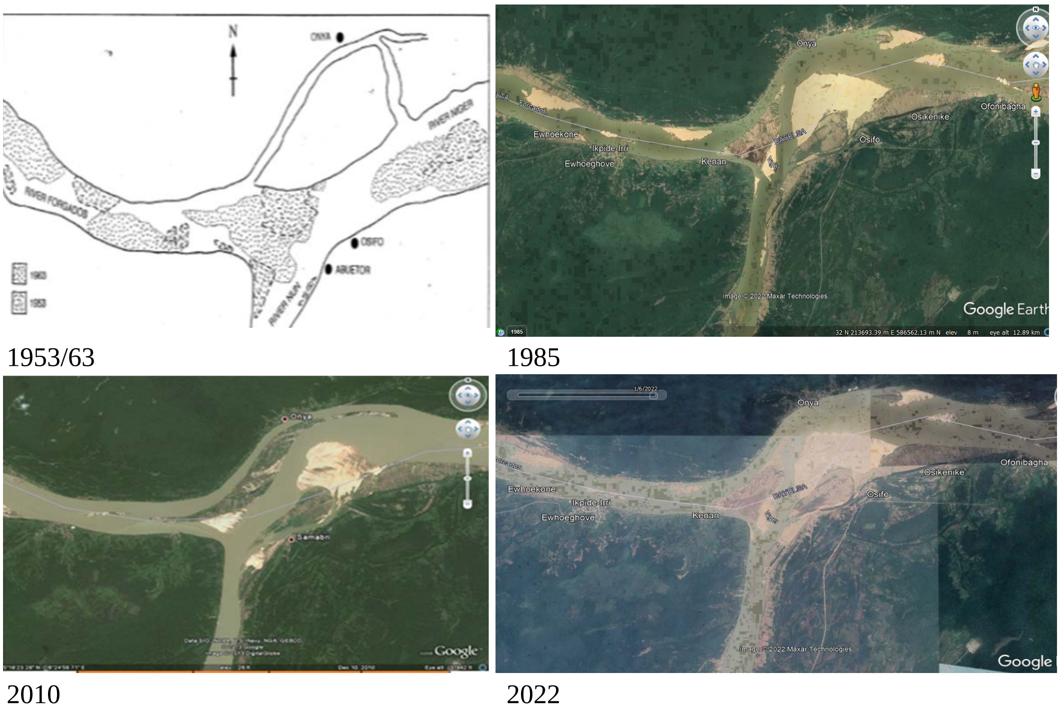

Figure 11. Evolution in geometry of the Sandbar at the Niger River bifurcation at Asamabiri from 1953 to 2022.

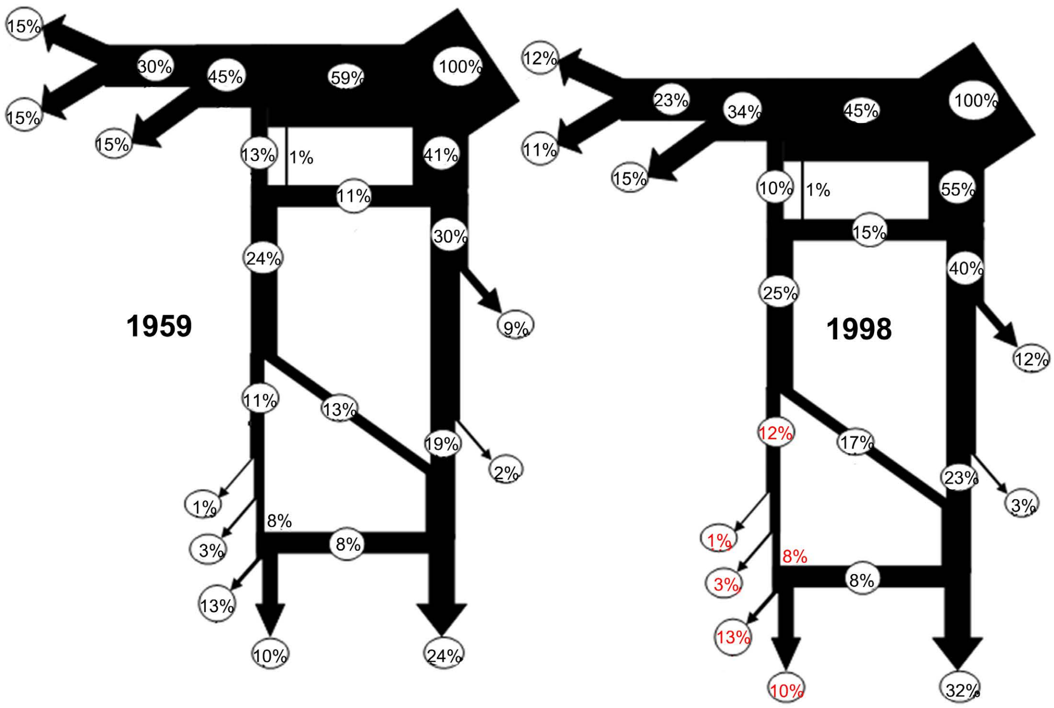

Figure 12. Model of pre-dam and post bifurcation dredging discharge distribution in the Niger Delta.

from the Niger River to Orashi River around Ndoni, and subsequently to Sombreiro River between Obrikom and Ahoada at peak flow, with corresponding effects on tidal excursion in the connecting estuaries.

Table 1. Discharge distribution at the Niger River bifurcation at Asamabiri from 1953 to 2012.

Survey Yr	Annual Discgage (m^3/s)	Discharge through Forcados (%)	Discharge through Nun (%)
1953/1954	NA	55	45
1959/1960	NA	60	40
1978	2499	55	45
1979	2464	55	45
1980	2358	55	45
1981	2364	55.01	44.09
1982	1871	54	46
1983	1267	55.01	44.99
1984	1353	55	45
1985-1997	NA	NA	NA
1998	5189	46	54
2012	31,000	46	54

Table 2. Comparative discharge of Niger River through secondary distributary creeks in 1961, 1998 and 2012.

Name of River/Creek	Max Flow velocity (m/s)	Volume (m^3/s)	% Discharge of Niger River by 1961	Average Post Kainji Dam Discharge (m^3/s)	Post (Agbere/Odoni) Dredge Discharge Distribution in 1998 (m^3/s)	2012 Discharge Volumes (m^3/s)
Forcados River at Asamabiri	1.14	9200	57.5	3680.00	2386.94	10120.00
Egbedi CR	1.18	4700	29.375	1880.00	1936.72	8211.18
Sagbama CR	1.24	2200	13.75	880.00	570.79	2420.00
Oguburi CR	0.96	2000	12.5	800.00	518.90	2200.00
Osiama CR	1.06	1800	11.25	720.00	467.01	1980.00
Bomadi CR	1.95	2650	16.56	1060.00	687.54	2915.00
Nikorogbo CR	1.22	2000	12.5	800.00	518.90	2200.00
Nun at Asamabiri	1.4	6800	42.5	2720.00	2802.06	11880.00
Kamborra CR	1.05	770	4.8125	308.00	199.78	847.00
Sengana CR	0.98	1900	11.875	760.00	782.93	3319.41
Ekole CR	1.18	1480	9.25	592.00	609.86	2585.65
Igeibiri CR	1	480	3	192.00	197.79	838.59
Bassa CR	1.18	1540	9.625	616.00	634.58	2690.47
Ikebiri CR	0.83	340	2.125	136.00	88.21	374.00

The amount of water safely discharged through the river is determined by the combination of available runoff and the capacity of the channel to evacuate them. The shear amount of discharge into delta towards peak flow is frequently beyond the capacity of the channels and could easily overwhelm the capacity of the network of distributaries' rivers/creeks and therefore predisposes the delta to flooding. The discharge through Brass River mouth for example, reflects the discharge hydrograph and the influence of the diurnal tidal cycle. Figure 13 presents the flood and ebb tide discharges on Brass River from July to December of 2000, the difference between the two being the net discharge into the ocean.

However, the daily discharges in the estuaries and river mouths, are also governed by the diurnal tidal cycles. The fluctuations of ebb and flood tide discharge through the Brass River estuary in the Niger delta is presented in Figure 14.

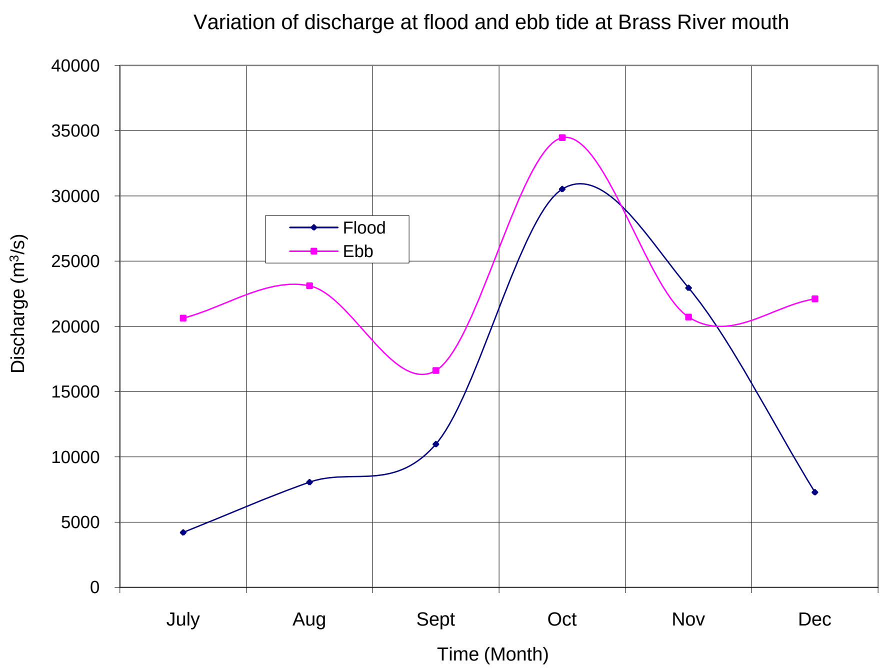

Figure 13. A comparison of ebb and flood discharge through the Brass River mouth following an annual cycle.

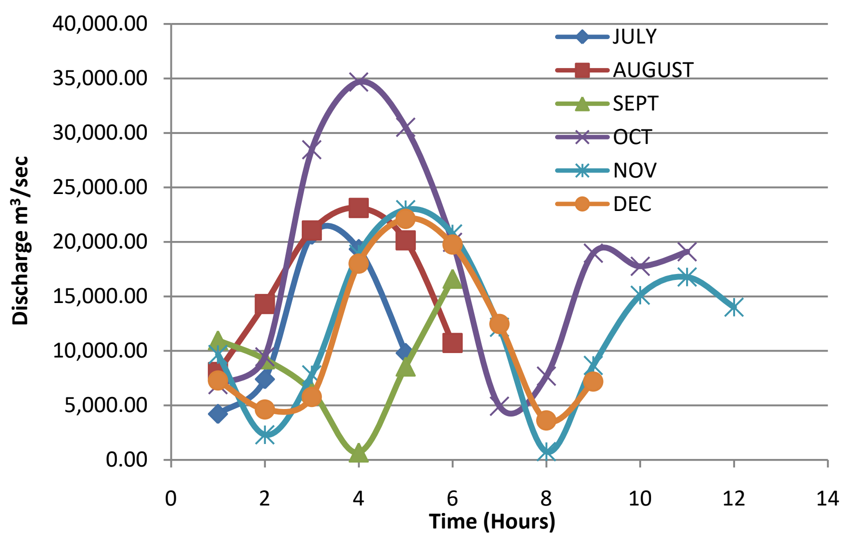

Figure 14. Fluctuations in the discharge through Brass River measured in 2000 with ADCP at different times of the day.

It is evident that the delta acts like a sponge, absorbing the shear amount of flow and releasing same through at least twenty-one outlet estuaries into the Atlantic Ocean.

7. Sediment Yield and Transport

Sediments supply to the Niger Delta comes largely from seven of the eight hydrological provinces in Nigeria that are within the catchment area and contribute flow to the Niger Delta. These sediments are derived from various sources including erosion within the semi-arid upstream catchment areas where streams are torrential and from bank failures in the alluvial riverbanks of the lower Niger River basin. Sediment mobilization and transport is also enhanced by the sparse vegetation cover which provides limited protection against weathering of the soil. The large catchment size combined with relative ease of entrainment ensures significant sediment supply to the delta. In the tropical forests upstream of the Niger Delta, for example, extremely high sediment yields occur after clearance and exposure of the soil to intense rainfall.

Pre Kainji-dam (1951-1957) annual suspended sediment load carried by the lower Niger at Onitsha was about 35 million tonnes [13]. Between 1963 and 1977 a total of 20.8 million tonnes including bed load and suspended load was transported past Lokoja, a station 115 km upstream of Onitsha. It is estimated that the Gongola River alone carried some 4.5 million tonnes; the Doga 2.5 million tonnes, the Katsina Ala 1.5 million tonnes and the Taraba 2 million tonnes. Survey records by NEDECO (1961) indicate that the total suspended load transported by Benue at Makurdi during 1932-1957 was about 22 million tonnes. However, between 1963-1977 the load was only 13.2 million tones, a decrease of 40% [8].

Investigations by NEDECO between 1959 and 60 in the Niger Delta showed that annual sediment transport through Onitsha between 1956 and 1960 varied from 16 to 19×10^6 m^3 distributed as 86% wash load, 8.5% suspended load and 5.5% bed load. In the same period, the discharge through Onitsha varied from 182 to 224×10^9 m^3. Further downstream at the bifurcation, Forcados River recorded an annual sediment transport of 6.8×10^6 m^3 at Onya as against 4.5×10^6 m^3 for Nun River at Asamabiri.

Sediment supply to the delta was expected to decline following construction of Kainji dam in 1968 due to reservoir sedimentation. Collins & Evans [14] estimated 70% reduction in sediment load as a result of dam. Similarly, Oyebande [15] estimated sediment retention in the Kainji reservoir of more than 70% of total sediment load. However average values calculated from published figures in Mahmood [16] gave an estimate of 79%. From these estimates it was clear that the Kainji dam trapped 75% of the total annual inflow of 8 million tonnes of suspended sediments.

In spite of retention of sediments at intermediate reaches of the lower Niger River, substantial volumes of sediments find their way to the river mouths and beyond to sections of the continental shelf. In this way, the delta has extended to areas previously occupied by the Atlantic Ocean. Because of this extension, the length of the rivers is increased continuously, with resultant decrease in the gradient of riverbed, and a corresponding reduced sediment-carrying capacity. As a result of the very small gradient of the riverbeds, considerable hydraulic resistance is generated aided by the passive resistance from flood tides, stagnating the river discharge towards the Ocean and restraining the backwater. This leads to increased riverbed sedimentation, raising the riverbed, reducing the flood storage capacity of the channel and consequently resulting in more frequent flooding.

8. Flux Efficiency and Self Cleansing Potential of Estuarine Rivers in the Niger Delta

The Niger Delta is subject to the influence of both marine and fluvial hydrological activities. The Niger Delta estuaries receive inflows of waters and sediments transported by the Niger and Benue River catchment systems, to the tune of more than 26,000 m^3/s at peak flows and subsequently discharges same into the Atlantic Ocean. At flood tide, saline water from the ocean ingresses through the same river mouth upstream [17]. Ebb and flood tidal discharges for major river estuaries in the Niger delta (**Figure 15**) were utilized in developing a flux efficiency index which is reflects potential efficiency of coastal rivers in disposing of pollutants.

Most of the rivers to the west of Brass which are fed by Forcados River exhibited relatively stronger flux efficiencies prior to 1998 by reason of receiving 59% of Niger River waters transported through Forcados River during this period. The rivers to the east between New Calabar and Imo Rivers exhibited very weak ebb tide asymmetry or net upstream flow largely because these rivers receive little or no freshwater influx from upstream sources. After 1998, the flow through

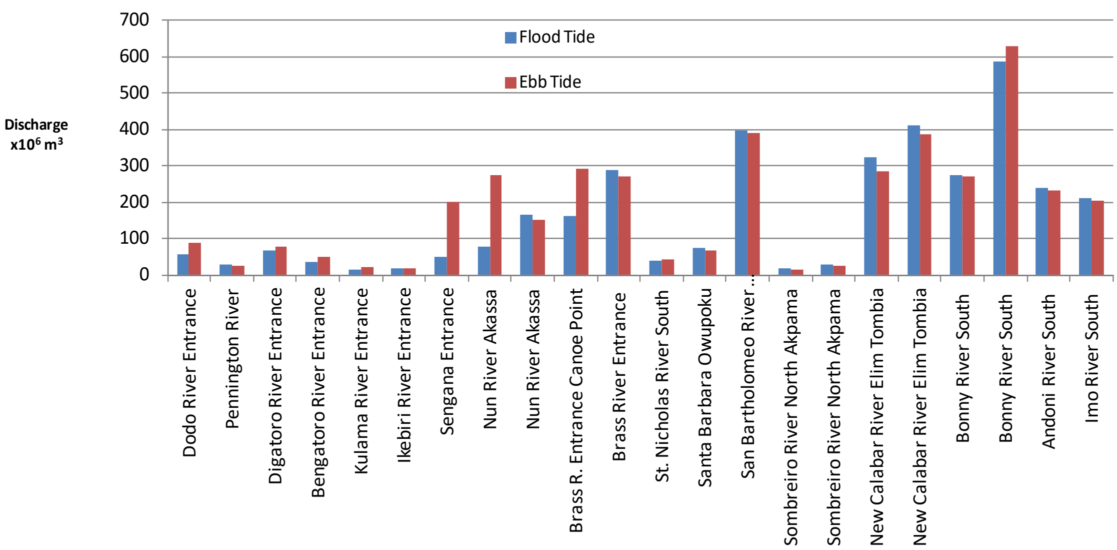

Figure 15. Variation of discharge across the Niger Delta.

Nun River was increased, with corresponding increase in freshwater influx into the rivers between Sengana and St. Nicholas Rivers. The effect of this increase also impacted directly on the flux efficiencies of these rivers.

9. Climate Change Impacts and Hydrological Hazards of the Niger Delta

With substantial variations to flood occurrence predicted as a result of climate change it becomes significant to investigate how global hydrological models process climate-forcing data. Agumagu O. and Todd M. [18] investigated projected hydrological effects of climate change on the Niger Delta region by simulating Runoff for present and future flood risk in the catchment of the River Niger using Global Hydrological Models (GHMs) from EU WATCH. The simulated discharges are comparable with the monthly gauge measurement along the River Niger from the Global Runoff Data Centre (GRDC).

As deltas are areas of continuous sedimentation, they undergo natural processes of digenesis, consolidation, compaction and ultimately subsidence. Although varied ground subsidence rates averaging 25 mm/year have been given [19], subsidence in general increases the vulnerability of the delta to flooding. The impact of sea level rise is exacerbated by subsidence which has been largely attributed to the large-scale oil and gas extraction in the Niger delta. When accelerated sea level rise is superimposed on a gradually subsiding Niger Delta, the extent of coastal areas exposed to flood is increased dramatically, threatening the possible existence of the indigenous people of the Niger Delta. A model study of the effects of sea level rise by Musa *et al.* [20], however, showed that it will not increase the lateral extent of flooded areas from both Nun and Forcados rivers, but will cause more areas to be flooded upstream. Secondly, it found that sea level rise will also be increase water depth in areas downstream of the Forcados River which will be further increased by land subsidence. An additional layer of flood vulnerability comes from sea level rise and increased precipitation associated with climate change, both of which further expose the Niger delta to floods of higher frequency and magnitude as well as intensification of erosional processes.

Flood and erosion in the Niger Delta are twin hydrological hazards, governed by inter-related processes [21]. Both hazards have a long history in the Niger Delta with records dating back to pre-independence [22]. Between 1959 and 1961 a detailed hydrological study of the Niger delta was carried out to provide essentially baseline data which has persisted to this time [13] without any significant updates. The ramified impacts of the absence of updated data for development planning have been repeatedly emphasized by Fubara [23] [24]. One of the key applications of hydrological data was to improve navigation in the Lower and Middle Niger Rivers. Attention to flood control in the region began with the commissioning of the Korean flood study [25] which came up with regional flood control strategies.

Flood awareness in the region is high because of the recurrent impacts of flood events. However, many significant projects were conceived and implemented without factoring their sensitivity to floods or capacity to exacerbate floods impacts. A good example is the East-West Road linking Portharcourt to Warri which runs perpendicular to the predominant flow direction without adequate provisions for runoff control as discussed by Abam *et al.* [26].

Although floods are natural phenomena, human activities have sometimes been blamed for their aggravation. Several human activities, some of which are designed to ameliorate flood impacts, such as construction of dams have inadvertently aggravated flood. Other activities such as alterations in the drainage patterns due to urbanization, agricultural practices and deforestation, have considerably changed the situation in whole river basins. Within the Niger delta, these activities have resulted in the steady increase of exposure to risk and vulnerability in flood-prone areas.

Although the delta has experienced several large flood incidents over the years, there has been no systematic inventory of flood events. In 1998, the spillway of Kainji dam was opened, resulting in prolonged flooding of the region. Similarly, in 2012, water released from the Lagdo (Camerouns) Kainji and Jebba dams flooded downstream areas embracing several states. These two incidents of recent memory witnessed floods with high water levels that should otherwise be receded by 90% in October extended to November. Most floods of above average magnitude and in particular these two large flooding events resulted in several deaths, loss of properties, severe health impacts, disruption of socio-economic and cultural activities, transportation and educational engagements and loss of agricultural yield. The impacts of Climate Change on Food Security are thus evident [27]. The Niger Delta was the most adversely affected, because the network of rivers and creeks in the area are structurally linked and serve as hydraulic extensions to the Niger/Benue Rivers system. The rivers and creeks within the Niger delta were overwhelmed by incoming flows and their discharge capacities exceeded, leading to overflows and the consequential flooding.

Flood impact in the region is exacerbated by a number of factors acting sometimes in combination, among which are: proximity to rivers and river network density, intensity of rainfall and amount, topography, widespread impermeable soil type. The comparatively disproportionate presence of these factors in the Niger delta makes it one of the vulnerable areas to flood. Flooding is a problem in both rural and urban areas across the region. Consequently, it is important to explore these to truly understand their roles.

Since the construction of Kainji dam in 1968, there have been over 200 dams in Nigeria [8]. Dam impounds water and sediments and become silted up in time if not maintained through dredging or other forms of de-silting. The usual outcome of dam construction across a river is the reduction in downstream water level. This has also been the case in the Niger delta. However, when dams get silted up, downstream flows are expected to recover to pre-dam levels.

It appears that the major driver of increasingly lower downstream water level is the underlining drought that has persisted over the period since construction of Kainji. This drought is also evident in the long-term flow data of Mean Daily Discharge (Cumecs) Per Annum (Figure 16) and also in the Yearly as well as monthly discharge of the River Niger at different reaches of the Niger River. The long-term flow data shows a continuing drought in spite of occasional surges in annual discharge values. From 1980 to 2000, the mean annual flow measured at Onitsha was only 4720 cubic meters per second, with a volume of 149 cubic kilometers per year; and the lowest flow ever recorded at Onitsha was 109 cubic kilometers in 1984.

Coastal floods are caused by exceptional high tides during Highest Astronomical Tide (HAT) or storm surges in the proximal high seas and oceans. The coastal area of the delta is dominated by a daily rise and fall in sea water level with a range at spring tide varying from 1.8 to 2.75 m in the west and east respectively. Such high tidal flood when associated with storm events which are expected to be more frequent with climate change, easily result in coastal flooding of Beaches and Barrier Islands, causing vegetation kill as exemplified by Figure 17.

Flash Floods also occur regularly in low-lying areas due to high intensity rainfall (often more than infiltration) or intense thunderstorms which accumulate water rapidly over an impermeable surface without adequate drainage capacity. These flood types may sometimes act in combination, especially in coastal urban cities which are simultaneously exposed to fluvial river system as well as coastal

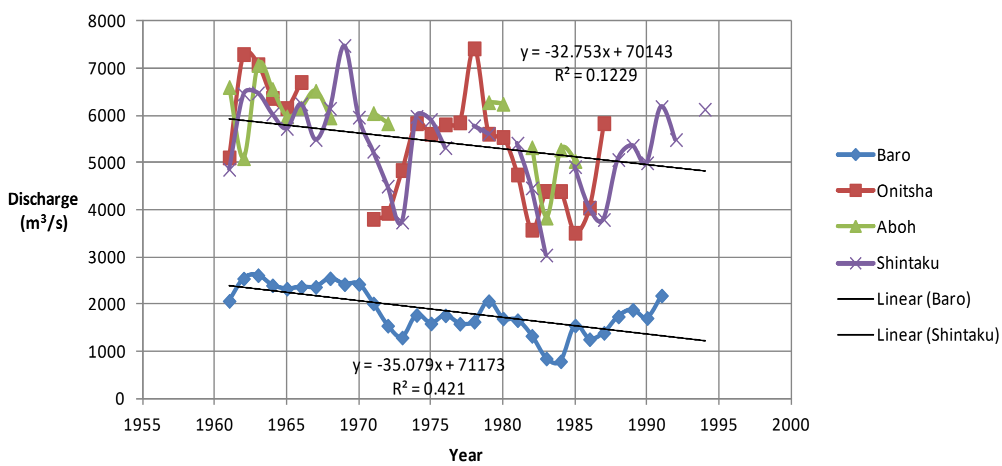

Figure 16. Mean daily discharge (in Cumecs) per annum of River Niger in some selected stations.

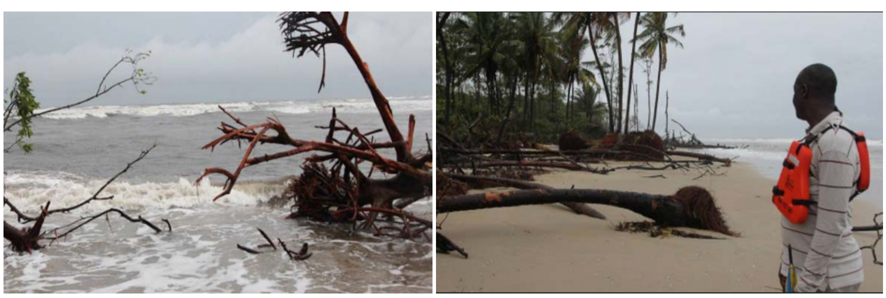

Figure 17. Coastal flood caused by storm surges leading to loss of vegetation.

influences. Coastal urban areas in the Niger delta such as PortHarcourt and Warri fit into this category and periodically experience flash floods induced by rainfall. To develop effective management approaches, it is important to understand how flood events are aggravated by a number of factors acting in combination such as nearly flat topography, low surface gradient which impedes runoff, widespread impermeable soil which minimizes infiltration, high water table which reduces additional storage capacity, high degree and rapid urbanization creating additional impermeable surfaces and Tidal action which offers passive resistance to flood water discharge into the sea at high tide. The combined action of these factors results in increased frequency of flooding, higher flood magnitudes and standing period.

One major effect of the flooding and recession cycle is the instigation of erosion through creation of channel instability. High water in river channels which exist during peak flood provides passive resistance to bank failures. However, when the water level recedes, this passive resistance disappears, and bank failure readily occurs. The concentration of bank failure episodes immediately following flood recession is the evidence that riverbanks are very sensitive to the removal of passive resistance.

10. Conclusion

The Niger Delta is the receptacle of both water and sediments from a catchment drainage area covering over 2 million km^2. The shear amount of discharge overwhelms the capacity of the network of distributaries' drainage rivers/creeks and predisposes the delta to flooding, in a process in which the delta acts like a sponge, absorbing the shear amount of flow and slowly releasing stored water through at least twenty-one outlet estuaries into the Atlantic Ocean. The variations in ecological zones present the delta as a sensitive and fragile ecosystem in which fresh and saline water ecosystems maintain a delicate and dynamic equilibrium. With 70% of the rainfall occurring in 4 month there is a potential for floods between May and September generated internally. Water level in the Nun River is generally higher compared to Forcados River, suggesting that canals connecting both rivers at the same reach would experience water movements from Nun to Forcados River. Presently, distributaries of Nun River have the highest capacity to evacuate pollutants, followed by Forcados River and lastly, rivers between New Calabar and Imo Rivers which receive little or no freshwater influx from upstream sources. Flood and erosion remain the major hydrological hazards in the region.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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