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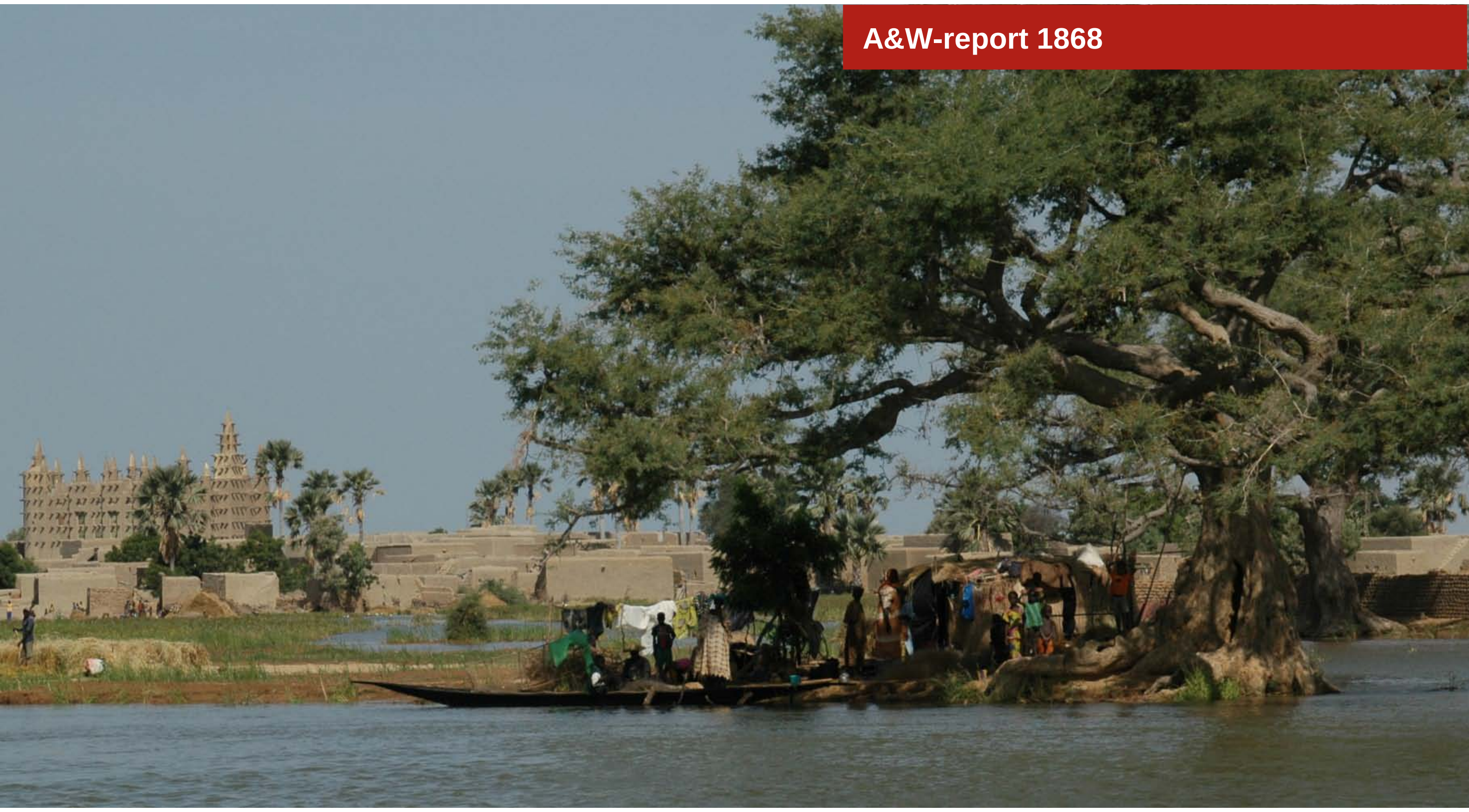
The impact of a lower river flow on the inundation, vegetation and land use in the Inner Niger Delta



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The impact of a lower river flow on the inundation, vegetation and land use in the Inner Niger Delta

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L. Zwarts

Cover photograph
Much will change in the Inner Niger Delta at the forecasted reduction of the flooding, and hardly none for the better.
Photo: Leo Zwarts

L. Zwarts 2012
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1 Introduction

The Niger and Bani Rivers show a large seasonal variation in their flow due to the short raining season in West Africa (June-October) and the long dry period (November-May). Without this large seasonal variation in river flow there would be no Inner Niger Delta (Fig. 1) and no annual flooding and deflooding of this huge area. Local rainfall is too limited to have an effect on flood height in the Inner Niger Delta. Hence its flooding is determined by the inflow from the Niger and the Bani (Fig. 1). The inflow of both rivers in turn relates to the rainfall experienced 600-900 km SW of the Inner Niger Delta.

Since the mid-1950s, the average flow of the Bani and Niger in August-October has varied between 1850 and 7200 m3/s, equivalent to a total seasonal flow of 14.7 and 57.2 km3 respectively. In 1984, the water level at the gauge of Akka in the centre of the Inner Niger Delta just exceeded 3 metres. In contrast, in 1957 and 1964, the water level in Akka reached the very high level of more than 6 metres (Fig. 2).

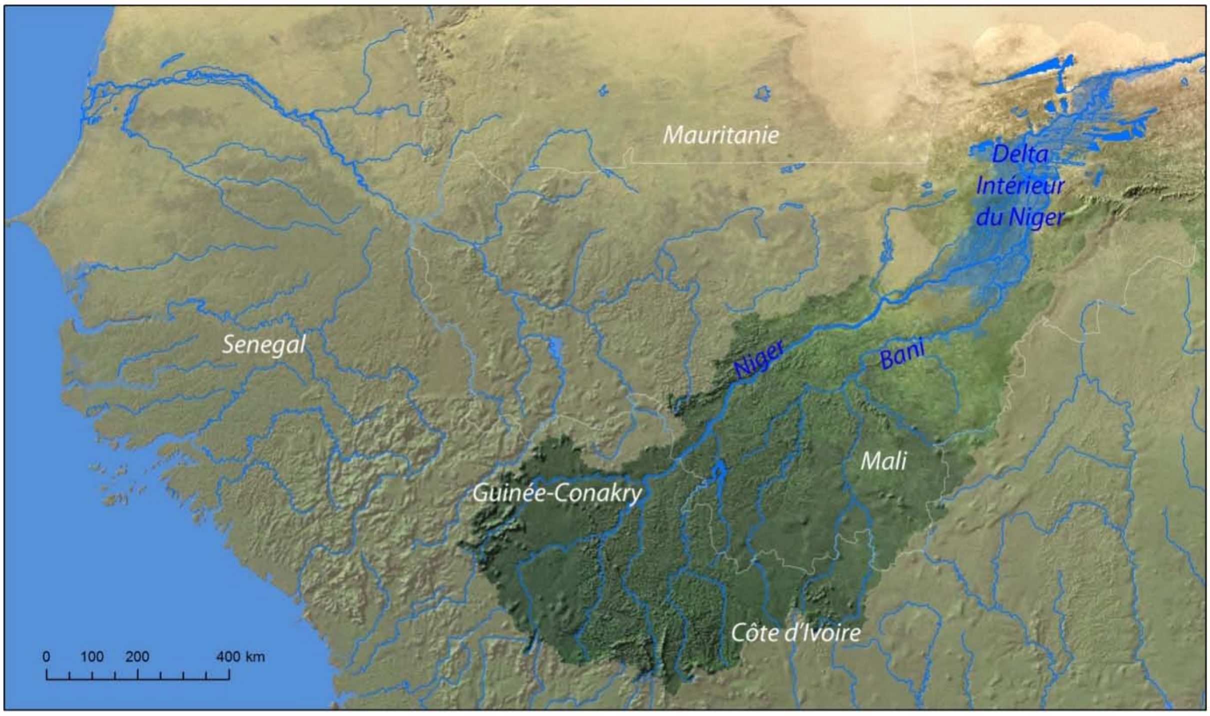


Fig. 1. The Niger rises in the Guinean Highlands. The main tributary of the Niger is the Bani which drains SW Mali and NE Ivory Coast. The catchment area of the Niger and Bani is given in bright colours. The flooding of the Inner Niger Delta is determined by the inflow from both rivers, which in turn relates to the rainfall experienced 600-900 km away in the same year and the ground water table such as determined by the rainfall during the preceding years.

Rainfall in the Sahel varies from year to year, but the overall trend over the last 120 years is downward. Most climate models predict a further decline. The Inner Niger Delta is still one of the largest riverine floodplains in the world. At an expected reduction of rainfall in the Upper Niger Basin by 20%, the Inner Niger Delta will lose 40% of its floodplains because of the expected lower ground water table. The planned hydrological interventions upstream (Fomi dam, extension of Office du Niger, Djenné dam) will cause a further loss (Zwarts 2010).

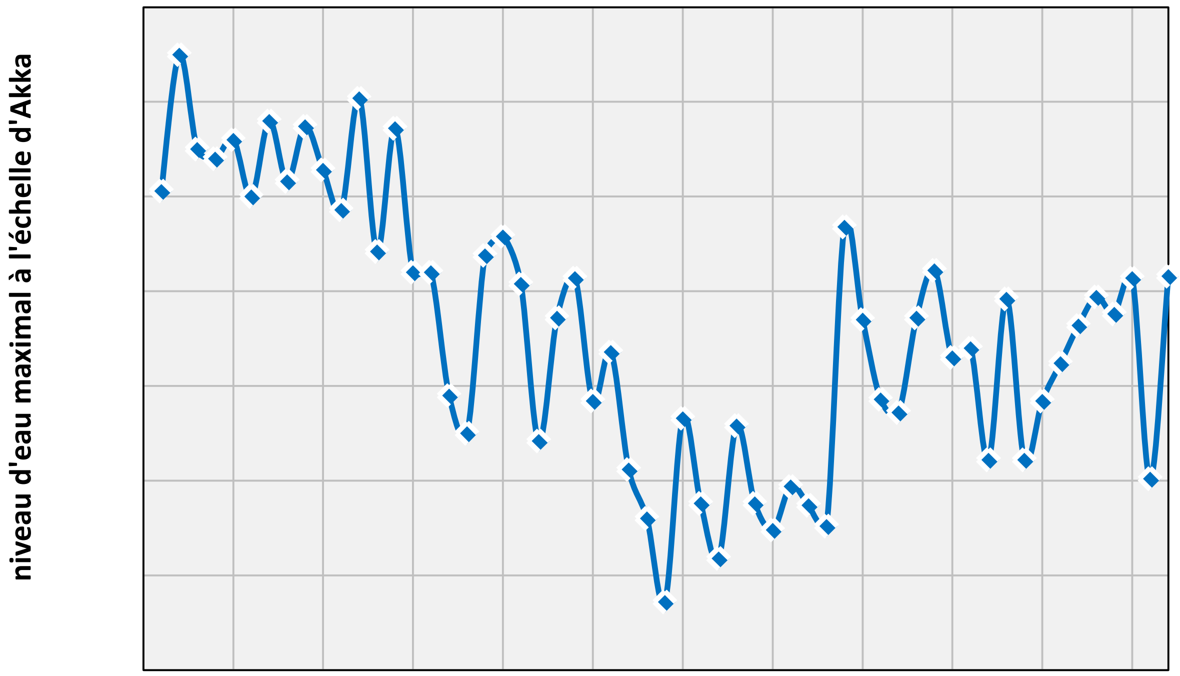


Fig. 2. The annual peak flood level in the Inner Niger Delta, measured on the gauge of Akka, has varied between 336 cm (in 1984) and 625 cm (in 1957) during the last 60 years; data from DNH.

This report deals with the expected changes in the inundation, vegetation and land use of the Inner Niger Delta at a declining river flow. It shows the huge reduction in the flood extent of the Inner Niger Delta if the peak flood level at the scale of Akka would decline from 500 cm to 400 cm or even 300 cm (Chapter 2). In contrast, the flooded surface during the dry season appears to be hardly affected if the water level during the dry period is reduced from 100 to 0 cm. The report also shows the expected change in the (woody) vegetation zones and the potential land use if the flood level would decline from 500 to 300 cm (Chapter 3 – 5).

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).

2 Water maps

Methods used to produce maps of the inundation zone

Topographical maps of the Inner Niger Delta show the floodplain as if it were flooded at a maximum level. Zwarts & Grigoras (2005) scanned the topographical maps to produce a map of the total inundation zone (Fig. 3).

Zwarts & Grigoras (2005; page 46-60) used satellite images to produce water maps of the Inner Niger Delta covering the full range of water levels. These water maps allow the determination of the relationship between water level (as measured in Mopti, Akka and Diré) and the inundated area. Water maps were combined to construct a digital flooding model. The flooding model is restricted to the area indicated as the oblique rectangle in Fig. 3. The position of the oblique rectangle is determined by the course of the satellite (SSW – NNE) and the dimensions of the satellite images (180 x 180 km). The Inner Niger Delta is covered by two Landsat images: one from the area between Djenné and Lac Débo (path 197/row 50) and another north of Lac Débo up till Timbuktu (path 197/row 49).

The data presented in this report also refer to the area within the oblique rectangle shown in Fig. 3. Hence the floodplains along the Bani upstream of Djenné are ignored as well as those along the Niger downstream of Timbuktu. Both riverine floodplains are adjacent to the Inner Niger Delta but usually considered as not belonging to the Inner Niger proper. Also some peripheral lakes along the NE side of the Inner Niger Delta (Lac Haribongo, Lac Garou, Lac Niangaye) are not included.

Land and water were distinguished on the satellite images by selecting specific wavelengths of Landsat TM band 5 and 7. As explained by Zwarts & Grigoras (2005: page 61-67), the water maps were combined to construct a common map with different water levels. This was done separately for incoming and for declining water. Here we use the composite water map for incoming water with equal intervals of 10 cm to show the flood extent at different peak flood levels.

Water maps at a water level of 500, 400 and 300 cm at Akka

Figures 4-6 show the flooded area at a peak flood of 500, 400 or 300 cm at the gauge of Akka compared to the maximally inundated areas, i.e. the flooded area at a peak flood level of about 600 cm. Since 1956 the highest annual flood level at Akka has varied between 336 and 625 cm (Fig. 2). Roughly four periods can be distinguished (Table 1): a flood level of 5-6 m in the 1960s, 4-5 m in the 1970s, 3-4 m in the 1980s and again 4-5 m in the 1990s and 2000s.

Period	Average, cm	Range, cm
1956 – 1969	572	510 - 625
1970 –1981	481	421 - 529
1982 –1993	388	336 - 433
1994 –2010	470	404 - 534

Table 1. The water level in Akka at the peak of the annual flood: average and range (minimum and maximum) during four periods. Same data as Fig. 2.

At a flood level of 300 cm not more than 4832 km^2 is flooded. This is twice as high at a peak flood level of 400 cm (9777 km^2). At 500 cm 17,313 km^2 is flooded and at 600 cm an estimated 22,000 km^2. The latter is an extrapolation since Zwarts & Grigoras (2005) based their analysis on satellite images where the flood height varied between -2 and 511 cm at the gauge of Akka.

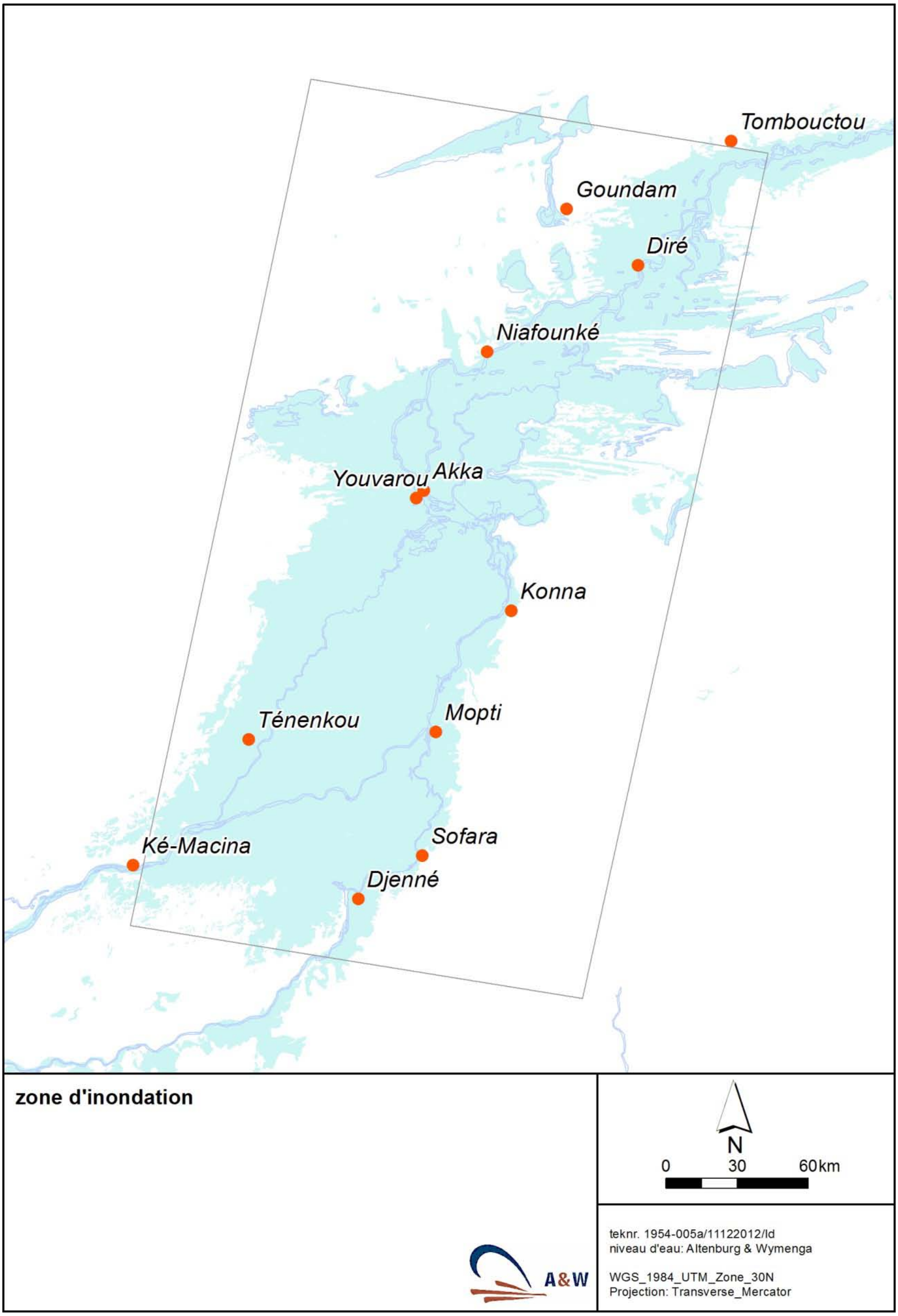


Fig. 3. The inundation zone of the Inner Niger Delta (blue), such as indicated on 11 topographical maps published by IGN in 1956. The maps are based on aerial photographs from the early 1950s when the floods were very high. The total surface of the floodplains amounts 31,448 km^2. The oblique rectangle refers to the area for which we determined the relationship between flood extent and flood level (see Fig. 4-7). The inundation area within the rectangle amounts to 27,352 km^2.

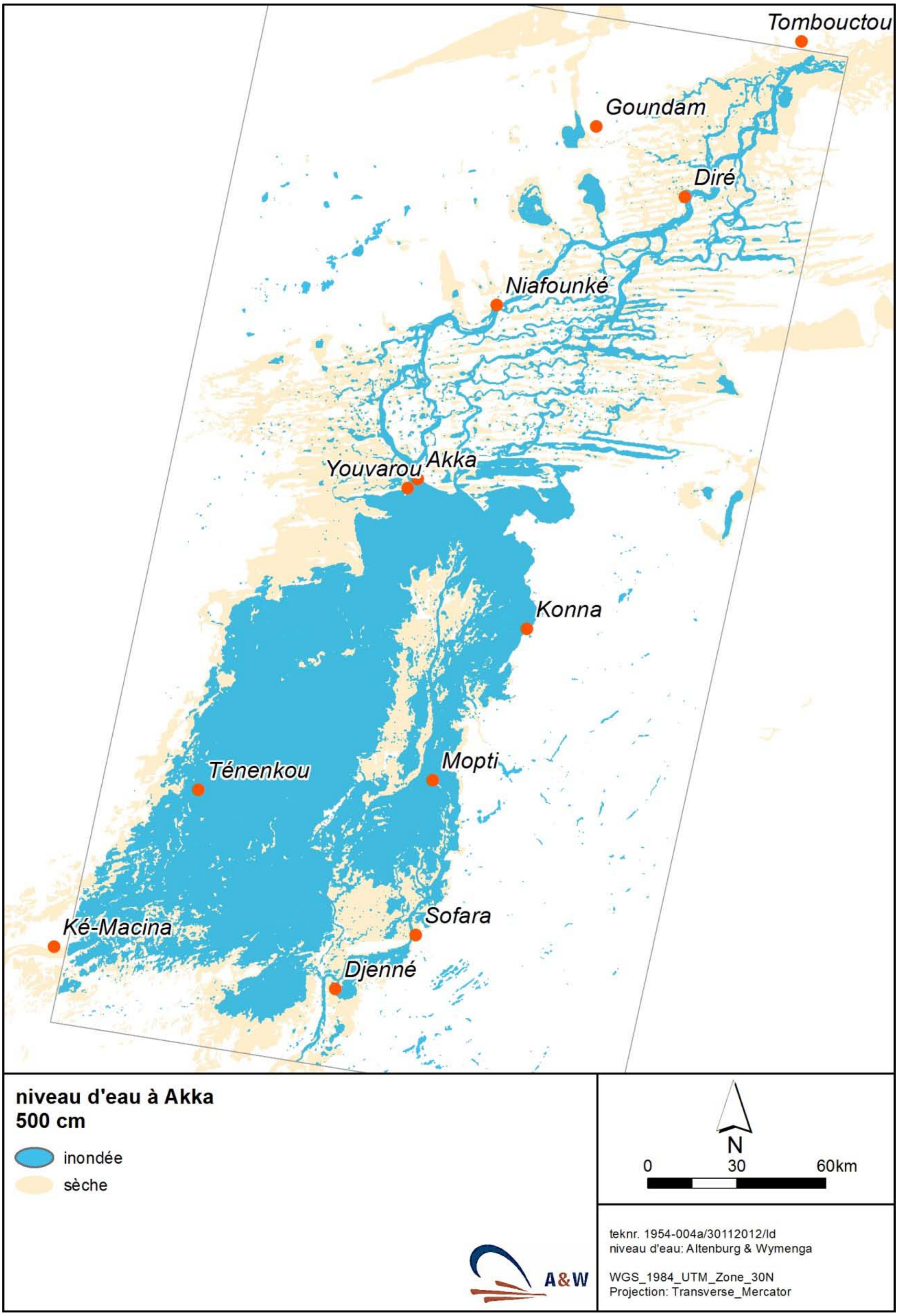


Fig. 4. The flooded area at a water level of 500 cm at the gauge of Akka (blue; total surface 17,313 km^2) within the oblique rectangle, compared to the total inundation zone at a high flood of about 600 cm (Fig. 3; yellow).

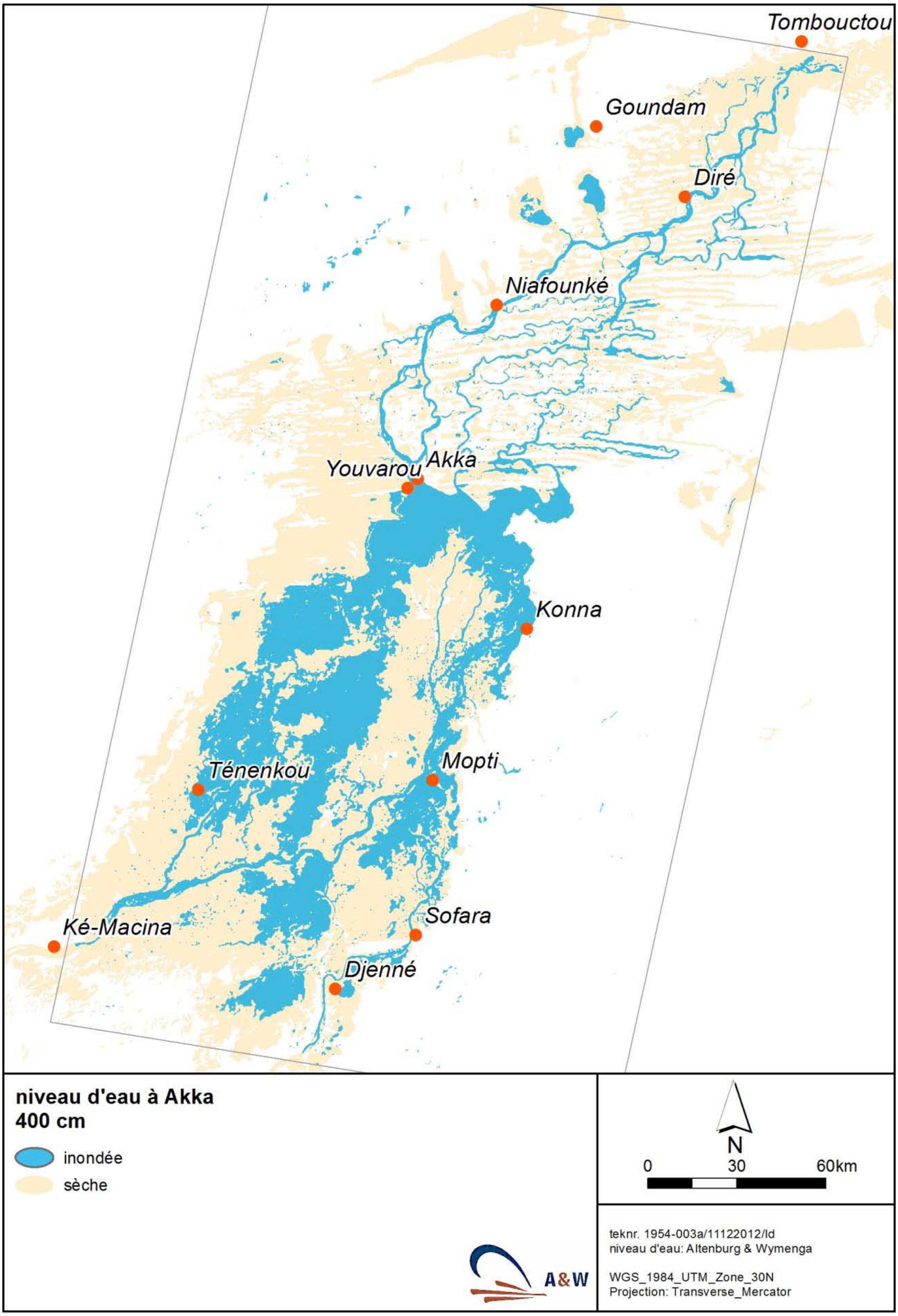


Fig. 5. The flooded area at a water level of 400 cm at the gauge of Akka (blue; total surface 9777 km^2) within the oblique rectangle, compared to the total inundation zone at a high flood of about 600 cm (Fig. 3; yellow).

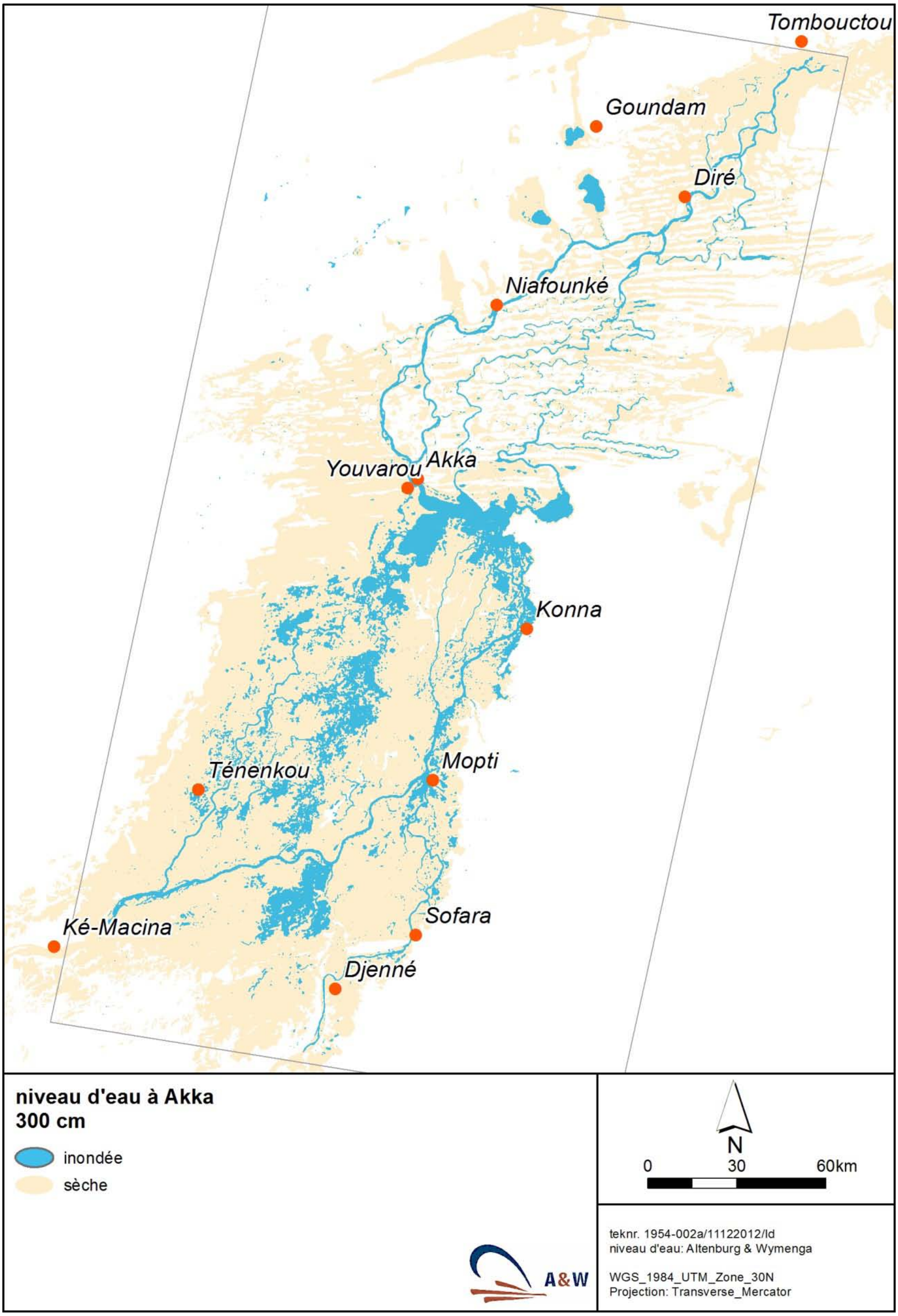


Fig. 6. The flooded area at a water level of 300 cm at the gauge of Akka (blue; total surface 4832 km^2) within the oblique rectangle, compared to the total inundation zone at a high flood of about 600 cm (Fig. 3; yellow).

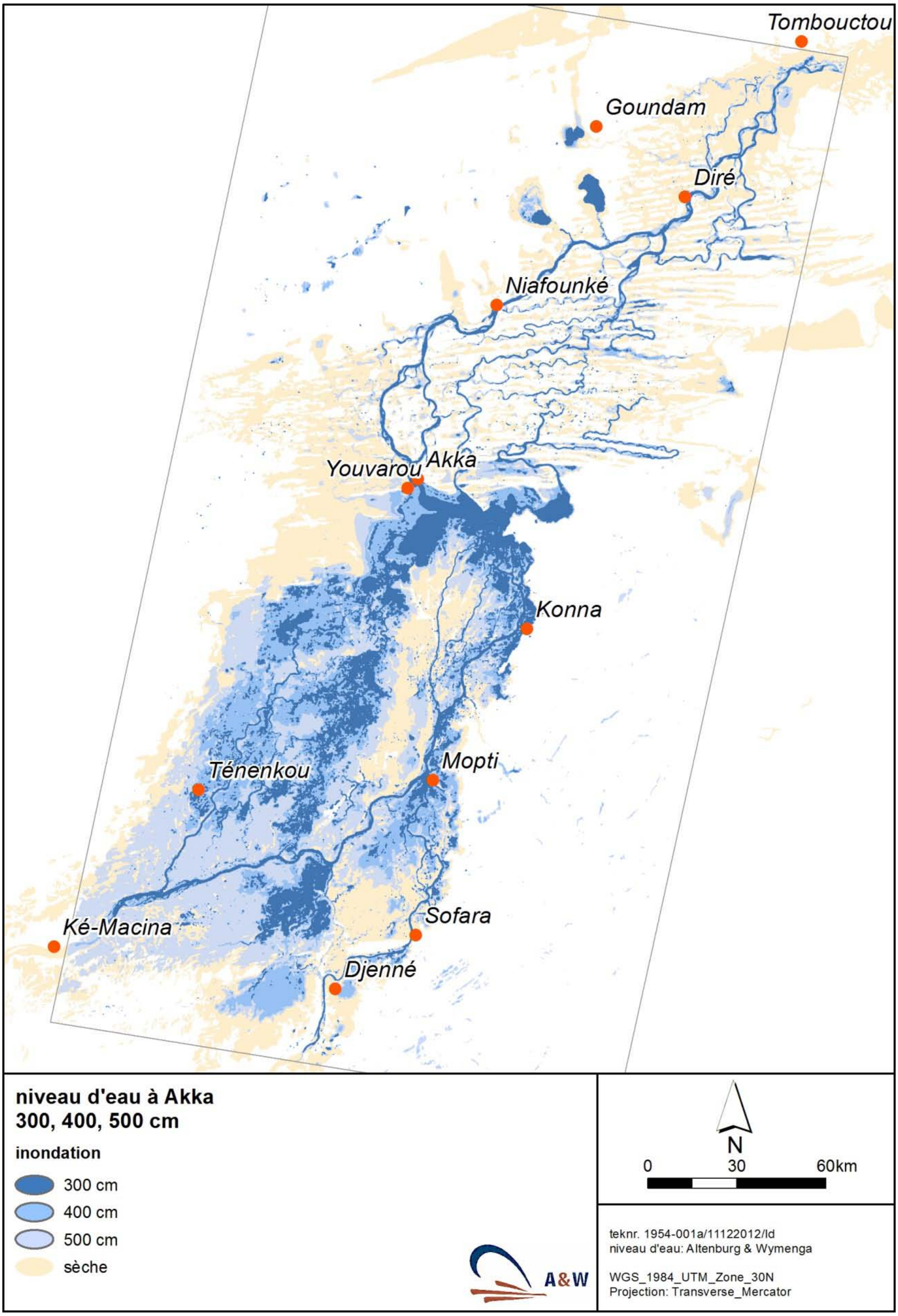


Fig. 7. The flooded area at water level of 300, 400 or 500 cm at the gauge of Akka (data from Fig. 4-6) (blue) within the oblique rectangle, compared to the total inundation zone at a high flood of about 600 cm (Fig. 3; yellow).

Water coverage at a water level of 600 cm at Akka

It should be noted that the estimated maximal flood extent of 22,000 km^2 at a peak flood of 600 cm is still substantially less than the total floodplain of 31,448 km^2 as shown on the IGN maps (Fig. 3). This apparent discrepancy is due to:

1. Fig. 3 includes the floodplains along the Bani upstream of Djenné and along the Niger downstream of Timbuktu; when the floodplains outside the oblique rectangle in Fig. 3 are excluded, there remains a surface area of 27,352 km^2.
2. Fig. 3 shows the total area flooded at a maximum in the course of a year, whereas Fig. 4-7 show the flood extent when the flood has reach a peak of 300, 400 or 500 cm. Due to the shallow northward slope of the floodplain flooding in the north is delayed with three months; by that time the southern floodplain has already been drained of water. Because our remote sensing analysis is based on actual water coverage (Fig. 4-7), the area flooded at any one time is always less than the total area flooded in the course of a year.

Although the flood extent at a peak flood of 600 cm is not precisely known, we may safely assume that all peripheral lakes are filled by the flood. Moreover, the zone indicated as yellow in Figures 4-7 ("yellow zone") as far as situated between Mopti and Niafunké is flooded at the peak of the flood. At that moment, the yellow zone in the south (between Ké-Macina and Sofara) is already deflooded whereas the flood has not yet reached the higher floodplains (yellow zone in Fig. 4-7) north of Diré.

Water coverage in the dry season

Figures 4-7 show the flood extent when the flood has reached a certain level. After that the water level in the Inner Niger Delta gradually declines until May-June. There is no relationship, at least during the last years, between the maximum annual flood level and the water level half year later in early June, which is probably due to variable amounts of water added and taken from the river system upstream of the Inner Niger in the dry season: much water is released from the Sélingué reservoir in the dry months but at the same time also much water is taken from the river at Markala by Office du Niger. Hence, the water level in the Inner Niger Delta during the dry season varies from year to year independent of the peak flooding.

The area still covered by water at such low water levels is limited. All floodplains are dry and, apart from the lakes and depressions being isolated in this stage of the flood cycle, the remaining water is found in the river bed of the Niger and the Bani. Before the onset of the raining season the Diaka, the main branch of the Niger between Diafarabé and Lac Walado is dry, as well as the many small branches, called Mayo's (of which the Mayo Dembi is the largest).

At a water level of 100 cm the surface area being covered by water amounts to 1616 km^2. This declines to 758 km^2 at a water level of 0 cm, a loss of 858 km^2 because the rivers become narrow and more and more sandbanks appear in the river bed, e.g. in the River Niger SW of Konna (Fig. 8).
At these low water levels, the three lakes in the centre of the Inner Niger Delta - Lac Debo, Lac Walado, Lac Korientze - remain connected to the river system. Lac Korientze is a deep lake and its shape does not change much at extremely low water levels, but Lac Walado and especially Lac Debo get smaller (Fig. 8).

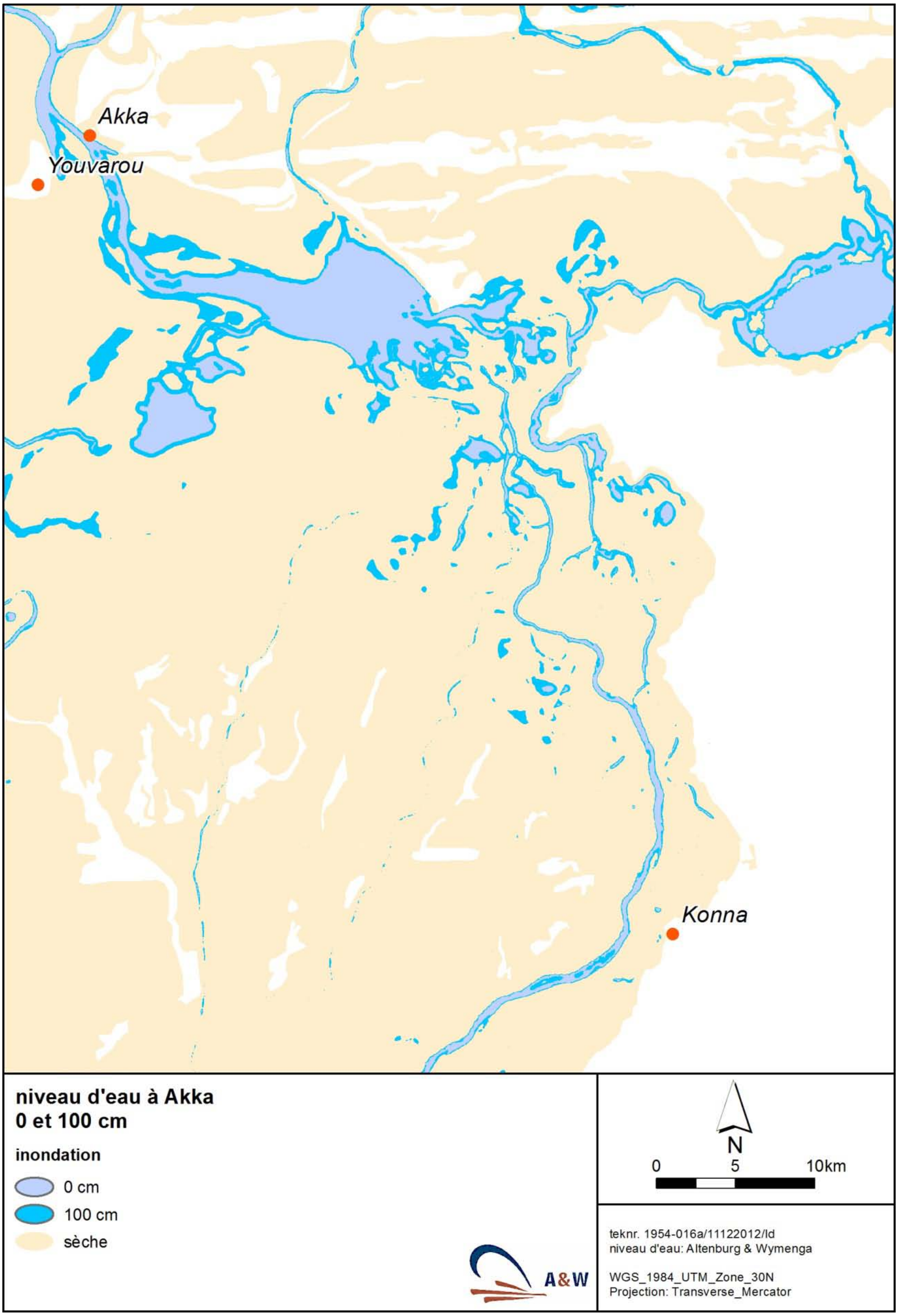


Fig. 8. The flooded area at water level of 0 or 100 cm at the gauge of Akka compared to the total inundation zone at a high flood of about 600 cm (Fig. 3; yellow). A selection has been made for the area between Akka and Konna. Note that a water level of 100 cm all floodplains are already dry, except the shallow borders of Lac Debo.

3 Vegetation

Zoning of the vegetation
The Inner Niger Delta is vegetated with plant and tree species that are adapted to steep fluctuations in water level, seasonal flooding and long dry periods. Wild rice *Oryza barthii*, for example, produces 2-metre-long stems and occupies the zone where the water column reaches up to 2 metres. Another grass species, *Echinochloa stagnina*, locally known as *bourgou*, has stems up to 3-6 metres and grows where the water depth is 4 m on average. During flooding, wild rice, *bourgou*, and also *Vossia cuspidata* (known as *didéré* in the Delta), form huge floating meadows. *Bourgou* has a high nutritional value and is therefore also planted by local people to be used as fodder for cattle during the dry season. Since the production of *bourgou* increases with water depth, the people plant *bourgou* in deeper water than wild *bourgou* would normally occupy (Zwarts et al. 2005).

People are cultivating an increasing proportion of the floodplains to grow rice. Cultivated rice *Oryza glaberrima* requires the same water depth zone as do wild rice and flood forests, and so extension of cultivated rice fields occurs at the expense of natural habitats. For similar reasons, forests have been removed on many places (see chapter 5).

The highest floodplains are covered by a tall grass species, Black Vetiver grass *Vetiveria nigritana*, and locally by *Acacia seyal* forests (Red Acacia or Shittim Tree). The lowest floodplains often become green as soon as a dense vegetation of grasses and Guinea Rush *Cyperus articulatus* emerges after the flood has passed. These green floodplains, however, are short-lived and quickly transform into dry dusty steppe with hardly any vegetation, a combined effect of the withering sun and intensive grazing by cattle, sheep and goats.

The distribution of vegetation zones can be described as a function of water depth, but as the flood level undergoes considerable annual variation, three questions arise: (1) do plant species colonise different zones with a change in flood level, and if so, does it occur immediately or is it delayed, (2) is a change in distribution mirrored by a change in the surface covered by water, and (3) what is the human impact on these natural changes?

There was indeed a shift in the distribution of *bourgou*, *didéré* and cultivated rice following changes in flood level. For instance, the low-lying Lac Walado has always been a lake where floating vegetation was restricted to the border zone. The lake was colonised by *bourgou* in 1985 and 1986, after the flood level had been low for a number of years (Zwarts & Diallo 2002). In the same period that *bourgou* settled in Lake Walado, elsewhere much larger *bourgou* fields were replaced by *didéré*. During the 1990s and early 2000s, we plotted *bourgou* fields for which we calculated maximum water depth using the gauge measurements at Akka and the digital flooding model. These data clearly show that *bourgou* usually grows where maximum water depth fluctuates between 3 and 5 m; *bourgou* showed the expected colonisation in response to a change in water level, albeit with a delay of about two years.

Expected vegetation change in response to a reduced flooding
Given that *bourgou* is dominant where the maximal water depth amounts to 3-5 m, the surface area of optimal *bourgou* habitat can be calculated for different flood levels, using the digital flooding model. In the same way the zone can be determined where *didéré* is expected to be dominant (water depth 2-3 m). Wild as well as cultivated rice is found at a similar water depth (1-2 m) and Vetiver grass in more shallow water (0-1 m).

The expected zoning of these four dominant vegetation types is shown in Fig. 9-12 for a peak flood level of 600, 500, 400 and 300 cm at Akka. It is evident from the maps that relatively small changes in flood level of the Inner Niger Delta have a large impact on the distribution of plant species restricted to a narrow range of water depths.

Table 2 gives for the distinguished global vegetation types the total surface areas, - in surface (km^2) as well as proportion of the total floodplain (%).

Table 2. The surface (km^2) being flooded at an annual peak flood level of 600 cm, 500 cm, 400 cm or 300 cm at the gauge of Akka, given separately for five water depth classes. The vegetation being dominant in the different water depth classes is indicated. The indicated surfaces refer to the area enclosed in the oblique rectangle shown in Fig. 3. The same data are shown in Fig. 9-12, presenting the expected shift of the vegetation types at a lower annual peak flood level. N.B.: the water depth refers to the water column during the peak flood.

habitat, km^2	water depth, m	peak flood level			
		600 cm	500 cm	400 cm	300 cm
open water	>5m	758	758	758	758
bourgou	3-5m	4074	2070	859	0
didéré	2-3m	4945	2004	1211	859
rice	1-2m	7536	4945	2004	1211
vetiver	0-1m	4687	7536	4945	2004
TOTAL		22000	17313	9777	4832

habitat, km^2	water depth, m	peak flood level			
		600 cm	500 cm	400 cm	300 cm
open water	>5m	3.4%	4.4%	7.8%	15.7%
bourgou	3-5m	18.5%	12.0%	8.8%	0.0%
didéré	2-3m	22.5%	11.6%	12.4%	17.8%
rice	1-2m	34.3%	28.6%	20.5%	25.1%
vetiver	0-1m	21.3%	43.5%	50.6%	41.5%
TOTAL		100%	100%	100%	100%

Since we have no data on the water depth of the zone remaining covered by water at 0 cm at Akka, we had to assume that the area (indicated as open water in Fig. 9-12) would remain open water independent of the water level. That is not entirely true, however. As remarked already, *bourgou* started to colonize the open water of Lac Walado in years with a very low water level. Hence *bourgou* will not disappear from the Inner Niger Delta if the water level would decline to 300 cm, but find a last refuge in Lac Walado and also Lac Debo. This does not change our conclusion that the surface area of *bourgou* will show a very large decline at a reduced flood level.

The Inner Niger Delta is no undisturbed natural ecosystem. The floating grass fields and the cultivated rice fields on the floodplains seem to be fully natural, but part of the *bourgou* is planted year after year and farmers work hard to remove wild rice and *didéré* from their rice fields. Moreover, two million cattle and four million sheep and goats graze the floodplains after the flood has passed. All in all, the Inner Niger Delta is a semi-natural habitat of which the natural resources are heavily exploited by the local population. Wild and cultivated rice are taken together as one category in Figures 9-12. The next chapters will show where farmers cultivate rice and where forests are still found.

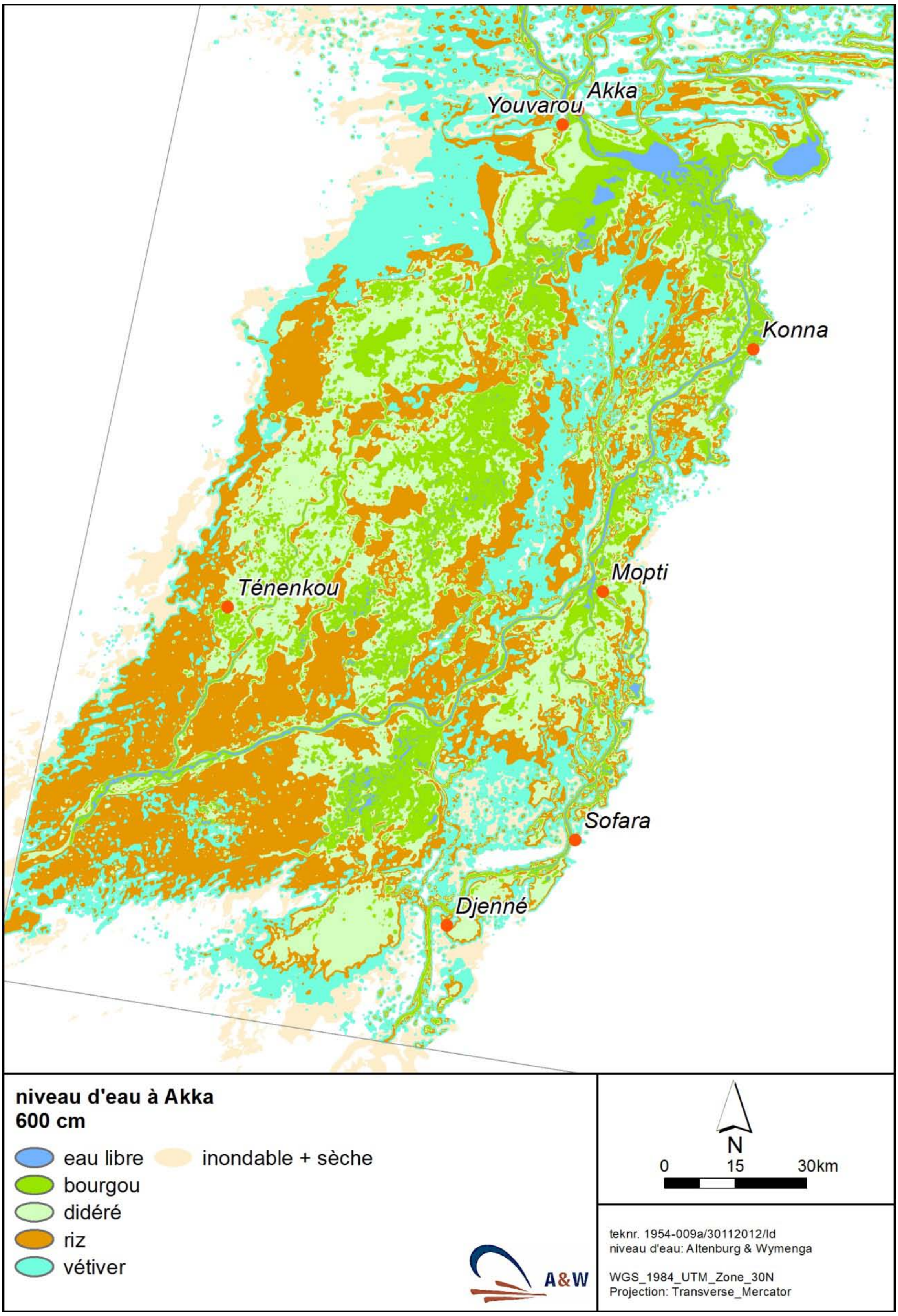


Fig. 9. The dominant vegetation types in the southern half of the Inner Niger Delta if the annual peak water level would be 600 cm at the gauge of Akka on average; further explanation in text.

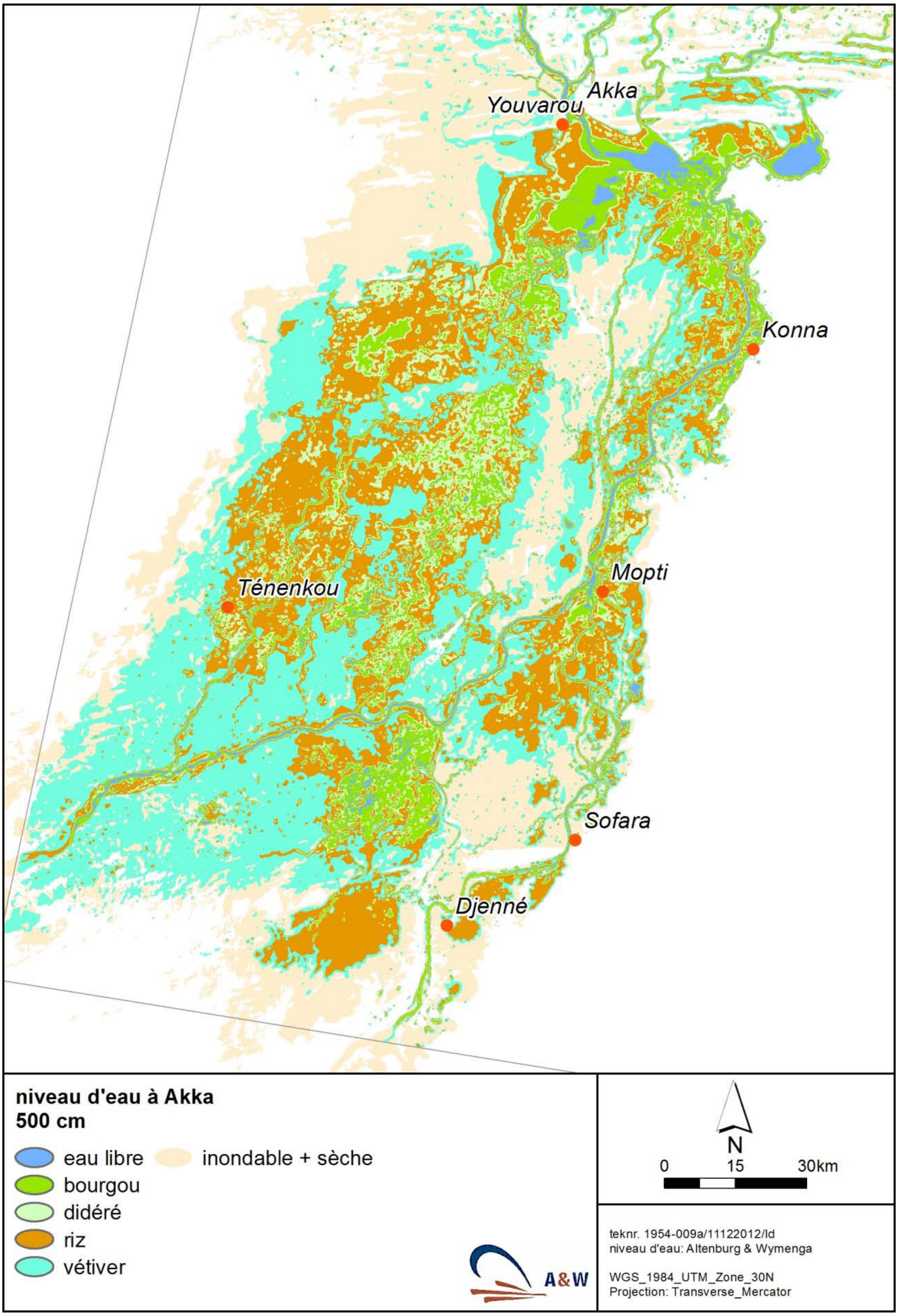


Fig. 10. The dominant vegetation types in the southern half of the Inner Niger Delta if the annual peak water level would be 500 cm at the gauge of Akka on average; further explanation in text.

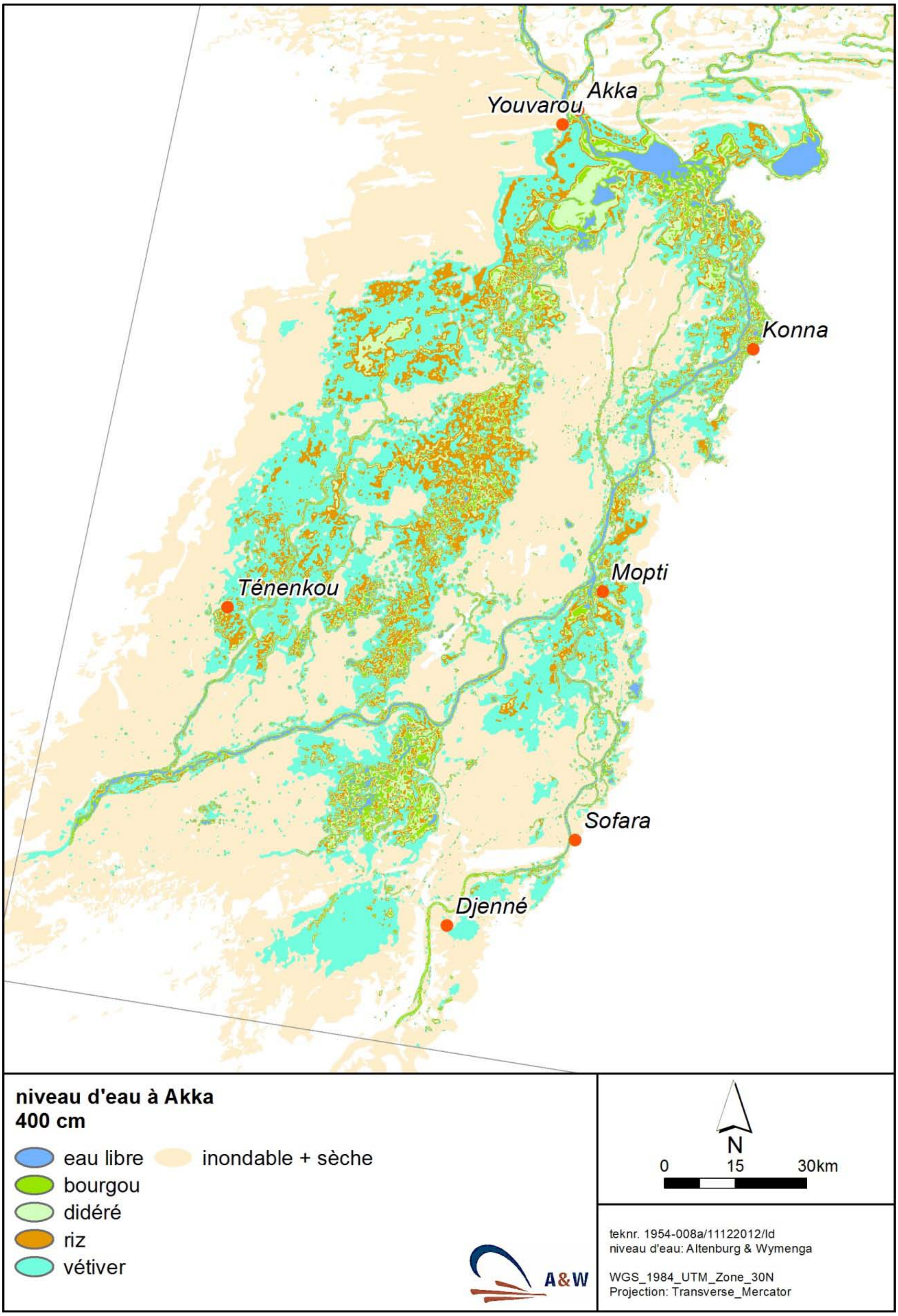


Fig. 11. The dominant vegetation types in the southern half of the Inner Niger Delta if the annual peak water level would be 400 cm at the gauge of Akka on average; further explanation in text.

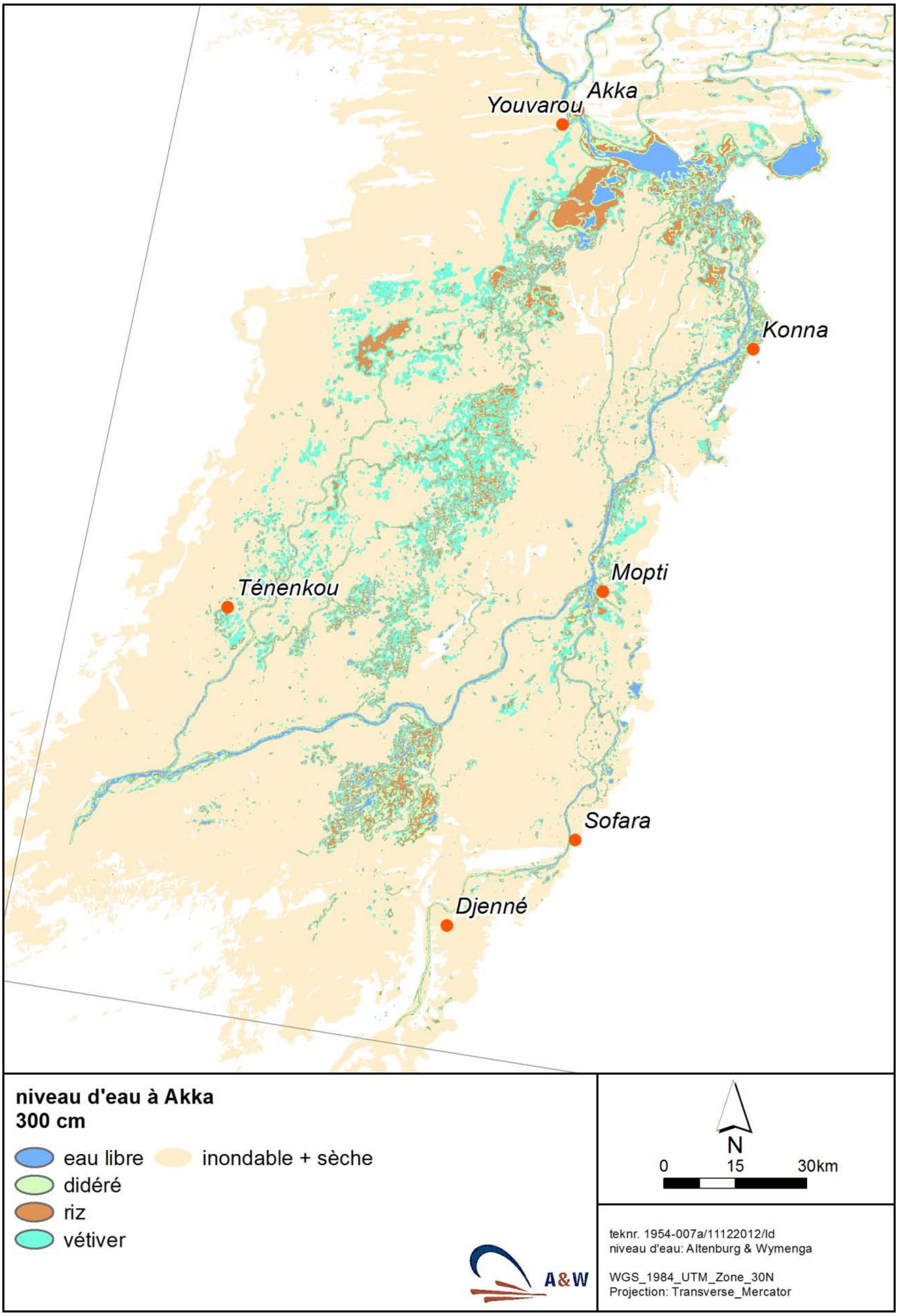


Fig. 12. The dominant vegetation types in the southern half of the Inner Niger Delta if the annual peak water level would be 300 cm at the gauge of Akka on average; further explanation in text.

4 Farmland

Farmers in the Inner Niger Delta grow rice on the floodplains, and millet and sorghum on the higher grounds and in the surroundings of the Delta. The farmers on the floodplains grow a rice variety *Oryza glaberrima* or floating rice which is well adapted to grow upwards with the rising water. Farmers have to sow the rice in a zone being flooded by one, or still better, two metres water to guarantee a flooding period of 3 months and achieve a successful harvest. Farmers cannot predict the flood level when they have to sow their rice at the onset of the local rains in June or July, but the flood level has shown a long-term fluctuation (Fig. 2), so the flood levels during the previous 5 or 10 years may therefore serve as a guideline in their decision where to cultivate their rice.

The annual maximal flood level varies between 400 and 500 cm in the present situation (Fig. 2). The zone with an optimal depth for growing rice (1-2 m water at the peak of the flood) is indicated for a flood level of 500 cm (Fig. 10) and 400 cm (Fig. 11). In total, 4945 km^2 would be available for rice

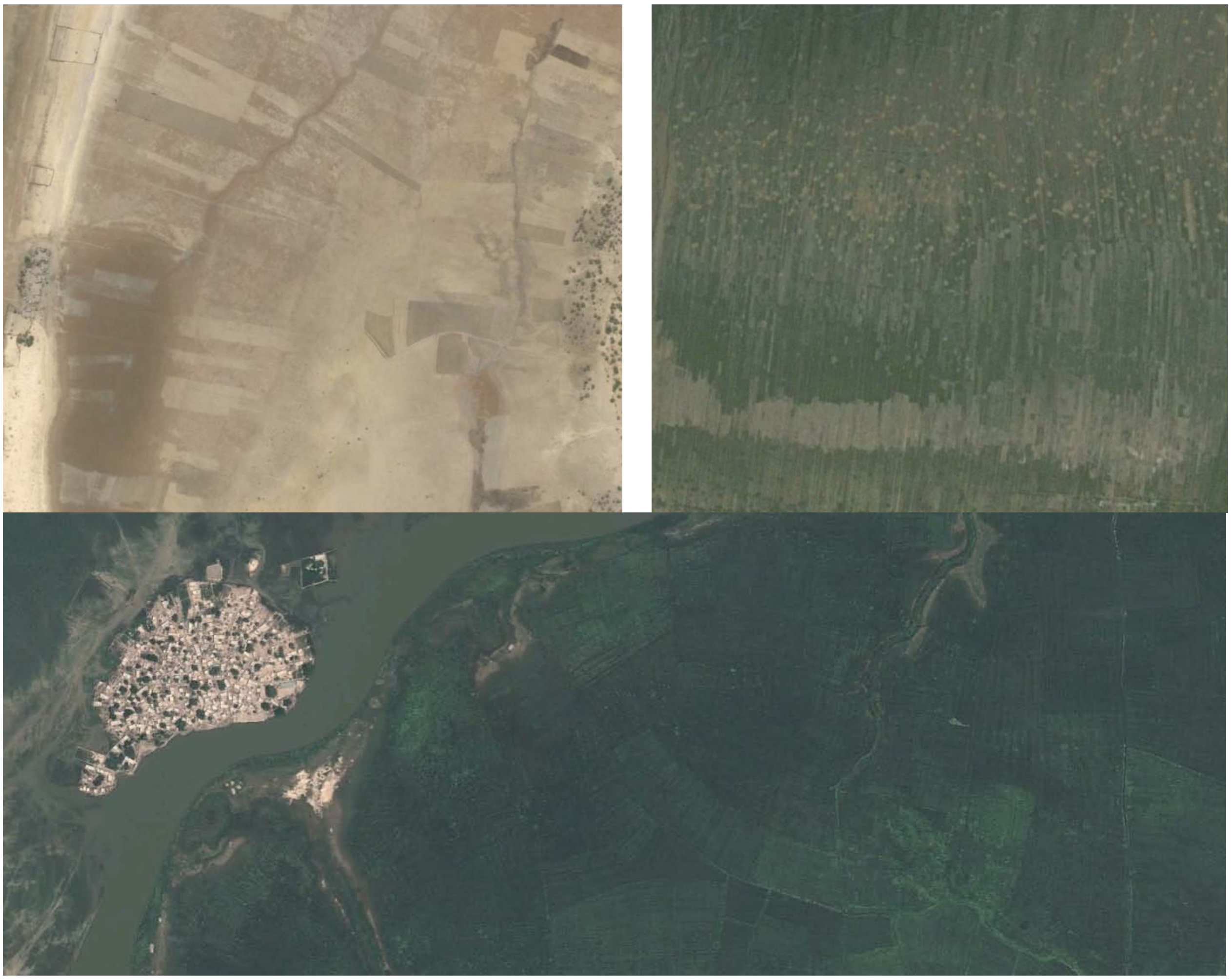


*Fig. 13. Farmland in the Inner Niger Delta is clearly visible on high resolution satellite images, - during as well as after the harvest. Top left: shallow valley where in the wet season rice has been grown (*riz de bas fonds*). Top right: elongated fields from the edge of the lake to deeper water, - used by farmers during receding water on the immersed grounds (*riz de décrue*). Below: rice fields on floodplains (*submersion libre*) around a village on a levee.*

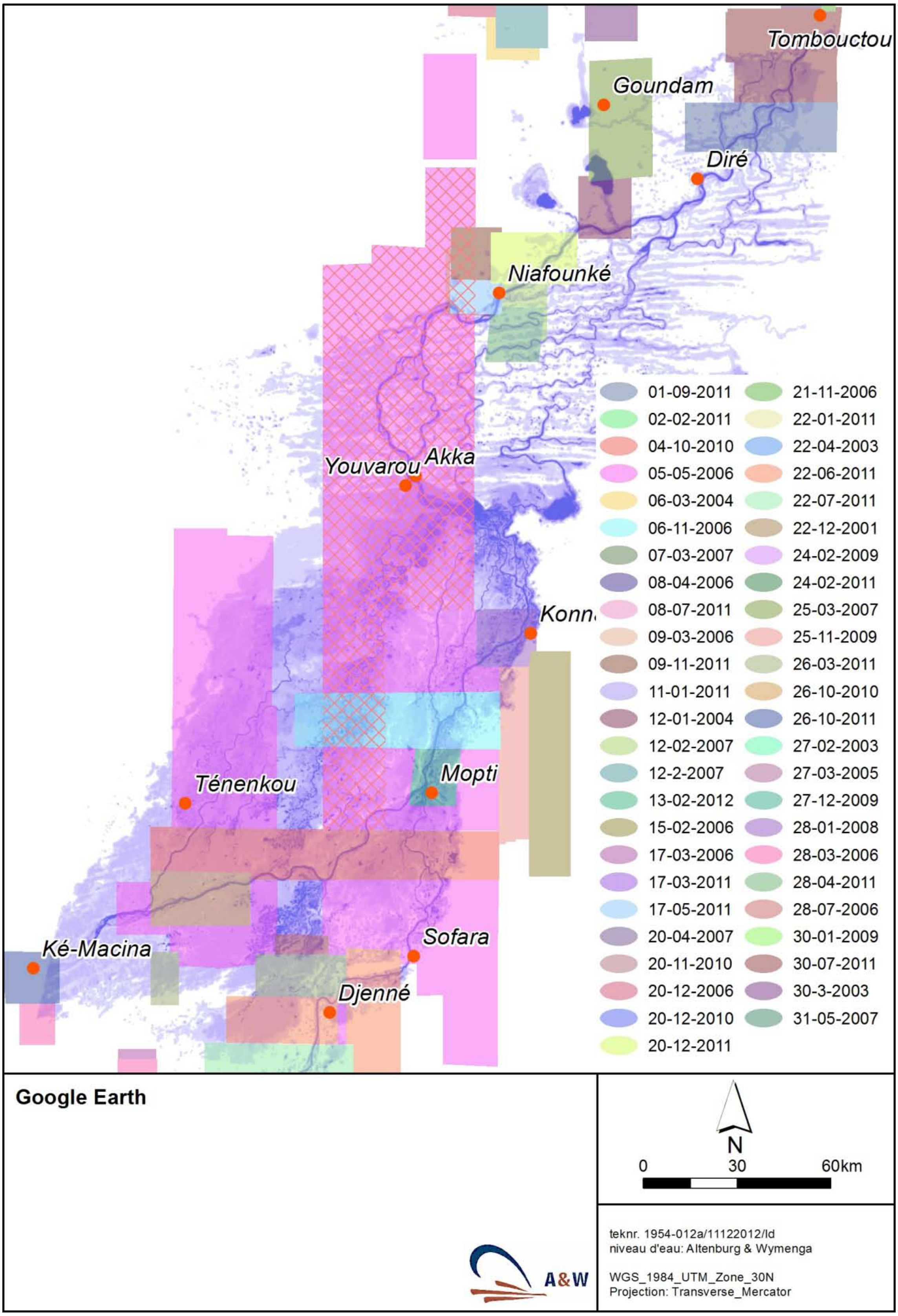


Fig. 14.The coverage of the Inner Niger Delta by high resolution Google Earth images from 2003 onwards. The cross-hatched area refers to area for which the tree canopy has been determined (see next Chapter). Less recent images, usually with a lower resolution, are available for the remaining part of the Inner Niger Delta. The state of affairs, shown on the map for September 2012, changes continuously since more recent images are added; fortunately, the older images remain available in the Google Earth system.

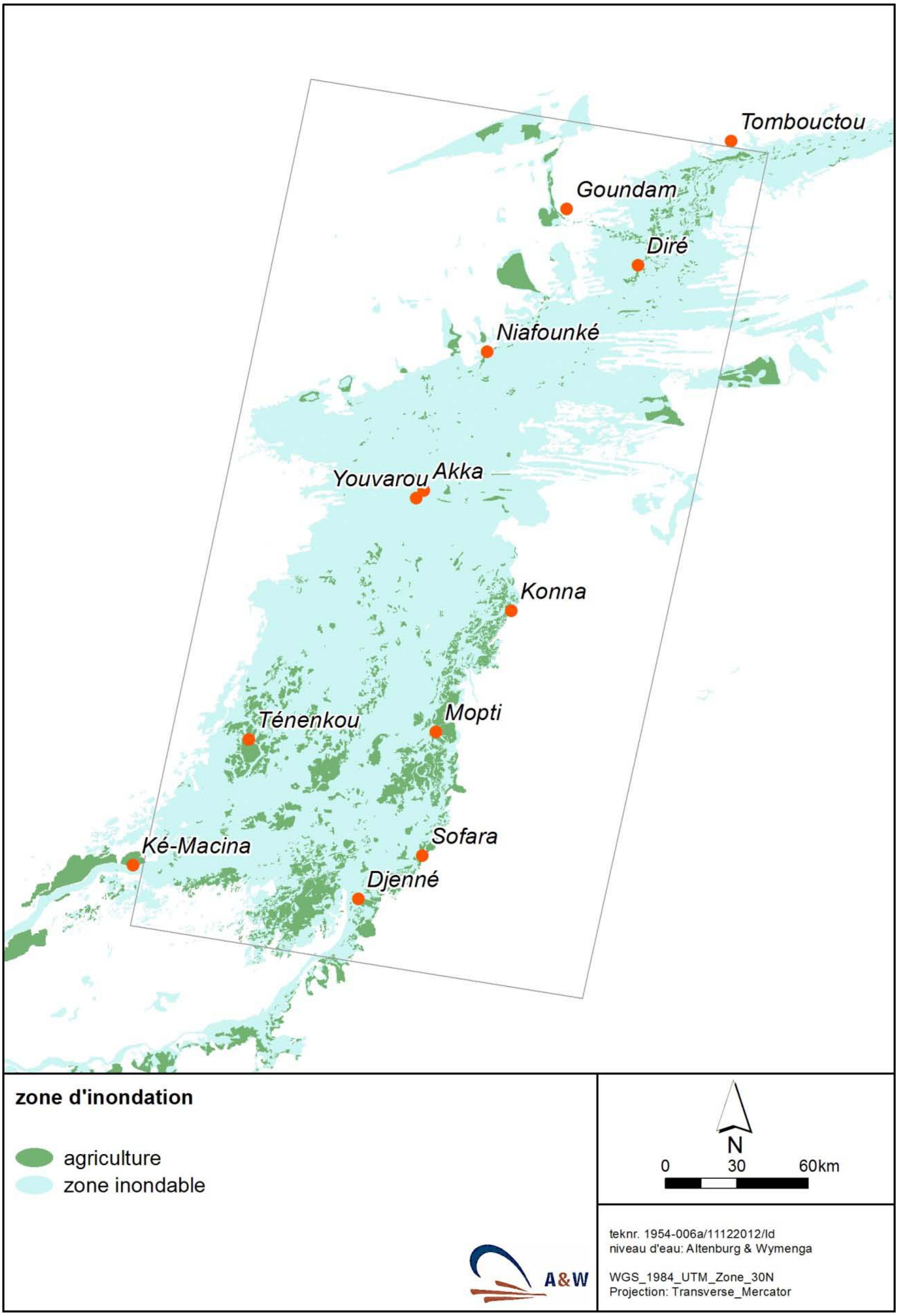


Fig. 15. Farmland (green) in the Inner Niger Delta (inundation zone (blue) from Fig. 3). The arable fields such as visible on Google Earth images taken at different dates (see Fig.14) were plotted in detail on a map. The total surface area of the arable fields amounts to 5005 km^2 of which 4380 km^2 on the floodplains and 624 km^2 being adjacent (e.g. the zone along the Niger River SW of Ké-Macina. Whether land is cultivated in a certain year depends in several areas on the water level. At a high water level, there is no agriculture, or only along the water's edge, in Lac Faquibine (in the very north) and several peripheral lakes, but the lake bottom is cultivated

at a lower water level, - and locally again with no or less arable fields after the lake has not been flooded for several years. Since traces remain visible more than one year, the area indicated as farmland also includes fallow land.

growing at a flood of 500 cm and 2004 km^2 at a flood of 400 cm (Table 2). A large part of this zone is not cultivated and - instead - covered by wild rice. The area in the Inner Niger Delta being actually cultivated for rice has increased from 160 km^2 in 1920 to about 1600 km^2 in 1980-2000 (Gallais 1967, Marie 2002, Zwarts & Kone 2005).

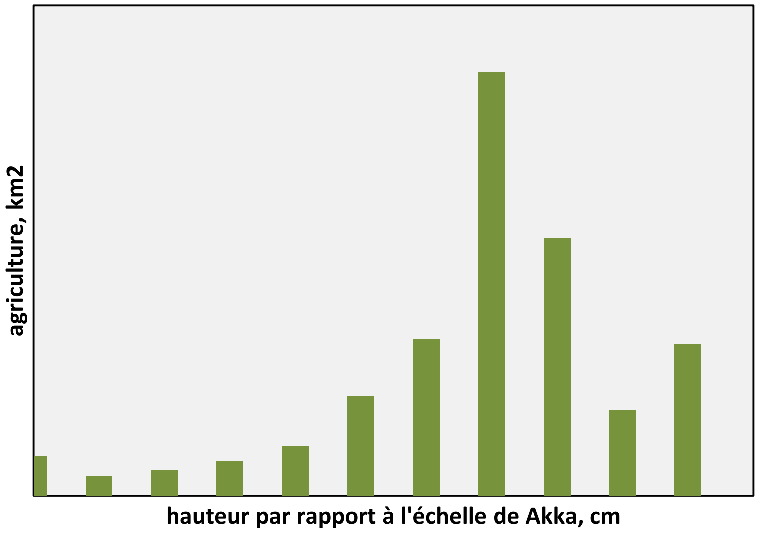


Fig. 16. The surface area being cultivated in the Inner Niger Delta as a function of the elevation relative to the scale of Akka; 25 = 0-50 cm, 75 = 50-100 cm, etc. At a peak flood of 500 cm, farmland at 375 (350-400) cm is covered by 100-150 cm of water. Total surface of arable land within the Inner Niger proper (the oblique rectangle in Fig. 3) is 3285 km^2.

Rice fields dominate in the low-lying floodplains; their total surface exceeds since some years the just mentioned 1600 km^2, but how much more is difficult to say. The areas being categorised as farmland in Fig. 15 include several types of agriculture. Zwarts & Kone (2005) arrived for the Inner Niger Delta at 1800 km^2 of "wet" farmland, of which 1200 km^2 rice fields on the floodplains (*submersion libre*) in the southern Inner Niger Delta, 350 km^2 managed by Opération Riz Mopti (*submersion contrôlée*) between Konna and Djenné, 126 km^2 irrigated fields (of which most between Diré and Timbuktu), 106 km^2 immersed areas in lakes (*riz de décrue*; mostly in the northern Delta), 40 km^2 depressions (*riz de bas fonds*; mostly in the northern Delta). To this may be added 350 km^2 of rice fields SW of the Inner Niger Delta proper managed by Opération Riz Ségou (*submersion contrôlée*). Fig. 16 shows that the actual area being cultivated amounts to 3285 km^2, thus much more than the earlier estimate of 1800 km^2 of wet farmland. Assuming that farmland above 450 cm at the gauge of Akka (in total 580 km^2) refers to "dry" farmland, the new estimate of the total surface of rice fields is about 2700 km^2.

More and more land is being irrigated. These irrigation fields are usually situated along the rivers Bani and Niger on the higher parts of the floodplains or even on areas being never inundated. That is why motor pumps are needed to pump water from the river to the fields. Nearly all farmland along the Niger River in the northern Delta (Fig. 17) depends now on irrigation.

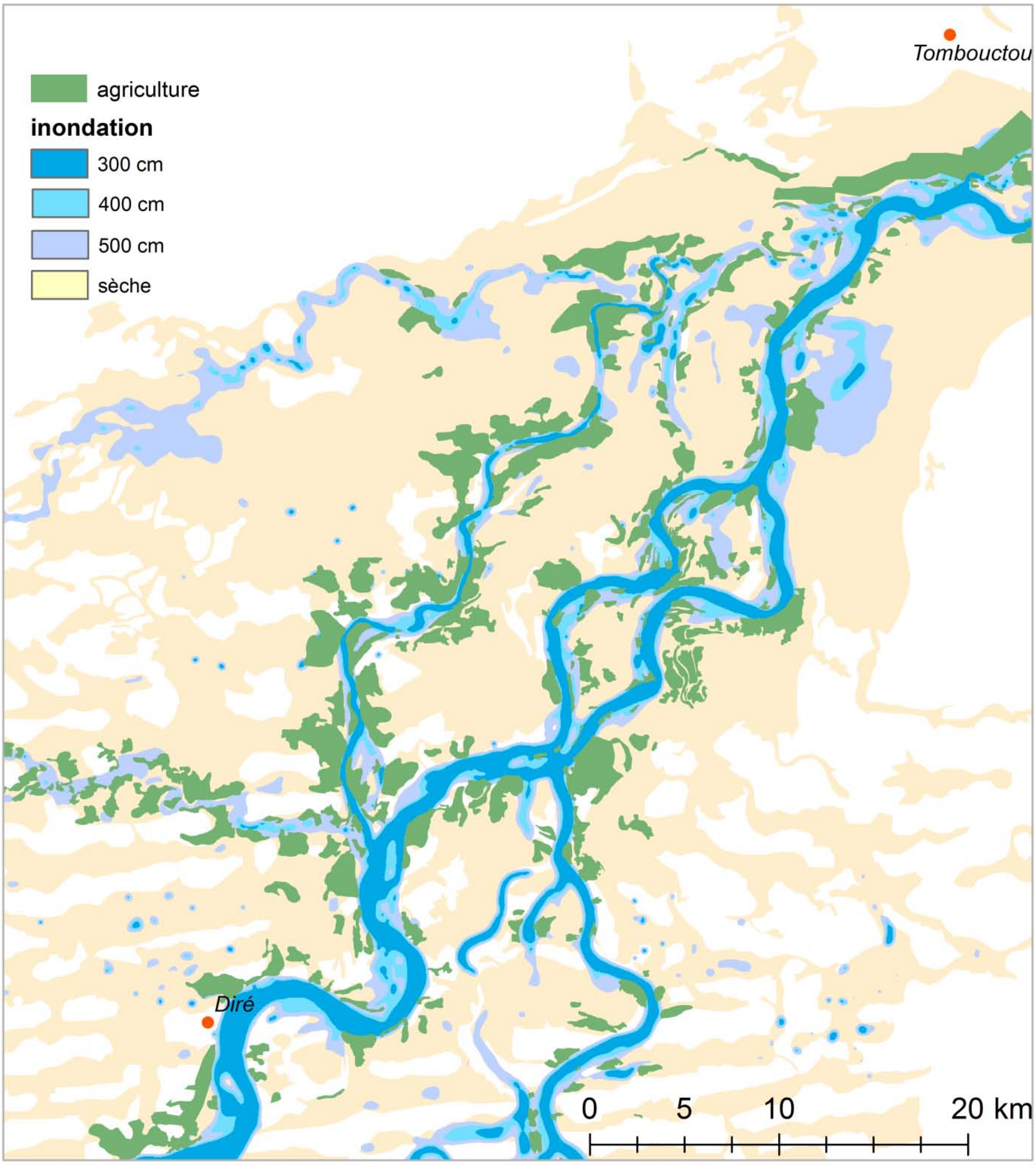


Fig. 17. Farmland in the northern Inner Niger Delta between Diré and Timbuktu; same information as Fig. 15, but given here on a larger scale. The rainfall is insufficient in this zone to grow rice or even millet and sorghum, but motor pumps allow farmers to irrigate their fields along the rivers. Most of these irrigated areas have been constructed during the last 20-30 years.

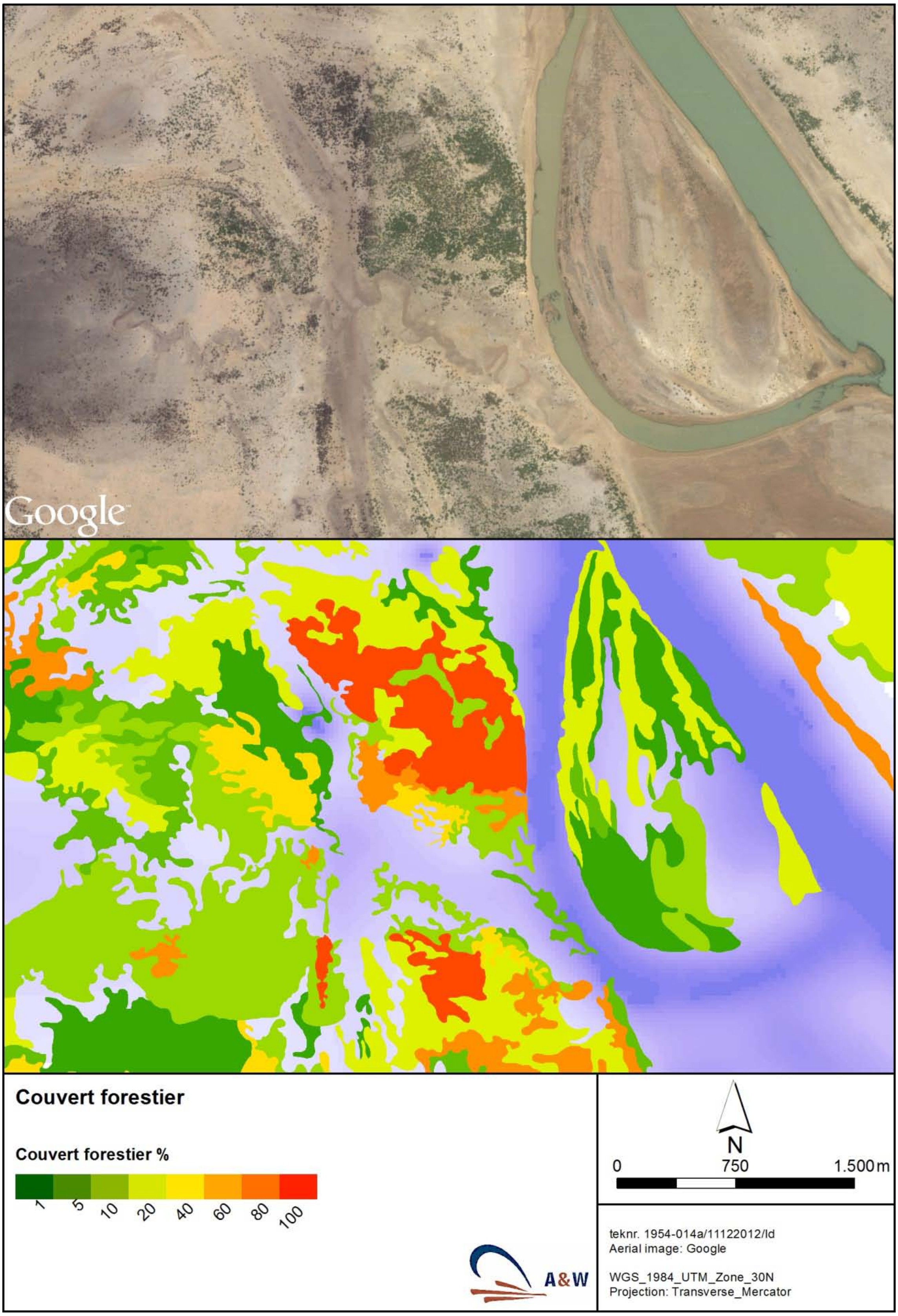


Fig. 18.Google Earth image of a floodplain NW of Youvarou (top). The selected area is partly bare and partly covered by Acacia forest, mainly Acacia seyal*. The tree density is highly variable. The map (bottom) shows the tree canopy for the same area. Eight categories were used to characterise the tree canopy, the relative coverage of the tree crowns in a horizontal plane. The background colours shows the elevation, from dark blue (deep water) to light blue (shallow water), given in 58 categories of 10 cm (0 to 580 cm relative to the gauge of Akka; same data as Fig. 4-7).*

5 Forest

No forests are indicated on the vegetation map of the Inner Niger Delta made by Zwarts *et al*. (2005) since the resolution of the satellite images used by them was too coarse to distinguish trees. Although there are hardly any forests in the Inner Niger Delta, trees occur in many areas, although in a low density. Hence to describe the distribution of the woody vegetation in the Inner Niger Delta it is necessary to distinguish areas with a variable density of trees. We distinguished eight categories based on the canopy, the relative coverage of the tree crowns (Fig. 18).

Mapping the woody vegetation in this way was time-consuming, so only a part of the Inner Niger Delta was done (Fig. 19). Within the selected area of 1956 km^2, woody vegetation was registered on 210 km^2. Thus 89% of the selected area is bare without any tree and within the zones where trees are noted, nearly everywhere the landscape remains very open with only scattered trees (Table 3).

canopy %	surface, %
1	20.4
5	24.1
10	18.6
20	17.6
40	9.7
60	6.2
80	3.3
100	0.1

Table 3. The surface area (%) with a different canopy. A selection has been made of the 1956 km^2 indicated in Fig. 19 minus the zones without any tree (1746 km^2). In nearly half of the zone where trees are found, the relative canopy is 5% or less.

For several reasons there are only a few trees in the Inner Niger Delta. The grazing pressure is so high that trees cannot settle. Within the Inner Niger Delta, less trees are found in the low-lying floodplains (Fig. 20 and 21), but this is not because of the deep flooding since some tree species (*Acacia kirkii*, *Ziziphus spina-cristii*) grow in water being flooded by 3-4 m of water. The Akkagoun and Dentaka forests (Fig. 20) could come into existence in the 1980s when grazing was prevented during some years. A second explanation of the open, bare landscape is that trees are removed by farmers when they made their fields and continue to do so in an attempt to reduce the number of seed-eating birds breeding in the trees in the direct surroundings of their fields. That is why rice field on the floodplains are tree-less (Fig. 19).

The on-going extension of farmland will cause a further reduction of the riverine forests on the remaining floodplains of Inner Niger Delta. On the other hand, dry woodland may reappear in areas being no longer inundated and, for that reason, left by the farmers (see Fig. 21).

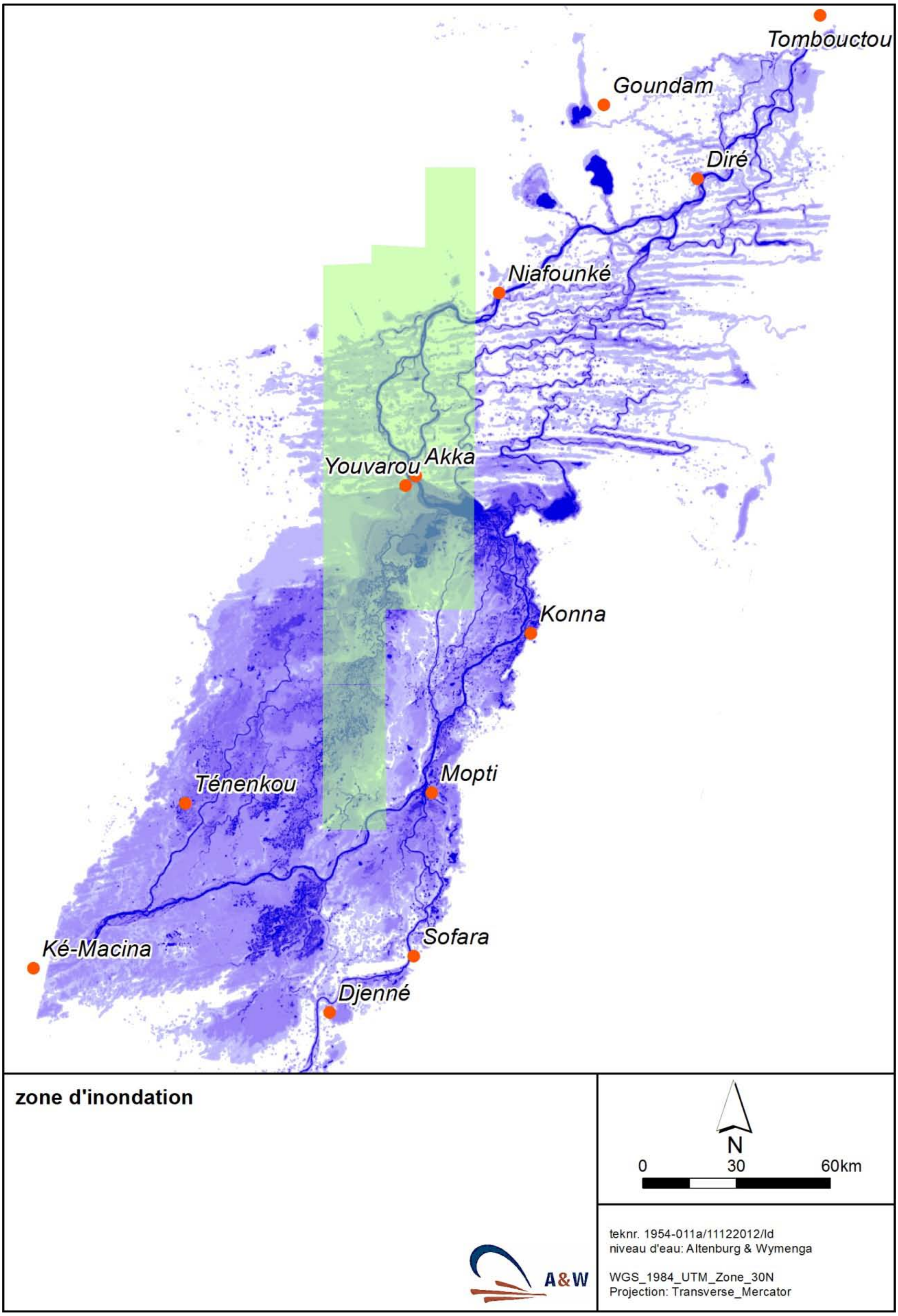


Fig. 19. The area (green) where the tree canopy has been determined in detail. This area amounts to 1956 km² which the larger part refers to a Google Earth image of 5 May 2006; see Fig. 14.

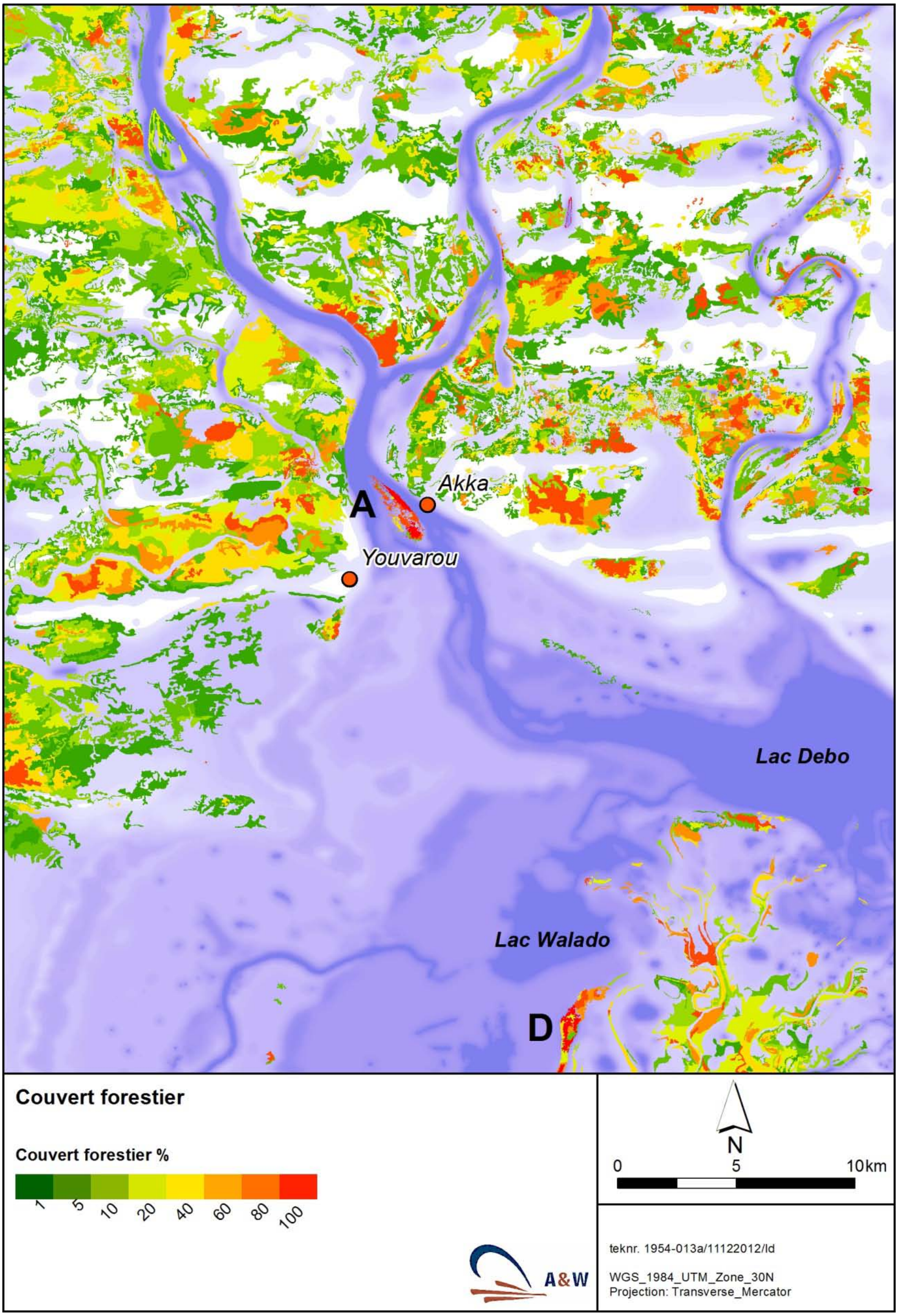
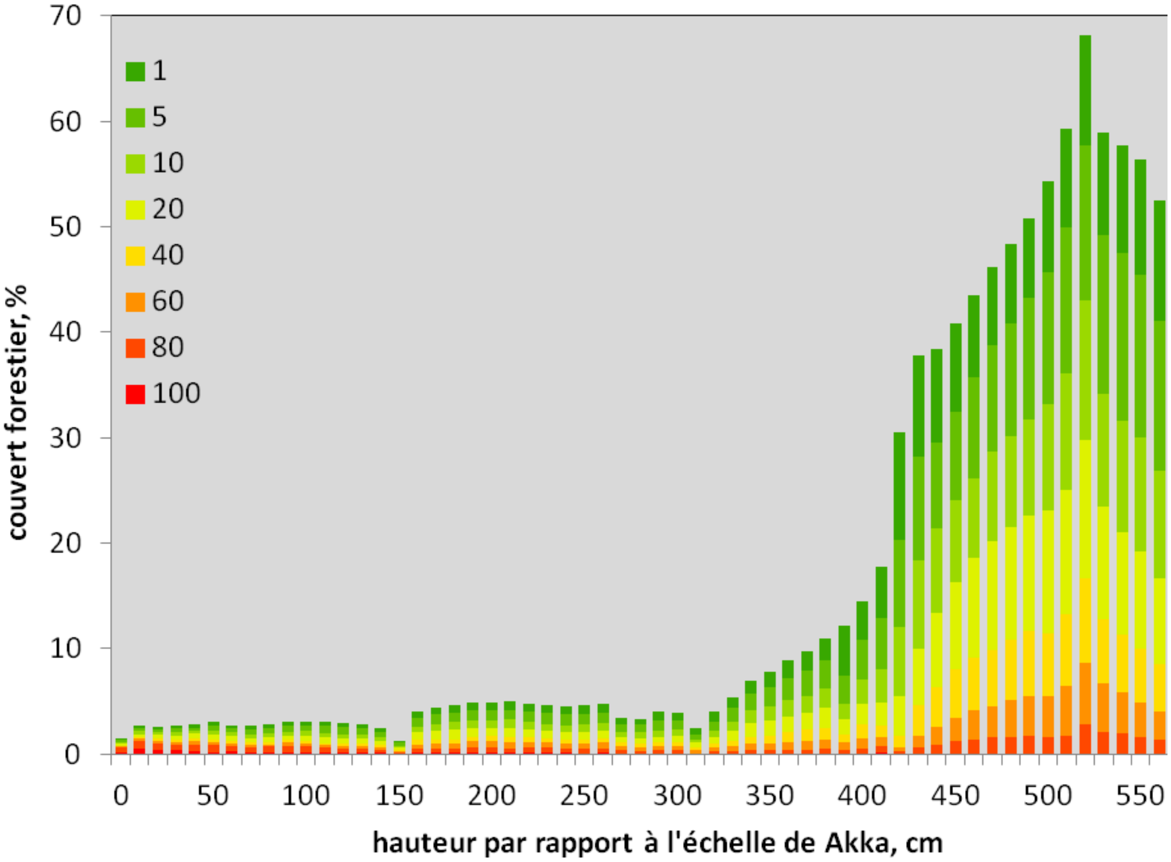


Fig. 20. The tree canopy in the surroundings of Akka and Youvarou. The background colours show the elevation, from dark blue (deep water) to light blue (shallow water) given in 58 categories of 10 cm (0 to 580 cm relative to the gauge of Akka; same data as Fig. 4-7). White areas: no trees and not flooded at a very high flood level of 580 cm. The flood forests of Akkagoun (= A) and Dentaka (= D) are indicated.



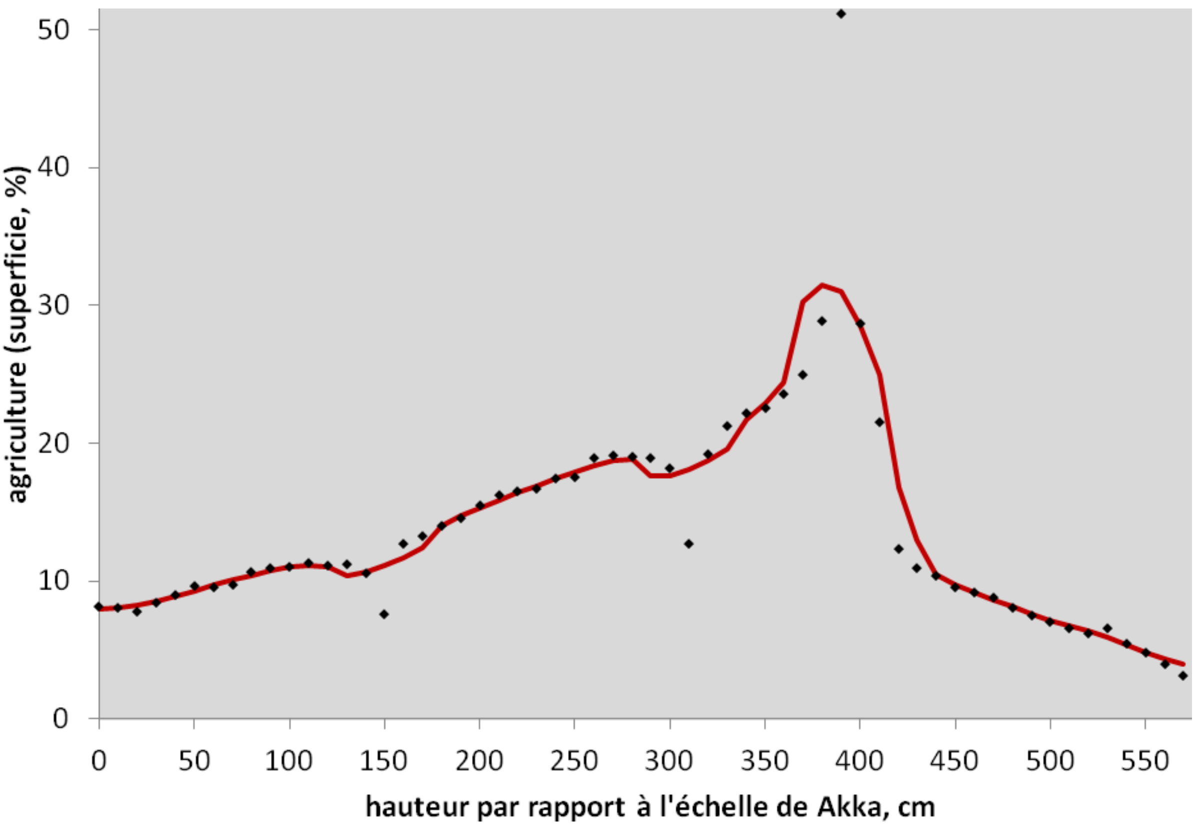


Fig. 21. The percentage per elevation zone in the Inner Niger Delta (altitude relative to the scale of Akka) being (top) covered by forest (shown separately per tree coverage) and (below) agricultural land.

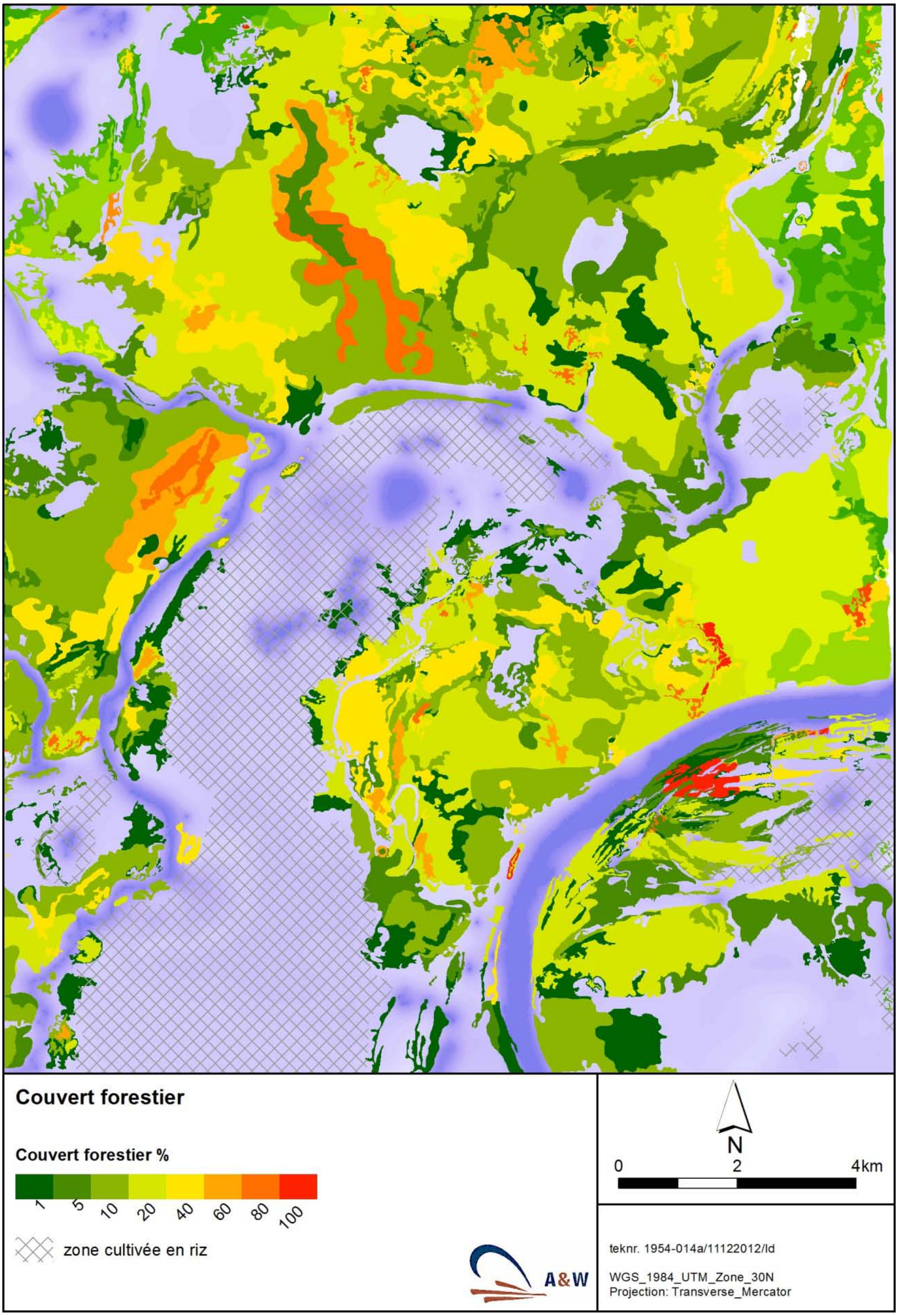


Fig. 22. The tree canopy in the surroundings of Koubaye-Kotaba and Dakobory, halfway between Mopti and Ténenkou, along the Niger River. All trees have been removed where farmers grow rice on the floodplains (riz à submersion libre; cross-hatched). The background colours shows the elevation, from dark blue (deep water) to light blue (shallow water) given in 58 categories of 10 cm (0 to 580 cm relative to the gauge of Akka; same data as Fig. 4-7).

6 Conclusions

During the last 20 years, the flooding of the Inner Niger Delta has varied between 4 and 5 m on the gauge of Akka, which is lower than the wet 1960s but higher than the dry 1980s (Fig. 2). Given the expected likely decline in the Sahelian rainfall and the planned dams in the Upper Niger Basin, the flood levels in the Inner Niger Delta may decline to levels between 3 and 4 m.

Whether the annual peak flood level varies between 4 and 5 m (as in recent years) or between 3 and 4 m (as foreseen) has a huge impact on the area being inundated (Fig. 3-7).

The occurrence of the dominant vegetation types is determined by flooding duration and water depth when the flood reaches its peak. The expected spatial distribution of different vegetation zones at different peak flood levels is shown in four maps (Fig. 9-12). At an average flood level of 300 cm, *bourgou* will nearly disappear due to a lack of sufficient deep water and be replaced by *didéré*. The expected total loss of the vegetation types within the floodplains at a reduction of the Inner Niger has been quantified (Table 2).

High resolution Google Earth images of the Inner Niger Delta (Fig. 14) were used to map farmland (Fig. 15) and calculate its surface area (Table 3; Fig. 16). The recent extension of irrigated areas in the northern Delta is remarkable (Fig. 17).

The woody vegetation was mapped for a part of the Inner Niger Delta (Fig. 18) using high resolution satellite images. Low-lying floodplains (Fig. 20) and rice fields (Fig. 22) were nearly tree-less. This is due to (1) the heavy grazing pressure, (2) the removal of trees by farmers when they make their fields, but also afterwards in an attempt to prevent seed-eating birds to breed in trees nearby.

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