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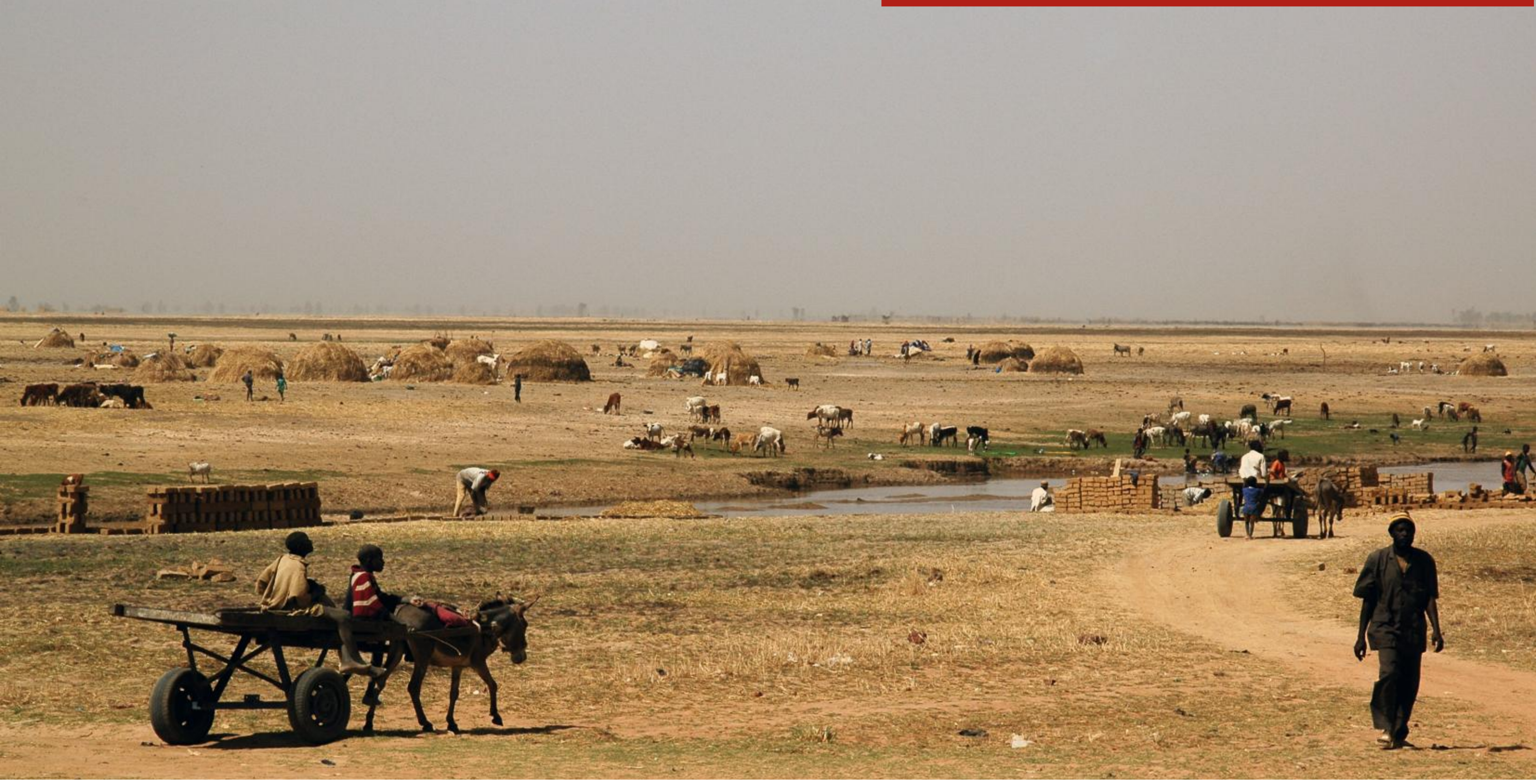
Does the Inner Niger Delta suffer from a reduced river flow in the dry season?

A&W-report 1938



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Does the Inner Niger Delta suffer from a reduced river flow in the dry season?

A&W-report 1938

L. Zwarts
J. van der Kamp

Cover photograph
Dry floodplains in the Inner Niger Delta in February 2007. Photo: Leo Zwarts

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1 Introduction

Rainfall in West Africa, and thus also the flow of the Sahelian rivers, shows a large annual and seasonal variation. People living along the Niger and in the Inner Niger Delta are adapted to these large fluctuations and make the best of it. The river flow in most rivers, also in the Niger and the Bani, is not any more unhampered since the construction of dams, water reservoirs and large irrigation schemes. This necessitates a water management of the Niger Basin taking into account the different river-dependent economic activities and international ecological interests. An integrated assessment was conducted by Zwarts *et al.* (2005) to determine the global role of dams and irrigation in the overall economy and ecology of the Upper Niger Basin, including the Inner Niger Delta. However, more detailed information is needed to answer specific questions about the actual management of the infrastructures, such as:

- Would the rice farmers in the Inner Niger Delta profit if Sélingué would start later in the wet season to withhold the water and what would be the costs for Sélingué?
- How much would the Inner Niger Delta gain if in disastrous dry years (such as in 1984), Sélingué would be partly filled and against which costs (less electricity; less irrigation in Office du Niger in the following dry season).

The list is much longer. This reports deals with one of such specific questions. Office du Niger takes at the Markala dam a very large part of the river water during the dry season for irrigation. To prevent problems downstream, 50 m^3/s has been fixed as a guaranteed, minimal flow downstream of the Markala dam. This minimal flow is mentioned, for instance, in the paper *Plan d'Action du Développement durable (PADD) du Bassin du Fleuve Niger*. In contrast, the *Commission de Gestion des Eaux* assumes that 40 m^3/s would be sufficient to prevent ecological and socio-economic problems downstream. This is confusing for Office du Niger as water manager of the Markala dam.

This paper analyses the consequences for the Inner Niger Delta if the flow during the dry season would be reduced to 40 or to 50 m^3/s.

Chapter 2 first describes the average impact of Sélingué and Markala on the seasonal variation in the river flow of the Niger.

Chapter 3 goes into more details and analyses how the impact of Sélingué and Markala differs from year to year and also compares the natural flow (before 1982) with the present situation (1982-2012). Chapter 3 also considers the impact downstream of the Talo dam and, finally, shows how the inflow for Niger and Bani combined, has varied the last 60 years.

Chapter 4 investigates the relationship between the combined flow of Niger and Bani into the Inner Niger Delta and the water level in the Inner Niger Delta, and shows how the occurrence of extremely low water levels has varied during the last 60 years. Finally, the chapter shows the impact of a flow of 40 and 50 m^3/s on the water level, but also on the surface area being inundated, in the Inner Niger Delta.

Chapter 5 uses the information from Chapter 4 to describe the impact of a low flow in the dry season on the ecological values of the Inner Niger Delta. The relationship between the number of water birds and water level during the dry season is shown for a large number of bird species.

Chapter 6 analyses how far socio-economic activities are dependent on a certain water level. This analysis is done for transport, fishery, agriculture during deflooding and agriculture within irrigation schemes.

Chapter 7 takes all information together to arrive at a conclusion whether the minimal flow at Markala should be maintained at 50 or can be lowered to 40 m^3/s.

1.1 Acknowledgement

The work is done in the framework of the project *Réhabilitation des Ecosystèmes Dégradés du Delta Intérieur du Niger* (REDDIN), a program of IUCN and Wetlands International, funded by the Swedish International Development Cooperation Agency (SIDA) / l'Agence Suédoise de Développement International (ASDI).

We thank Direction Nationale de l'Hydraulique (DNH), Direction Nationale de l'Energie du Mali (EDM) and Office du Niger (ON) for their cooperation and willingness to provide their data. This report could not have been written without their daily effort since dozens of years.

2 Seasonal variation in river flow

2.1 Data

The water level in the Inner Niger Delta and along the Niger and Bani Rivers is daily measured by Direction Nationale de l'Hydraulique (DNH). These measurements are converted by DNH to river flow (m^3/s) using curvilinear regression equations. The outflow at the Sélingué dam is measured by EDM; the inflow in the reservoir is estimated taking into account the water loss due to irrigation and evaporation. The water level directly upstream and downstream of the Markala dam is registered by Office du Niger (ON). The water intake for irrigation and the river flow downstream of Markala are also daily noted by Office du Niger.

This report uses the daily measurements of the stations indicated in Fig. 1. The analysis is restricted to the period 1956 – 2012. Sélingué was constructed between 1979 and 1981; the daily inflow and outflow since 1-1-1982 have been used in the analysis. We could use the daily measurements of the water intake at Markala since 1-1-2000, supplemented with monthly means for the period August 1988 – December 1999.

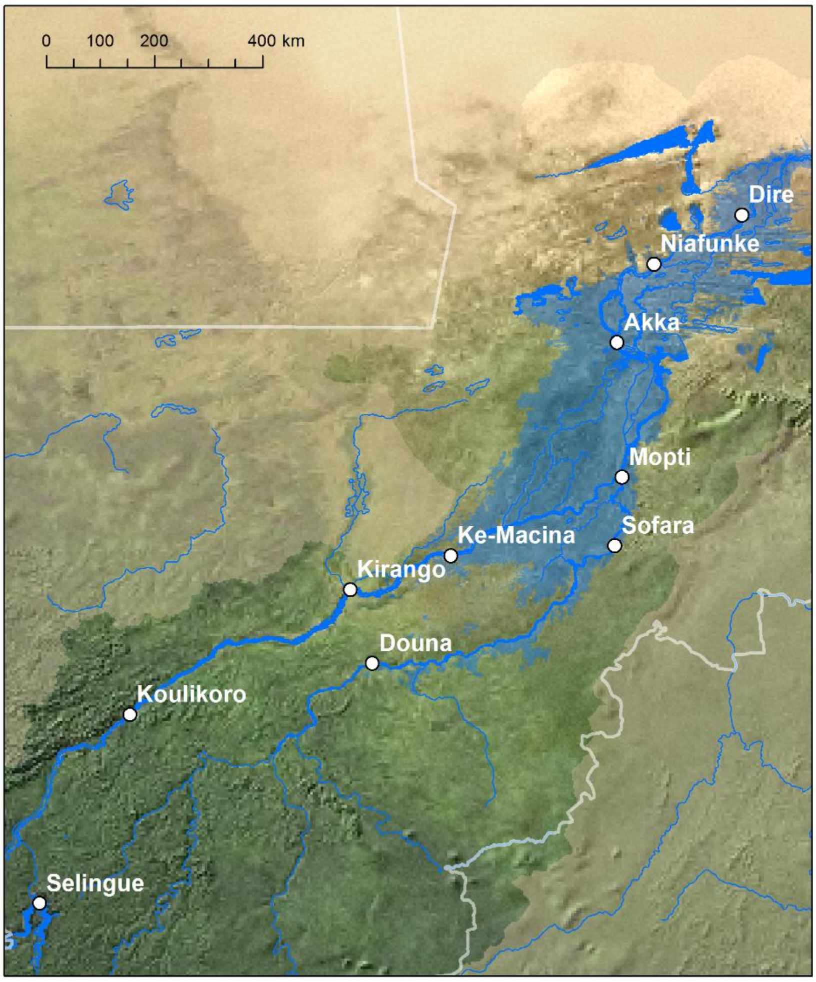


Fig. 1. The hydrometric stations along the Niger and Bani and in the Inner Niger Delta relevant for this study.

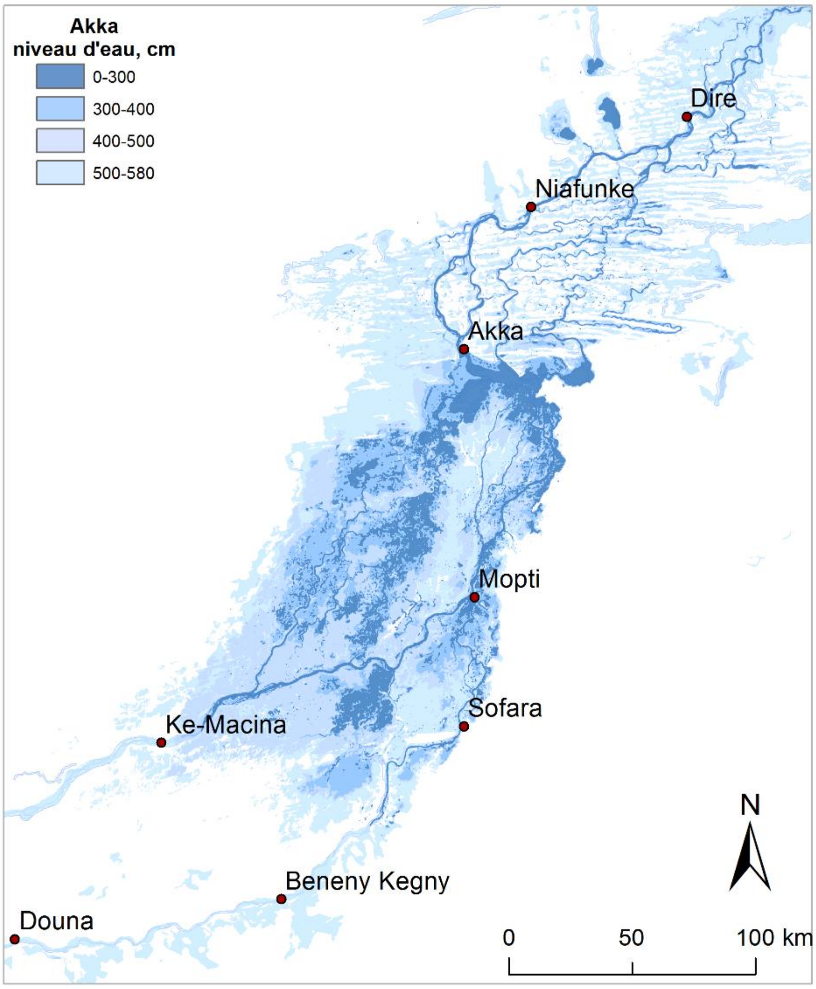


Fig. 2. The hydrometric stations in the Inner Niger Delta relevant for this study. The different blue colours show the area being inundated at different flood levels at Akka.

The hydrometric stations in the Inner Niger Delta relevant for this study are shown in Fig. 2. All data since 1956 are used in the analysis. The gauge in Akka does not measure very low water levels, i.e. if the water level is below 0 cm on the local scale. Fortunately, there is a very high correlation between the water levels measured in Akka and in Niafunké three days later:

Akka (cm) = 0.89* Niafunké (cm) -29.8; (R= 0.998; selection made for April and May 1955-2013).

This function was used to reconstruct the lacking measurements of Akka.

2.2 Impact of Sélingué and Markala on the seasonal variation of the river flow

The river flow of the Niger varies seasonally, reaching a peak of 3800 m^3/s late September in Koulikoro (Fig. 3). During the long dry season, the river flow declines to arrive at its lowest level (137 m^3/s, on average) in late March.

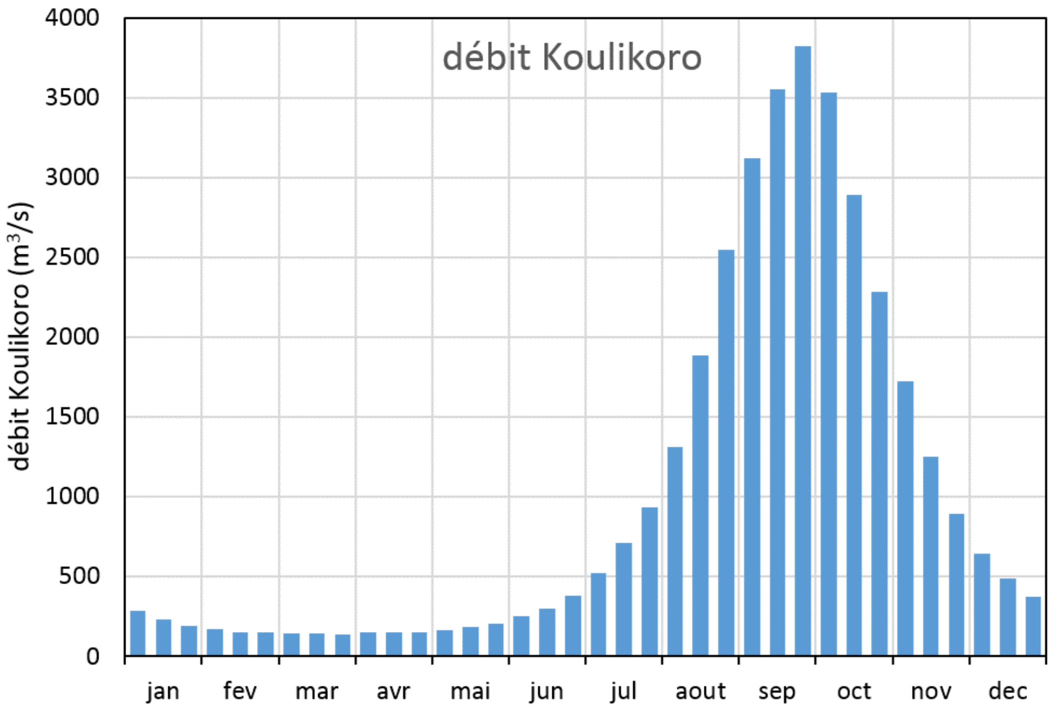


Fig. 3. The seasonal variation in the flow of the Niger River at Koulikoro (m^3/s), averaged for ten-days periods; 1956-2013. Data of DNH.

The seasonal variation shown in Fig. 3 is due to the short rainy season (June-October), with a maximal rainfall in August. The shape of the curve shown in Fig. 3 has been changed, however, since the construction of the Sélingué reservoir. When the reservoir is filled from late July to late November, water is withheld, while water is added to the river flow while the reservoir is emptied during the rest of the year. Most water is withheld in early August, - being, on average, 500 m^3/s (Fig. 4), which is 16% relative to the flow of the Niger at Koulikoro. The relative impact of Sélingué is much larger in the dry season. On average, 100 m^3/s is released from the reservoir between early April and mid June (Fig. 4), which is 47% of the average river flow at Koulikoro at the same period (222 m^3/s). Thus, the river flow of the Niger at Koulikoro during the dry months has become twice as large due to the Sélingué reservoir.

The Markala dam allows Office du Niger to irrigate the *Delta mort*. The total water intake, being registered daily, varies seasonally and amounts to, on average, 100 m^3/s from mid-June to early September. At the end of the rainy season the water consumption increases from 100 m^3/s early September to 144 m^3/s early October, after which it gradually declines to 43 m^3/s early December. Between mid-December and early June, the water intake gradually increases from 46 to 95 m^3/s.

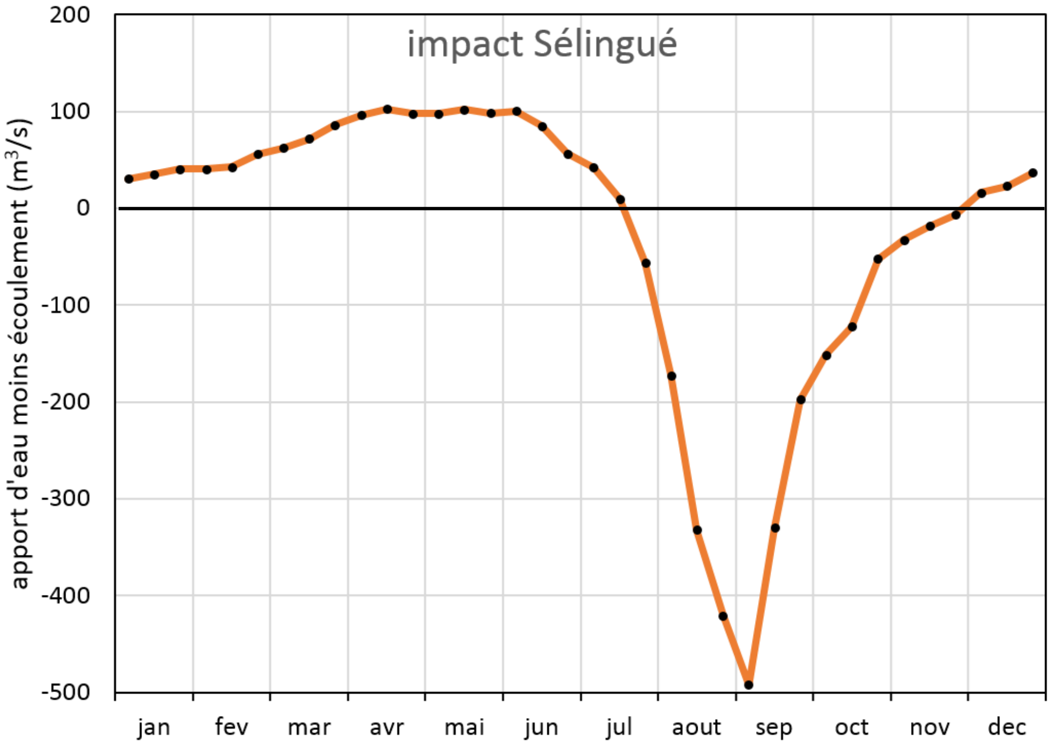


Fig. 4. The impact downstream of the Sélingué reservoir on the river flow (m^3/s), calculated as the difference between the inflow into the reservoir and the outflow from the reservoir, averaged for ten-days periods; 1982-2013. Data of EDM. To empty the lake, water is released from early December to mid-July (outflow larger than inflow). The lake is filled from late July to late November (inflow larger than outflow).

When Office du Niger takes 100 m^3/s in August, it is only 3%, on average, of the river flow, but when 80 m^3/s is taken in March and April, it is equivalent to 55% of the river flow. The blue line in Fig. 5 shows the water consumption by Office du Niger as percentage of the river flow.

Since the impact of both infrastructures is largest in the dry months, it is worthwhile to analyse this in more detail (Fig. 6). The water released at Sélingué gradually increases from 43 m^3/s in early February to 102 m^3/s in early March and remains on that level until late May. The water intake by Office du Niger follows more or less the same seasonal trend, increasing from 66 m^3/s in early February to 100 m^3/s in mid-June.

The water intake by Office du Niger in the dry season has a large impact on the flow of the river downstream of Markala. The river flow downstream of the dam is measured at two hydrometric stations: Kirango very close to the dam and Ké-Macina 100 km downstream of the dam. The daily flow measurements of both stations are highly correlated and, on average, do not differ from each other. In this report we use the measurements at Ké-Macina.

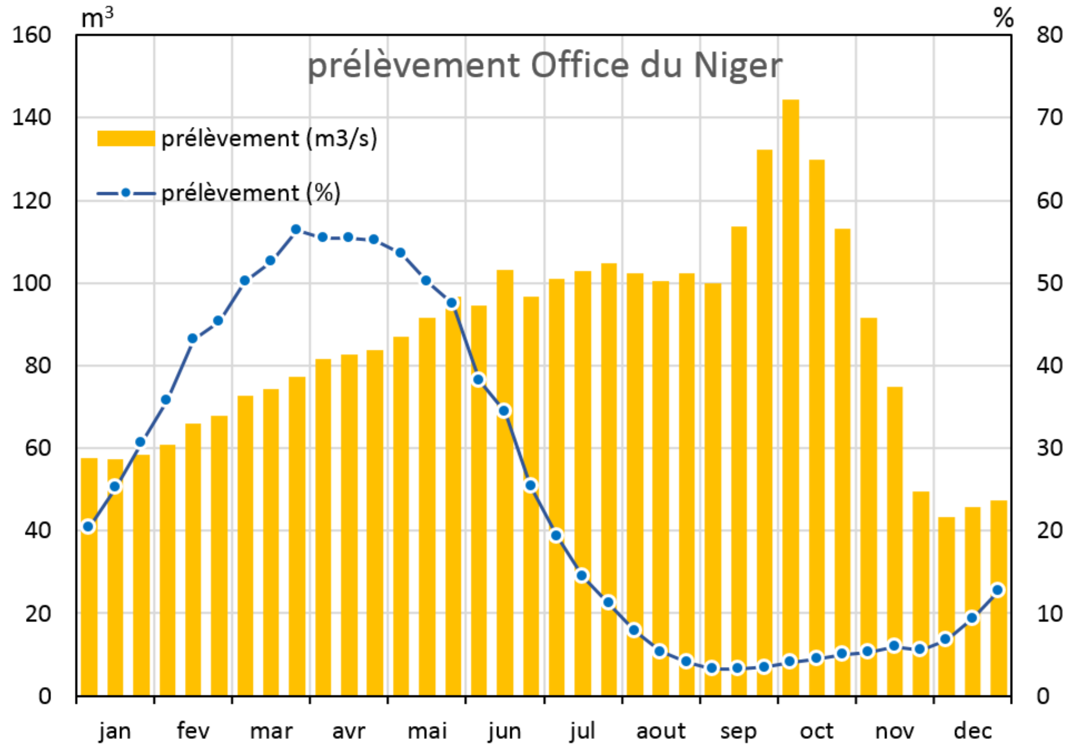


Fig. 5. The water taken from the Niger (m^3/s) by Office du Niger near the Markala dam at point A, averaged for ten-day periods; 2000-2013. Data of Office du Niger. The yellow bars give the water intake as m^3/s (left axis) and the blue line the water intake as % relative to the river flow at Koulikoro three days before (right axis). The lag of three days is based on the average difference between the timing of the peak flow in Koulikoro and Markala.

The average flow in Ké-Macina amounts to 52-57 m^3/s between mid-March and early May (blue bars in Fig. 7). Without the water intake by Office du Niger (yellow bars in Fig. 7), the flow in this period would have been 140 m^3/s.

In conclusion: (1) On average, Sélingué and Office du Niger lower the peak flow in September by 500 and 100 m^3/s, respectively, (2) Sélingué adds 100 m^3/s to the river flow in the dry months, (3) Office du Niger takes 100 m^3/s from the river in the dry months. Hence the water added by Sélingué in the dry season is, on average, fully consumed by Office du Niger.

The graphs in this chapter all show the seasonal variation, averaged over many years. The next chapter analyses the annual variation of the river flow in the dry season and shows how this variation is due to the decisions made by the managers of Sélingué and Office du Niger.

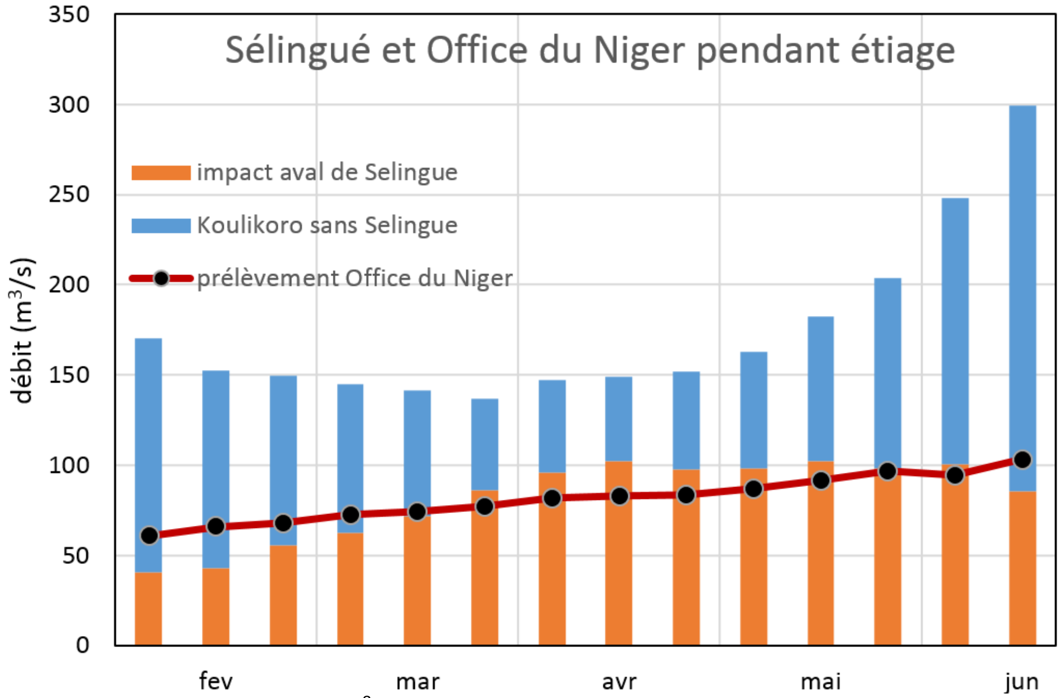


Fig. 6. The average river flow (m^3/s) at Koulikoro and the average water intake by Office du Niger between early February and mid June, averaged for ten days periods; 2000-2013. Same data as given in Fig. 1-3. The flow at Koulikoro has been split into the natural flow if there were no Sélingué reservoir (blue bar) and the additional water released from the Sélingué reservoir (blue bar). It is obvious that Office du Niger takes, on average, the additional water released from the Sélingué reservoir.

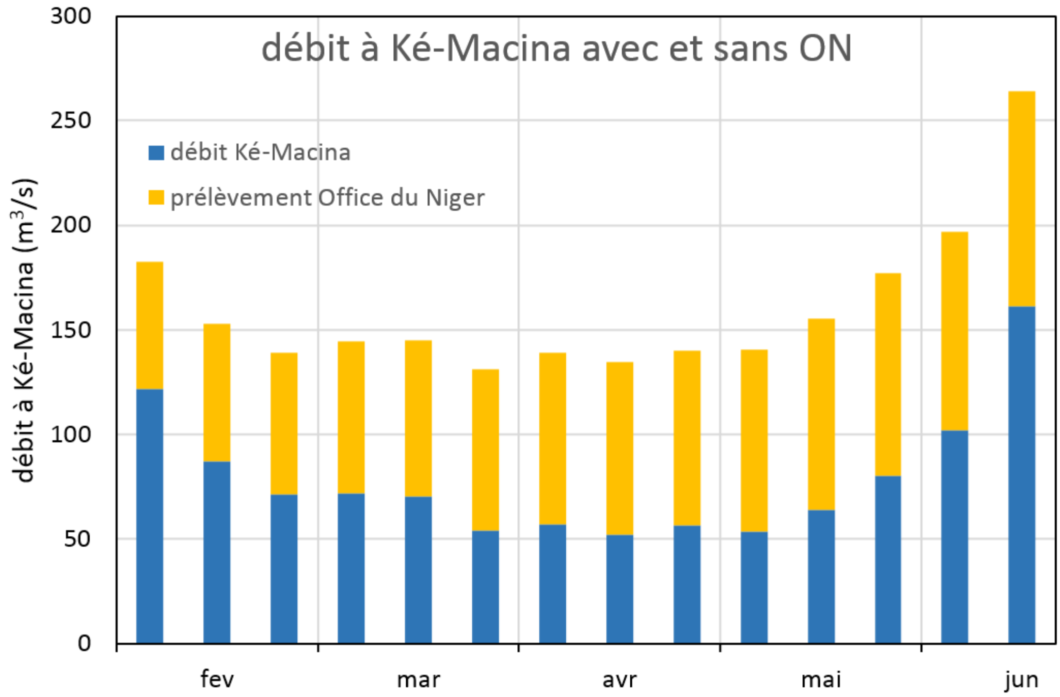


Fig. 7. The actual river flow (m^3/s) at Ké-Macina (blue bars), between early February and mid June, averaged for ten days periods; 2000-2013. The yellow bars show the water taken from the Niger at Markala. The top of the yellow bars shows the river flow without water intake by Office du Niger.

3 Annual variation in river flow during the dry season

3.1 Impact of Sélingué

The peak flow in September is higher in years with a lot of rain but when the peak flow is high, the seasonal curve of the river flow is different too. When the peak flow in September is high, the flow is already high in August and when the peak flow in September is low, the flow is usually also low in August. More important for us is that the river flow in a wet year remains at a relatively high level during the months after the rainy season. Even in May, the year-to-year variation in river flow is still related to the peak flow eight months before in September (Fig. 8).

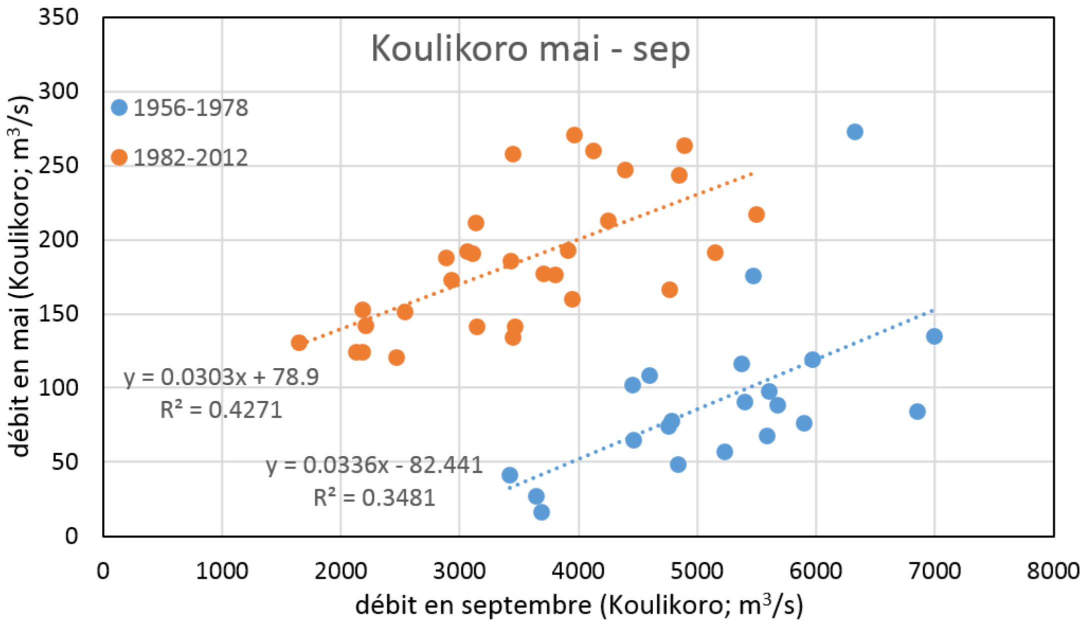


Fig. 8. The average river flow (m^3/s) at Koulikoro in May as a function of the flow at Koulikoro in September the year before. The relationship is given for 1956-1978 (still without Sélingué reservoir) and 1982-2012 (with Sélingué reservoir). It is obvious that the high peak flow in September still has an impact on the river flow 8 months later, before as well as after the construction of the Sélingué reservoir.

The river flow at Koulikoro in May becomes nearly three times as large (from about 50 to 140 m^3/s) if the flow in September the year before doubles from 3500 to 7000 m^3/s. This is the average trend shown as the blue line in Fig. 8, but the scattering around this line, shown as the blue dots, is large. Hence, although there is a clear trend, the peak river flow in September is not a good predictor of the flow eight months later. One reason of the scattering is that in some years the flow already starts to increase in May due to an early start of the rainy season (as was the case in May 1958 when the flow in May increased to 263 m^3/s).

Fig. 8 shows the relationship between the flow in September and May separately for two periods: before and after the construction of Sélingué. After the reservoir had been constructed, the river flow of the Niger became much larger due to the release of 100 m^3/s in April and May (Fig. 2). Since 1981, the river flow at Koulikoro in September has varied between 1650 and 5500 m^3/s, whereas the flow in May varied between 121 and 171 m^3/s. The trend line for the period 1981-2012 is given in brown. Remarkably, the trend lines before and after the construction of Sélingué show the same slope: In both periods, the flow in May increases by 3 m^3/s if the flow in September before is 100 m^3/s higher. It is also remarkable that, independent of the river flow in September, the river flow in Koulikoro in May has become 150 m^3/s higher after the construction of Sélingué. One would expect a difference of 100 m^3/s (the amount of water being released), but apparently, the releases over several months have a cumulative impact on the flow at the end of the dry season.

In conclusion: the river flow of the Niger in Koulikoro in the dry season depends on the peak flow during the previous wet season, before as well as after the construction of the Sélingué reservoir. The releases at Sélingué during the dry season have enhanced the flow in the dry months independent of the peak flow in September.

3.2 Impact of Sélingué and Office du Niger

Office du Niger takes annually, on average, 87 m^3/s, from the river. This has varied hardly since 1987. The lowest annual water intake was in 1994 (79 m^3/s) and the highest in 2002 (96 m^3/s). The water intake is a bit higher in years with reduced local rainfall, but there is no increase over the last 24 years. However, when the long-term trends are analysed per month, there appeared to be a small decline in the average intake in December. In contrast, there is an increase over the years in March and April (Fig. 9). The water consumption in both months has varied between 60 and 70 m^3/s before 1998, but since1997 it has increased to 70 - 90 m^3/s in most years.

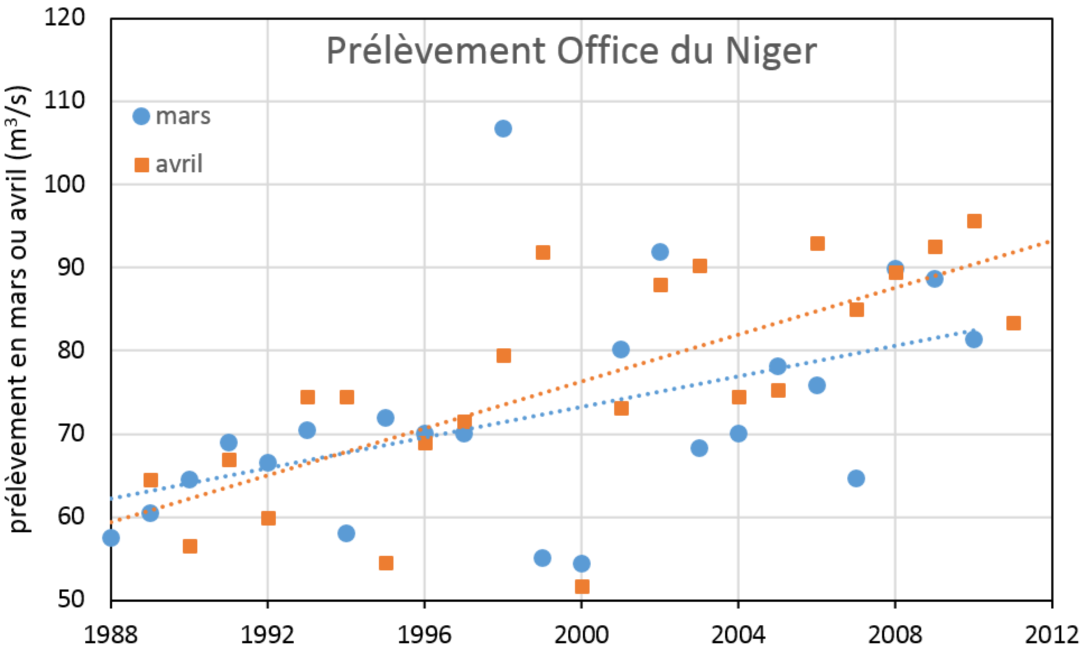


Fig. 9. The monthly water intake by Office du Niger in March (blue dots) or in April (brown dots) between 1988 and 2012. The trend lines are shown, but there seems to be no gradual increase over the years, but instead a higher water intake since 1998, compared to the 10 years before.

There is a large year-to-year variation in the river flow downstream of Markala during the dry season. Fig. 10 shows the annual variation for April and May, the two months during which the river flow is at its minimum with 51 m^3/s, on average, in April as well as in May. In years with a low flow in April, the flow was also usually low in May, but the correlation is not high ($R = 0.68$). The next chapter further analyses how often the flow at Ké-Macina has been below the critical level of 40 or 50 m^3/s, but this section first attempts to explain why the annual variation has been so large.

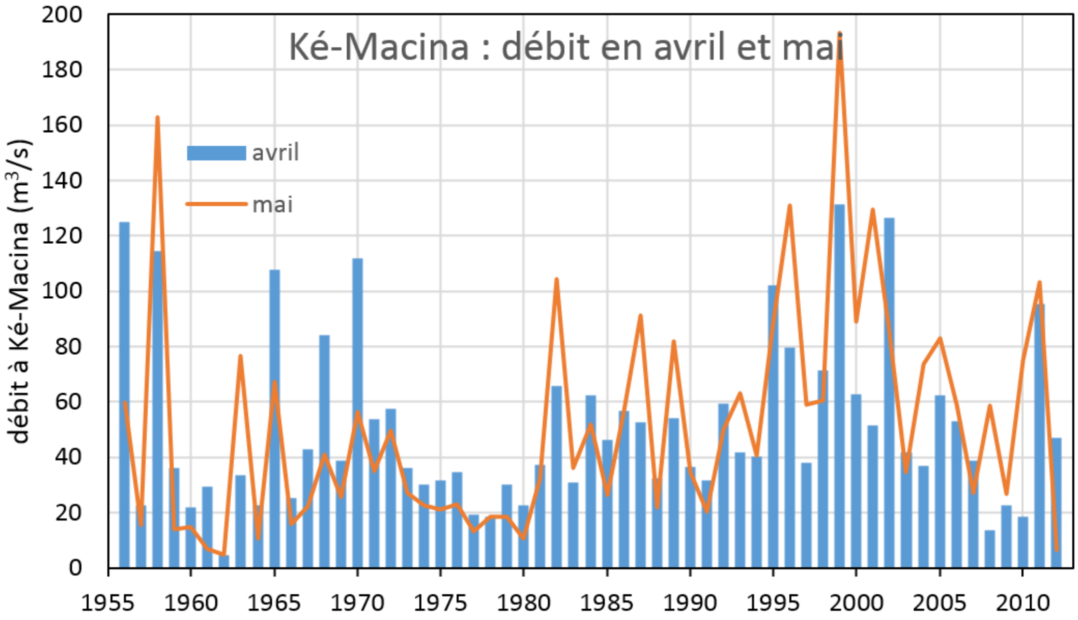


Fig. 10. The annual variation in river flow at Ké-Macina (m3/s) in April (blue bars) and in May (brown line).

Fig. 13 shows for the month of May to what degree the annual variation is related to the peak flow during the preceding wet season on the one hand and the releases at Sélingué in May and the water consumption by Office du Niger (also in May) on the other hand. Like in Koulikoro (Fig. 8), the river flow in Ké-Macina in May is higher when the peak flow in preceding September has been high too (Fig. 10). And also, like in Koulikoro (Fig. 8), the impact of Sélingué is obvious, being 60 m^3/s higher since its construction compared to the years before. As described above, this difference was 150 m^3/s in Koulikoro. The reason for the smaller difference is due to the water intake by Office du Niger.

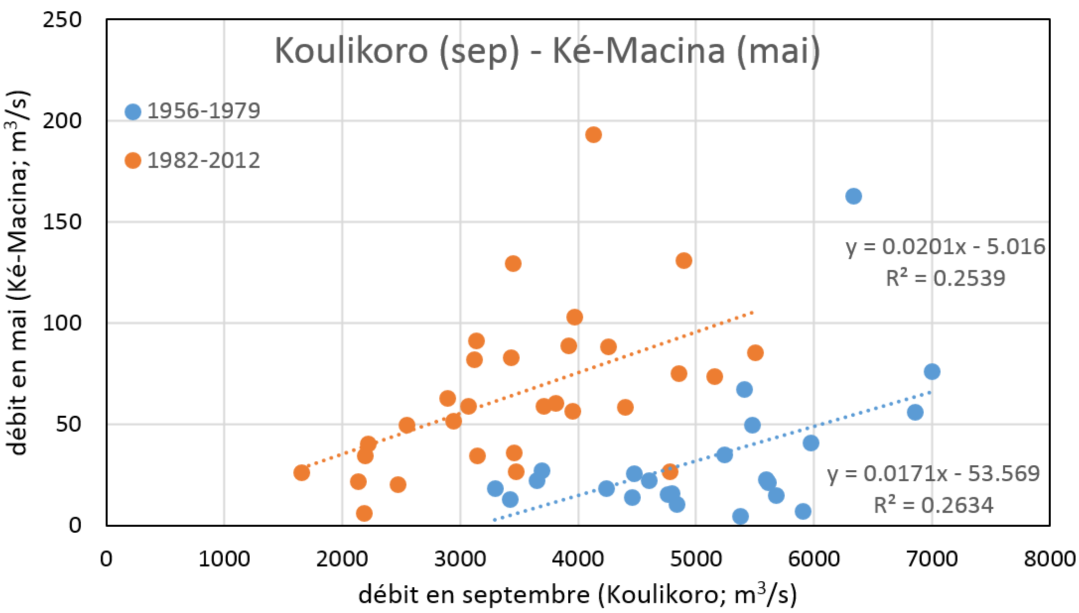


Fig. 11. The average river flow (m^3/s) at Ké-Macina in May as a function of the flow at Koulikoro in September the year before. The relationship is given for 1956-1980 (still without Sélingué reservoir) and 1981-2012 (with Sélingué reservoir). It is obvious that the high peak flow in September still has an impact on the river flow 8 months later, before as well as after the construction of the Sélingué reservoir.

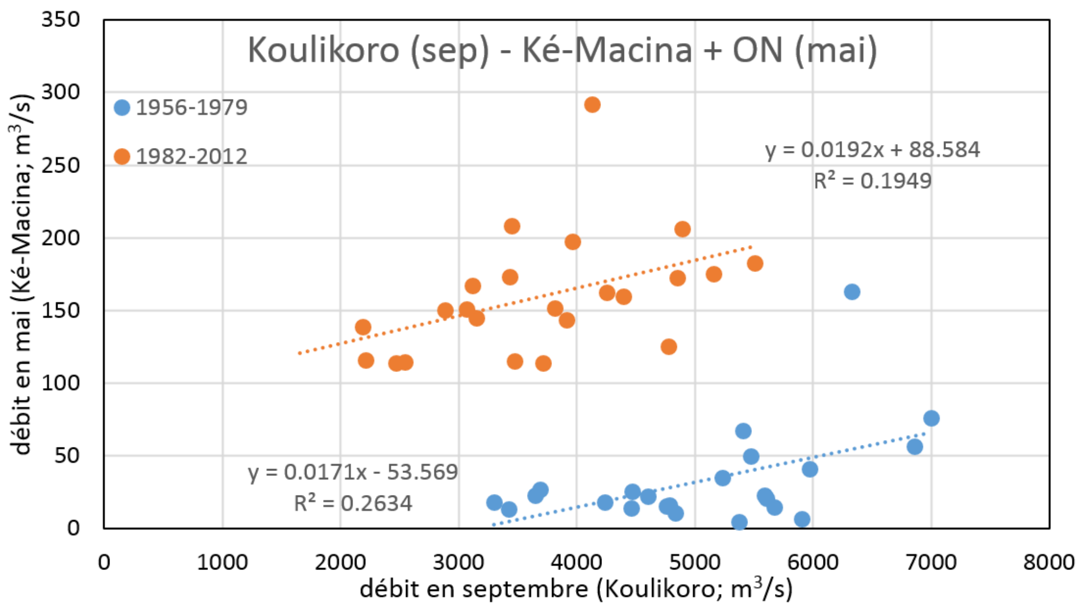


Fig. 12. The same graph as Fig. 10, but the water intake by Office du Niger in May has been added to the the flow in Ké-Macina to reconstruct the "natural" river without Office du Niger. As in Koulikoro, the difference between the two trend lines is 150 m^3/s, being the impact of Sélingué independent of the peak river flow 8 months before.

The theoretical water flow at Ké-Macina without water intake by Office du Niger may be calculated by adding the average water intake by Office du Niger in May to the measured river flow in the same month. The reconstructed river flow in Ké-Macina in May is shown in Fig. 12. Independent of the peak flow in the preceding month September, the flow was 150 m^3/s higher after the construction of Sélingué, - exactly the same as in Koulikoro (Fig. 8).

In conclusion: the river flow of the Niger in Ké-Macina in the dry season shows a large year-to-year variation. As in Koulikoro, the flow in the dry season depends on the peak flow during the previous wet season, before as well as after the construction of the Sélingué reservoir. The releases at Sélingué during the dry season have enhanced the flow in the dry months independent of the peak flow in September.

3.3 Impact of Talo

The Bani is the main tributary of the Niger. The year-to-year variation in the river flow is for the Bani much larger than for the Niger. In the wet 1950s and 1960s, the flow of the Bani was about half of the flow of the Niger, but in the dry 1970s and 1980s, the flow of the Bani was severely reduced to about 1/10 of the flow of the Niger. Also the seasonal variation in the flow is for the Bani much larger than for the Niger. The flow of the Bani even (nearly) stops in dry years.

Fig. 13 shows the year-to-year variation in the river flow during the dry season at Sofara. Sofara is situated along the lower Bani, 60 km upstream from Mopti where the river flows into the Niger. During the Great Drought (1969-1993), the flow at Sofara was reduced to usually less than 10 and mostly near to 0 m^3/s in April and May. The river flow in April and May is highly correlated (R=0.92). Thus, when the flow is low (or high) in April, it will also be low (or high) the next month.

The large variation of the flow in May can be explained with the peak river flow eight months before (Fig. 14). The data have been split up before and after 2006/2007 when 150 km upstream of Sofara the Talo reservoir was constructed. Due to the Talo dam the river flow downstream has increased by about 25 m^3/s independent of the peak flow in the year before. Hence, the enhanced flow of the Bani since 2007 from, on average, 12 m^3/s in April before 2007 to 40 m^3/s after 2007 and from 8 to 35 m^3/s in May (Fig. 13) has nothing to do with the peak flow in the preceding September, but all with the construction of the Talo dam.

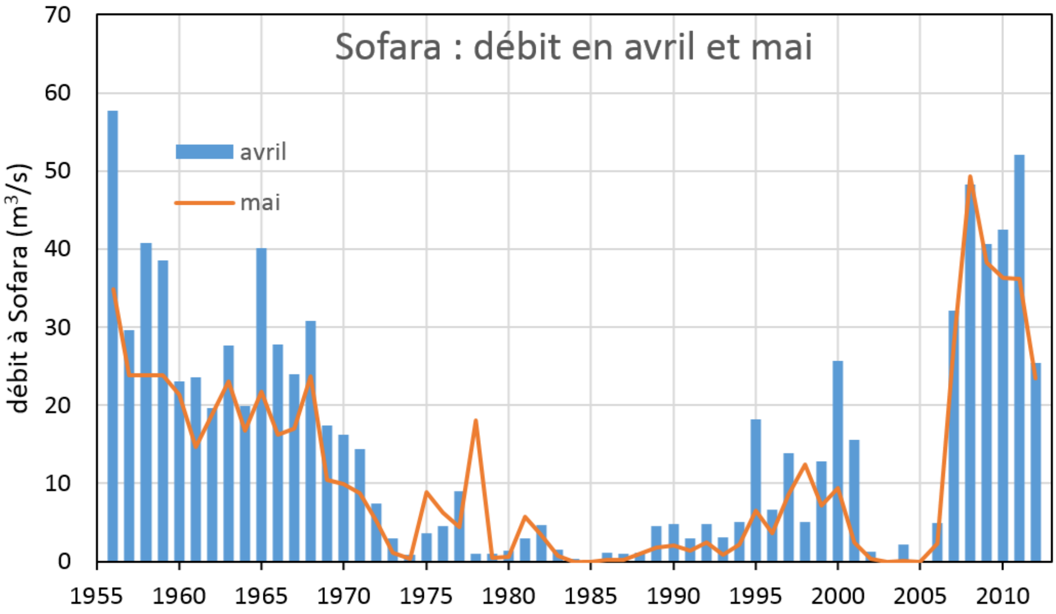


Fig. 13. The annual variation in river flow at Sofara (m3/s) in April (blue bars) and in May (brown line).

The Talo dam was meant to create a reservoir of maximally 50 km^2 to be filled with 0.18 km^3 water. In fact, since the construction of the Talo dam, the river bed of the Bani far upwards of Douna (where the road from Segou to Mopti crosses the Bani) is filled up during the dry season. The daily measurements of the water level at Douna (80 km upstream of the Talo dam) show that water level is enhanced by 3 m in early March declining to still 1.5-2 m above the normal level in early May. Unfortunately, the hydrological impact of the Talo dam was difficult to indicate, because the daily measurements of the water level in Douna since the construction of the Talo dam could not any longer be converted to river flow due to the reduced flow currency. However, the seasonal shift in the flow downstream of the Talo dam, such as measured in Sofara, is an indirect but good measure to determine the precise impact of the Talo dam on the river flow of the lower Bani and thereby on the flooding of the Inner Niger Delta. The measure is indirect since the water released in the dry season is equivalent to the water withheld in the wet season.

In conclusion: the river flow of the Bani at Sofara in the dry season shows a very large year-to-year variation. As in the Niger (Koulikoro and Ké-Macina), the flow of the Bani in the dry season depends on the peak flow during the previous wet season, before as well as after the construction of the Talo reservoir. The releases at Talo during the dry season has enhanced the flow in the dry months independent of the peak flow in September.

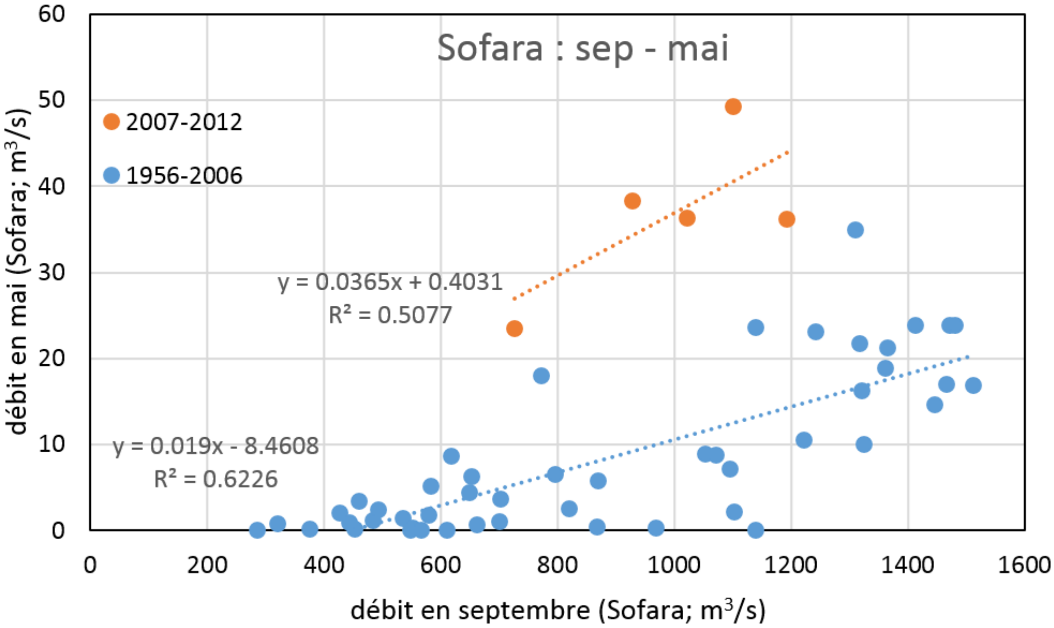


Fig. 14. The average river flow (m^3/s) at Sofara in May as a function of the flow at Sofara in September the year before. The relationship is given for 1956-2006 (when there still no Talo reservoir) and 2007-2012 (with Talo reservoir). It is obvious that the high peak flow in September still has an impact on the river flow 8 months later, before as well as after the construction of the Talo reservoir.

3.4 The combined inflow of Niger and Bani

The peak flow of the Bani and the Niger is well correlated: when there is a lot of rain in the Upper Bani there is usually also much rain in the Upper Niger Basin. However, when the river flow in the dry season is compared, there is no relationship (R=0.00). Hence years with a low flow in May at Ké-Macina may sometimes compensate with a high flow in Sofara and other way round (Fig. 15).

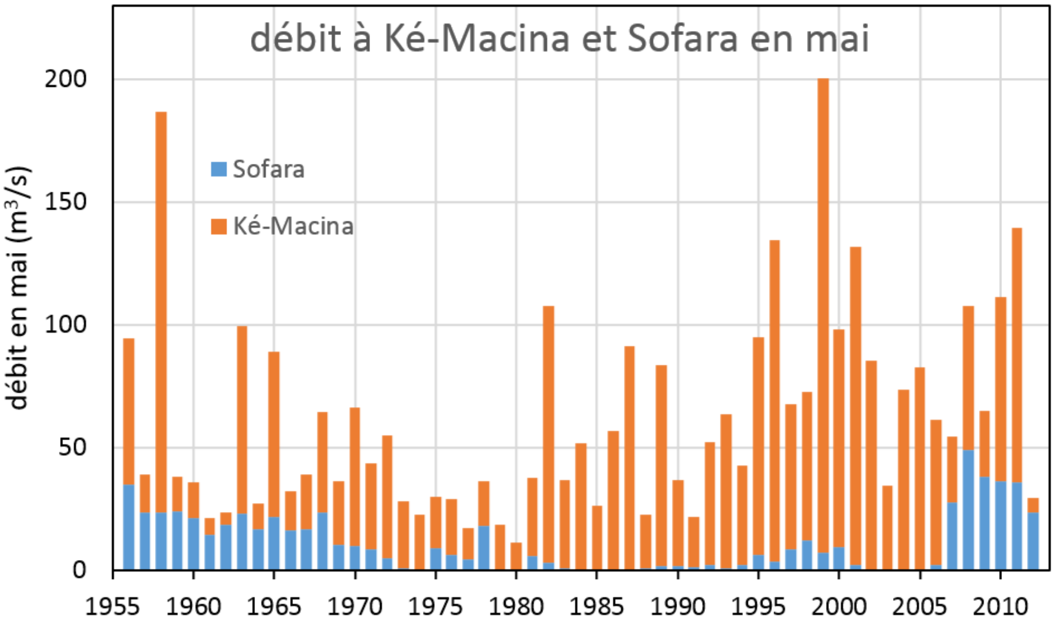


Fig. 15. The annual variation in river flow at Sofara (blue) and Ké-Macina (brown) (m^3/s) in May.

4 Inflow and water level in the dry season

4.1 The lowest water level

There is a high correlation between the inflow of the Niger and the Bani and the water level such as measured in the Inner Niger Delta. The average flow of the Bani and Niger in August-October has varied between 1850 and 7200 m^3/s, equivalent to a total seasonal flow of 14.7 and 57.2 km^3 respectively. In the dry year 1984, the water level at the gauge of Akka in the center of the Inner Niger Delta just exceeded 3 meters. In contrast, in the wet years 1957 and 1964, the water level at Akka reached the very high level of more than 6 meters. For the dry months, we found a similar relationship between inflow and water level. The water level is determined by the actual inflow, but also by the inflow in the days and even weeks before. Moreover, it has to be taken into account that the rate of flow in the dry months is slow. Fig. 16 shows the average decline of the water level in the Inner Delta from early February onwards. The lowest water level in Ké-Macina is reached in early May, ten days later in Mopti, 20 days later in Akka and Niafunké and 30 days later (early June) in Diré.

<u>In conclusion:</u> the lowest water level in Ké-Macina is measured in early May and in Diré in early June and for the stations in-between in mid-May (Mopti) and late May (Akka, Niafunké).

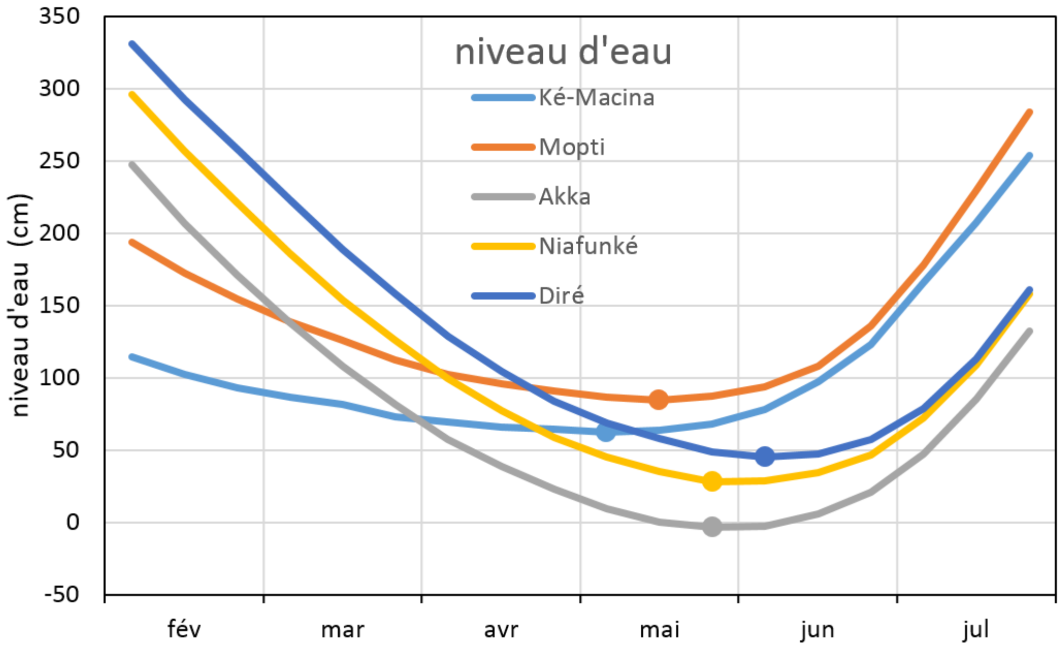


Fig. 16. The average water level (cm) such as measured on five gauges in the Inner Niger Delta between early February and late July, averaged for ten-day periods; 1956-2013. The dot shows when the lowest water level is reached. The five hydrometric stations gauges use different scales which explains that the lowest value is -4 cm in Akka and 85 cm in Mopti. The measurements below 0 cm in Akka were reconstructed using the scale of nearby Niafunké (and the very high correlation between the water level in Akka and in Niafunké three days later).

4.2 Inflow and water level

The relationship between the inflow, combined for Ké-Macina and Sofara, and the water level in Mopti and Akka was calculated in different ways. The water level, averaged for ten-day periods were related to the average flow in the same ten days, the previous 10 days, the average of same and previous 10 days, etc. The best fit was found between water level and the average inflow during the same and previous 10-day periods combined. The correlation was high (R=0.85) but there was still a scattering around the calculated regression line. To remove this scattering, the inflow was assembled in 12 classes of 10 m^3/s. The averages of these 12 classes are plotted against each other in Fig. 17.

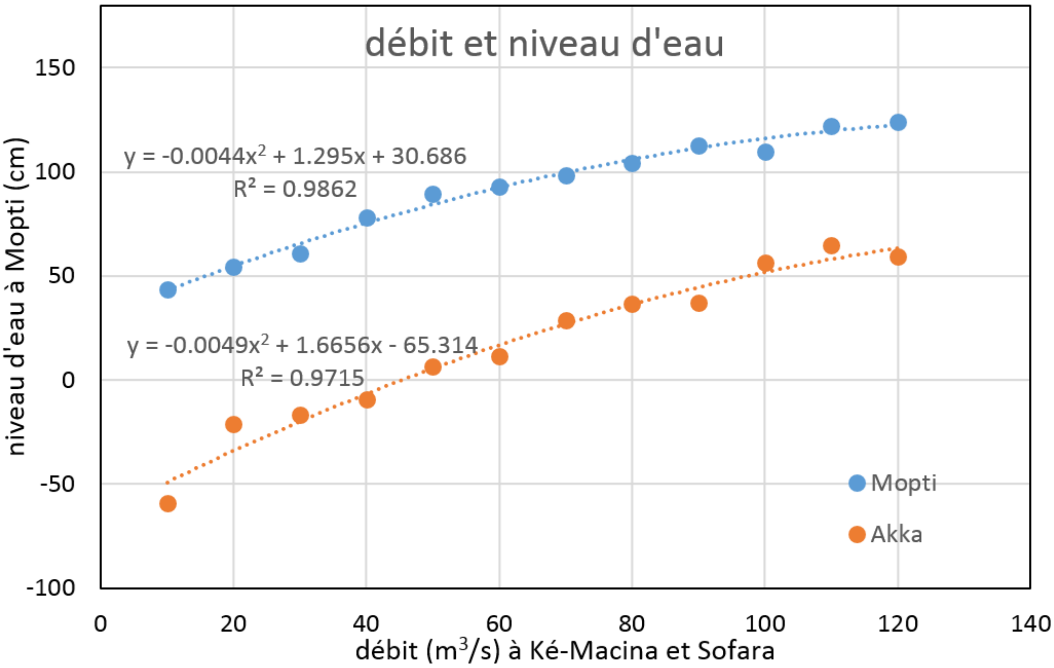


Fig. 17. The relation between the water level in Mopti and Akka (averaged for 10-day periods) and the average inflow (m^3/s for Ké-Macina and Sofara combined) during the same and the previous 10-day periods (Mopti) or the previous two 10-day periods (Akka). The average values are calculated for March, April and May 1956 – 2013.

The relationship was also calculated for Akka. In this case, the best fit was found when the water level in Akka was related to the average inflow of the two previous 10 day periods, as expected given the time lag between Ké-Macina+Sofara and Akka (Fig. 16).

The most important conclusion from this graph is that the water level in Mopti will be about 84 cm and in Akka 6 cm at a 50 m^3/s inflow combined for Niger and Bani. At an inflow of 40 m^3/s, the water level will decline to 75 cm in Mopti and -6 cm in Akka. It is important to know this relationship, since several ecological and socioeconomic functions can be related to the water level in Mopti and Akka and, using this graph, also to the inflow.

In conclusion: The water level in Mopti during the dry season (March-May) is related to the combined inflow of Niger and Bani averaged for the preceding 20 days. The water level in Akka is related to the average inflow 10 to 30 days before.

4.3 Frequency of extremely low water levels

This section describes how often the water level in the Inner Niger Delta has been below certain levels. The number of days during which the water level in Mopti has been below 80, 70, 60, 50, 40 and 30 cm is shown in Fig. 18. The cumulative frequency for Akka (water level below 0, -10, -20, -30,

-40, -50, -60, -70 cm) is given in Fig. 19. Both graphs show the huge year-to-year variation in the number of days during which the water level in Mopti or Akka has been (very) low.

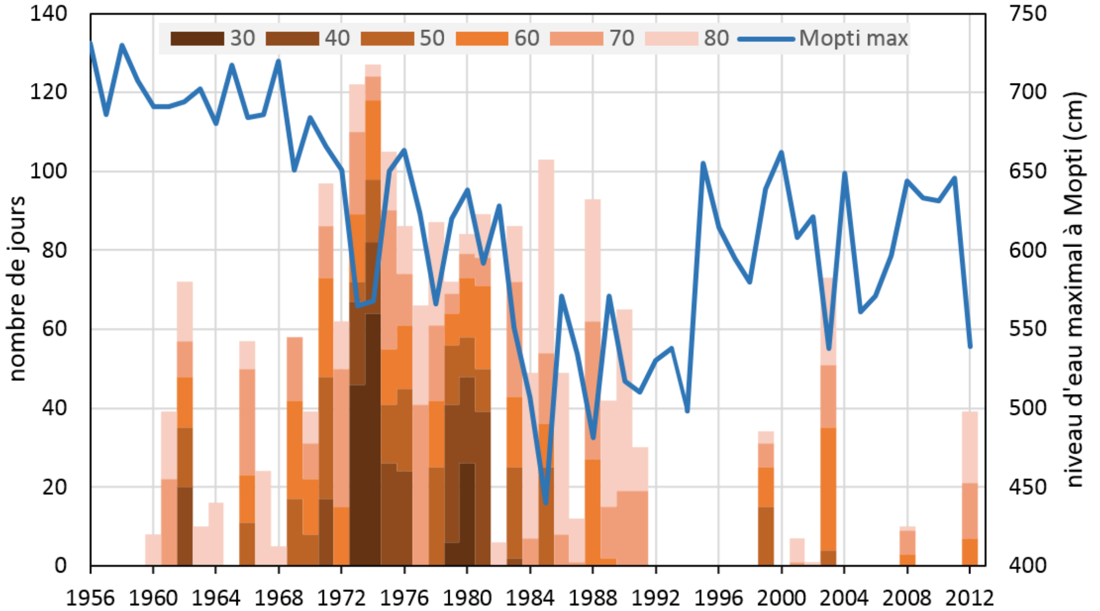


Fig. 18. The number of days in a year during which the water level has been below a certain level on the gauge of Mopti: dark brown: 30 cm or less, less dark brown: 30-40 cm, etc. (left axis). The blue line gives the maximal flood level in Mopti the year before (cm; right axis).

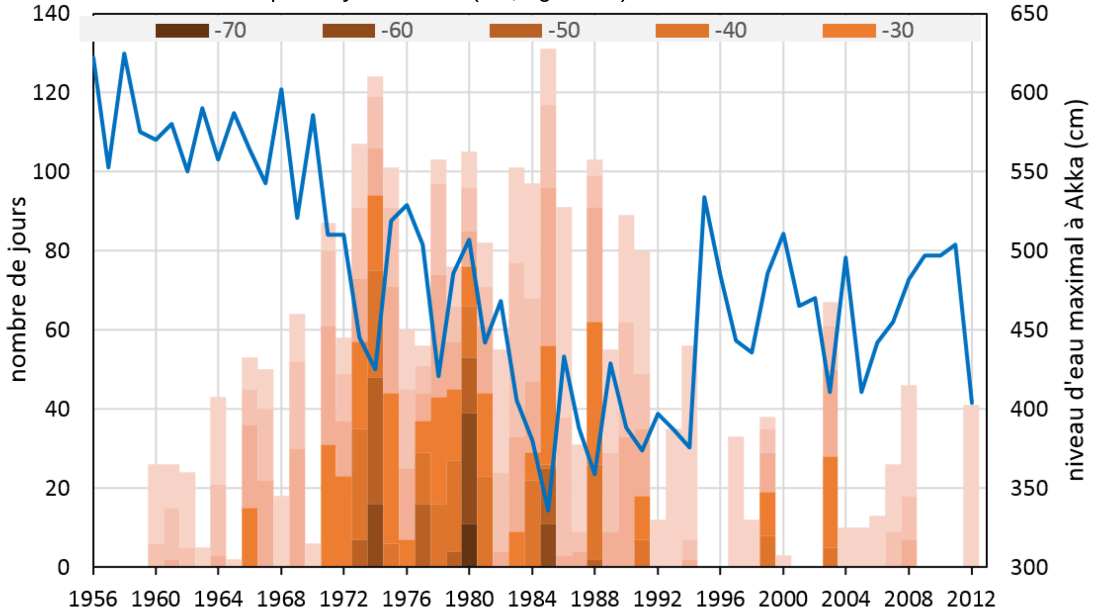


Fig. 19. The number of days during which the water level in Akka has been below a certain level: dark brown: 30 cm or less, less dark brown: 30-40 cm, etc. (left axis). The blue line gives the maximal flood level in Akka the year before (cm; right axis).

As shown in Fig. 12 and 14, the inflow was dependent on the peak flow the year before, but different before and after the construction of the Sélingué and Talo reservoir. Hence, a similar relationship may be expected for the duration of (very) dry periods. The previous section showed that if the inflow declines below 50 m^3/s, the water level is equal to or below 84 cm in Mopti and 6 cm in Akka. Hence we counted per year the number of days during which the water level in both stations was below these levels and related that to the peak water level the year before (Fig. 20 for Mopti and Fig. 21 for Akka).

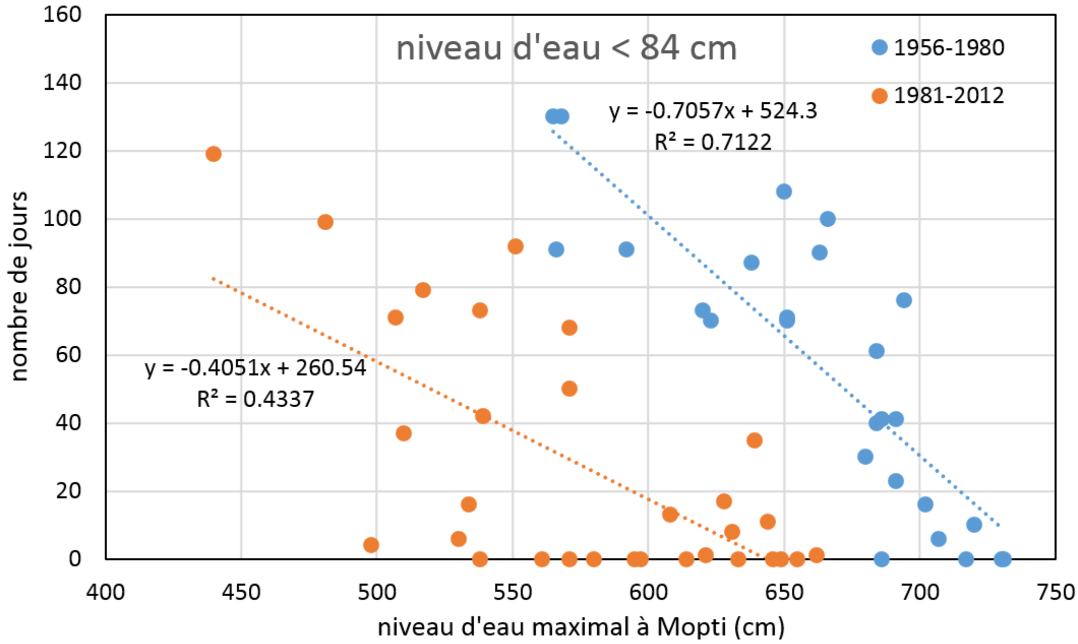


Fig. 20. The number of days during a year in which the water level in Mopti has been below 84 cm as a function of the peak flood level the year before; blue and brown symbols refer to the years before and after the construction of Sélingué in 1980, respectively. The water level of 84 cm corresponds with an inflow of 50 m^3/s).

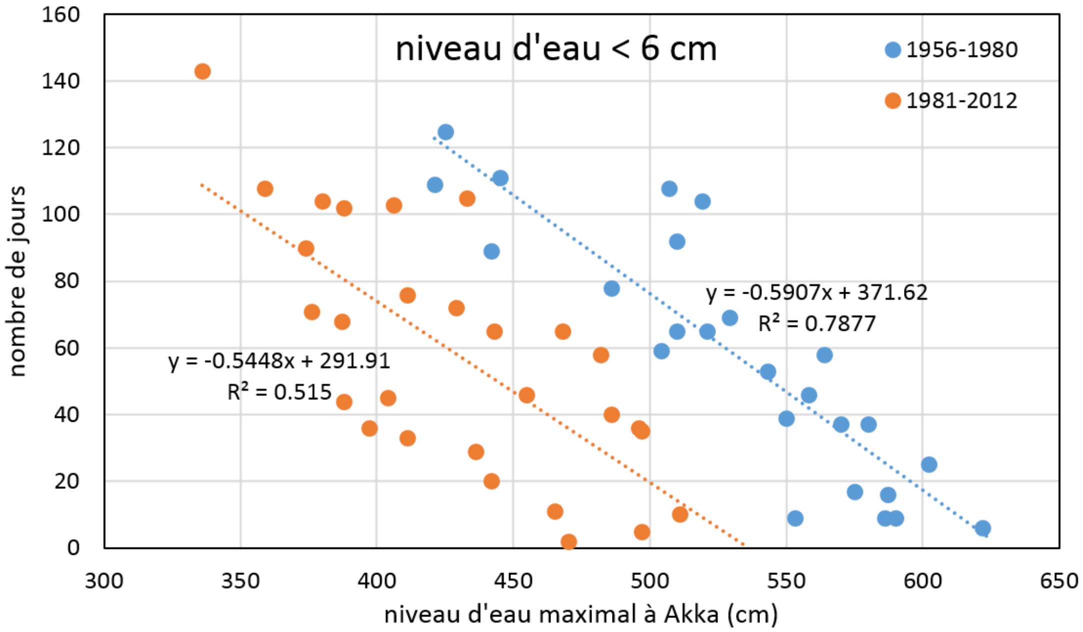


Fig. 21. The number of days during a year in which the water level in Akka has been below 6 cm as a function of the peak flood level the year before; blue and brown symbols refer to the years before and after the construction of Sélingué in 1980, respectively. The water level of 6 cm corresponds with an inflow of 50 m^3/s.

Before the construction of the Sélingué reservoir, the duration of the dry period was clearly related to the peak flood level some months before. The correlation is less pronounced in recent years, but more important is that the duration of the dry period has become much shorter, as also shown in Fig. 21.

Fig. 21 shows the yearly variation in the period during which the inflow was below 40 m^3/s and below 50 m^3/s. The calculations were done separately for Mopti and for Akka. The trends for both stations

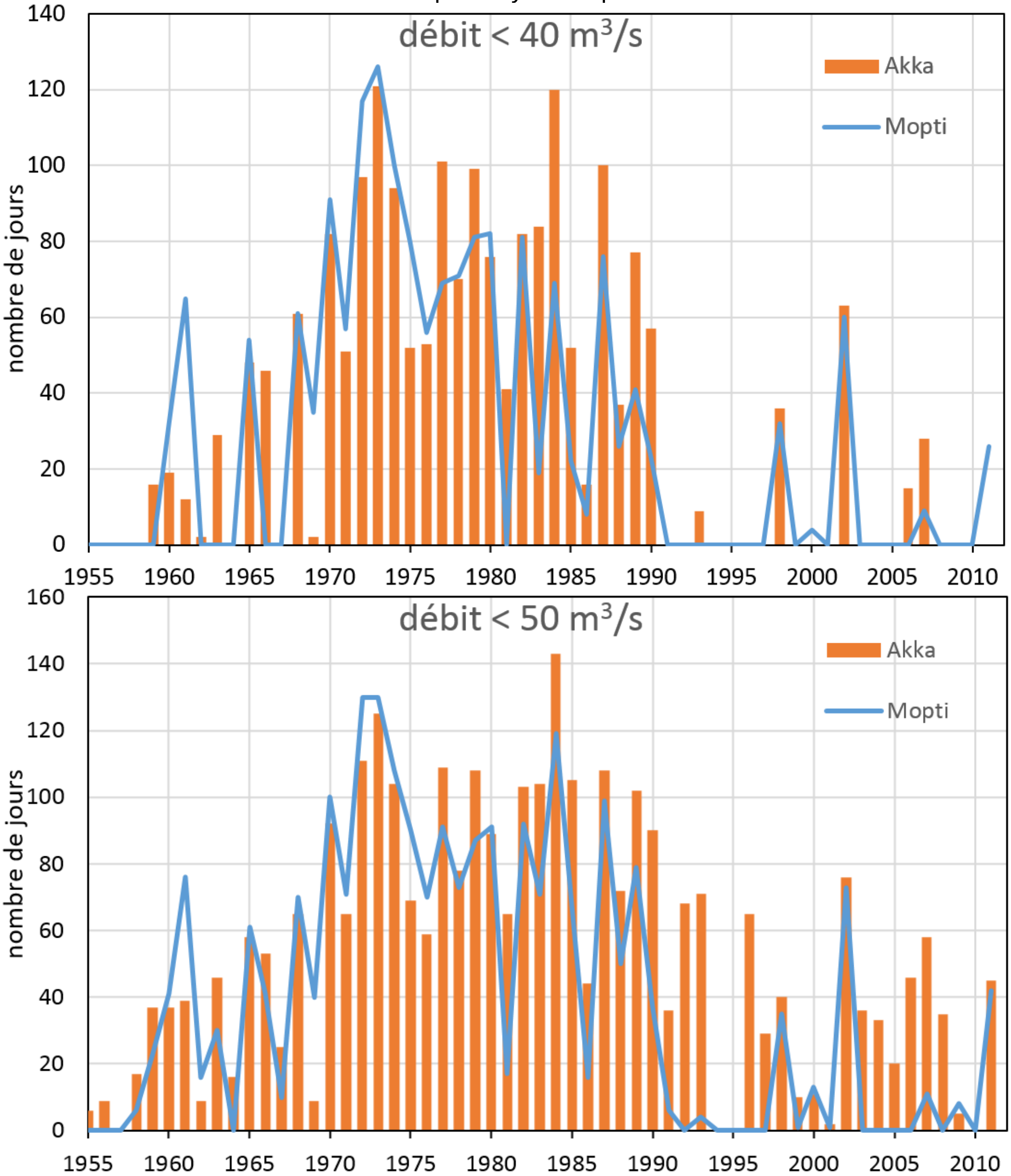


Fig. 22. The number of days during a year in which the water level in Akka(brown bar) and Mopti (blue line) has been below 75 and -6 cm, respectively, corresponding with an inflow of 40 m^3/s (top) or below 84 and 6 cm, respectively, corresponding with an inflow of 50 m^3/s (bottom).

are the same. The correlations are high (R=0.83 for 50 m^3/s and R=0.85 for 40 m^3/s). Also the duration of the dry period at 40 and 50 m3/s is highly correlated (R=0.95 for Mopti and R=0.91 for Akka), On average, the duration of the dry period is 20 days longer, in Mopti as well as in Akka, if the inflow is not 50 but 40 m^3/s.

In conclusion: the combined impact of Sélingué and Office du Niger on the inflow and the duration of the dry period in the Inner Niger Delta is very large. Dry periods during which the inflow is below 40 or 50 m^3/s are rare since the construction of Sélingué and only occur when the peak flood level has been low.

4.4 Water level and inundation

During flood recession, the water level in the river system drops at 2-3 cm per day, but in lakes isolated from the river system only 0.7 cm evaporates daily. When the water level in Akka has receded from 300 to 100 cm, half of the floodplain remains connected to the river system after a high flood (such as in 1999), but the low flood level in 1984 was insufficient to reach many lakes and depressions that consequently were deprived of their seasonal water boost.

When the flood peak has been low, the water coverage during receding water and in the dry season period is directly related to the water level as measured in Akka and Mopti because most areas being covered by water are still connected to the river system. However, when the flood peak has been high, the water coverage during receding water is mainly determined by the level of the flood peak. The higher the flood the larger the area being inundated and the more lakes and small depressions have been filled with water. When these lakes and depressions become isolated from the river system during the deflooding, the water level declines in the river system faster than in the isolated water bodies. Hence beside the level of the flood peak, the time passed since the water level has reached its peak determine where isolated and temporary lakes with water can be found. This means that in years with a high flood, the impact of the inflow during the dry season is limited to the small part of the flood system still connected to the river.

Fig. 23 and 24 show the water coverage on 14 February and 8 July 1985 for the southern half of the Inner Niger Delta. The flood in 1984 was extremely low, but the water level in February was still relatively high: 78 cm in Mopti, 14 cm in Akka and 89 cm in Diré. The water has already started to increase on 8 July, at least in the southern Delta: The water level in Mopti has increased nearly 50 cm to 137 cm, but it still has declined 16 cm in Akka (to -2 cm) and nearly 70 cm in Diré (to 20cm).

A comparison of the two maps shows that water remains present in the Niger and Bani Rivers, but the Diaka (connecting the Niger River near Diafarabé and Lake Walado near Youvarou) is partly dry. Also the other smaller creeks (called Mayos) are partly dry as well as nearly all floodplains. Lake Korientzé is deep and hardly shrinks at a lower water level. In contrast Lake Debo gets smaller and Lake Walado may even be (nearly fully) uncovered at a low water level. The two maps also show that even after the very low flood of 1984, a part of the water is not connected to the flood system during the retreat of the flood.

The water coverage at a lower level cannot be indicated due to lack of satellite images with a lower water level. From our own field experience and stories from local people we know that even at the lowest water level (50-60 cm lower than shown in Fig. 23), the Niger and Bani remain intact (although shallow and locally even very shallow), Korientzé remains a large lake and Debo became more or less a wide river. Hence, the changes compared to what is shown in Fig. 23 and 24 are very small.

In conclusion: the water coverage during the dry season is mainly determined by the level of the flood peak: the higher the flood, the more lakes and depressions are filled. The water coverage declines during the deflooding, relatively fast in the areas still connected to the river, but slow in water bodies which became isolated. Hence, the inflow during the dry season has only a limited impact on the water coverage in this time of the year. If the water level drops to extremely low levels, the area being covered by water declines too, but not much.

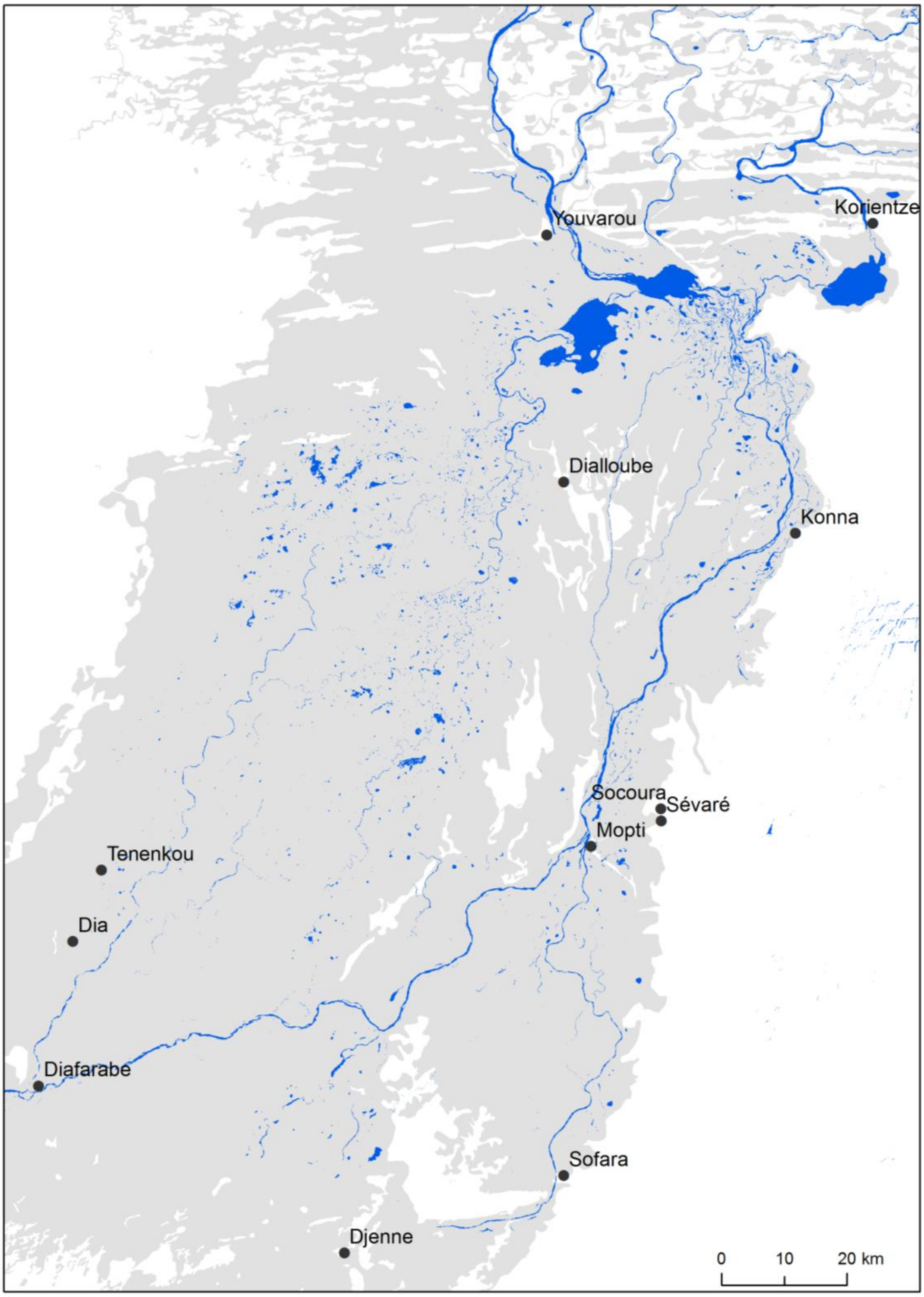


Fig. 23. The water coverage on 14-2-1985, when the water level in Mopti was 78 cm and in Akka 14 cm.

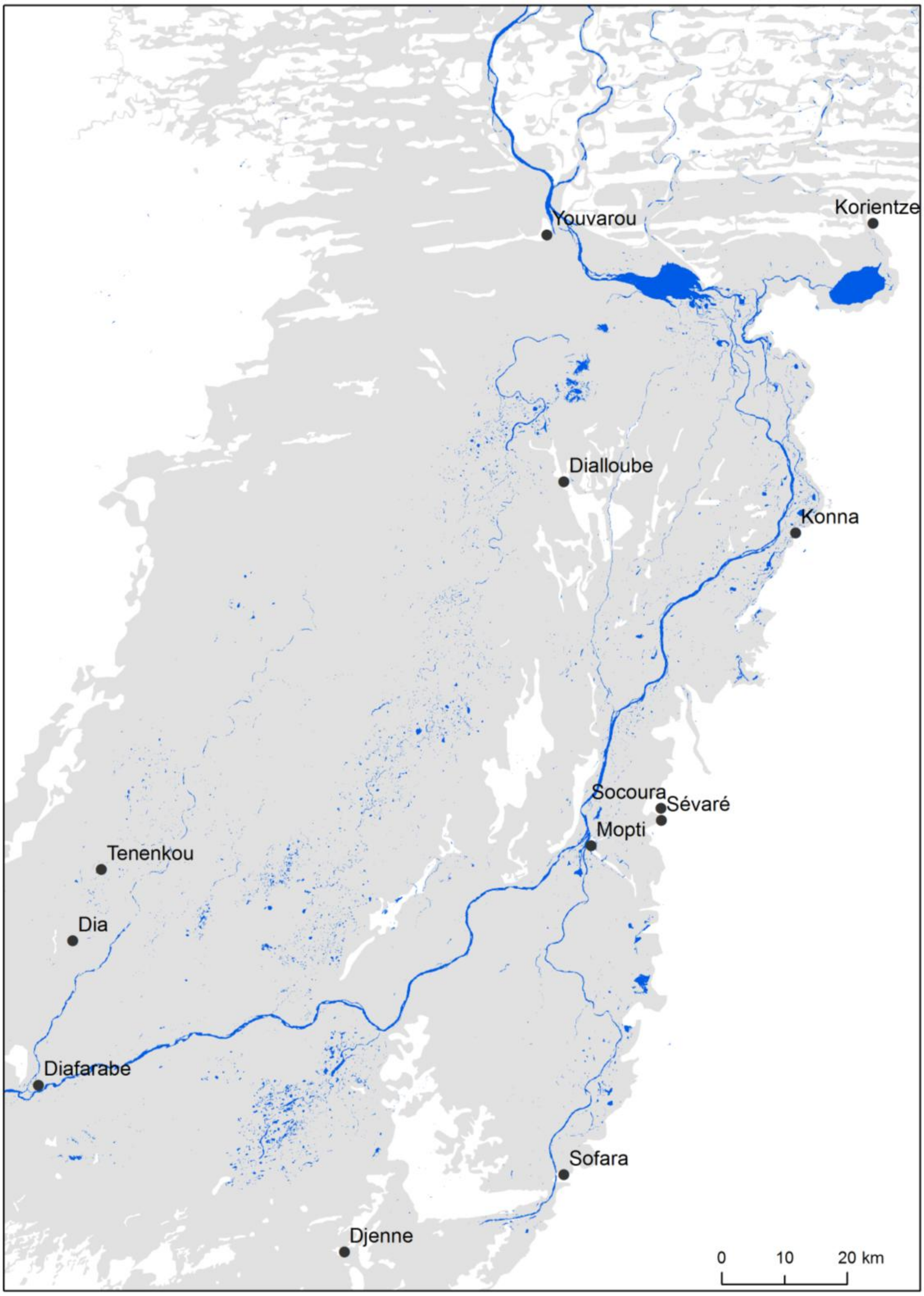


Fig. 24. The water coverage on 8-7-1985, when the water level in Mopti was 137 cm and in Akka -2 cm.

5 Ecological impact of a low inflow

The ecological function of the Inner Niger Delta predominantly depends on its flooding: the higher the flood, the larger the flood extent and the higher the ecological values. However, its ecological function is not primarily related to the peak flood level itself, but to the *variation* in water level during the flooding and deflooding. Floodplains are so productive and are such ecological hotspots due to this dynamic process. To maintain these values, the water in the dry season should be so low that floodplains are fully dry. If not, areas remaining covered by water are invaded by vegetation types being considered as less valuable or even as a pest (e.g. *Typha*).The main problem in most riverine floodplains in the world is not a water level being *too low* during the dry season, but *too high* due to water regulation in rivers and construction of dams.

The Inner Niger Delta attracts millions of water birds and birds bound to trees and shrubs which breed in Europe and Asia and spend the northern winter in Africa. Many of these birds do not survive their wintering period if the flood has been low, partly due to lack of food, but - especially for the larger bird species - mainly because more birds are killed by the local people. In dry years waterbirds are forced to concentrate in fewer sites, which makes them highly vulnerable to catching with standing nets by the local people. In the Inner Niger Delta very few Garganey are offered for sale on the market in wet years, but up to 70,000 are traded in dry years. The same difference was found in Pintail and Ruff (Zwarts *et al.* 2009).

Migratory birds leave the Inner Niger Delta in March, but a part of them stay. Also the African water birds remain in the Inner Niger Delta during the dry months. These birds get concentrated in the last remaining water bodies. Water bird counts are performed in the central lakes (Lake Debo, Walado, Korientzé) since 1992 (Fig. 25). Most of these counts were done in January-March, but 15 counts are available for the months April, May and June between 1999 and 2006. The water level in Akka varied for these 15 counts between -25 cm and 120 cm. We will use these data to evaluate the ecological impact of the water level during the dry months.

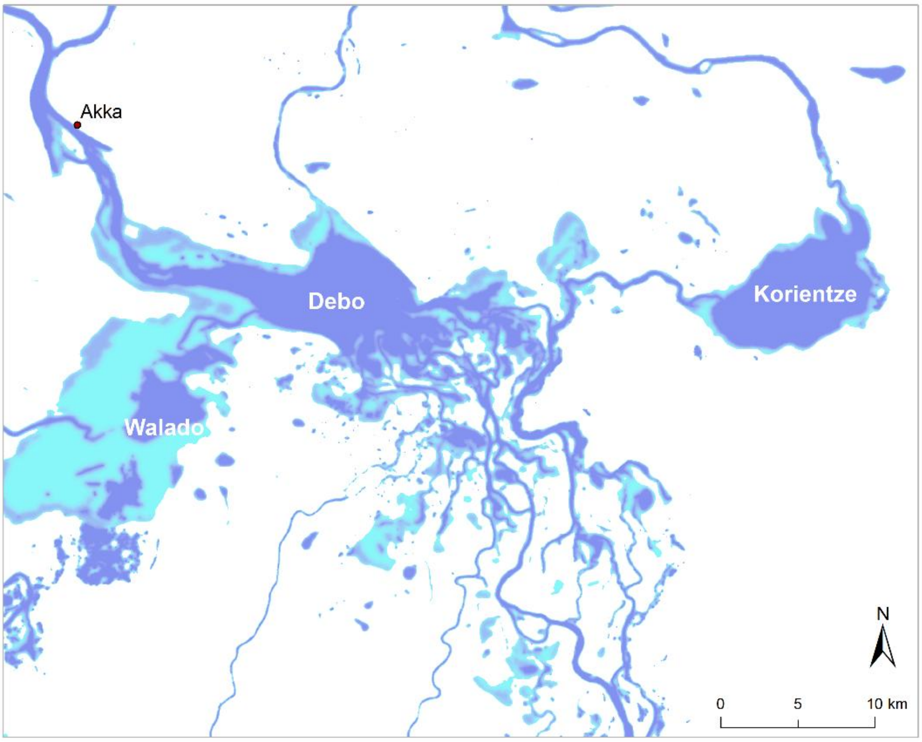


Fig. 25. The central lakes (Debo, Walado and Korientzé). The water coverage is shown for the range 0 to 140 cm at Akka; 0 = dark blue, 140 = green-blue, with intermediate colours for the classes in-between.

The bird numbers shown in the graphs (Fig. 26-28) were counted in the three lakes, according to methods described by van der Kamp *et al.* 2002, 2005).

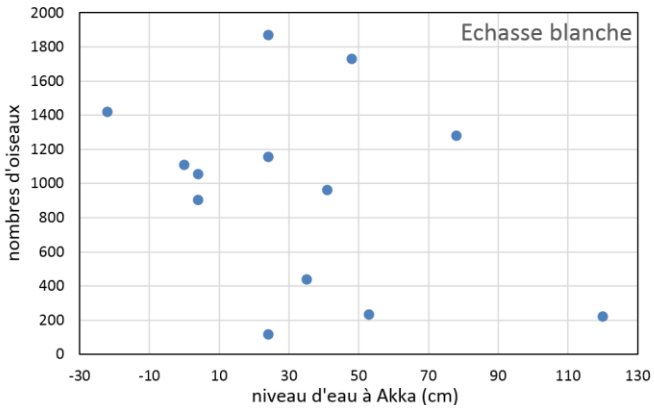


Fig. 26. Number of Black-winged Stilts present in the central lakes (Fig. 26) in April-June as a function of the water level in Akka.

The Black-winged Stilt is a bird species feeding in shallow water and may even be found in the smallest shallow depressions. At a declining water level, the numbers in the central lakes go up, since the last remaining water bodies elsewhere in the Inner Niger Delta became dry and thus unavailable as feeding area for this water bird species. We would expect a similar increase at lower water level in other water birds as well, but that is not the case.

Fig.26 shows for 4 water bird species, that the numbers in April-June declined at a lower water level. These four species do not feed in the water as the Black-winged Stilt but in the vegetation or on the wet ground. They disappear from the central lakes at a lower water level due to the shrinkage of their available feeding area.

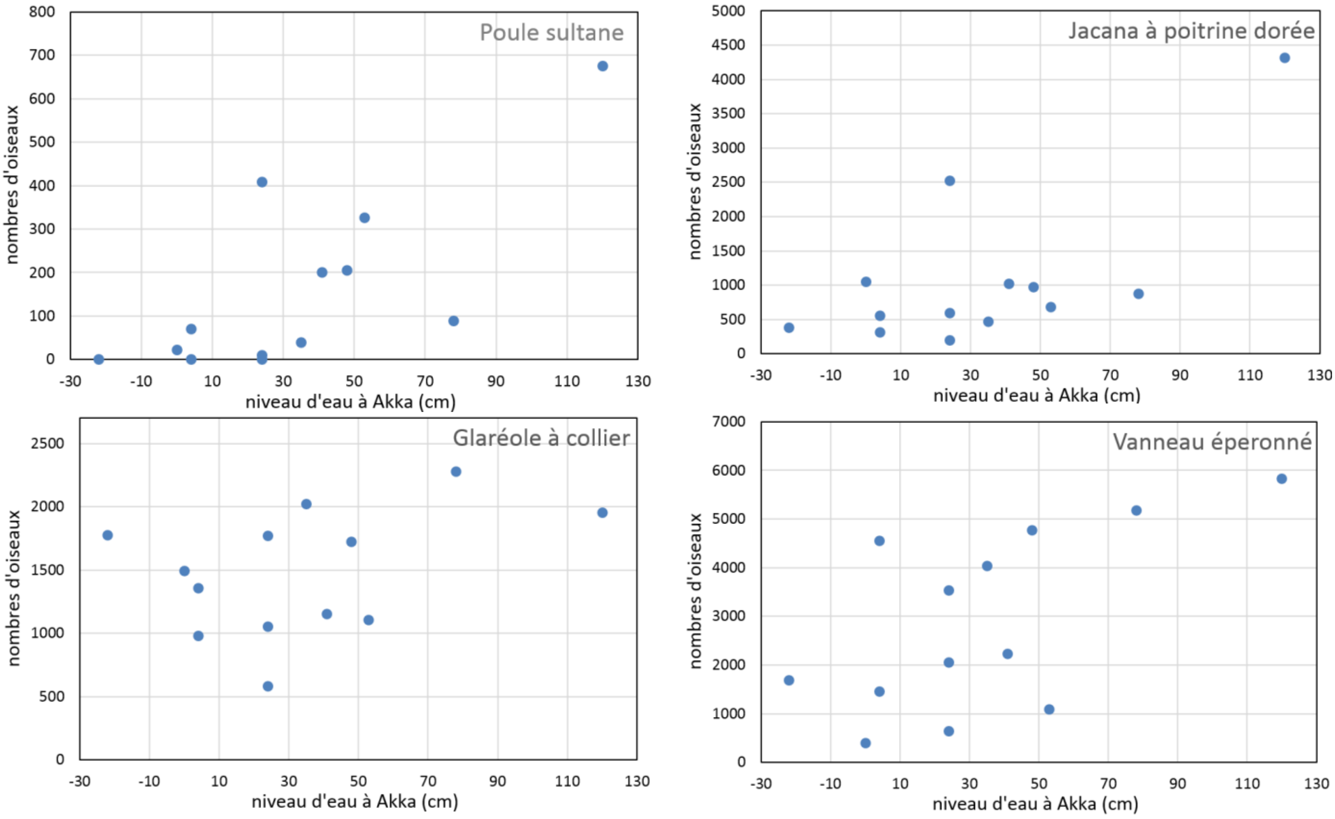
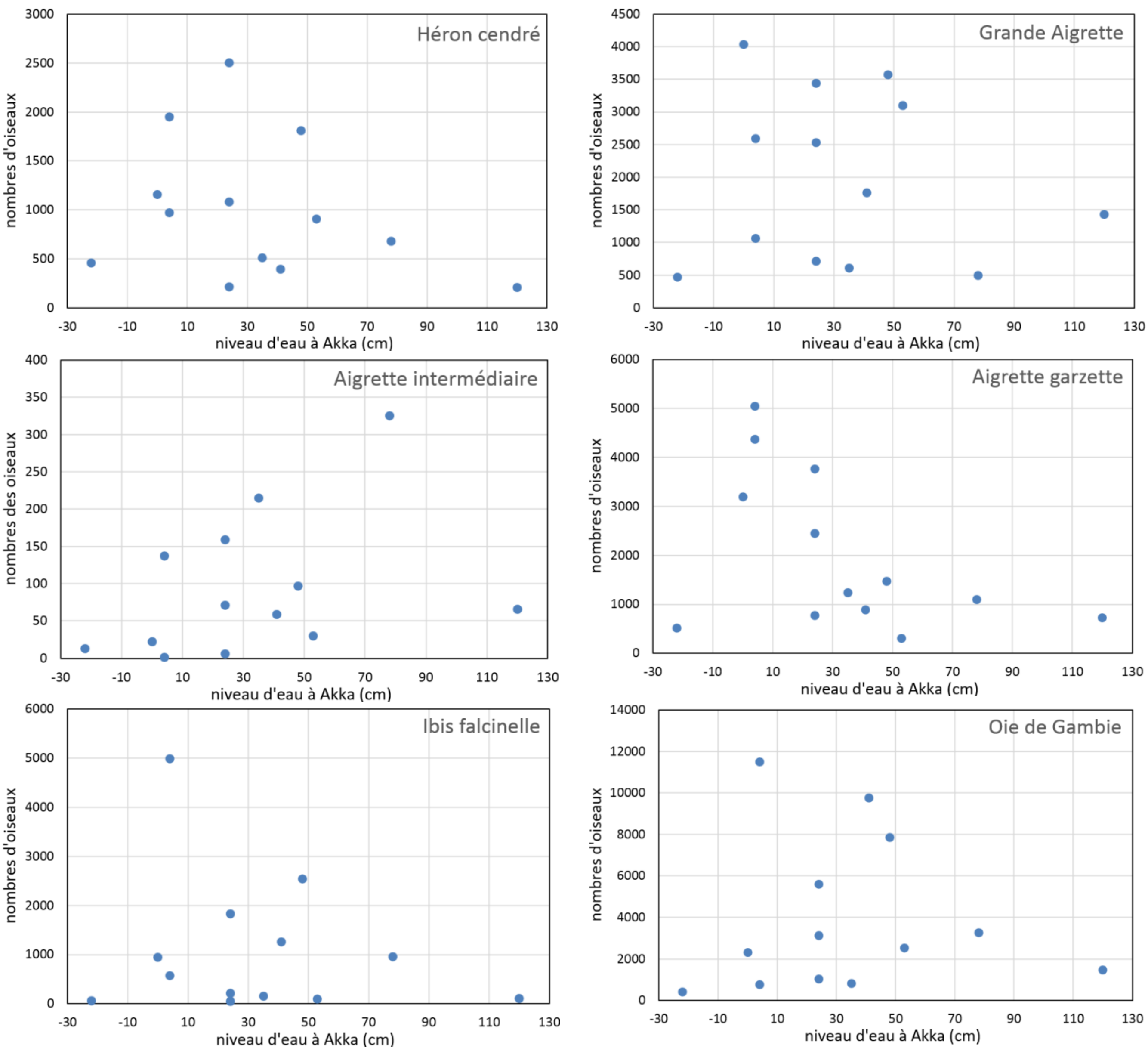


Fig. 27. Purple Swamphen, African Jacana, Collared Pratincole and Spur-winged Lapwing: numbers present in the central lakes (Fig. 25) in April-June as a function of the water level in Akka.

In most water bird species, the observed numbers are determined by two opposite trends when the water level declines. On the one hand an increase of numbers due to the loss of suitable feeding areas elsewhere in the Inner Niger Delta at a declining water level. On the other hand, the central lakes lose at a declining water level their function as feeding area at very low water level by which the numbers start to decline. As a consequence the highest numbers of most species are seen at intermediate water levels and not at the lowest and highest water level during the dry season. Fig. 28 shows for 11 other water bird species the relationship between counted numbers and water level.

Where do the birds go when they have to leave the central lakes at a very low water level? In this time of the year the Sahel is dry everywhere, so there is hardly any alternative. Most likely they die. For several species remarkably large numbers are concentrated in the central lakes. To give one example: Del Hoyo *et al.* (1995) mention about the occurrence of the the Kittlitz's Plover in Africa "flocks of 100-200 bird reported..", but in the central lakes up to 14,000 plovers have been counted!



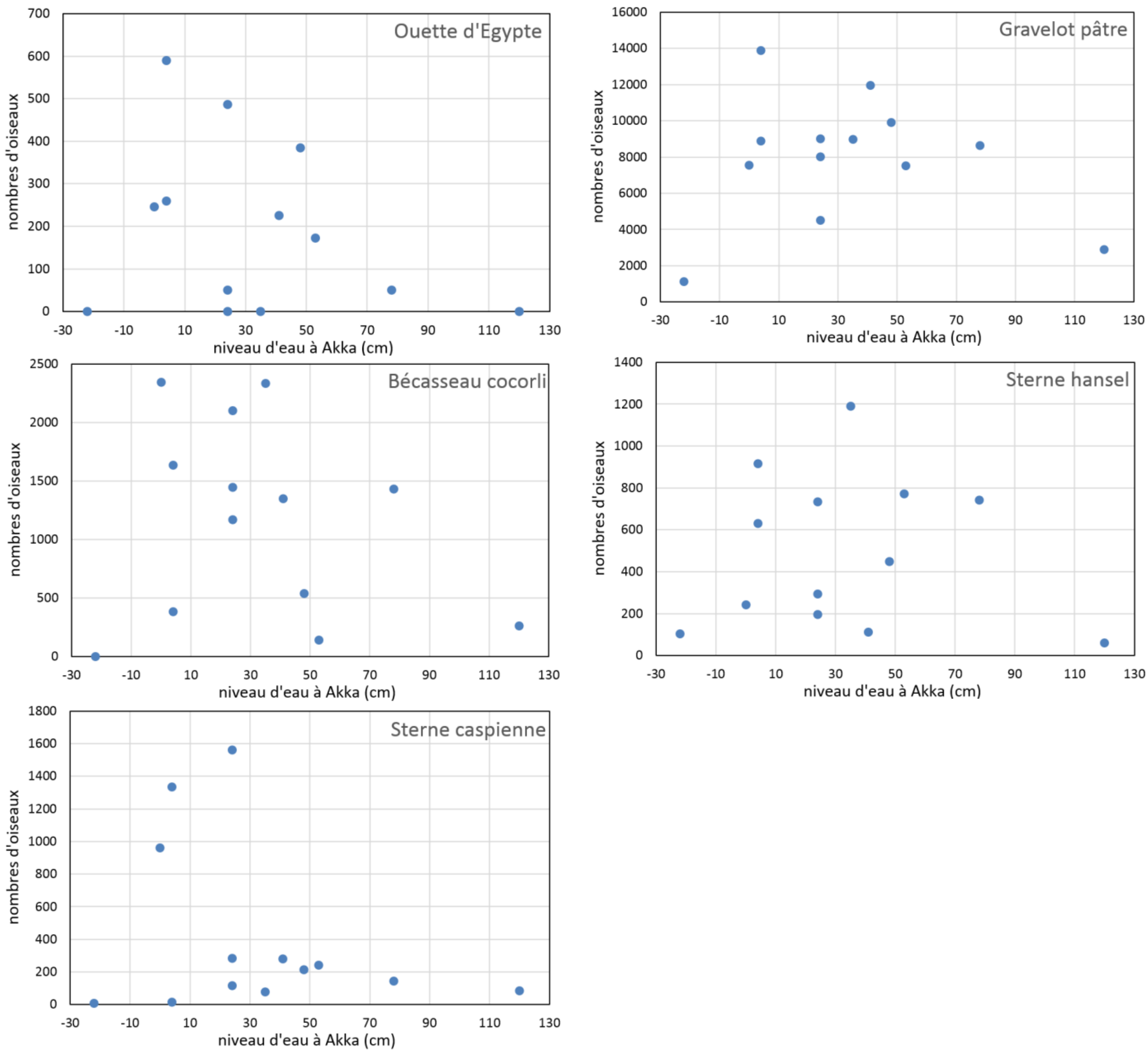


Fig. 28. Grey Heron, Great Egret, Intermediate Egret, Little Egret, Glossy Ibis, Spur-winged Goose, Egyptian Goose, Kittlitz's Plover, Curlew Sandpiper, Gull-billed Tern and Caspian Tern: numbers present in the central lakes (Fig. 26) in April-June as a function of the water level in Akka.

The central lakes are always part of the river system even at the lowest river flow. Hence the water level is directly determined by the river. To prevent mass mortality among water birds concentrated in these last remaining water bodies, it should be prevented that the water level is lower than about -10 cm at Akka. As shown in Fig. 19, to guarantee a water level of -10 cm, the flow of Ké-Macina + Sofara should be 40 m^3/s.

To conclude: From an ecological point of view, riverine floodplains have to be uncovered for which a low river flow in the dry season is required. However, if the flow becomes very low, water birds in the Inner Niger Delta are losing the last remaining feeding areas and most probably do not survive such a dry period. This does not yet occur at an inflow of 40 and certainly not at a flow of 50 m^3/s. Hence, ecologically spoken a minimum flow of 40 m^3/s is still acceptable. It should be prevented, however, that the flow becomes lower than that.

6 Socio-economic impact of a low inflow

6.1 Transport

Boats are the only means of transport in the Inner Niger Delta during the wet season. Road transport becomes possible during the dry season, but as long as the water depth is sufficient to transport persons and freight, boats are used, being less expensive than using cars.

The big boats connecting the cities in the Inner Niger Delta have a capacity of 400 persons and 350 tons of freight. Since these boats need a water depth of about 4 m, their use is limited to the wet season. During the dry season, smaller boats can still carry passengers and freight along the Bani and the Niger, and locally also elsewhere.

<u>In conclusion:</u> A low water level severely limits the transport by boats. Thus, from this point of view each reduction of the water level during the dry season limits the use of boats for transport. Thus a minimum flow of 50 m^3/s is preferred above 40 m^3/s.

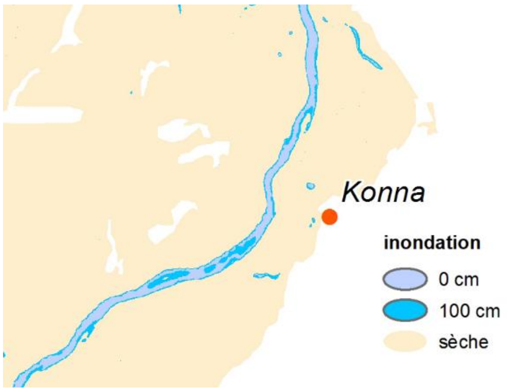


Fig. 29. What remains of the Niger River near Konna (from 20 km upstream to 10 km downstream of Konna) when the water level in Akka declines from 100 cm (light and dark blue) to 0 cm (light blue). At a water level of 0 cm, many rock and sandbanks near Konna are uncovered and the boats have to manoeuvre between the banks. Note that the map shows the water coverage independent of depth, even if the water depth is some cm. Source: Zwarts (2012).

6.2 Fishery

The daily fish catch is low when the floodplains are covered by water but gradually increases during the deflooding when the fish are forced to leave the floodplains and get concentrated in the last remaining water bodies. Hence the fish campaign starts in January-February and ends in May-June. An extremely low water level in the dry season has direct and indirect impacts on the fishery in the Inner Niger Delta. Before these impacts are evaluated it has sense first to describe how fisheries have changed over the last 50 years.

Kodio *et al.* (2002) found that individual fishermen caught most fish (35/kg/day, on average) when the water level has declined by 2-3 meter, which is usually the case in early February. Later in the season fish are more concentrated and easier to catch, but instead of a further increase of the daily catch, there is a gradual decline to a meagre 7 kg/day by the end of June. They conclude that this decrease is due to depletion and that nearly all fish had been captured by the end of the fish campaign. This conclusion has far reaching consequences. The fish stock of a year depends on the spawn and fry produced by the few fish still alive fish at the end of their first year and the very few fish older than one year.

When Kodio *et al.* wrote their paper, the exploitation system had already changed, but since then there were more changes. The fishery became much more intensive after the introduction of nylon nets in the 1960s. The captured fish became smaller and the mesh size decreased simultaneously from 5 cm before 1975 to 3-4 cm in the 1980s (Laë *et al.* 1994). At present most nets have even a mesh width of 1 cm.

Fishermen have also continuously adapted their fishing techniques. In the past, they waited till the fish had migrated from the emerging floodplains to the creeks and/or the fish were concentrated in the shallow water of the isolated water bodies. They still put out large fyke nets in the creeks, but individual fishermen have started to dig narrow drainage channels (usually < 1 m) through the river banks to catch the fish in these outlets. In this way, individual fishermen can catch fish before they arrive at the (often large, communal) fykes in the creeks. Although this technique may seem profitable for the individual fisherman, it is damaging to the fishery as a whole, since it causes a faster drainage of the floodplains, as a consequence of which the growing season is limited and the captured fish becomes smaller.

Since some years, fishermen started to enclose the bourgou fields with very long, fine-meshed nets, with the intention that all fish leaving their enclosed floodplains at deflooding are captured in a fyke. Again, although apparently a profitable way to catch small fish, it is very damaging since only a fraction of the trapped fish is captured and all other fish die when the bourgou field is dry. Moreover, the fish are captured earlier in the season and thus still small. The fraction of fish surviving the fish campaign during the last years must have become even smaller than in the years described by Kodio *et al.*

Al these changes have had a huge impact on the fish stock. Fish older than one year have become increasingly rare in the Inner Niger Delta. Fish species have adapted to this extreme predation pressure by advancing their age of reproduction. The capture within a year depends on the reproductive capacity of the few fish still alive after the intensive fish campaign. The fish campaign is more intensive if the water level in the dry season becomes very low. The short-term advance of a very low water level in the dry months is obvious since more fish can be captured (Fig. 30). In the long-term there is not much to gain, however, since the risk is getting larger that the reproductive capacity is reduced so much that it has a negative impact on the fish production the next year.

There are no effective statutory regulations limiting the present over-exploitation of fish in the Inner Niger Delta. The only way to limit the over-exploitation, is to prevent that the water level during the dry season is declining too much.

Fishery is more than annual production (i.e. harvested biomass) and annual trade given in tons. A study of the annual reports of OPM might reveal how much the species composition has changed during the last dozens of years. Although worthwhile, this is out of scope of this study.

In conclusion*:* a very low water level allows the fishermen to catch the last remaining fish. To protect fishermen from themselves, very low water levels should be prevented, however. For this reason a minimum flow of 50 m^3/s is preferred above 40 m^3/s.

6.3 Agriculture during deflooding

Most farmers in the southern part of the Inner Niger Delta grow floating rice on the submersed floodplains. Most of the farmland in the southern part of the Inner Niger Delta indicated in Fig. 31 are rice fields on the floodplains. Growing floating rice on the floodplains is not possible in the northern half of the Delta since the flood arrives too late, the flooding is too short (or even absent) and the rainy season is too short and unpredictable. Many farmers in the northern part of the Inner Niger

Delta start to prepare their land immediately after the floodplains are uncovered. First the crops can grow in the

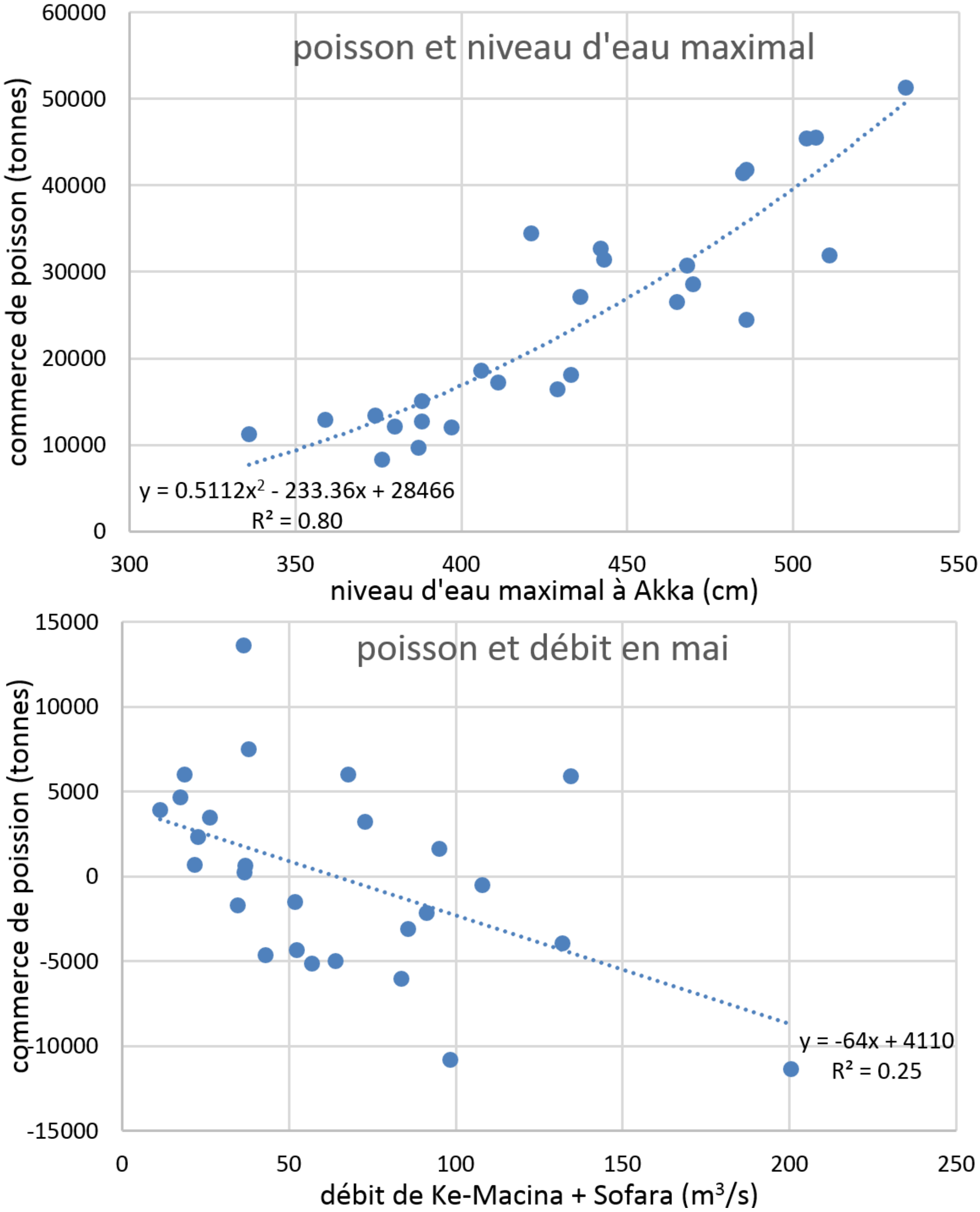


Fig. 30. Upper graph. The annual trade (ton fresh fish equivalents) as a function of peak flood level (Akka, cm) in the previous year; 1977-2003. Fish data of OPM; source: Zwarts *et al.* 2005.

Lower graph. The deviation between the actual fish trade from the trade predicted from the peak flood level (using the function given in upper graph) as a function of the flow (m3/s) in Ké-Macina + Sofara in May.

An example to clarify what we did: the annual trade in 1989 amounted to 16400 ton. The peak flood level in 1988 was 429 cm,. The regression line gives a predicted trade of 22400 ton. Hence the actual trade was 6000 less than expected. In the lower graph, this -6000 ton is plotted against the river flow in May. The same is done for all data. The lower graph can be understood as the impact of the flow in May, after a correction has been made for the flood peak of the year before. If the flow in May is less than 50m^3/s, the annual catch is 3000 ton above average and if the flow is more than 50 m^3/s the catch is 2000 ton below average.

still wet ground, but later on farmers have to walk up and down between their cropland or garden and the river or lake nearby to water their crops.

This system is used everywhere in the Inner Niger Delta on a small scale, for instance in gardens near villages along the rivers, but it occurs on a larger scale in the northern lakes, such as in Lac Horo. The opportunities for this way of agricultural production are limited after the peak flood level has been low. Lakes and depressions are not filled with water at low flood peak and thus remain dry. Among the large lakes in the NE and NW of the Inner Niger Delta, Lac Horo is the only large lake being filled with water after a low flood. In the region of Timbuktu*, culture de bas fonds* (crops grown in depressions) is cultivated on 40 km^2 and *culture de décrue* (grown in emerged areas, such as lakes) on 100 km^2 according to estimates of DRAMR-Tombouctou; see also Fig. 32.

For several reasons the river flow during the dry season has hardly any impact on agriculture during the deflooding. First, a large part of the farmland used during the deflooding is situated along water bodies being isolated from the river system in the dry season (Fig. 32). These lakes and depressions are preferred by the farmers since the water level goes down at a slow rate (0.7 cm/day due to evaporation). The decline of the water level within the river system (2-3 cm/day) is so fast that it only has sense to grow vegetables on the immersed land if the river remains nearby later in the season. Hence, there is no agriculture on the extensive flat floodplains, but only along the steep and narrow banks of the rivers. Secondly, as far as there is agriculture during deflooding in the areas remaining connected to the river system, harvesting occurs before or during the early dry season.

In conclusion*:* most of the agriculture during deflooding is not affected by the water level (and thus water flow) during the dry season.

6.4 Irrigation

The agricultural productivity on the floodplains of the Inner Niger Delta varies from year to year, being dependent on the flooding and the local rainfall. Most areas being cultivated in the Inner Niger Delta are flooded if the water level in Akka is between 350 and 400 cm. Motor pumps allow farmers to irrigate their land. Nearly all these irrigation fields are situated along the river Niger on the higher parts of the floodplains or even on areas being never inundated. There are only a few and small irrigation schemes in the southern half of the Inner Niger Delta (Fig. 31), but extensive schemes have been constructed last years in the northern half (Straub 2007; Fig. 32). Nearly all farmland along the Niger River in the northern Delta depends now on irrigation. With a few exceptions, all irrigation schemes are found, where even in years with a very low flow during the dry months water is still available nearby.

Is irrigation more expensive if the water level in the river is low? Most pumps are situated close to the river on the high river bank. People pump the water during the dry season about 6 m upwards. At a river flow of 40 instead of 50 m^3/s, the water level will be 12 cm lower (Fig. 17). Since the fuel consumption during pumping is mainly determined how much the water is pumped up, an additional 12 cm would increase the fuel consumption by not more than 2%.

In conclusion: most irrigation schemes are situated along the Niger River where even during the lowest water level, it is still possible to pump water from the nearby river. Hence for the majority of the farmers using irrigation, it hardly matters whether the flow is 40 or 50 m^3/s.

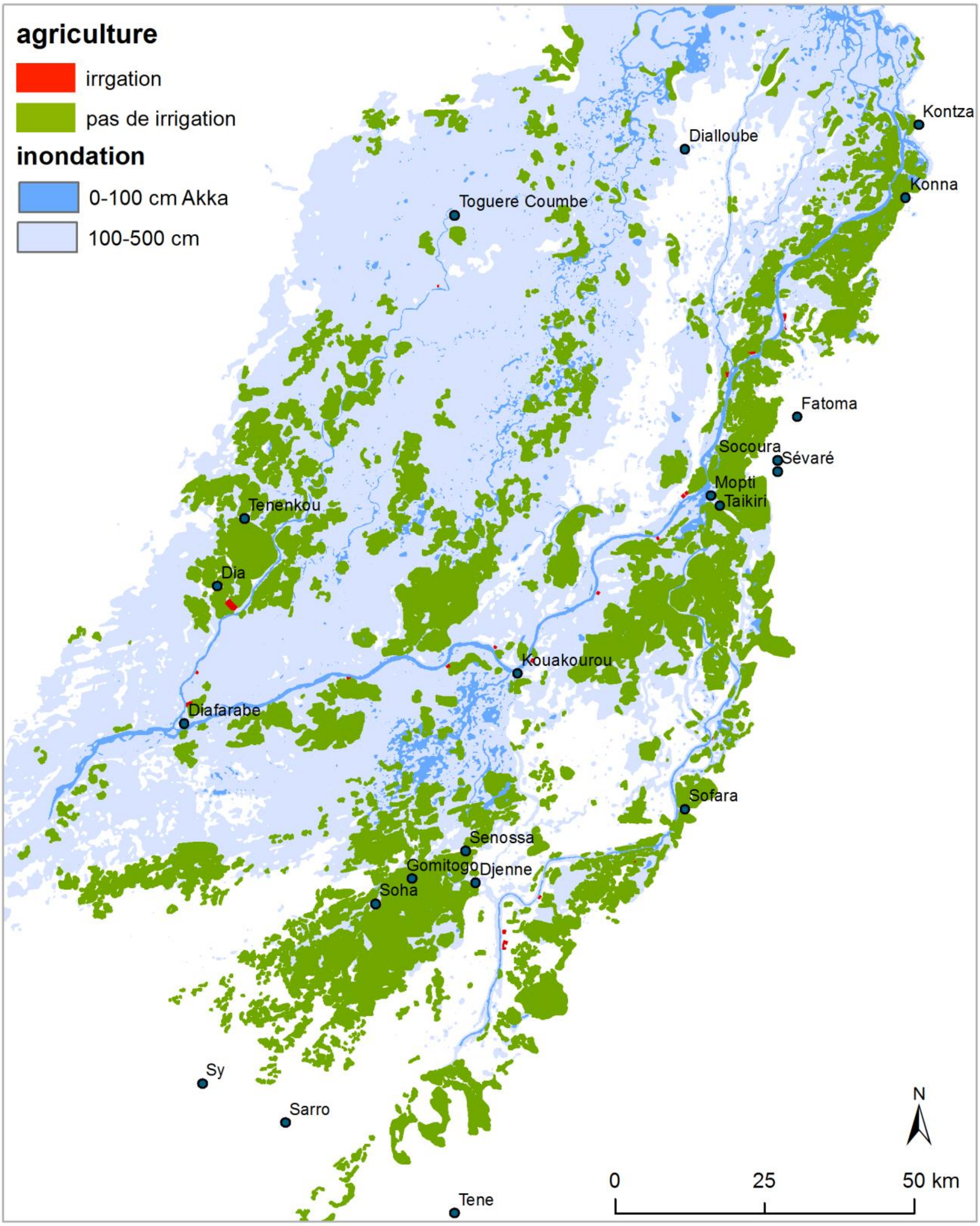


Fig. 31. Agriculture (red: irrigated; green: non-irrigated) in the southern part of the Inner Niger Delta (inundation zone at 100 cm in Akka: dark blue or at 500 cm: light blue). Google Earth images (2003-2013) were used to identify farmland. Farmland in the Inner Niger Delta is clearly visible on high resolution satellite images, - during as well as after the harvest. Irrigation schemes are recognizable on the satellite images in the dry season when they are clearly visible as green patches in a dry, yellow world. It is more difficult, however, to distinguish irrigated and non-irrigated fields in the wet season when all is green. Irrigation schemes have mostly rectangular structures and dikes and we used this information to recognize irrigation schemes. Moreover, we could use the atlas of the irrgation schemes in the northern half of the Inner Niger Delta (Straub 2007) to indicate the irrgation

schemes.

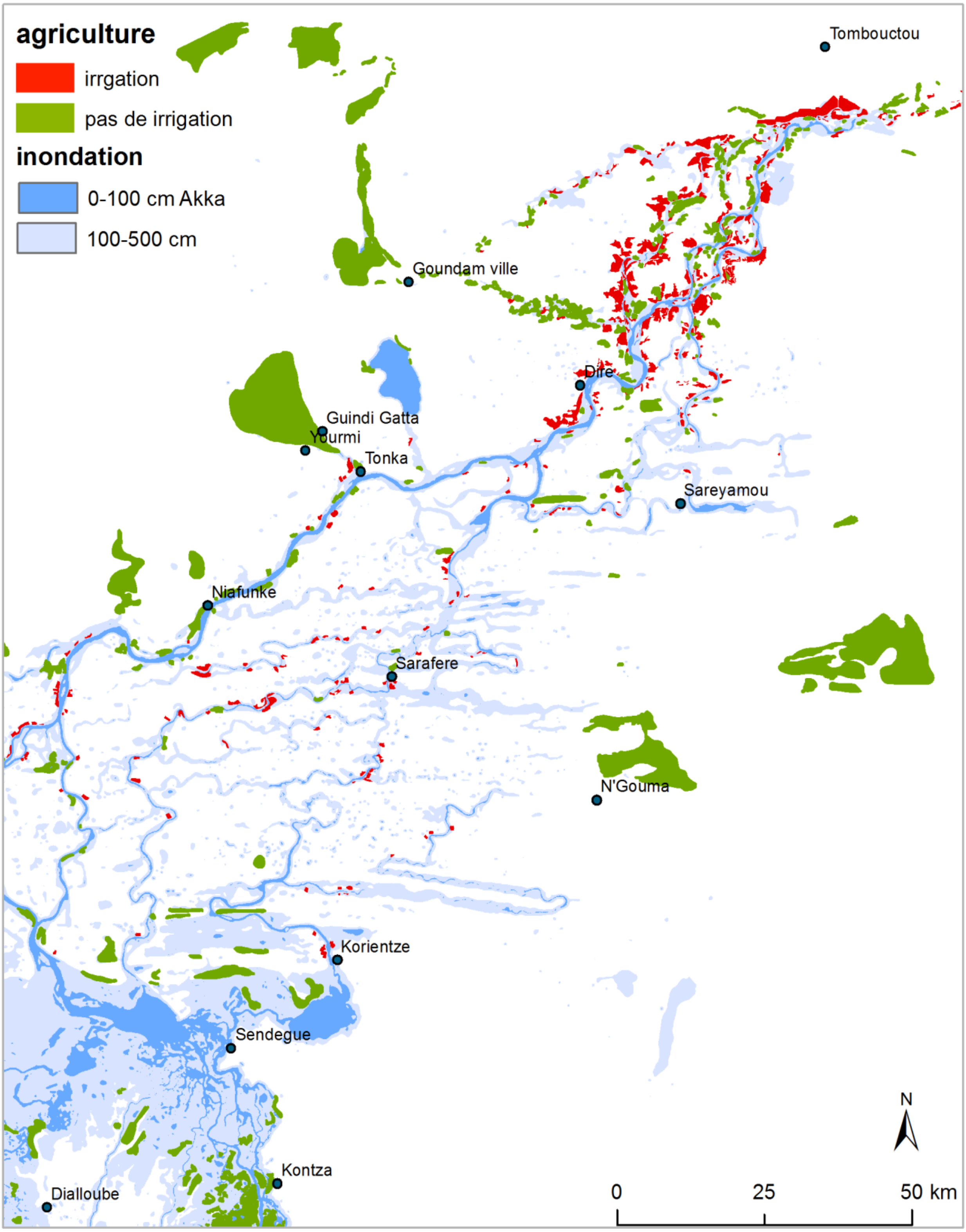


Fig. 32. Agriculture (red: irrigated; green: non-irrigated) in the northern part of the Inner Niger Delta (inundation zone at 100 cm in Akka: dark blue or at 500 cm: light blue). For explanation: see legend of Fig. 31

7 Discussion and summary

7.1 River dynamics and seasonal floodplains

Most riverine floodplains in the world are found in the sub-tropical zone due to the short, intense rainy season and long dry season in-between. The water level in most African riverine floodplains varies between 0.5 and 2.5 m during the course of the year, but the Inner Niger Delta stands out since the water level varies seasonally 4-5 m (being 3.5 m in dry years and 6 m in wet years).

Upstream dams lessen the river dynamics and have an impact on floodplains in several ways (Fig. 33). Fig. 33 shows the impact of Sélingué (and Fomi, if constructed) on the Inner Niger Delta. The water intake by Office du Niger causes a further decline of the peak flow but also lessen the flow during the dry season. Thus, the combined impact of both infrastructures on the Inner Niger Delta is a further decline of the peak flood level, but their impact during the dry season is opposite. In fact, the additional water released by Sélingué (100 m^3/s) is fully captured by Office du Niger.

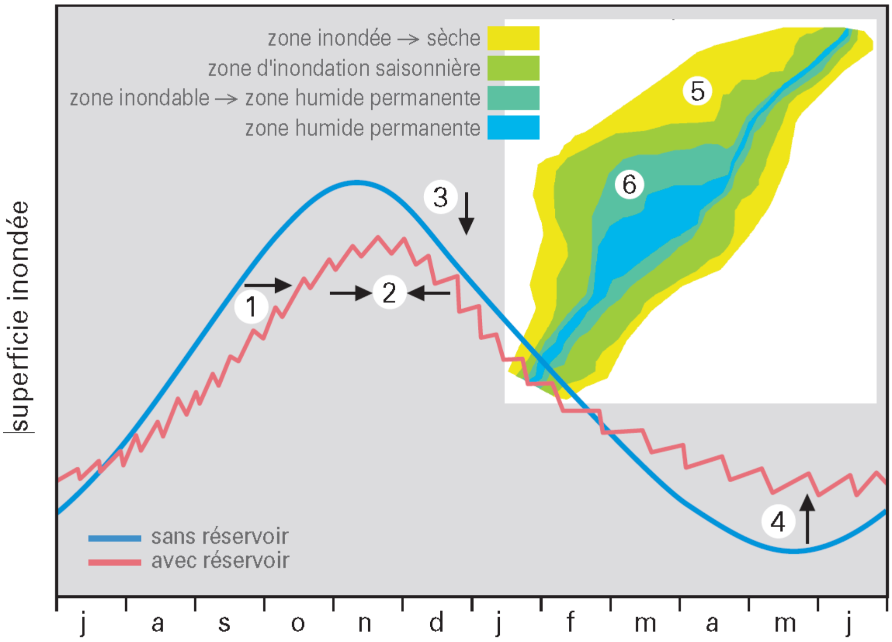


Fig. 33. Upstream reservoirs have an impact on floodplains in several ways. When the reservoir is filled at the start of the rainy season, it retards flooding (1) and lowers the peak level (3). This also reduces the flood extent (5). Some months later, when the reservoir is emptied, the low water level is raised (4), causing an extension of the permanent marshes (6). These man-induced changes turn the higher floodplains into drylands (5) and the lower floodplains into permanent marshlands (6); the remaining seasonal floodplains contain less water for a shorter period (2). The irregular water releases from the reservoir cause erratic short-term fluctuations in water level, unlike the normally gradual daily increase and decrease of water level associated with unhampered flooding and deflooding. From: Zwarts *et al.* 2009/2012.

The impact of Fomi on the Inner Niger Delta will resemble Sélingué, although the amount of water withheld in the wet season and the releases during the dry season will be about twice as large as Sélingué. Fomi will allow Office du Niger to enhance the irrigation capacity during the dry season. But will indeed the water intake in the dry season become three times as large as at present? If so, we may assume that it will take many years before this amount of water is taken indeed. Thus, we have to bear in mind that after the construction of Fomi the water level in the Inner Niger Delta will be enhanced considerably during the dry season.

7.2 River flow and inundation of the Inner Niger Delta in the dry period

As long as Fomi has not been constructed, Office du Niger cannot enhance its water intake during the dry season, without impairing the interests downstream. This report has analysed the relationship between the flow in the dry season and the ecological and socio-economic functions of the Inner Niger in an attempt to answer the question whether the guaranteed water flow at Markala / Ké-Macina should be set at 40 or 50 m^3/s. The main findings are summarized below:

On average, Sélingué and Office du Niger lower the peak flow of the Niger at the entrance of the Inner Niger Delta in September by 500 and 100 m^3/s, respectively.Sélingué adds 100 m^3/s to the river flow in the dry months, while Office du Niger takes 100 m^3/s from the river in the same dry months. Hence the water added by Sélingué in the dry season is, on average, fully consumed by Office du Niger.

The river flow of the Niger in Koulikoro in the dry season depends on the peak flow during the previous wet season, before as well as after the construction of the Sélingué reservoir. The releases at Sélingué during the dry season have enhanced the flow in the dry months independent of the peak flow in September.

The river flow of the Niger in Ké-Macina in the dry season shows a large year-to-year variation. As in Koulikoro, the flow in the dry season depends on the peak flow during the previous wet season, before as well as after the construction of the Sélingué reservoir. The releases at Sélingué during the dry season have enhanced the flow in the dry months independent of the peak flow in September.

The river flow of the Bani at Sofara in the dry season shows a very large year-to-year variation. As in the Niger (Koulikoro and Ké-Macina), the flow of the Bani in the dry season depends on the peak flow during the previous wet season, before as well as after the construction of the Talo reservoir. The releases at Talo during the dry season has enhanced the flow in the dry months independent of the peak flow in September.

The peak flow of the Bani and the Niger is well correlated: when there is a lot of rain in the Upper Bani there is usually also much rain in the Upper Niger Basin. However, when the river flow in the dry season is compared, there is no relationship. Hence years with a low flow in May at Ké-Macina may sometimes compensate with a high flow in Sofara and other way round.

The lowest water level in Ké-Macina is measured in early May and in Diré in early June and for the stations in-between in mid-May (Mopti) and late May (Akka, Niafunké).

The water level in Mopti during the dry season (March-May) is related to the combined inflow of Niger and Bani averaged for the preceding 20 days. The water level in Akka is related to the average inflow 10 to 30 days before.

The combined impact of Sélingué and Office du Niger on the inflow and the duration of the dry period in the Inner Niger Delta is very large. Dry periods during which the inflow is below 40 or 50 m^3/s are rare since the construction of Sélingué and only occur when the peak flood level has been low.

The water coverage during the dry season is mainly determined by the level of the flood peak: the higher the flood, the more lakes and depressions are filled. The water coverage declines during the deflooding, relatively fast in the areas still connected to the river, but slow in water bodies which became isolated. Hence, the inflow during the dry season has only a limited impact on the water coverage in this time of the year. If the water level drops to extremely low levels, the area being covered by water declines too, but not much.

7.3 Ecological values

From an ecological point of view, the flooding dynamics should be preserved as much as possible. An essential part of the dynamics is that the floodplains are actually dry for at least some months to prevent that permanent marshland comes into existence. For the Inner Niger Delta this implies that the water level has to decline to about 0 cm in Akka. We calculated that at an average minimal flow of 40 and 50 m^3/s the water level declines to -6 and 6 cm in Akka, respectively. This difference is too small to worry about. There is one reason, however, to prefer a minimum flow of 50 m^3/s: water birds get concentrated during the dry season in the last remaining water bodies, but if the water level declines below 0 cm in Akka, the numbers decline, most likely due to a higher mortality.

7.4 Economic values: transport

During the deflooding of the Inner Niger Delta, transport by boat declines, but cars are used more. Transport by boat is relatively cheap, hence a higher water level during the dry season makes transport, on average, more profitable. The difference is not large since large boats connecting the cities in the Inner Niger Delta are only used at a higher water level.

7.5 Economic values: fishery

A low water level in the Inner Niger Delta permits fishermen to capture more fish during the dry season. Hence, they gain from a reduced river flow of 40 instead of 50 m^3/s. However, to prevent a long-term damage to the fish stock, it is also for the sake of the long-term perspective of the fisheries in the Inner Niger Delta, to keep the minimum river flow at 50 m^3/s.

7.6 Economic values: agriculture during deflooding

Most farmland used during the deflooding is situated in *mares (*depressions) and along the shore of larger lakes. The flooding of these water bodies is determined by the flood peak. For this type of agriculture a high flood peak is essential, but the river flow and thus the water level in the river and the creeks and lakes during the dry months has no impact on the just mentioned depressions and lakes where most farmland is found. Hence whether the flow during the dry season is 40 or 50 m^3/s has hardly any impact on the agriculture during the deflooding.

7.7 Economic values: agriculture in irrigation schemes

Nearly all irrigation schemes in the Inner Niger Delta have been constructed near deep water, where, even at a very low water level, water from the river can still be pumped to the irrigation scheme. Hence whether the flow during the dry season is 40 or 50 m^3/s has hardly any impact on the agriculture in irrigation schemes.

7.8 Health

This report did not consider the relationship between health and minimum water flow, due to lack of data. The impact should not be ignored, however. Cholera is not uncommon in the Inner Niger Delta. The risk of cholera is larger during the dry season when the people are concentrated around the last remaining water bodies. It is conceivable that the risk of this, and other, epidemic diseases during the dry season becomes larger in years with a low flow. Quantitative data on the relationship between health and minimum water level are lacking, but it is obvious that very low flows should be avoided.

7.9 General conclusion

It is recommended not to lower the total inflow into the Delta from 50 to 40 m^3/s given the negative impact this will have on some (not all) stakeholders. However, since Talo releases 20-30 m^3/s extra in the dry season, the minimum flow at Markala can safely be reduced from 50 to 40 m^3/s.

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