Modification of Niger Delta physical ecology: the role of dams and reservoirs

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Abstract The Niger Delta is a 40-km² sedimentary basin with a complex river network and a fragile ecology in which fresh and saline water ecosystems maintain a dynamic equilibrium. Large-scale upstream impoundment in dams and reservoirs have over the years drastically reduced flow and sediment delivery to the coast resulting in adjustments to ecological boundaries, coastline geometry, lowered flood water levels and upstream migration of tidal influences. However, as the reservoirs get silted up, they no longer function as effective flow buffers, occasioning increased floods towards the pre-dam levels.

Key words Niger delta; ecology; dynamic equilibrium; dams; sediment delivery; coastal erosion; morphology; riverine; river modification; wetlands; saline intrusion

INTRODUCTION

The River Niger drains a large part of West Africa and discharges its waters and sediments into the Niger Delta and its extensions into the Atlantic Ocean. Over the years, this process has resulted in the formation of a complex and fragile delta with rich biodiversity. The interaction of the drainage processes with the environment has resulted in the evolution of ecological zones as shown in Fig. 1. These are dry flat land, dry land with abundant swamp zones and freshwater swamps. Others are mangrove swamps, beach ridges and bars. These ecozones 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.

Although the geo-ecological boundaries in Fig. 1 are indicated as lines, in actuality, there exists in the field, a transitional zone of variable width, characterized by mixed attributes. The extent of the variation is usually a function of hydrology, topography and soil type. A change in any of these factors has the potential of altering ecological equilibrium and boundaries. The present study investigates the impact of upstream dams and reservoirs on these factors particularly, hydrology, and the changes in riverine ecological conditions that these have introduced in the Niger Delta.

HYDROLOGY

The hydrology of the Niger Delta is dominated by three types of flow; a unidirectional flow in the upper Niger delta, a bidirectional tidal flow in the coastal area and estuaries, and a mixed flow, in which the uni- and bidirectional attributes are combined in the transitional zone.
Fig. 1 Ecological areas and boundaries in the Niger Delta.
A typical hydrography for the upper Niger Delta shows a dry season period of some five months (December–April) followed by a gradual rise in water level, reaching a peak around September/October. The interior backswamps are frequently flooded before the attainment of peak floods because of their relative low elevation and structural connections to the main drainage channel. The water so accumulated in the backswamps does not often have a way to discharge or drain by gravity because of the very low gradient and permeability of the subsoil. The water level starts falling rather abruptly, soon after attainment of peak water stage, reaching its dry season level in less than 45 days. The actual discharge depends on the climatological conditions.

The coastal area of the delta is dominated by a daily rise and fall in water level with a range at spring tide varying from 1.8 to 2.75 m in the west and east respectively. This tidal fluctuation is accompanied by a cyclic diurnal change in water quality due to the mixing, in continuously varying proportions of freshwater discharged from upstream areas with the sea water. The zone of mixing migrates up and down the estuary and river with saline contamination extended furthest upstream at spring high tide during the period of low freshwater flush (January–May).

SEDIMENT YIELD AND TRANSPORT

Sediments transported to the Niger Delta are derived from seven of the eight hydrological provinces in Nigeria (Fig. 2). These sediments are derived from various
sources including erosion within the semiarid upstream catchment areas where streams are torrential and from bank failures in the alluvial river banks of the lower Niger River basin.

Sediment yield estimates in hydrological provinces impacting on the Niger Delta have provided a guide to the potential sediment availability in the region (Table 1). Hydrological province 5 (Fig. 2), which subsumes the Niger Delta has the least in terms of sediment yield.

Detached sediments invariably become entrained in the runoff in three main ways, bed load including saltation, suspended load and solution load. The greater part of the suspended load is carried off to sea or deposited on the flood plains. The annual suspended sediment load carried during the pre-dam years (1915–1957) by the lower Niger at Onitsha was about 35 million tonnes (Oyebande et al., 1980). Between 1963 and 1977 a total of 20.8 million tonnes including bed load and suspended load was transported past Kogi, a station 115 km upstream of Onitsha. 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. 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 tonnes, a decrease of 40%.

Investigations by NEDECO (1959), indicate that the proportion of bed load varies from 5% in the lower Benue and lower Niger to 6.5% in the upper reaches of the two rivers. In the upper Niger around Baro and Jebba, average silt concentration was 60–110 mg l$^{-1}$, while the maximum observed in the pre-Kainji period at the present site of the dam was 250 mg l$^{-1}$ (Oyebande, 1981).

### RESERVOIR IMPOUNDMENT

Drainage analysis of Nigeria (National Inventory on Dams, 1986) suggests that seven of the eight hydrological provinces impact directly on the Niger delta. These seven provinces, comprising Niger North, Niger Central, Niger South, Upper Benue, Lower Benue and the Eastern Littoral, have a combined catchment area of 1 413 986 km$^2$ and reservoir capacity of 29 578.7 million m$^3$. A total of 135 small, medium and large dams and reservoirs are located within the seven hydrological zones impacting directly on the Niger Delta. The potential impoundment of these dams and reservoirs over time,

<table>
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<th>Hydrological province</th>
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assuming they were filled each year show the influence of the large capacity dams (Fig. 3). However, during the dry years that predominated the record period, this was not nearly so. The cumulative impoundment reflects the volume of water trapped in the reservoirs that would otherwise be transported to the Niger Delta.

Collins & Evans (1986) had estimated percentage reduction in sediment load as a result of dam construction to be 70%. Similarly, Oyebande et al. (1980) estimated sediment retention in the Kainji reservoir of more than 70% of total sediment load. However average values calculated from published figures in Mahmood (1987) gave an estimate of 79%. From these estimates it was clear that the Kainji dam traps perhaps more than 6 million out of the total annual inflow of 8 million tonnes of suspended sediments. If the Lokoja dam project (with a planned capacity of 68 km$^3$) takes off, although this is unlikely in view of the huge cost and environmental impact, then the deposition of silt in the lower Niger and the concomitant flooding will be substantially reduced.

**IMPACTS ON PHYSICAL ECOLOGY**

**Increased upstream evaporation**

The average water depth in most Nigerian dams is less than 7.5 m. This implies that the impounded water is essentially spread over large areas, thereby enhancing evaporation. The reservoir areas of Kainji dam which are characterized by prolonged high temperature, low rainfall (794 mm), and low relative humidity exhibit evaporation values that are in excess of rainfall. An estimated average of $18.4 \times 10^9$ m$^3$ of water is lost from the reservoir area of Nigerian dams annually. About 24% of this volume is contributed by the Kainji dam reservoir. Surface water lost to evaporation in the upstream catchment areas has little prospect of reaching the Niger Delta. As a result,
downstream discharge and water levels are expected to be significantly modified in contrast to pre-dam values.

**Water levels and discharge**

The Kainji dam (capacity = $30 \times 10^9$ m$^3$) commissioned in 1968 was the first large dam built on the Niger River basin. Before the Kainji hydro-dam came into operation, the average yearly discharge at the confluence of the Benue and Niger rivers (Lokoja) was a daily average of 7000 m$^3$ s$^{-1}$. Beets (1988) reported an average drop of 20% immediately following the commencement of operations at the Kainji dam due to impoundment in the reservoir. This discharge rate was constant until 1981 when another drastic drop of 45% was noticed. This later drop in discharge was attributed to the operations of Bakolori, Kiri and Pankshin dams (with combined reservoir capacity of $5.6 \times 10^9$ m$^3$) commissioned in 1982. Impoundment in these dams reduced the discharge at Lokoja from 7000 to 3000 m$^3$ s$^{-1}$.

Analysis of the variation in maximum water level in Lokoja and some locations in the Niger Delta together with historical data on the operation of the dams suggested that the water level in Lokoja and downstream locations fell further in 1983 and 1984 due to combined effects of meteorological drought and the operation of Goronyo, Zobe, Shiroro and Shindam dams whose combined reservoir capacity stood at $12 \times 10^6$ m$^3$. These variations in total discharge induced mainly by the runoff control of dams have lowered the peak water level at Lokoja from about 11.13 to 9.6 m and is further reflected in downstream water levels as exemplified by those observed at Peremabiri (Abam, 1999).

**Modification of river morphology**

The large-scale impoundment of upstream reservoirs has reduced downstream flows. Accordingly downstream flow volumes and velocities are reduced. As a consequence, the competence of the Niger River in its downstream segment is reduced. The reduction in flow velocity encourages deposition within river channel and is reflected as shallower river cross-sections and enlarged sand bars.

Assessment of the spatial distribution and relative sizes of sand bars indicate increased deposition over the years of impoundment. The sand bar just north of Patani on the Forcados River increased from 0.1701 km$^2$ in 1963 to 0.486 km$^2$ in 1988. Similarly, the sand bar at Anibeze east of Patani on the same river, increased from 0.3645 km$^2$ to 0.9315 km$^2$ in the same period. A similar trend is observed on the River Nun where the sand bar just south of Odoni increased its size by 100% between 1963 and 1988. The sand bar opposite Odi not only increased in size, it also expanded in the upstream direction. At Sampor, a major river channel was completely silted up. Several other sand bars on the river between Onitsha and the bifurcation of the Niger into the Forcados and Nun rivers have evolved into larger sand bars, thereby significantly modifying the river morphology. The NDES environmental change atlas for this area (NDES, 2000) confirm that changes have largely been confined to the
flood plain. It was this channel modification which adversely affected the economy of the river channel that influenced the Federal Government's plan for large-scale dredging of the River Niger.

**Flood plain ecology**

As a result of the lowering of the water level, the flood plain of the Niger River system has shrunk in size. In response, there has been a noticeable increase in housing development in the "reclaimed flood plains" as well as in the backswamp forests which are generally lower in elevation than the natural levees.

The shrinking of the flood plain gradually engineered a change in the soil moisture conditions, with a corresponding change in plant speciation. Already, several of the fish-spawning areas within the freshwater swamps have been lost due to low flood levels. Also, silt nutrient supply to the forest has been drastically reduced for the same reason. A variety of wild life species intolerant of ecological change are bound to suffer stress (Bruce, 1995) and eventually extinction. Already ecologists have reported the disappearance of some species of fish, birds and other wild life downstream of dammed rivers (Crisp, 1985).

**Saline intrusion**

A further concern of the reduced water levels in rivers is the increased tidal influence in upstream areas. This is exacerbated by an increase in mean sea level due to global warming. The hydrographs for upstream locations such as Yenagoa, located 300 km from the coast is showing tidal influences that were never known before. Indeed preliminary results of resistivity surveys and borehole water analysis suggest that saline contamination is an increasing threat to potable water supply in the coastal urban region. In Port Harcourt and Warri for example, chloride concentrations of 150 mg l\(^{-1}\) were recorded at depths of 72 m in 1997.

**Sediment transport**

Pre-dam annual bed load transported by the Niger River system amounted to about 0.31 \(\times\) 10^6 m\(^3\) (NEDECO, 1959, 1961). Similar measurement on the Benue River indicated a bed load of about 0.6 \(\times\) 10^6 m\(^3\) with a suspended load of about 11 \(\times\) 10^6 m\(^3\) (NEDECO, 1959, 1961).

A net sediment load of some 15 million tonnes year\(^{-1}\) is produced between Yola and Makurdi, much of which would be trapped at the Lokoja dam, if and when it is built. But as stated earlier, its construction is very unlikely. These values may have changed significantly with increased impoundment in upstream dams.

These sediments that flow past the dams and reservoirs are redistributed in the course of downstream drift. According to Peterson (1986), the percentage distribution of sediments to rivers and creeks is determined by discharge. In the Niger delta,
sediment redistribution will be further dependent on the peculiarities of the river system and the network of distributary rivers and creeks. Abam & Beets (1995) had noted that the mobility and shape of the sand banks is a major factor in discharge distribution. Consequently, changes in sand bank location and geometry determine river cross-section, discharge and sediment load that flow past them and in this way invariably, affect downstream ecology.

Coastal erosion

The combined effect of reservoir sediment impoundment and increased in-channel sedimentation is a reduction in the sediment load of coast bound waters. The sediments entrained in the flow are distributed in proportion to the discharge of the distributary rivers and creeks (NEDECO, 1961). Since historical records of discharge distribution to the east and west delta indicates 55% preference for the western delta, it is expected that sediment delivery to the coast of the western delta would be significantly higher.

This skewed distribution was also maintained during the period 1983–1984, which happened to be that of a very severe drought in the Sahel and the Sudan, when the lowest flow volumes in 40 years were recorded. Although significantly higher, the sediment delivered to the western delta has not been sufficient in sustaining accretion in the area. This is evident from a comparison of satellite imageries of the coastal area between 1963 and 1988, around two strategic river estuaries, which together control 30% of the Niger River discharge, namely, the Forcados and Ramos rivers (Fig. 4). The significant coastline recessions revealed in this is strong evidence of the large sediment impoundment of dams, particularly Kainji which was commissioned in 1968.

Indeed recent investigations by Ibe (1986) have revealed a net retreat of the coastline in the eastern section of the Niger Delta and only marginal accretion in limited sections of the western Niger Delta. The net erosion of the eastern coastline is explained by its non-direct connection to the Niger–Benue river system that conveys the bulk of the sediments. Furthermore, the drainage rivers in the east delta have limited extent and catchment size in comparison to their western counterparts. The erosional stress being experienced at the coast presently will gain further strength with the anticipated rise in mean sea level because of the associated stronger coastal hydraulic forces.

These patterns of coastline development contrast with an earlier report which reflected the pre-Kainji dam status and suggests a strong erosional stress and a shift in the existing ecological balance. The presence of strong erosional stress suggests that there is not enough sediment reaching some sections of the coast to sustain the existing ecological balance between coastal erosive processes and construction river hydrological processes.

Emerging trends

The dams have gradually silted up with the continuous entrapment of sediments, thus decreasing their capacity to impound water. Consequently, the dams are no longer able
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Fig. 4 Coastline changes at Forcados and Ramos river estuaries between 1963 and 1998.
Fig. 5 Variation in maximum water level downstream of Kainji dam. (Numbers in parentheses are reservoir capacities in million cubic metres.)

to function effectively as flow buffers. Floods in downstream locations are therefore expected to increase towards pre-dam levels, except when dam reservoirs are dredged to increase their holding capacity. Figure 5 suggests that already, water levels depressed following intensive dam construction between 1968 and 1985 are beginning a modest upward trend. Flooding was particularly severe in 1988 and 1994, forcing people to seek shelter on higher ground, leaving crops and houses to be destroyed. However, the new flood water carries only little or no sediments compared with the pre-dam years.

CONCLUSIONS

The dynamic riverine ecological equilibrium is under threat, as a consequence of upstream dams and reservoirs. The consequent reduced water level and discharge and lower sediment transportation capacity have not been sufficient for maintaining the ecological equilibrium especially around the coastline.

A reduction of the sediment supply feeder function of the upstream river systems combined with the rise in mean sea level has changed the distributive forces at the coast into destructive forces.
Coastal and tidal influences have moved further upstream, raising fears of contamination of aquifers by saline water.

There is an indication of the return to pre-dam ecological conditions as the reservoirs are increasingly becoming silted up.

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