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IMPACT OF AGRICULTURAL WATER ALLOCATION ON THE ECOSYSTEMS IN THE INNER NIGER RIVER DELTA

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ABSTRACT: The Niger River is a lifeline for humans and biodiversity in Africa's Sahelian region. Owing to climate change and population increase over the past three decades, the inhabitants of the Sahel have witnessed that their ecosystem is under threat, and a significant reduction of its resources has occurred, particularly in the Inner Niger Delta. In the recent years, because of the Malian government's policy of developing large-scale irrigation, a sustained rate of expansion of around 5,000 ha of new reclamation area has been seen each year in Office du Niger located upstream of the Inner Delta. The expansion of annual rice double cropping and sugarcane cultivation constitute the main factors for the reduction of the water resources downstream in this Delta. This paper analyzes the hydrological impacts of this large-scale irrigation and crop pattern on the floodplain of the Inner Delta during high-flow and low-flow periods. The study results indicated that despite the rainfall and recent increases in upstream flows of the Niger River, the flooded area size has reduced. We could confirm that the annual average water-withdrawal proportion barely changed during the high-flow period but changed significantly during the low-flow period when the size of the paddy rice and sugarcane area increased. Therefore, changing the crop pattern toward vegetables instead of paddy rice and sugarcane during the low-flow period might be a solution.

Keywords: Office du Niger, Inner Delta, Irrigation, Ecosystems

1. INTRODUCTION

The Republic of Mali is a landlocked country in West Africa; it is the eighth-largest country in Africa, with an area of 1,241,190 km² and a population of approximately 16.8 million (2013). According to the UNDP report (2015), 50.6% of the population lives below the income poverty line ($1.25/day), and 10.8% lives in near-multidimensional poverty [1]. With 80% of its population engaged in agricultural activities, this sector is the cornerstone of Mali's economy and shows great potential to drive economic growth. Over 31% of the population is exposed to food insecurity [2]; however, only 7% of 43.7 million hectares of arable land is currently cultivated. Potential irrigable lands that are currently developed correspond to 2.2 million hectares or 14% of the total [3].

Approximately half of Africa's total wetland area comprises floodplains. These include famous large-scale examples, such as the Inner Niger Delta in Mali, the Okavango Delta in Botswana, the Sudd of the Upper Nile in Sudan and the Kafue Flats in Zambia, that cover several thousand square kilometers [4].

Beyond the town of Ségou, the Niger River forms a vast inland delta (41,800 km²); it joins with its main tributary, the Bani, at Mopti and then forms several lakes. The watershed area of this Inner Delta covers 130,000 km².

The rapid expansion of irrigation upstream in Office du Niger, irrigated only by the diversion dam of Markala, has had a significant impact on the availability of water resources in the Niger River and its associated delta downstream.

To address this problem, this investigation analyzes the historical variation of the Niger River hydrology and the evolution of irrigated areas and seasonal crop patterns in Office du Niger, which is by far the largest water user.

The objectives of this study are twofold: 1) to analyze the Niger River discharge and rainfall, and 2) to evaluate the irrigated land and seasonal crop pattern water use of Office du Niger and its impact on the flooded area of the Inner Delta.

2. FIELDS AND METHODS

2.1 Study Area

2.1.1 The Niger River Basin in Mali

The Niger is the main river in Western Africa; it extends approximately 4,185 km (2,600 mi), of which 1,700 km (1,060 mi) flows through Mali (Fig. 1). Its source is in the southeastern part of the Guinea Republic, and the total catchment area of the Niger River is 2,117,700 km² (817,600 mi²).

In the 1960s, the independent countries (Benin, Burkina Faso, Cameroon, Côte d'Ivoire, Republic of Guinea, Mali, Niger, Nigeria, and Chad) of the Niger River Basin decided to coordinate their efforts to use natural resources with a priority on water resources. The Commission of the Niger River was renamed the Niger Basin Authority (NBA) on November 21, 1980.

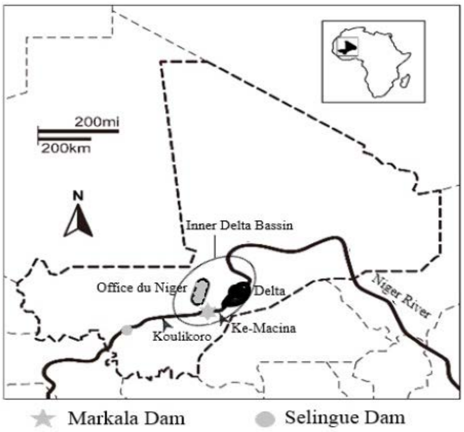

Fig.1 Niger River and Inner Delta in Mali.

In Mali, the Sélingué dam located upstream on the Niger River has been used for hydropower since 1982. The Markala dam, which opened in 1947, is a diversion dam used to irrigate the surrounding area of Office du Niger.

In the past, no scientific research was conducted specifically on the influence of agricultural land expansion and seasonal crop pattern in Office du Niger on the river flow in the Inner Delta. The former studies mainly focused on the hydrological regime and the influence of climate change [6-8].

2.1.2 Office du Niger Agricultural Area

The irrigation area of Office du Niger is located at the death Delta "*delta mort*", an ancient branch of the Niger River in the westerly region of the Inner Niger Delta "*delta vif*". This irrigation zone covers a gross area of 2,458,506 ha with an irrigable area of 1,947,406 ha. 1,445,000 ha are fed by gravity-assisted water from the Markala dam, and by 2015, only 138,000 ha were developed.

2.2 Data Collection

The data for water flow, rainfall, irrigated land water use, seasonal crop pattern, and aerial photographs were obtained from different sources. The data sources are listed in Table 1.

Table 1 Data type and data sources

No.	**Stations**	**Source**	**Date**	**Data type**	**Reference**
1	Mopti meteorological	Malian Meteorological Service	1961-2014	Annual rainfall	Fig. 2, Fig. 3, Fig. 6
2	Koulikoro, Ke-Macina, Mopti, Akka, and Dire	Malian Government Hydraulic Service	1960 - 2015	Water flow	Fig. 4, Fig. 5, Fig. 6
3	---	Office du Niger		Irrigated land, seasonal crop pattern and water use	Fig. 8, Fig. 9
4	---	Malian Government Hydraulic Service	1970	Remote sensing data (Landsat images, 2014) and aerial photographs	Fig. 7

2.3 Calculation Procedures

2.3.1 Hydrologic data analysis

The correlation coefficient between rainfall and river flow reflects the degree of linear association between rainfall and river discharge [5]:

$$r_{X,Y} = \frac{s_{X,Y}}{s_X s_Y} = \frac{1}{N-1} \frac{\sum_{i=1}^{N}(x_i - \bar{x})(y_i - \bar{y})}{s_X s_Y} \quad (1)$$

Where the standard deviation is

$$s^2 = \frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2 \quad (2)$$

2.3.2 Agricultural Data Analysis

The crop water productivities for different crops, crop evapotranspiration, irrigation efficiency, crop production, and crop price were calculated using Eqs. 3 and 4. A comparison was made between the principal crops in terms of crop water productivity and the profit-water ratio during the dry period (March-May) according to Eq. (5):

$$WP = \frac{P}{WR} \quad (3)$$

$$PW = WP \times CP \quad (4)$$

$$WR = (ET_c + Per - R) \times 1 \times Eff \quad (5)$$

where WP is water productivity [kg/m^3], P is crop production [kg/ha], WR is the water requirement [m^3/ha], PW is the profit-water ratio [\$/m^3], CP is crop price [\$/kg], ET_C is crop evapotranspiration [mm/year], Per is percolation and seepage [mm/year], R is effective rainfall [mm/year], and Eff is irrigation efficiency.

3. RESULTS

3.1 Rainfall and Evapotranspiration

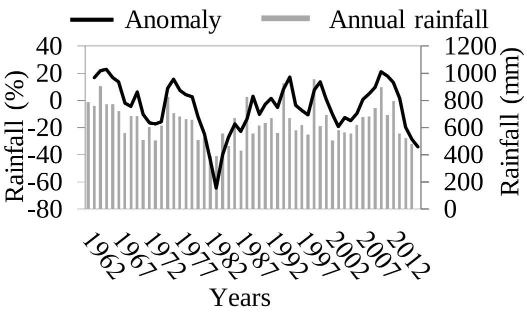

Fig.2 Annual rainfall and anomaly rainfall in relation to the average rainfall from 1961 to 2014 (raw data from Mopti met station).

The daily reference evapotranspiration (ET_0) in the Inner Delta is very high, particularly during the dry season (March–May). The annual ET_0 ranges from 4.72 mm/day in August to 8.63 mm/day in April (Fig. 2).

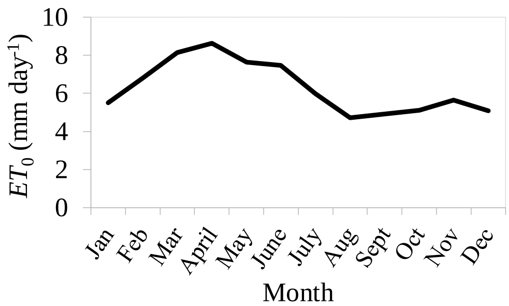

Fig.3 Daily average ET_0 at Mopti Station (Inner Niger River Delta) during 2015 (Source: FAO CLIMWAT).

3.2 Hydrology of the Niger River

To characterize the hydrological regime of the Niger River, the Koulikoro station was selected for statistical analysis; it is located approximately 200 km upstream from the Markala dam. The Koulikoro station has been operational since 1907 and has provided a continuous data set since its inception. This station, therefore, allows for the characterization of the hydrology of the Niger River with an acceptable level of precision.

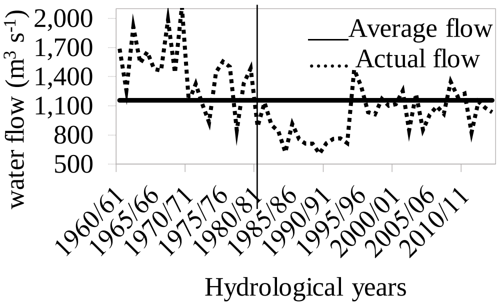

Fig.4 Flow characteristics of the Niger River before and after the construction of the Sélingué dam in Koulikoro located 200 km upstream of the Markala dam. (a) Natural flow conditions, (b) flow conditions after the Sélingué dam construction in 1982.

During the period between 1907 and 1982 and prior to the construction of the Sélingué dam, the highest flow rate recorded was 7,586 m³/s in 1928. Following the dam construction between 1982 and 2014, the highest flow rate of 5,500 m³/s was recorded in September 2001. According to the historical variation in the hydraulic flow of the Niger River from 1960 to 2015, the flow may be classified as follows (Fig. 4):

- A period of high flow from 1960 to 1969 with an annual average flow rate of 1,654 m^3/s.
- Two periods of average flow (1970–1981 and 1995–present) with an annual average flow rate between 1,226 and 1,301 m^3/s.
- A period of low flow from 1982 to 1994 with an annual average flow rate of 776 m^3/s.

Figure 5 (b) clearly shows the increase in water intake and water loss between Koulikoro and Ke-Macina during the period of low flow despite the improvement in the Niger River flow in comparison with the situation in the 1970s and 1980s. The water-loss gap between water inflow and outflow of the river in this section changed from less than 20% in the 1960s to 70% today during the low-flow period. The percentage of water levy by Office du Niger River ranges from an average of 3% in September to 69% in May.

A minimum flow rate of 40 m³/s was

established downstream of the Markala dam through an agreement between the Governments of the NBA countries. Despite this agreement, recent hydrometric surveys at the Markala-downstream station show that, at present, the minimum flow conditions are not maintained continuously. For the last five years (2011–2015), the flows recorded downstream of the dam were less than 40 m³/s for an average of 73 days per year (source: Office du Niger).

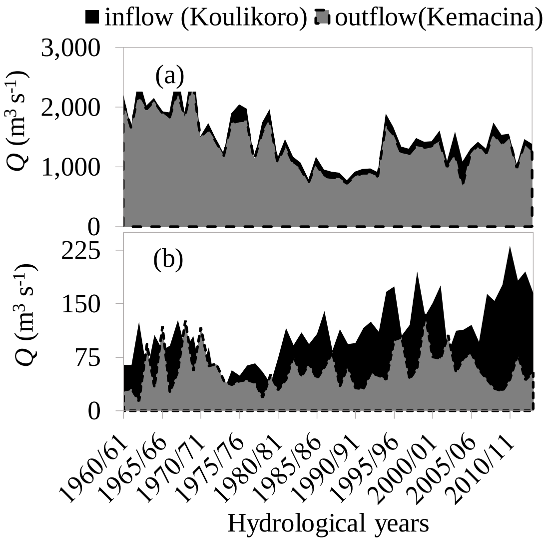

Fig.5 Inflow and outflow at the Markala dam located upstream of Inner Delta (for the period 1960–2015). (a) High-flow period (from June to February), and (b) low-flow period (from March to May). The inflow was measured at the Koulikoro gauging station 200 km upstream from the Markala dam and the outflow was measured 30 km downstream from the Markala dam.

2.1.1 Impact of Rainfall on the River Flow

Figure 6 illustrates a positive partial association and a non-linear association between rainfall and river discharge in the Inner Delta with a correlation coefficient compute from equation 1 with a value$r_{X,Y} = 2.6 \times 10^{-3}$ tends to 0.

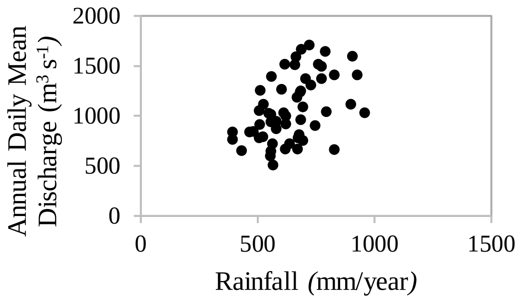

Fig.6 Scatterplot of rainfall and river discharge in the Inner Delta from 1960 to 2015. The discharge was measured at the Ke-Macina gauging station (located in the Inner Delta) and the rainfall was measured at Mopti, located at the center of the Inner Delta.

2.1.2 Inner Delta Flooded Area, the Ecosystem and Office du Niger Agriculture pattern

Muriel Bergé-Nguyen and Jean-François Crétaux [6], used a simple combination of a threshold technique performed on the MODIS

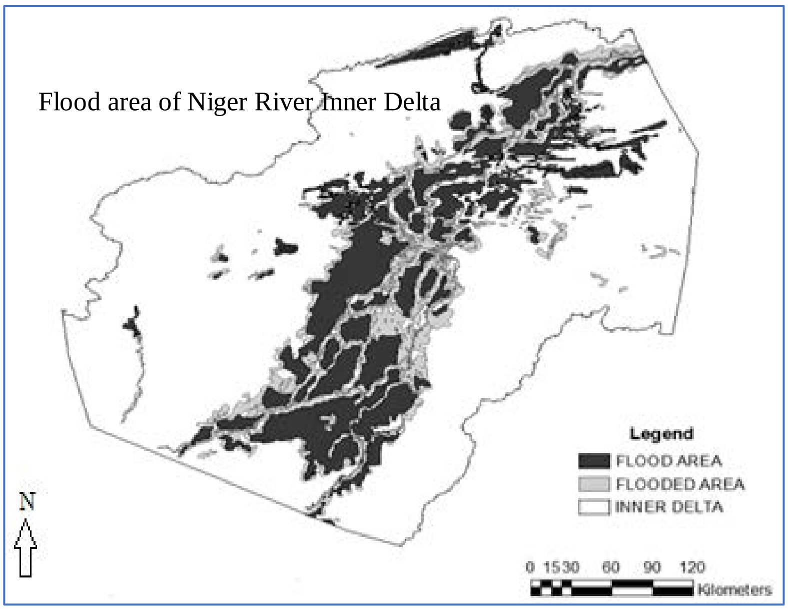

Fig.7 Change noted in the Inner Delta flooded area between 1970 and 2014 using ArcGIS (Black: both March 1970 and April 2014, Gray: April 2014 only).

Band 5 and Normalized Difference Vegetation Index (NDVI) to delineate the shallow, sediment laden, open waters of the IND flood plain in short term from 2000 to 2014. As result, they found that the inter-annual flooding peak appears in the year. 2000, 2001 2003 and 2007.

In this paper, remote sensing data and aerial photographs of the dry period of 1970 and 2014 were analyzed using ArcGIS. The results indicate that 16,041 km² of the maximum flooded area of 20,851 km² of the Inner Delta between the period 1970 and 2014 were lost, representing a change of 23% over the last four decades (Fig. 7). During the same period, the irrigated area of Office du Niger increased by 67% (from 58,287 to 138,418 ha).

From 2000 to 2014, the total cultivated area during the dry period increased from 17,102 ha (34% DC, 32% of rice and 34% Sugarcane) to 43,703 ha (24% DC, 39% rice and 37% Sugarcane), as shown in Fig.8.

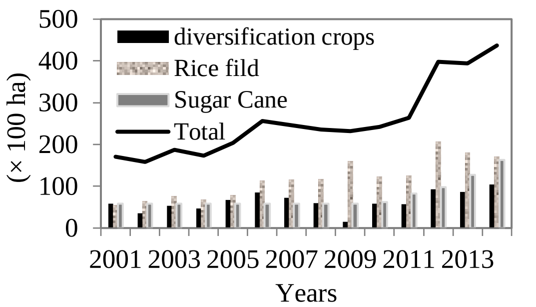

Fig.8 Evolution of diversification crops, sugarcane, and rice cultivation field surface area during the dry period from 2000 to 2014 (data source: Office du Niger annual activities reports from 2001 to 2014).

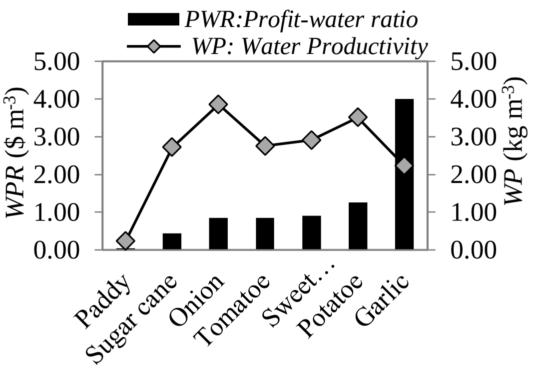

Fig.9 Profit-water ratio and crop water productivity for paddy rice, sugarcane, and diversification crops, such as vegetables (onions, tomatoes, and sweet potatoes), during the 2014 dry period.

Using data on evapotranspiration, efficiency of irrigation systems, crop yields, and crop price data for the dry season of 2014, a comparison was made between some principle crops based on crop water productivity and the profit-water ratio (Fig. 9).

Figure 9 clearly indicates that paddy rice and sugarcane are less profitable in terms of water productivity (*WP*) and the profit-water ratio (*PWR*) than diversification crops. Paddy rice has the lowest benefit (*WP* = 0.24 kg/m^3 and *PWR* = 0.09 \$/m^3) while onion and potato have the highest water productivity (*WP* = 3.86 and 3.51 kg/m^3), and garlic has highest profit-water ratio (*PWR* = 3.13 \$/m^3).

4. DISCUSSION

The rapid development of the large-scale schemes in the Office du Niger area, which are irrigated upstream, may have a significant impact on the Niger River's hydrology, as well as the floodplain and the ecosystem of the Inner Niger Delta. In this study, changes in the Inner Niger Delta as result of the expansion of the irrigated area and cropping pattern of Office du Niger were evaluated.

The 1960s coincided with a period of increased rainfall. However, during the 1970s and 1980s, a large rainfall deficit was recorded that resulted in a great drought in the Sahel countries. Sahel rainfall has been linked to Atlantic as well as Mediterranean SSTs (Sea Surface Temperatures) via evaporation rates and the supply of moisture [7]

Recently, the variability in the rainfall in the Inner Niger Delta has increased, although the level remains below the average of 646 mm/year, with a minimum of 390 mm recorded in 1980 and a maximum of 957 mm recorded in 1999 (Fig. 2). The rainfall in the catchment area, however, does not significantly affect the water level of the Inner Delta floodplain (Fig. 6).

The Sélingué reservoir for hydropower production has changed the flooding curve. The peak level is reduced because the reservoir is filled in the early wet season and emptied in the dry season by which the river flow of the Niger became twice as high in April and May. Therefore, the relationship between the water level in the early wet season and the peak flood level has changed [8].

The current water allocation rules prioritize irrigation water demands in order to secure food production and alleviate poverty in the long term. This makes irrigated agriculture in the Niger River Basin insensitive to decreased runoff as a result of the projected climate changes, but it places pressures on the existing reservoir systems to provide a reliable water supply for hydroelectricity production, navigation, and environmental flows [9].

During the high-flow season from June to February, almost all the crop cultivated is paddy rice and sugarcane in Office du Niger (118,418 and 16,276 ha in 2014, respectively) and other irrigated areas upstream of the Inner Niger Delta. Despite the high demand for water for paddy rice and sugarcane, the impact on the Niger River flow, which can reach more than 5,500 m^3/s, remains very low (Fig. 5a).

On the other hand, during dry periods when the upstream flow rate is below 200 m^3/s (Fig. 5b), the cultivation of paddy rice and sugarcane (both high water consumption crops) increased instead of the diversification crops (DC) (onion, garlic, tomatoes, corn, potatoes etc.) as shown in Figure 8. In the past, paddy rice cropping was avoided during this season. However, since the year 2000 the Malian government has decided to introduce paddy double cropping, which increased from 5,430 ha in 2000 to 17,037 ha in 2014 with a peak of 20,661 in 2012 (available data). The sugarcane cultivation area also increased during that same period, from 5,800 ha to 16,276 ha. The cultivated area of diversification crops, which are the alternative to paddy rice during the dry season, resulted in the highest profit economically and in terms of water savings (Fig.9). However, it does not follow the trend, as more farmers prefer paddy rice. There are four main reasons for the farmers' reluctance:

- No proper irrigation system is available to small farmers (use of containers is prevalent),
- Access to the market is very difficult during the harvest time,
- The harvest occurs at the same time resulting in a low price on market,
- The lack of refrigerated storage, and processing and packaging industries.

To minimize the impact of Office du Niger on the Inner Delta, the following actions are required:

- Limiting paddy rice cultivation during the dry period (March to May),
- Limiting the extent of sugarcane fields,
- Changing of crop pattern during the dry period and opting to grow diversification crops (vegetable and others),
- Reducing the length of rice growth stage by using new varieties.

5. SUMMARY

At present, water has become a constraining factor in the development of irrigated agriculture in Mali and the preservation of the Inner Niger Delta ecosystem.

- After the major droughts in the 1970s and 1980s, rainfall in the Inner Delta region has improved over the last decade. This condition, however, remains fragile as it has been impacted by climate change (Fig. 2).
- Despite the recent improvements in the upstream flow characteristics of the Niger River, water reaching the Inner Delta is reducing. This occurs mainly during the dry season (March-May) and is largely due to water withdrawals for irrigation as a result of paddy rice and sugarcane cultivation located between Koulikoro and Markala as well as between the recently constructed dams of Talo and Djenné on the Bani (tributary river) (Fig. 5 and 7).
- During the last three decades, the floodplain of the Inner Niger Delta has been reduced by 23%, and the irrigated area has increased by 51%.
- To formulate a balance between the conservation of the Inner Niger Delta floodplain and the development of irrigated agriculture, some action needs to be taken. Suggestions include the following: limiting the area available for sugarcane, reducing rice to vegetable crops during the dry period, and reducing the rice growth stage through the introduction of new varieties.

6. ACKNOWLEDGMENT

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