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An Evaluation of the Sediment Storage in the Niger Inland Floodplain in Mali

N'dji dit Jacques Dembele
Department of Quaternary Geology and Morphology, China University of Geosciences, Wuhan, China

Abstract: Between the cities of Ségou and Diré in Mali, the Niger River enters into a large alluvial plain (60,000 km^2): the Niger Inland Delta. The presence of this floodplain has an important impact in the sediment budget of the River. Using the methods of sediment balance analysis (sediment input and output), this study shows that 16.9-50% of the sediments provided by the upper Niger Basin (76.5%) and the Bani River Basin (23.5%) is stored. The sediment flux and storage vary with the water discharge. The two main parts of the inland delta: the southern delta or the lakes area and the northern delta called the erg region behave differently. The southern delta is a sediment sink (26-53% of sediment deposited); the erg region is an area of erosion. The main consequence of this sediment storage is the aggradation and the geomorphological change of the floodplain.

Key words: Sediment storage, floodplain, Mali, Niger River, Niger Inland delta

INTRODUCTION

The Niger River (4200 km) is the longest river in West Africa and the third on the African continent after the Nile River (6500 km) and the Congo River (4700 km). It covers a drainage area of 2.26 millionkm^2 that comprises Guinea, Mali, Cote d'Ivoire, Burkina Faso, Niger, Benin and Nigeria where it ends in the Atlantic Ocean.

The river rises in the Fouta Jalon Mountains (800 m) in Guinea. After the city of Ségou in Mali it enters a large quaternary alluvial plain made by its own deposits. This area is known as the Niger inland delta or the Niger central delta or Niger inner delta because its geomorphology recalls that of rivers mouth. In this area the river divide into a multiplicity of anabranches, lakes and swamps subject to seasonal flooding.

The presence of such a plain is very important in the sediment budget of the river because flood-plains by their morphology and topography are sediment traps and they may in many cases reduce significantly the river's total suspended load (Walling, 1996). In assessing rivers sediment budget, the sediment storage is an important factor and part of the equation:

Sediment Budget = Total denudation-Sediment storage + Channel erosion.

Even if in the sediment budget assessment, the colluvial and alluvial storage are often considered as residue (Bravard and Petit, 1998), they can have considerable proportions in the total global budget and can reach 70-80% (Kondolf and Matthews, 1991). Alluvial deposits usually occur in floodplains were the velocity of water decreases.

The Niger inland delta is such an alluvial plain. So, it is quite evident that its presence on the Niger River's course can have an important impact in the river's sediment delivery to the Atlantic Ocean.

This study aims to evaluate the amount of sediments that are sequestered in this area and its impact in the area's environmental change.

Because of the plains and the waters provided by the rivers, its anabranches and the lakes, the area has been for centuries an area of high agricultural, pastoral and fishing productions. It is also an important area for the world biodiversity with more than 120 fish species, more than 350 bird species. It receives 1 million birds from 80 countries around the world every year. But the fact is that the lake has been drying in the past few years. In assessing environmental change in this area biological, hydrological, climatological and chemical variables are often used and a few accounts are given to geomorphological change. But it is evident that in such areas as flood-plains, sediment sequestration can lead to the accretion and drying of the lakes. This study by the results it provides contributes to solve such deficiency. It will also help to understand the sedimentation patterns of the inland delta and the geomorphological features related to them.

The study area: Located in the Sahel region of the Republic of Mali, between 13°30' and 17°00' north and 2°30' and 5°30 west, the Niger inland delta is one of the largest floodplain in the world. It covers more than 60,000 km^2 and is bounded in the west by the plain of the "dead delta" an inactive floodplain which is a result of the

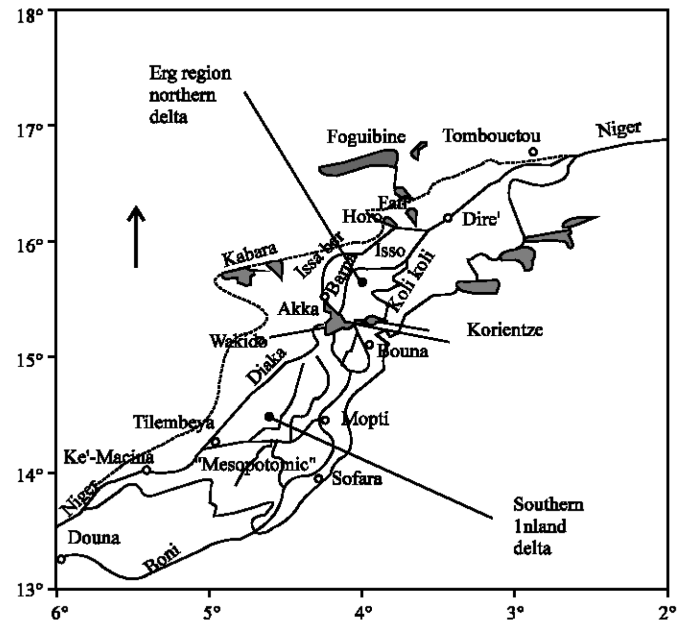

Fig. 1: Map of the Niger inland delta

river's quaternary deposits, in the east by the Dogon Plateau (400 m) and in the north by the sand dunes of the Sahara desert. The Inland delta begin before the city of Mopti when the river is joined by its main tributary, the Bani River and ends at Dire when the different branches join together again (Fig. 1).

Geomorphologically, the inland delta can be divided into 2 parts: the southern delta also called the lacustrine region and the northern part called the Erg region or the Erg of Niafunké.

The lacustrine area is a vast alluvial plain subject to widespread flooding (20,000 km^2 of this area flooded every year). It begins in the city of Ke-Macina (Niger River) and Douna (Bani River) and ends in the north by the mouth of the central big lakes (Débo, Walado and Korientzé lakes). The slopes are very low, about 2-3 cm km^{-1}, causing low water flow velocities of 0.3-0.6 m s^{-1}.

In the erg region, the river flows around dune formations that are oriented West-East. The inundated areas are mainly along the river's bed and some lakes scattered along the river: lakes Tanda, Kabara, Tagadjiji, Horo, Fati, Télé and Faguibine covering 10, 000 km^2 in the left bank, Aougoungou, Niangaye, Do, Garou and Aribongo covering 4000 km^2 in the right bank.

In this area the slope gradient decreases to 1cm km^{-1} between the cities of Niafunké and Dire, the eastern boundary of the inland delta.

Hydrologically the Inland delta receives its water from the main Niger River and the Bani River. Rising in the Guinean region under the equatorial Guinean climate (2000 mm y^{-1}), the Niger at Ke-Macina collect the water of a drainage area of 141,000 km^2 and provides the inland delta with 20.4-41.6 km^3 of water volume per year. The Bani river, with a smaller drainage area of 102,000 km^2 provides from 4.3-14.8 km^3. Another small river called the Kara River contributes with 5.1-14.8 km^3. This amount of water is the main provider of suspended load from the Upper Niger drainage basin to the Niger inland delta. But most of this water is lost in the inland delta because of evaporation. The evaporation is estimated to be about 2260-2360 mm per year. So, 9.33-42.7 billions m^3 of water is lost in the floodplain.

Geologically, the inland delta is a young delta with quaternary deposits. It was formed when during the tertiary to the lower Pleistocene periods when the Niger River was endhoreic. It used then to flow into some big lakes in the Azaouad region in the Malian Sahara. Nowadays these lakes have disappeared. It is thought that it was in the lower Pleistocene or Holocene periods that the Niger River started flowing over the Tossaye dyke and has been captured by the Tilemsi River rising in the Adrar des Iforas Mountains in the north of Mali. The River then started flowing to the Atlantic Ocean. The reason for this change is still unknown.

MATERIALS AND METHODS

When studying such phenomena as the sediment budget (the sediment input and output) on a river system different complementary methods can be used, such as:

- Sediments traps (Brunet and Gazelle, 1995; Sim mand Walling, 1998).
- Sediments coring and analysis of Cesium 137 (Simm, 1995; Walling, 1996; Allison, 1998).
- Solid transportation model related to a hydraulic model (Pizzuto, 1987).

None of these methods has ever been used in the Niger Inland Delta. The elaboration of a Hydraulic model of the Delta is not easy because of its geomorphic complexity.

In the absence of these methods, the only solution relies on the calculation of the suspended load balance (balance of sediments input and output along the system).This method has been used successfully by Walling (1986) and Brunet and Haiada (1996). The same method was used in this research.

The data for the sediment balance in the system are from three main hydrological stations, two at the entrance of the delta: Ke-Macina on the main Niger River and Douna on the Bani River, the third one at the mouth of the inland delta (Dire). Some data are from some secondary stations located inside the region along the lakes and branches. These stations were set up by ORSTOM now IRD in the context of the EQUANIS (Environnement et la Qualité des Apports du Niger au Sahel) project between 1991 and 1998.

The data has been aggregated spatially for analysis. The area has been divided in two sectors:

- The first from the entrance of the delta to the mouth of the main lakes that we called the southern delta.
- The second from the Débo Lake to the eastern boundary of the area: the erg region.

These two areas because of their different topography and geomorphology must certainly have different impact on the sediment storage.

RESULTS

Sediment input in the inner delta: The upper Niger drainage area has provided from 1992-1998 1718.6×10^3 tones per year of sediment volume to the inland delta. The two tributaries contributed differently. The Niger River main channel provided 1296.6×10^3 tones per year and the Bani River 422×10^3 tones per year that represent 75% for the Niger River and 24.6% for the Bani, respectively.

This sediment discharge is highly correlated to the water discharge (Fig. 2 and 3): 944.6 m^3 s^{-1} for the Niger River and 226.5 m^3 s^{-1} for the Bani River. The correlation coefficient between the sediment flux and the water discharge is 0.96 for both rivers. But the sediment load of

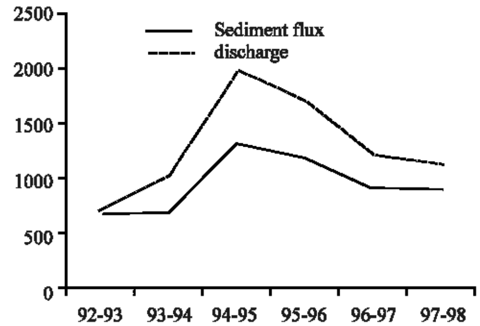

Fig. 2: Inter-annual variability of water discharge (m^3 S^{-1}) and sediment flux (10^3 tones) from the Niger River at Ke-Macina Station

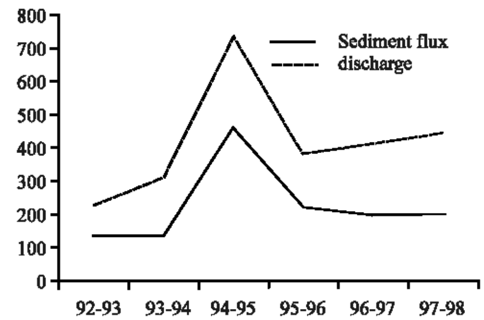

Fig. 3: Inter-annual distribution of the water discharge (m^3 S^{-1}) and Sediment flux (10^{3}tones) from the Bani River at Douna Station

the Bani River seems to be higher than that of the Niger main channel, respectively 61.5 and 43.03 mg L^{-1}. The reason is that the drainage area of the Bani is smaller with many human activities. The Bani drainage area has been an area of cotton plantation for a long time and the fields have replaced in many areas the natural vegetation that resulted in an increase of the erosion rates. Secondly the Bani River's basin is composed mainly of tertiary sandstones. The fluctuation in the sediment flux follows the water discharge variations.

The sediment influx in the inland delta is also characterized by an annual and inter-annual variability. The higher discharge was recorded in the hydrological year 1994-1995 when the water discharge reached 1320 m^3 s^{-1} for the Niger River and 459 m^3 s^{-1} for the Bani River. The corresponding sediment inputs are correlatively high: 1974×10^{3}tones per year and 729×10^3 tones per year. But the lower water discharge does not correspond to the minimal sediment input. In the hydrological year 1993-1994 when the Niger River's discharge fell to 647 m^3 s^{-1} and the Bani River 135 m^3 s^{-1} the sediment discharge was still high. The

Table 1: Correlation coefficient for the different variables Niger River

	Sediment flux	Sediment load	Water discharge	Erosion rate
Sediment flux	1			
Sediment load	0.59	1		
Water discharge	0.96	0.34	1	
Erosion rates	0.95	0.95	0.95	1

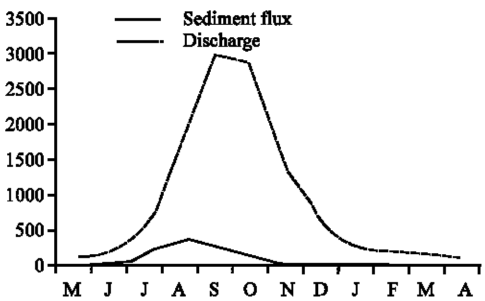

Fig. 4: Monthly distribution of water discharge (m^3 S^{-1}) and sediment influx of the Niger River at Ke-Macina Station. The sediment flux (10^3 tones) follows quite perfectly the water discharge

lower sediment flux was recorded in the hydrological year 1992-1993 that was, respectively 715×10^3 tones per year for the Niger and 229×10^3 tones per year for the Bani. The main reason is the change in the erosion rates.

There is a good correlation between the water discharge, the sediment load and the erosion rates: 0.95 (Table 1).

The monthly record shows a variation of the sediment influx with the water discharge. From May, when the rains start falling in the upper Niger River's basin, the water discharge start to rise and attain its maximum in September then decrease to the minimum in April. The Niger River has a uni-modal regime. The sediment flux follows the water discharge rise. The maximum water discharge in September is 3014 m^3 s^{-1} for the Niger and the corresponding sediment influx is 408×10^3 tones per year. The lower discharge is recorded in April (82.4 m^3 s^{-1}) with a related discharge of 2.6×10^3 tones per year (Fig. 4 and 5).

But for the Bani River the maximum discharge is in September, 884 m^3 s^{-1} but the maximum of sediment flux is in April: 153×10^3 tones per year. The pattern seen on this river is mainly due to the area of the drainage basin and the water flows much quicker.

The sediment load is higher for the first month of the hydrological year from May to September. They account for 248.1 mg L^{-1} for a yearly total of 398 mg L^{-1} that is 62.3%. The main reason is that the erosion rate in such tropical areas is very high at the beginning of the rainy season when the vegetation cover is very low and during these months the river remobilizes some of the sediment deposits from previous years.

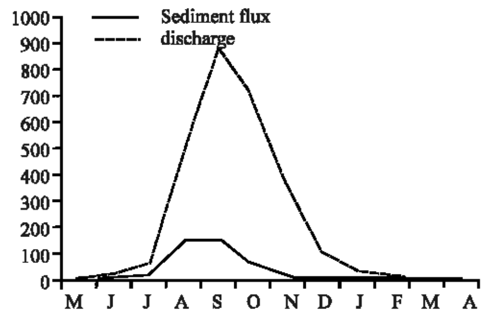

Fig. 5: Monthly water discharge (m^3 S^{-1}) and sediment flux (10^3tones) from the Bani River at Douna Station. The sediment flux follows the water discharge fluctuations but not as perfectly as for the Niger River: The 2 maximums do not correspond

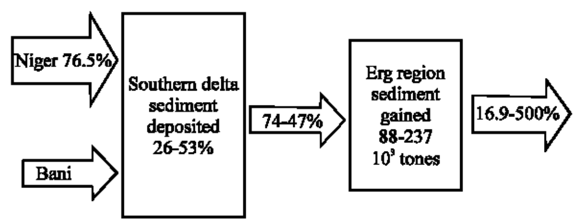

Fig. 6: Sediment balance of the inland delta from 1992-1993 to 1997-1998

Mineralogically, these sediments are mainly clays: kaolinite (20%), illite (20%) and montmorrillonite (30%). Some sands are also inputted in the inland delta. These are mainly from the erosion of granite and gneiss and Birriman formations in the upper Niger. But the Bani River provides most of the detritus sediments.

In total, the upper Niger River drainage basin and the Bani river basin provides an important amount of terrigenous sediments in the Inland delta every year. This sediment influx varies from year to year following the water discharge variation. But what happens to these sediments when they get to the inland delta?

Sediment output from the Inner delta: From the data collected, the sediment influx to the inland delta during these 6 years totals 10,322×10^3 tones per year. But only 6,069×10^3 tones per year have passed out of the area. So during these 6 years 4,253×10^3 tones per year of suspended sediments have been deposited. That means 41.2% of the sediments entering the area are sequestered. But this sediment deposition is characterized by a spatial and temporal variation.

Spatially, the two main areas of the inland delta as defined before retain the sediment differently (Fig. 6).

The lacustrine area receives the sediments from the upper land but loses only $5,874\times10^3$ tones per year. This amount is lower than the total output of the inland delta. This area seems to be a sediment sink in the Niger River's drainage basin. This is mainly due to its low topography and the presence of the main lakes and swamps. It sequesters 26-53% of the sediments entering the delta.

In the erg region, there is a gain of sediments. 195×10^3 tones per year were gained within the observation period mainly from the river's channel bed erosion and the remobilization of Aeolian deposits from the Sahara desert.

From 1992 to 1998, the sediment storage in the area varied from 17-50%. So, 160×10^3-$1,216\times10^3$ tones per year were deposited.

In the erg region there has been a gain of 19×10^3-88×10^3 tones per year. But this sediment gain does not affect sensitively the global sediment balance of the whole inland delta that remains high.

DISCUSSION

From the data gathered it appears evident that an important amount of sediments is stored in the delta every year especially in the southern area that bears the main lakes, resulting to an accretion and aggradation in the inland delta.

The stranding problem is an environmental issue in this area. The surface area of the inland delta was larger reaching 80,000 km^2 (Gallais, 1967). Its area has been decreasing. During some years only 20,000 km^2 are flooded. Many researches have put forward the problem of the climate variability and human activities.

This research shows that the geomorphological change in the Inland delta is an important factor that must be taken into account. Indeed, the climate variability is a big issue for the Shelia countries like Mali because from the 1960's the rainfall has been decreasing with some severe droughts occurring in 1973, 1984 and 1990, but it does not fully explain all the dynamics in the Inland delta. Its effect is mainly limited on the sediments flux variation, because the sediment flux seems to be well correlated to the water discharge. The main relation climate-geomorphology could be the changes in the vegetation cover in the upper Niger drainage basin that impacts directly and positively the erosion rate. Since 1955, the successions of dry years combined with human activities have reduced significantly the forest areas on the upper Niger River Basin. That has amplified the level of land erosion.

As it appears in this research, an important amount of these terrigenous sediments ends in the Niger Inland Delta where they are sequestered.

This geomorphological change must be taken into account as Mali is planning to construct a dam at Tossaye at the eastern end of the Inland delta. That will surely increase the aggradations of the inland delta lakes. The dyke of Tossaye used to be an interfluve separating the Niger Basin and the Tilemsi River Basin. The construction of a dam over the dyke will first affect the water budget. An important amount of water will be stocked and correlatively the quantity of sediment stored will increase.

This sedimentation pattern could also explain the dynamic of the Inland delta's geomorphology during all the quaternary epoch. The presence of such large inactive floodplains or dead deltas in the west and the south of the actual inland delta must be related to this sediment accretion. The Inland delta seems to be moving further east as it appears on Satellite images.

However, the lack of quaternary sediment core data makes it difficult to conduct detailed studies of the geomorphological dynamics in the Inland delta.

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