

PART 3

THE EVOLUTION OF RICE-GROWING AREAS

from 1952 to 2015.

Flooded rice cultivation (1952, 1975, 1989, 2015) :

**its relationship with plant formations, soils, and
floods**

1 - INTRODUCTION

1.1 - Objectives

Our aim is not to study the agricultural production systems of the Inner Niger Delta in detail. Such a study would require accurate information on farms, including an assessment of their number, and a description and classification of a sample of them. Our more modest objective is to identify the extent of rain-fed and flood-irrigated rice cultivation over a long period (from 1952 to 2015), to analyze its spatial distribution, and try to understand the relationships between rice fields and human parameters (population distribution, territorial boundaries, etc.) – as well as with physical parameters (what types of vegetation are cleared? How does this clearing relate to flooding?) in order to analyze the strategies used by rice farmers.

1.2 - Sources

For this analysis, we rely on three main sources of data:

- The study entitled *Evolution of land use and vegetation in the Sudano-Sahelian zone* of the CIPEA project in Mali, conducted by Mark Haywood, published by CIPEA in 1981¹.
- *The Map of Agricultural Land Use from the P.I.R.L. project* (Project for the Remote Sensing Inventory of Wood Resources), published in 1990 in the Republic of Mali by the Ministry of the Environment and Livestock.
- *Digital data on rice cultivation areas* (irrigated and rain-fed), a study conducted by Léo Zwarts in 2015, which he kindly shared with us.

1.2.1 - The study by Mark Haywood (1952 & 1975)

The area studied by Mark Haywood in "*Evolution of land use and vegetation in the Sudano-Sahelian zone of the CIPEA project in Mali*" covers 46,000 km², situated between the latitudes of 13°55' and 16° north, and the longitudes of 6°40' and 4°30' west (excluding the northwestern part located within Mauritanian territory).

The study therefore covers part of the low plateaus west of the Office du Niger, the entire Dead Delta, and the western part of the Inner Delta, thus representing about one-third of the whole Delta.

In terms of latitude, it covers a rainfall gradient ranging, in 1980, between 600-700 mm isohyets in the south and 300 mm in the north.

The themes studied and mapped relate to the location of villages, archaeological sites (tumuli covering ancient villages), water resources, signs of land degradation, and cultivated areas.

¹M. Haywood, *Changes in land use and vegetation in the Sudano-Sahelian zone of the CIPEA project in Mali*. Working paper No. 3, Addis Ababa, CIPEA, 1981, 187 p.

This diachronic study is based on two IGN aerial surveys:

- Mission 75 MAL 32/500 P - IRC (1:50,000, panchromatic and color infrared images)
- Mission AOF 019 - 1952 (1:50,000, panchromatic images)

For cultivated areas, Mark Haywood distinguishes mainly between the following themes:

Table 1: Classification of themes in the CIPEA study

Classification by M. Haywood	Delmasig classes
Dry farming	1
Rice fields (Office du Niger and Opérations Riz)	3
<i>Private</i> irrigated crops	Not recorded
Degraded natural vegetation	Not entered
Rain-fed and river-fed rice cultivation	4
Rain-fed rice cultivation fallow land	6

NB: Private irrigated crops are located on the outskirts of the Office du Niger. The term refers to rice crops located outside official perimeters and irrigated by diverting water from drains.

The results of photo interpretation, after some field verification for 1975, were mapped in 10' arc squares, corresponding to the basic grid of the IGN 1:200,000 map. The photos were re-calibrated in relation to villages and the hydrographic network. Each page of M. Haywood's work compares the situation in 1952 with that in 1975. The squares are marked with a letter from A to M designating the latitude (from 16° to 14° north) and a number designating the longitude (from 6° 40 to 4° 30 west).

In this work, we only use the eastern part of the grid (between 14° and 15°50 in terms of north latitude, 5°40 and 4°30 in terms of west longitude), which covers approximately the western part of the Inner Delta and its western margin in contact with the Dead Delta. The rest of the study, covering the Dead Delta and the Office du Niger area, is outside the scope of our work.

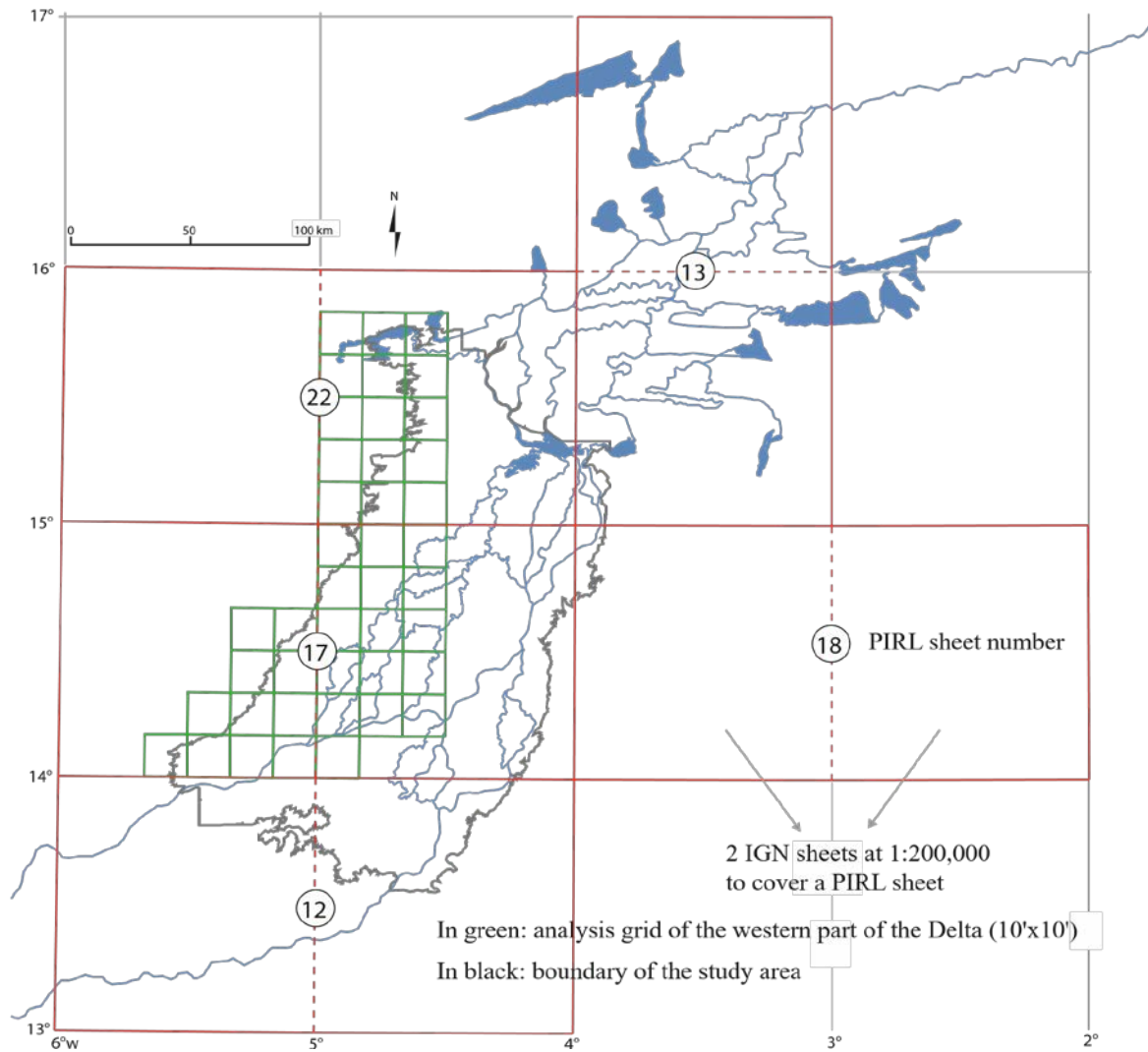
1.2.2 - Map of agricultural land use. (PIRL 1989)

This is a 1:200,000 scale map published in the Republic of Mali in November 1990, as part of the P.I.R.L. project. The work was carried out by a group of research and design institutions (SYSAME - BDPA - SCET AGRI - CTFT²). This map, which uses the IGN topographic background on a scale of 1:200,000 on sections combining two contiguous IGN maps, provides a representation of land use based on SPOT images dating from 1987, 1988, or 1989 (October to December), depending on the location.

The images were analyzed visually from color paper prints, and not through digital analyses. The layer of themes recognized on the SPOT images was then transferred to an IGN background.

The Inner Delta and its margins are covered by a combination of five sections, or ten IGN sheets on a scale of 1:200,000:

² C.T.F.T. Tropical Forestry Technical Center, now CIRAD Forêt

Figure 1: PIRL maps and study area

The cultivated plots or blocks of plots are classified into five categories, as shown in Table 2

Table 2: Classification of agricultural systems (PIRL project)

P.I.R.L.	Definition of each class
C6	Permanent dry farming system or short-term fallow
C7	Dry farming or long fallow itinerant cropping system
C9	Rice cultivation with hydraulic facilities (rice fields of the Office du
C10	Flood receding rice cultivation ³
C10	Area likely to be partially cultivated with rice at the date of the satellite

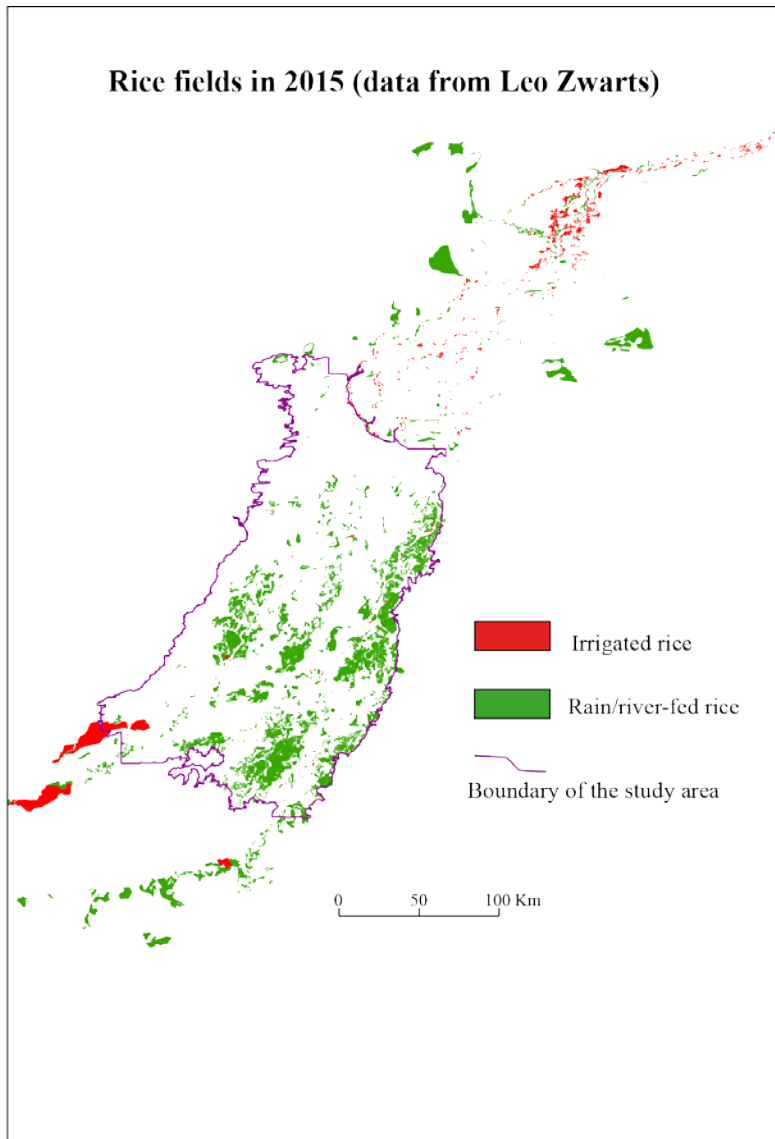
1.2.3. Data from Léo Zwarts (2015):

The author used Google Earth images to map crop parcels in the Niger Valley and the Inner Delta from San to Timbuktu. For each crop block, he indicates whether it carries irrigated rice (value 1

³ This is a misnomer referring here to the rain-fed and river-fed rice cultivation system as practiced in the Inner Delta.

for the rice item) or rain-fed rice with uncontrolled flooding (value 0 for the rice item). The file includes 2,687 crop blocks covering a total of 526,281 ha. (**Figure 2**).

Figure 2: Rice fields in 2015



2 - METHODOLOGY AND DATA QUALITY ISSUES

2.1 - Data entry and processing

For the 1989 data, taken from the P.I.R.L. maps, only the plots relating to the Delta and part of its dry margins were entered. This work was carried out on an A0 digitizing table, sheet by sheet, each sheet covering $1^\circ \times 1^\circ$, or half a map. The base maps in ArcInfo, referenced by latitude/longitude, bear the name of the corresponding IGN map sheet (Mopti, San, Niono, Sa, Niafunké, etc.). The separate covers are then assembled into a single one that is projected in UTM zone 30, and named SAU90 after projection, so that it overlaps with the other GIS covers and provides a metric basis for calculating areas. The plots or blocks of plots are classified into five categories, represented in the associated database by

the value of an item named "culture__89" for the general coverage drawn from the aforementioned work.

Table 3: Correspondence between the P.I.R.L classification and the culture_89 item in the SAU90 coverage

Crop_89	Class of origin	Definition of the original map
1	C6	Permanent dry farming or short-term fallow system
2	C7	Itinerant dry farming or long fallow systems
3	C9	Rice cultivation with hydraulic facilities (rice fields of the Office du
4	C10	Floodplain rice cultivation ⁴
5	C10	Area likely to be partially cultivated with rice at the date of the

We retain the five classes defined on the P.I.R.L. maps for some of our cartographic representations. However, in subsequent calculations, we retain only three classes, with the following grouping

- 1 + 2 (C6 + C7): dry crops
- 3 (C9): controlled flooding rice cultivation (paddies)
- 4 + 5 (C10 + C10'): rain-fed and river-fed rice cultivation (assimilating areas "likely to be rice fields" with areas actually used for rice cultivation)⁵

For the 1952 and 1975 data, the data entry procedure is simple: each 10' x 10' square is carefully referenced by latitude/longitude. The different themes are then digitized (at a table or on screen, using a scanner). Each cover represents a base square. The 42 covers—for each period—are then assembled and projected in UTM, resulting in two base covers named SAU75 and SAU52 after projection in UTM zone 30.

Table 4: Correspondence between the CIPEA classification and items culture_75 and culture_52 of the SAU_75 and SAU_52 covers

Item culture_75	Classes distinguished by Mark Haywood
1	Dry farming
3	Rice fields (Office du Niger and Opérations Riz)
4	Rain-fed and river-fed rice cultivation
6	Rain-fed and river-fed rice fallow land

For the 2015 data, we extracted information that strictly corresponded to the Delmasig study area (*Shape: Ricefield_zwarts_delta*). This shape comprises 1,677 blocks covering an area of 320,225 ha, divided between two values in the Ir (Irrigated) field: "0" for rain-fed rice (1,614 blocks covering 308,161 ha) and "1" for irrigated rice (63 blocks covering 12,064 ha). 183 plots have an area of less than 1 ha (covering a total area of 13.3 ha). These very small plots have been removed from the file.

⁴*Ibid.*

⁵ See below, p. 16.

The data from Mark Haywood (1952 and 1975) were then compared with those from the P.I.R.L. and from Leo Zwarts (2015) for rain-fed rice between 1952⁶, 1975, 1989, and 2015, using the four following shapes: Ricefield_2015_Veg7, SAU90, SAU75, and SAU52, and taking into account the fact that the SAU90 and Ricefield_2015_Veg7 shapes cover the entire Delta, while the SAU75 and SAU52 shapes cover only the western part.

2.2 - The problem of data quality

Before presenting the main results of our analyses, we must express some cautious reservations about our comparisons, for reasons related as much to the definition of the themes as to the spatial accuracy of the data.

2.2.1 - Definition of themes and media

The data for 1952, 1975, 1989, and 2015 do not all come from the same sources, and the media used are not the same: panchromatic aerial photos for 1952, color infrared for 1975, SPOT images for 1989, and Google Earth for 2015. The definition of the themes is also somewhat different, particularly regarding rain-fed and irrigated rice, since Mark Haywood represents areas cultivated with rice and rice fallow land, while the P.I.R.L. project team only takes cultivated areas into account. On the basis of data analysis, rice cultivation areas appear to have decreased between 1975 and 1989, at least in the western part of the Delta. As a first hypothesis, we could suggest that the analysis based on SPOT images minimizes rice cultivation areas, while aerial photos tend to maximize them. Color infrared, in particular, clearly highlights geometric shapes that are suggestive of plots of land, although the existence of these plots has not always been confirmed during the field checks carried out by Mark Haywood and Pierre Hiernaux. Confusion between existing rice fields and fallow land, even very old fallow land, may therefore arise from photographs. However, we will later see that this methodological hypothesis is probably not the only one that can be put forward to explain the differences recorded between 1975 and 1989.

2.2.2 - Data accuracy

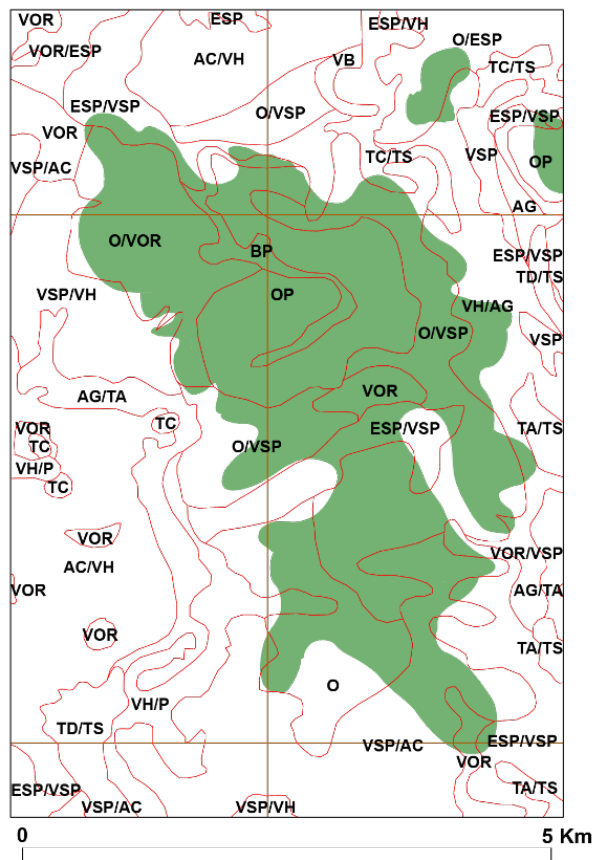
The use of spatial operators makes it possible to analyze vegetation formations coinciding with cultivated areas and then deduce what formations have been cleared. However, the method has its limitations: those of the spatial accuracy of the data, and therefore of the validity of the proposed intersections. As we explained in Part 1, the accuracy of the spatial location of vegetation formations is in the order of 200 to 300 meters on the ground, these values being a maximum rather than an average, as the positioning errors of VEG4 vs. VEG7 are not cumulated. The accuracy of the spatial data for cultivated land in 1975 is believed to be of the same order of magnitude, as these data were mapped from the same photographic coverage, on the same background and by the same person—Mark Haywood—which limits the risk of relative inaccuracy. We are more cautious about the spatial accuracy of the 1952 data, which were taken from older aerial imagery of poorer quality than the color infrared images available for 1975. The 1989 data are derived from an analysis of SPOT images reported on the IGN 1:200,000 background. A priori, the accuracy with which cultivated areas were located in 1989 should be at least as good as that obtained by photo interpretation. Visual comparisons – and comparisons of measurements – show that, regardless of the coverage used (SAU52, SAU75, SAU90), there is a very high degree of similarity in outlines and shapes between crop blocks and the boundaries

⁶ For 1952, the cultivated areas are taken directly from Mark Haywood's tables.

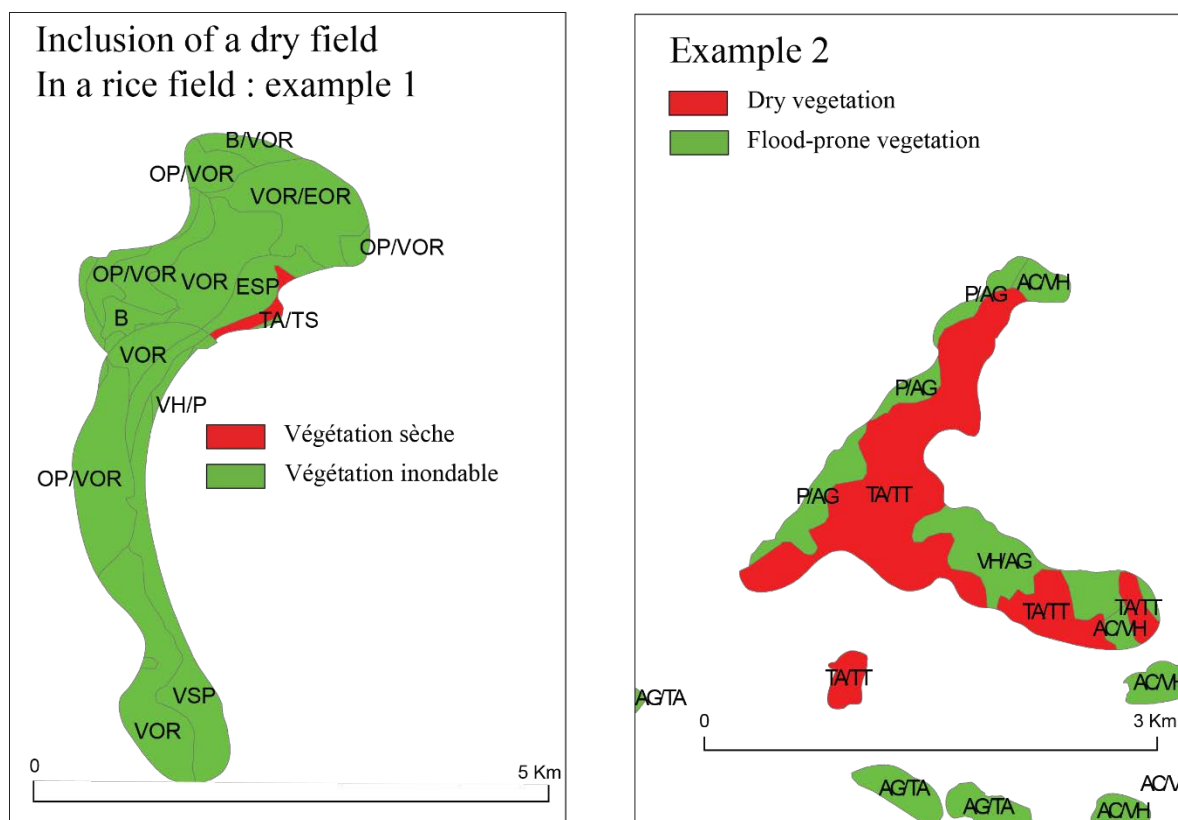
example from 1952 will help to clarify this. Because the data appear to be less accurate in 1952, the first anomaly appears earlier, in the 18th ranking, while the cumulative area under rice cultivation exceeds 80%. This concerns the TC formation, of which 698 ha appear to have been cleared for rice cultivation, which is clearly an error. These cumulative errors (142 in total) represent 1.2% of the total cultivated area. The largest individual error concerns 37 ha, the twentieth 9 ha, and the last one around **1.5 m²**!

However, the processing of the 2015 data poses other problems, and a distinction must be made between possible spatial location errors and thematic errors. Although Google Earth provides information on the presence of plots, it does not allow us to know whether the mapped plots are exclusively rice fields or whether other types of crops are also present; nor does it allow us to differentiate between crops grown during the year under study and recent fallow land. In order to be able to differentiate between rice crops and other types of crops (dry crops, gardens, etc.) with a high degree of probability, we compared the plots identified by Léo Zwarts with the Veg7 coverage of vegetation formations, which also include water depths (*shape Ricefield_2015_Veg7*). Part of the mapped plots prove problematic, with the inclusion in the rice plots of fragments of non-flooded vegetation formations and/or floodable, but very shallow formations.

Figure 4: 2015 A map of plots and vegetation formations



Figures 5 and 6: The inclusion of *toggere* in areas defined as rain-fed and river-fed rice fields.



The example in Figure 4 shows that the geometric accuracy between a rice field and the vegetation formations in which it has been cleared is acceptable. However, with the 2015 data, we encounter a problem of thematic definition, as shown in the examples in Figures 5 & 6. In example 1, the inclusion of TA/TS in the rice field concerns only a very small area (9 ha and 100 m wide). This situation is undoubtedly due to the relative inaccuracy of Veg7, which, as mentioned above, allows for discrepancies of 200 to 300 m, compared to satellite imagery.

In example 2, we are faced with another scenario: the TA/TT dry formation is large (215 ha). It seems difficult to classify this plot as a rice paddy. We propose removing plots located on dry formations (level 11) or on mosaics combining a dry formation with a flood-prone formation, which in most cases is a formation prone to flooding by runoff (levels 21, 31, 41, 61, PAM, PAN, PAR, PAS formations), from the "rice" areas. We will thus distinguish between "gross" cultivated areas corresponding to the data entry and "net" cultivated areas, after eliminating plots located on improbable vegetation formations.

By applying this principle to all the data, we are able to offer a higher level of confidence in the data, as the ratio of the net area to the gross area. We have, however, retained rice fields located on very slightly

flooded vegetation formations (between 10 cm and 30 cm of water compared to the reference flood) as "possible" rice fields. We will see later that while such a choice seems unlikely in 1975, 1989, and 2015, it is perfectly understandable in 1952, which is why we have not excluded these shallow formations from the definition of net rice field areas. We will return to this choice on a case-by-case basis.

Table 5: Accuracy of rice areas in 1952, 1975, 1989, and 2015

Year	Gross area	Net area	Confidence
1952 (West Delta)	56,960	53,812	94.5
1975 (West Delta)	98,644	95,656	97.0
1989 (West Delta)	77,042	76,308	99.0
2015 (West Delta)	84,824	82,071	96.8
1989 (entire Delta)	158,767	156,961	98.8
2015 (entire Delta)	304,660	281,778	92.5

The reliability of data on rain-fed and irrigated rice areas varies between 92.5 % and 99 %. The data for 1989 (SPOT satellite image) and 1975 (IFR aerial photograph) are very reliable, those for 1952 (old panchromatic aerial photograph) less so. The data for 2015 raise questions: they appear to be good in the western part of the Delta (96.8%) and fairly poor for the Delta as a whole (92.5%). We will address this apparent contradiction later on. In the rest of our analyses, we will use the net area values, which we believe better represent the reality of rice cultivation in the Delta, considering the errors linked to spatial inaccuracy as acceptable "background noise."

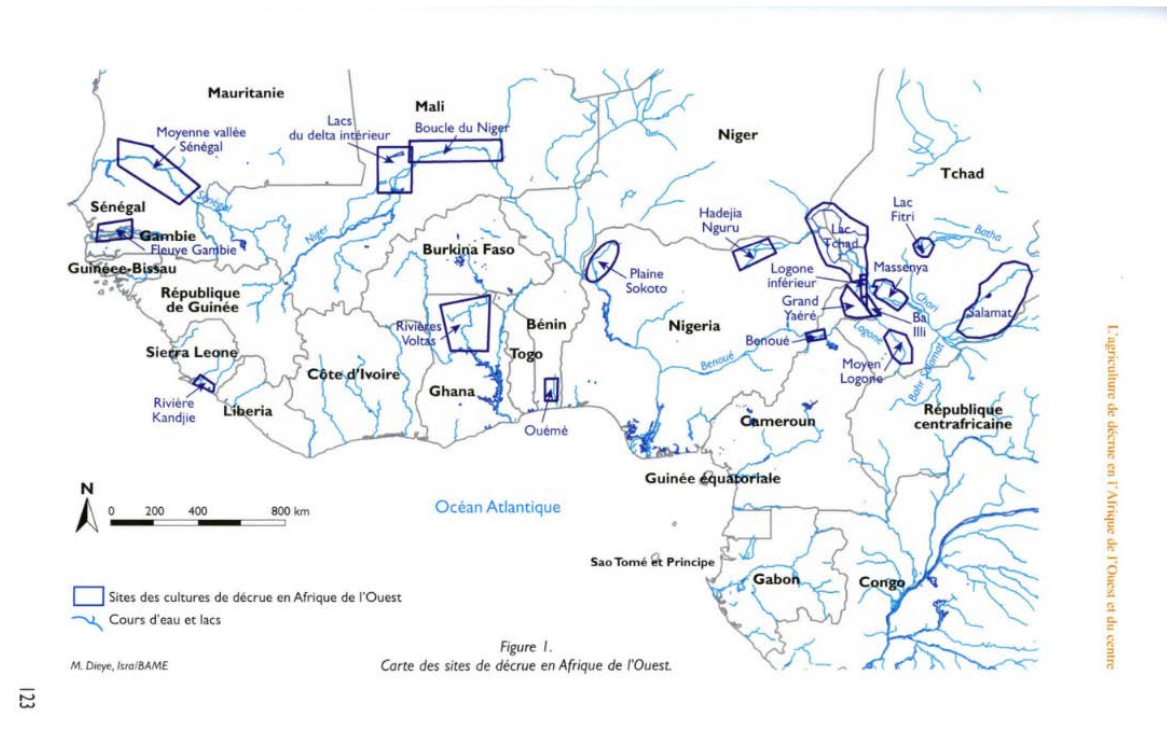
3 - RICE CULTIVATION IN THE INNER DELTA

Rice is the staple food for 4 billion people worldwide. It requires hot summers and a significant amount of water (approximately 5,000 liters per kilogram of rice). There are a vast number of rice varieties and rice cultivation systems. Rice can be grown under rain-fed conditions (2 m of rainfall) in open fields, even on steep slopes (e.g., the mountains of northern Thailand). Most often, it is grown using irrigation, but it can also be simply flooded. Two flooded systems coexist: cultivation based on flood-recession and rain/river fed cultivation, which uses floating rice. Flood-recession rice cultivation uses upright rice varieties, as is the case in the Tsiribihina Delta in Madagascar (Mollard E., Walter A.). The seeds, sown very densely, are broadcast onto a plot that is still wet during the receding floodwaters. Three weeks later, the rice is transplanted into the water as it slowly recedes. If necessary, a second transplanting is carried out, in step with the receding floodwaters. Yields are around 2 tons/ha. (*Flood-recession rice farming* (Photo from the cited publication))



In Mali, floodplain crops cover 60,000 ha located around the lakes north of Lake Débo to Lake Faguibine and in the Niger River bend. These may include sorghum, often accompanied by cowpeas or rice. (Sultan B and all), as shown in the map below.

Figure 6: Floodplain crops in West Africa



Map taken from the cited publication (Chapter 8)

In the Inner Delta, rice cultivation is primarily rain-/river ed. It relies on floating rice varieties. The stem, which contains air that allows the panicle to remain above water, grows as the floodwaters rise (up to 5 meters for some varieties). Seeding takes place at the start of the rainy season, and the floodwaters then take over. It is an extensive system, a very simple one without any water control, but with very low yields, as we will see later.

3.1 – The three coexisting rice farming systems in the Delta:

3.1.1- Irrigated rice cultivation

Irrigated rice farming is widely practiced in the Office du Niger, located west of the Delta, in a former dead arm of the river. Irrigation is gravity-fed from the Markala Dam, situated just upstream of the Inner Delta. The total cultivated area (2022/2023 season) covers 115,000 ha, yielding 800,000 tons of rice, in addition to 400,000 tons of vegetable crops. The expansion of the Office du Niger, which has given rise to numerous large-scale projects since the colonial era, is nevertheless limited by the Niger River's very low low-water flows at the end of the dry season, which constrains irrigation capacity at the start of the season.

The introduction of irrigation in the Inner Delta is more recent and goes back to the 1990s. These PPIVs (“Small Village Irrigation Perimeters”) are located along the Delta’s main waterways (Niger, Bani, Diaka).

In 1998, there were 154 of these small village irrigation perimeters (PPIVs), covering a total area of approximately 1,400 ha. These systems are relatively simple. A PPIV is a polder protected from flooding by dikes. Irrigation is carried out using a motor pump, usually diesel-powered, which feeds a retention basin followed by canals that distribute the water by gravity. Seeding takes place at the end of the dry season thanks to irrigation. The rice is then transplanted, and harvesting occurs in September–October. With mineral fertilizer applications (100 kg/ha of urea and 50 kg/ha of phosphate) (Bouaré K.,N.,- 2012), agronomic results are good, with yields generally exceeding 6 t/ha during the rainy season and reaching up to 9 t/ha during the dry season (Ducrot R., Zaslavsky, J., Magassa H. 2002)



4

5 Photos by Kadidia N. Bouaré (diesel motor pump and distribution canals)

In 2015, Leo Zwarts identified 63 irrigated areas, covering a total area of 12,064 ha. Two large areas (5,133 and 4,433 ha) are ORS (Operation Rice Segou) plots, fed by gravity from Markala in the municipalities of Kokry Centre and Macina. The other 61 areas comprise PPIVs irrigated by pumping, covering a total area of 2,498 ha. Two of these are large, covering 308 ha north of Diabozo and 157 ha south of Kakagnan. All the others cover between 90 ha and 1.6 ha, with the vast majority covering between 20 and 40 ha.

Table 6: Production trends on PPIVs from 1994 to 2004

Agricultural seasons	Seasonal crops				Off-season crops			
	Transplanting	Harvest	Yield	Production	Transplanting	Harvest	Yield	Production
	ha	ha	kg/ha	Tons	ha	ha	kg/ha	Tons
1994–95	57.89	57.89	4538	262	20	20	5277	105
1995–96	22	22	4591	101	0	0	0	0
1996–97	45.75	45.25	5380	243	20	20	5318	106
1997–98	62.4	61	5566	339	40	40.975	6001	246
1998–99	193.25	193.25	6200	1198	0.53	100.53	5844	587
1999–00	167.6	167.6	6500	1089	86.825	85.825	6183	530
2000–01	214.28	209.01	6625	1384	11.05	110.8	5965	656
2001–02	98.7	98.7	7393	716	20.5	20.5	6692	137
2002 - 03	252.59	251.66	6870	1728	217.45	217.15	7068	1513
2003 - 04	204.31	164.24	6662	1094	40	40	7082	283

Source: Ducrot R., Zaslavsky J., Magassa H.

3.1.2- Rice cultivation in paddies

Rice cultivation in paddies (in 1989) is the result of two former public development projects: Operation Rice Segou (ORS) and Operation Rice Mopti (ORM), located respectively on the left bank of the Niger River upstream from Ké Macina and east of Mopti, extending further south to the commune of Sio.

According to P-A Gosseye and M. Van Duiven-Booden⁷ (1990), the 15 ORM plots cover 44,140 ha, of which 33,156 ha are used for rice cultivation, and those of the ORS cover 34,000 ha. M. Kuper and H. Maïga⁸, drawing on available literature⁹, note that in 1999, the harvested areas did not exceed 12,000 to 15,000 ha for the ORM plots.

The estimates we use, based on a 1989 map, indicate a total of just over 33,000 ha for all ORS (16,774 ha) and ORM (16,620 ha) plots. This is most likely to be a minimum harvested area, which should be considered in relation to the floods of the late 1980s.

These plots have very limited technical efficiency and do not allow for true irrigated rice cultivation. In particular, it would appear that these structures, designed at a time when floods were stronger and more regular, revealed all their shortcomings from the moment they were put into service, which also coincided with the series of low floods that predominated between the early 1970s and the mid-1990s. The plots are not level, and the height of the water—and its effectiveness—varies within the same compartment, provided, that is, that it is actually reached by the flood. Submersion is controlled by means of water intakes and small dykes that "delay the rise of the water during the flood and block the water during the ebb."¹⁰ If the level is too low, or the submersion too late or too short, the results, which remain very mediocre, are severely compromised. When the flood is insufficient, crops fail, due to lack of water.

According to the same authors, the cultivated varieties are floating rice varieties of Asian origin (*Kao Ghew*) or upright varieties such as IR8, developed by IRRI. *Oryza glaberrima*, because of its plasticity and its ability to "contaminate" other varieties, is prohibited. In 2015, Leo Zwarts classified ORS plots as irrigated plots, and ORM plots in the Mopti-north and Mopti-south basins as rain-fed rice cultivation, i.e., without water control, which seems to indicate a shift in the areas concerned to either irrigated (ORS) or rain-fed rice cultivation, due to the deterioration of equipment (ORM-Mopti).

The graphs below, taken from tables provided courtesy of the Director of the O.R.M., show that yields remain very low even in years with good flooding, such as 1974–75 (1,475 kg/ha) or 1999–2000 (1,500 kg/ha). In bad years, harvests can reach zero, as was the case in 1984–85. In addition to very poor yields (30-year average: 1,100 kg/ha), which are hardly different from those of traditional rain/river fed rice cultivation, the considerable discrepancies between the areas sown and the areas actually harvested (54%) attest to the vulnerability of these systems. A ranking of years based on the harvested area/sown area ratio shows that for low or very low floods (below 5.50 m in Mopti), the ratio is almost always less than one-third. Harvested areas exceed three-quarters of the sown area only in good years, with floods

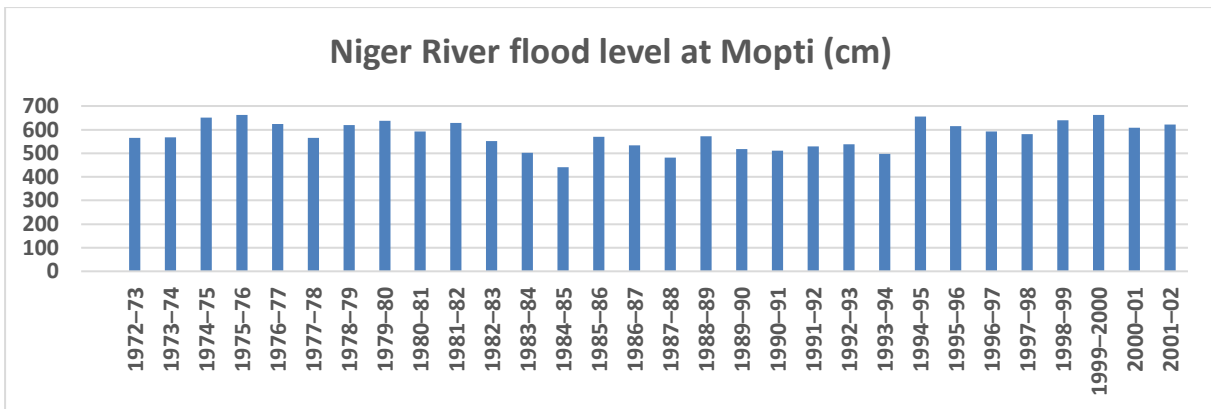
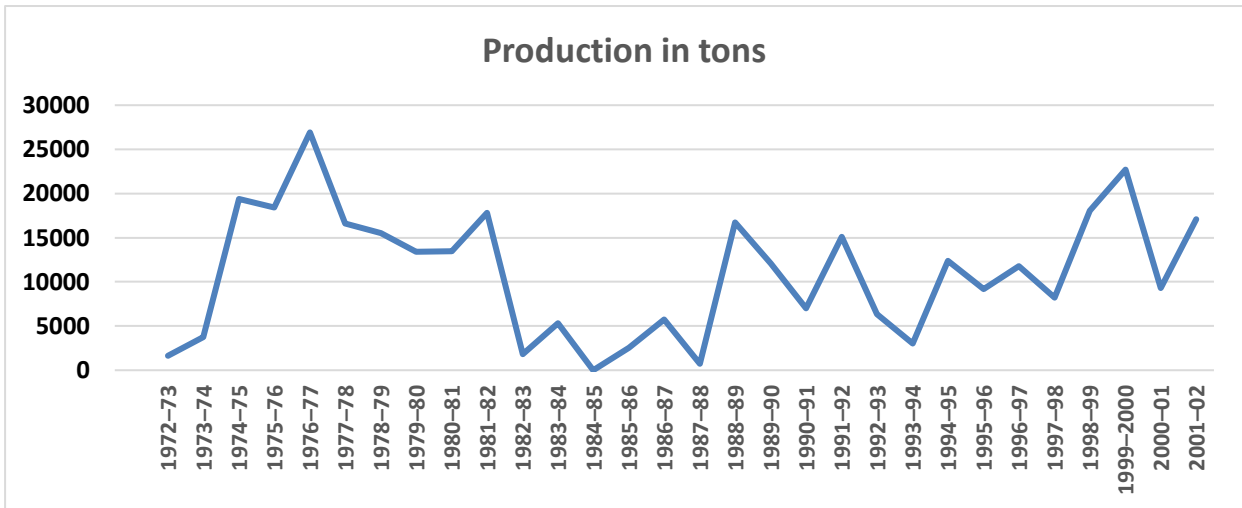
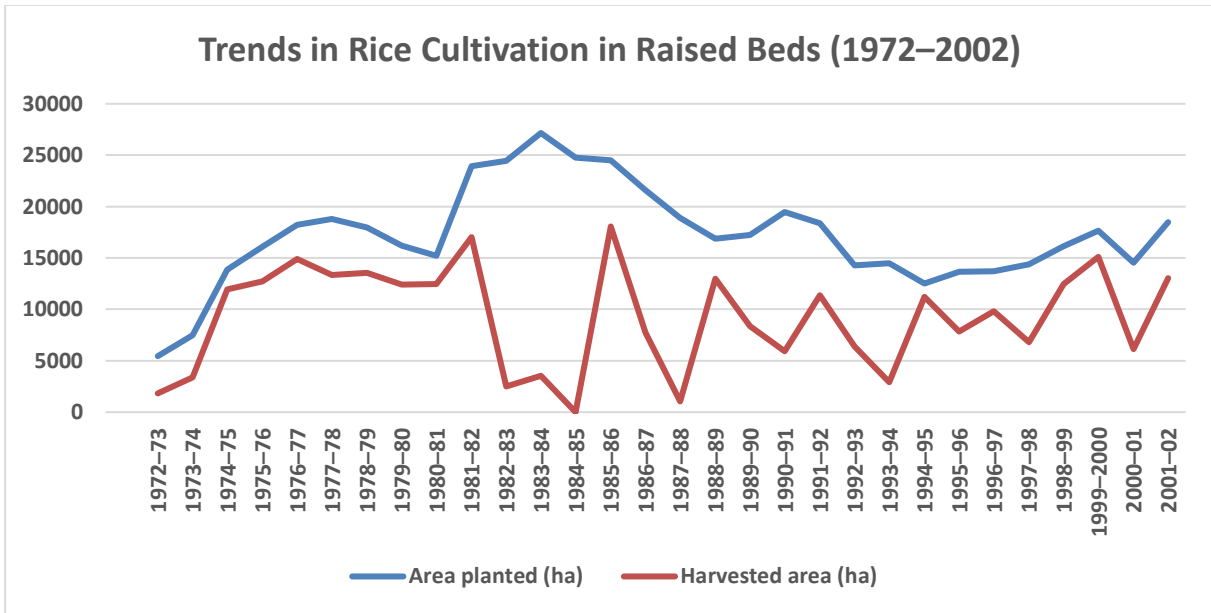
⁷ M. Van Duiven-Booden and P-A Gosseye, (eds), *Competition for limited resources: the case of Mali's fifth region. Report 2: Plant, animal and fishery production*. Wageningen (Netherlands): CABO and Mopti (Mali): ESPR, 1990, 266p. + appendices.

⁸ M. Kuper and H. Maïga, "Marketing of traditional rice in the inner Niger delta," Bamako, April 2000, 33p.

⁹ K. Denon (*et al.*), "Rice farming without water control in the central Niger River delta," Paper presented at the CNRS/CIRAD symposium, *What future for rice farming in West Africa?* Bordeaux, 1995.

¹⁰ M. Kuper and H. Maïga, *Ibid.*

reaching or exceeding 6.20 m in Mopti (1980–81 and 1988–89, with water levels slightly below 6 m, being exceptions,).



3.1.3- Rain/river fed rice cultivation or uncontrolled flooding

Rain/river fed rice cultivation is a very simple farming system with no control of the flooding. It still occupies first place in the Inner Delta.

A study of the Delta's vegetation communities has highlighted the importance of wild rice communities—*Oryza barthii* and *Oryza longistaminata*—in the Delta's aquatic landscapes. Jean Gallais, citing P. Viguier (1939), highlights the long history of rice cultivation in the Delta, based on a floating variety of rice, *Oryza glaberrima*, descended from the domestication of *Oryza barthii* around 500 BCE, likely in the inner Delta. Recent research at the Djenné-Djeno archaeological site, located 3 km southeast of the present-day city of Djenné, has uncovered significant remains of a city founded around 250 BC, which had a population of 10,000 by the year 800. Djenné-Djeno notably traded in salt from the Sahara, produced pottery, and practiced rice cultivation. *Oryza glaberrima*, a highly adaptable species, includes a large number of varieties¹¹, some early-maturing ones with short cycles ranging from 90 to 130 days, and others late-maturing ones with cycles ranging from 150 to 210 days. The growth of these floating rice varieties begins with the rains and continues with the floodwaters, hence the term rain/river fed ("pluvio-fluvial") applied to this form of rice cultivation without water control. These rice varieties can tolerate submersion of up to three meters and withstand water rise rates of approximately 5 cm per day.

This local species is not the only one cultivated by rice farmers in the Delta. As early as 1914, floating varieties of *Oryza sativa*, of Indochinese origin, were introduced in Mopti. Starting in 1920, upright varieties of *Oryza sativa* were also introduced. Although their yields were much higher than the floating varieties, they proved ill-suited to the fluctuations of the floodwaters. In 1999, a study conducted by M. Kuper and H. Maïga showed that *Oryza glaberrima*, despite its shortcomings (low yield, dehiscent panicles that easily shatter upon maturity), remains the most widely cultivated rice in the Inner Delta. This red rice is also sought after by consumers for its flavor.

Table 8: Rain/river fed and irrigated rice yields (1987-1999)

Years	Yields			
	≤ 600 kg/year	600 to 700 kg/year	From 700 to 800 kg/year	> 800 kg/year
	1990-91	1987-88	1988-89	1996-97
		1989-90	1991-92	1998-99
		1993-94	1992-93	
		1997-98	1994-95	
			1995-96	

¹¹ According to P. Viguier, *Les emblavures de 1935** (1939), cited by J. Gallais, *Le Delta intérieur du Niger, étude de géographie régionale**, Dakar : IFAN Monograph No. 79, 2 vols., p. 247, there are reportedly 41 such species.

Jean Gallais estimates the yields of *Oryza glaberrima* for the year 1958 at 700 kg/ha, with values that could exceptionally reach 1,200–1,300 kg, but could also be less than 600 kg. In 1958, he reports a gross yield of 630 kg/ha for one farm, or a net yield of 540 kg/ha after deducting seed. More recent results, reported by Mr. Kuper and based on information from the DRAMR, show yields that fluctuate, depending on the year, between 550 and 900 kg/ha, making it one of the least efficient rice-growing regions in the world.

The farming system is simple: preparation for a new rice paddy begins during the previous year's flood season by cutting down the natural vegetation, which does not re-grow at that time. The grass is left in place and will be burned after the floodwaters recede, once it has dried. The plots are plowed either at the end of the cycle (February, March, or April), after the previous harvest, or at the start of the rainy season (June, July, or, more rarely, August). The month of May marks a pause in soil preparation work (due to intense heat, hardened soil, and fatigue among the plowing oxen, which are poorly fed at this time of year). Early plowing is often followed by a second plowing at the start of the rainy season, just before broadcast seeding (60 to 80 kg/ha). Low-lying rice fields are seeded before those located at higher elevations, with the highest fields seeded between mid-July and August. Weeding of the rice field usually takes place in early September, before the floodwaters arrive, when the rice is 20 to 30 cm tall. The rice begins to grow with the rain, and the floodwaters must then take over no later than 15 days after the last "useful" rain (rainfall of at least 3 mm). Harvesting, which takes place in the water, begins in October–November for the earliest varieties and extends through December–January for the later varieties. The abandonment of a rice paddy, which is then left fallow, is not due to a loss of soil fertility but to the proliferation of wild grasses that restore the original vegetation cover. *Oryza barthii*, whose presence, as we will see later, often guides the choice of vegetation to be cleared, has deep rhizomes that are particularly difficult to eliminate, thus very quickly contaminating the rice paddy, which is then abandoned.

Jean Gallais indicates (page 219) the number of workdays required per hectare:

Clearing by Balagou (scything)	12 days
Plowing	20 to 80 days depending on the soil
Sowing	½ day
Weeding	7 days
Late-season weeding	3 days
Harvest	7 days
Threshing	6 days

One hectare of rice paddy requires between 44 and 104 days of labor; a new rice paddy requires between 56 and 126 days. Jean Gallais notes that this makes it a very extensive system when compared to the schedule of Asian rice farmers working in irrigated systems.

3.2 - Changes in the area under rain-fed and flood-irrigated rice cultivation from 1952 to 2015

While rain-fed rice cultivation, or with uncontrolled flooding, is often described as archaic, it still ranks first in the Delta, both in terms of cultivated area and production volume. Its mobility leads it to compete with other production systems, particularly pastoralism, for the use of space within the Delta. In order to better understand these issues, we will analyze this rice production system along two lines:

1 - The evolution of rice-growing areas in relation to population growth, but also the spatial distribution of rice fields in the Delta in 1989 and 2015, with a focus on the western part of the Delta where we have data for 1952 and 1975, covering a period of more than 60 years (1952-2015), thus raising the issue of agricultural nomadism already described by Jean Gallais.

2 - The complex relationships between rice fields, plant formations, and flooding. What areas do rice farmers clear in the Delta? Which plant formations are most sought after? What lessons can be learned from the evolution of their choices between 1952, 1975, 1989, and 2015, in terms of their strategies and in terms of the issues related to other possible forms of land use?

Between 1935 and 2015, the area of rain-fed and river-fed rice fields increased from 64,500 ha to 282,000 ha, a **multiplier rate of almost 4.4**. How did the population change during the same period? Given that rice cultivation in the Delta is mainly subsistence farming, did per capita availability change between 1957 and 2015? In other words, do people eat better or worse now than they did 60 years ago?

Table 9: Changes in rice cultivation areas in the Delta from 1920 to 2015.¹²

Period	Rice area (in ha)	Observations
Around 1920	16,000	From Diafarabé to Lake Debo
1935	64,500	30,000 ha (Macina District) 32,000 ha (Mopti District) 2,500 ha (San District)
1957-58	79,000	40,000 ha (Macina District) 35,000 ha (Mopti District) 4,000 ha (San District)

¹² The sources used to construct this table are as follows:

For 1920, *Archives of the Mali Department of Agriculture* (anonymous report), approximate date 1920, in J. Gallais, *Le Delta intérieur du Niger, étude de géographie régionale*, Dakar : Mémoire de l'IFAN n°79, 2 vols., p.247.

For 1935, P. Viguier, *Les emblavures de 1935* (1939) p. 3, in J. Gallais, *Ibid.*

For 1957-58, J. Gallais, *Ibid.*

For 1989 and 2015, P.I.R.L. maps and data from Léo Zwarts

1989	157,000	83,000 ha (Tenenkou District: Macina) 47,000 ha (Mopti District) 27,000 ha (Djenné District)
2015	282,000	63,000 ha (Tenenkou District) 108,000 ha (Mopti District) 94,000 ha (Djenné District) 17,000 ha (Macina and Youvarou Circles)

For the 1957-58 period, Jean Gallais, referring to the 79,000 hectares of rice fields and the 170,000 inhabitants of the Delta plains at that time, including 63,000 rice farmers, made the following observations: the 79,000 hectares of land cultivated with rice represented 10% of the 800,000 hectares of rice-growing land in the Delta. **The area cultivated with rice in 1957-58 was around 0.47 hectares per inhabitant (i.e., per mouth to feed)** and nearly 2.5 hectares per worker. He added the following observations: the ratio of cultivated area per capita tended to decline, and cultivated areas were not significantly increased by using a plow rather than a hoe. On average in the Delta, the area cultivated per worker was 2.46 ha in the case of hoeing, and 2.79 ha in the case of plowing, which was beginning to spread.

In 1989, the agricultural land use map we refer to estimates the area cultivated with rain-fed and irrigated rice fields at 136,000 ha, to which can be added 23,000 ha classified as "suitable for rice cultivation" at the date of the satellite images. These 23,000 ha are located in three specific areas: in the territory of Diondori, in Togoro Kotia and Toguere Coumbe, and finally in the territory of Konna. Interviews with Malian researchers¹³, as well as the study by M. Kuper and H. Maïga, lead us to equate these "possible" areas with areas actually cultivated with rice, which therefore can be said to cover 159,000 ha (gross area - 157,000 ha net area), a total slightly higher than the estimates of M. Kuper and H. Maïga, who evaluated the area under rice cultivation in the 1990s at between 115,000 and 130,000 ha.¹⁴

It can be seen that from 1958-59 to 1989, the area of rain-fed and irrigated rice cultivation doubled. What about the area under rice cultivation per capita? Basing his study on the 1987 census, Herry¹⁵ estimates the population of the Delta at 400,000, with 70.2% of this population engaged in rice cultivation as their main or secondary activity. On the other hand, workers (men aged 10 to 65) represent 32.8% of the Delta's population, which would therefore include 92,000 rice farmers.

Our own estimates, also based on the 1987 census, are more restrictive than those put forward by Herry. The rural population of the Delta plains was counted, using satellite imagery according to three methods. The rural population living within the limits of the 6.60 m reference flood level in Mopti

¹³ Notably Brehina Kassibo, member of GREDEF, who works on the municipalities mentioned.

¹⁴ M. Kuper & H. Maïga, *op. cit.*, p. 3

¹⁵ C. Herry, "Démographie des pêcheurs" in QUENSIERE J. (ed.), *La pêche dans le Delta Central du Niger. Volume 1*. Paris: ORSTOM/Karthala, 1994, 495p.

did not exceed 328,000 people in 1987, or 337,000 if we use the limits of the ecological study, which includes the dry margins to the south and west (as well as part of Farimaké). And, finally, 382,000 inhabitants, if we include a 500-meter band around the ecological boundary, with the second estimate seeming to be the closest to reality.

We therefore believe that the rural population living within the boundaries of the Inner Delta reached a maximum of 340,000 people in 1987, with 157,000 hectares of land cultivated with rice in 1989 (maximum estimate). In other words, if we compare the situation in 1958-59 with that in 1989, we see that the area under rice cultivation has doubled in thirty years, while the **per capita availability, in the best case scenario¹⁶, has remained more or less constant (0.45 ha/person in 1989 compared to 0.47 ha/person in 1957-58)**. According to C. Herry's demographic data, rice farmers represent approximately 78,000 workers (70.2 % of the population, including 32.8 % of men aged 10 to 65). The area cultivated per worker in 1989 was therefore just over 2.1 ha.

In 2015, basing ourselves on the 2009 population census, we estimate the rural population of the Delta at 620,000 inhabitants and the area under rain-fed and irrigated rice cultivation at 282,000 ha. This suggests an area **of 0.45 ha available per person**.

Two key points emerge from these estimates: between 1958 and 2015, the population of the Delta increased 3.6-fold over nearly 60 years, while the area of rice fields followed the same trend, increasing 3.6-fold. The area cultivated per capita, i.e., ultimately, per mouth to feed, in the most favourable scenario, is likely to have remained stable at around **0.45 ha**, or an average of 300 to 310 kg per person per year (raw rice, from which reserves for seeds must also be deducted). Despite the statements made by Delta residents, reported by Mr. Kuper, who claim to "grow five times more rice with the plow than their parents did"¹⁷, the reality seems somewhat different, with a sharp decline in the area cultivated per worker, which is said to have fallen from 2.7 ha to 2.1 ha between 1958 and 1989.

These data depict rice cultivation as strictly subsistence-based and increasingly space-intensive, with results that suggest stagnation, in terms of per capita availability. Technical stagnation is evident in the continued use of *Oryza glaberrima*, which is dependent on rainfall and flooding, but is also reflected in yields, which have hardly changed in 60 years. The same conclusions emerge from the detailed study by M. Kuper and H. Maïga on rice trade in the Delta. In good years, the quantity traded does not exceed 10,000 tons, or 10% of its maximum production. In bad years, the Delta suffers from a rice deficit. In 1957-58, Jean Gallais discreetly suggested rice cultivation was in decline. Sixty years later, there is no evidence to refute his assessment.

This picture is barely qualified by the still limited development of PPIVs benefiting from irrigation hardly. The irrigated area in the Delta (excluding large perimeters because they produce rice mainly for sale in the capital) amounted only to 2,498 ha in 2015. With yields reaching 6 t/ha, the total production is around 15,000 tons per year, which is still insignificant, compared to a rain-fed and river-fed production of around 200,000 tons per year in 2015 (with an average yield of 700 kg/ha). Even when they are profitable (which is not always the case), PPIVs only benefit a limited number of farmers and can only marginally change the situation of the Delta's population.

¹⁶ Our estimates are minimum for the population and maximum for cultivated areas.

¹⁷ M. Kuper & H. Maïga, *op. cit.*, p.9

3.3 - Rice cultivation remains nomadic.

In 1957-1958, Jean Gallais placed particular emphasis on the mobility of rice farming: "By continually moving the rice-growing stratum up and down the plains according to the floods, the Delta rice farmer is an itinerant cultivator"¹⁸. He concluded: "Rice farming in the Delta is more nomadic than the Sudanese cereal farming practiced on dry edges."¹⁹

What is the situation regarding agricultural nomadism in 2015? To attempt to answer this question, we will compare the locations of rice fields between 1989 and 2015 across the entire Delta, as well as over a 60-year period in the western part of the Delta (west of 4°30'), offering a diachronic comparison (1952, 1975, 1989, and 2015) of the spatial spread of rain-fed and river-fed rice fields, which will provide us with a better understanding of the nomadic nature of this agricultural system.

On another scale, we will examine the distribution of cultivated land by municipality. This question is twofold: can the population and rice farming be reconciled at the municipal level? And, if the answer is negative, is the municipality, as the new territorial framework and socio-political entity in charge of development, the appropriate space unit for analyzing the very specific problems posed by rain-fed and river-fed rice cultivation in the Delta?

In 1989, five rice-growing basins stood out:

- First, the rice fields of the Tenenkou region, located on either side of the Diaka, the main tributary of the Niger. They begin north of the large town of Dia and extend to Kamaka Debere, north of Diondori. This first large rice-growing basin extends northwards to the Toguere Coumbe basin, which reaches 15°10' north latitude.
- The second rice-growing basin is located on the central axis of the Delta, along the Mayo Kootya. It begins in the south, near Ouro Modi on the left bank of the Niger, and forms a string of secondary basins around Mourrah (from Ouro Modi to Sare Hamadou), around Kadial and, in the northern part, from Sare Faba to Sormé.
- The third basin is located north and southwest of Mopti, in the Bani-Niger Mesopotamia, in the territory of the commune of Soye (formerly Leyde Sebera) and in the northern basin of Mopti.
- The fourth large basin is located in the central southern part of the Delta, between the right bank of the Niger and the latitude of Djenné to the south. It includes the Yongari Mangari and Pondori basins.
- Finally, a fifth group of rice fields is located in the Konna region, along the Niger and Mayo Ranéo rivers.

In 2015, the large rice-growing basins occupied the entire right bank of the Niger from south of Mopti (Sebera basin) to Konna, Pondori (Djenné), the Tenenkou basin, and the Mourrah basin. While in 1989 rice fields occupied large areas north of Tenenkou and Mourrah, this was no longer the case in 2015, when rice was generally grown mainly in the southern half of the Delta, whereas, in 1989, most rice fields were concentrated in the center of the Inner Delta.

¹⁸ Jean Gallais, *Le Delta intérieur du Niger, étude de géographie régionale (The Inner Niger Delta, a regional geography study)*, Dakar: IFAN Memoir No. 79, 2 vols., p. 228

¹⁹*Ibid.*

An analysis of the global map highlights the changes that occurred between these two dates. One might have expected rice-growing areas to have simply expanded around the existing centers in 1989, following the growth in rice-growing areas from 157,000 ha in 1989 to 282,000 ha in 2015. The map shows that this is not the case: the growth in rice-growing areas has been accompanied by very significant changes in the location of rice fields. The area common to both 1989 and 2015 is only 59,000 ha, with only 38% of the rice fields cultivated in 1989 still in use in 2015. These rice fields common to both dates represent only 21% of the area cultivated in 2015.

Figures 7 & 8: Rice fields in 1989 and 2015

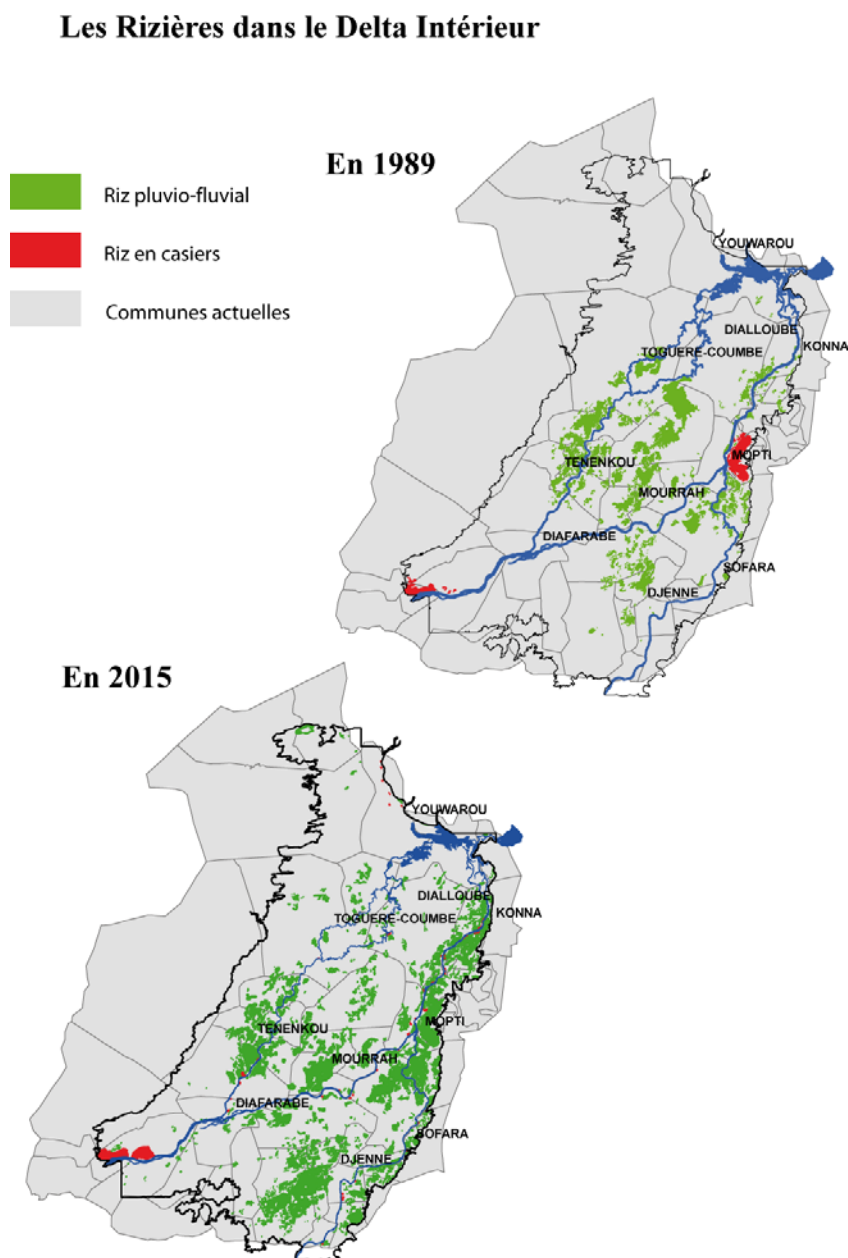
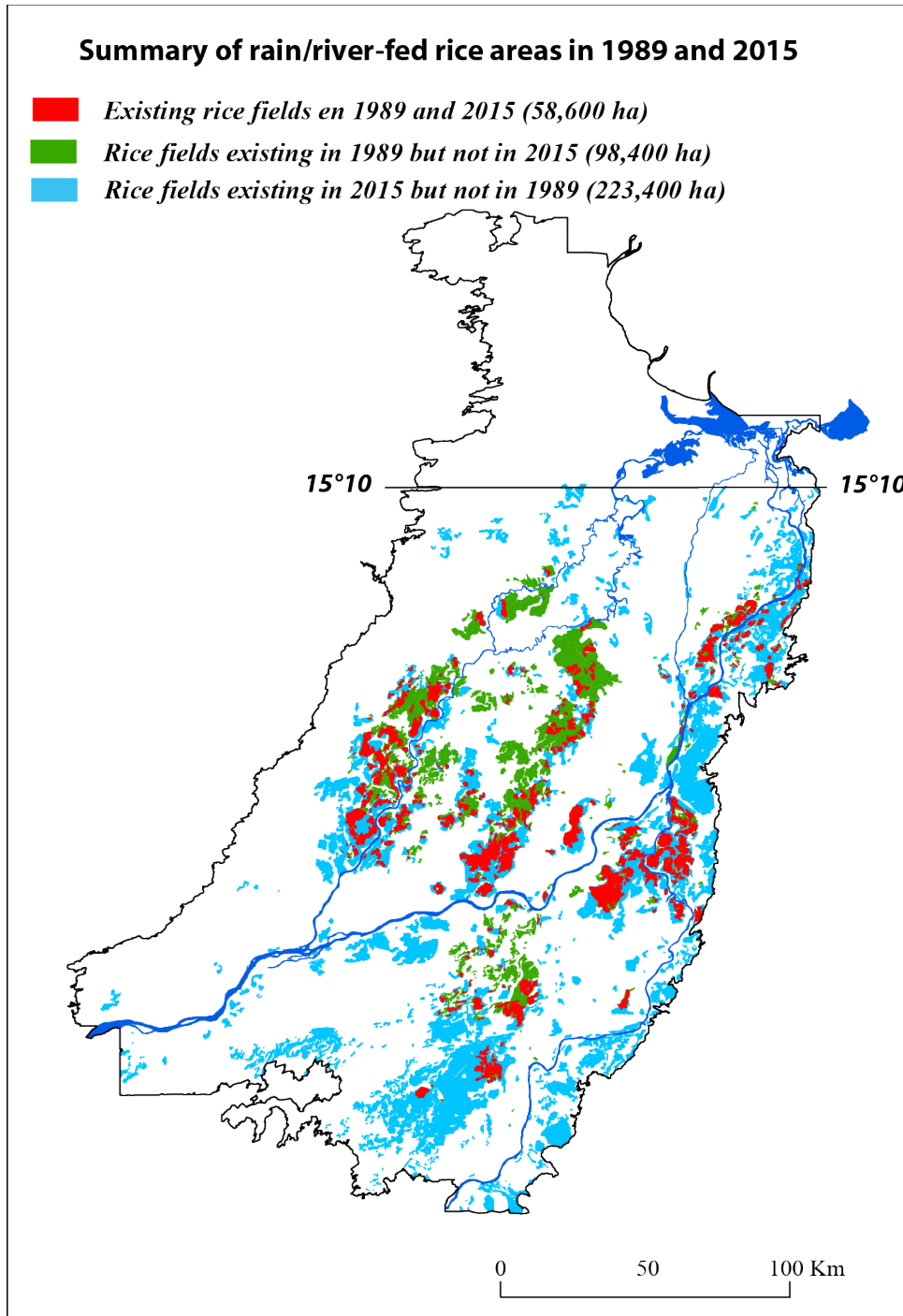


Table 10: Changes in the location of rice fields 1989-2015

Year	Area of rice fields (ha)	Common 1989/2015 (ha)	Municipal fraction %
1989	157,000	58,600	38
2015	282,000	58,600	21

Figure 9: Rice fields in 1989 and 2015

3.3.1 - Cultivated land per municipality and per capita

Is the mobility of rice fields resolved within the framework of the new municipalities established by the decentralization law? In other words, are the movements observed taking place over relatively short distances, compatible with the size of municipal territories, or do they escape this new territorial logic?

Table 11: Rain-fed and irrigated rice areas by municipality and per capita in 1989 and 2015

Name Municipality	Population 1987	Population 2009	Rice fields 1989 (ha)	Rice fields 2015 (ha)	Rice field ratio ha/person (1989)	Rice field ratio ha/person (2015)
BIMBERE TAMA	5 316	8 239	603	3278	0.11	0.4
BORONDOUGOU	6 424	8 070	917	4703	0.14	0.58
DANDOUGOU	7 420	9 410	23	4861	0	0.52
FAKALA						
DEBOYE	16 180	23 152	118	778	0.01	0.03
DERRARY	5 413	6 962	558	2176	0.1	0.31
DIAFARABE	10 945	14 907	0	3556	0	0.24
DIACA	14 321	19 480	1466	11524	0.1	0.59
DIALLOUBE	22 155	30 948	4884	9946	0.22	0.32
DIANKE	5 013	10 447	0	0	0	0
DIONDORI	15 756	20 492	15296	10191	0.97	0.5
DJENNE	18 037	26 267	96	4087	0.01	0.16
FAKALA	20 200	33 714	1	6068	0	0.18
FARIMAKE	7 024	11 916	0	0	0	0
FATOMA	9 953	14 910	0	2036	0	0.14
FEMAYE	10 495	16 324	0	1056	0	0.06
KEWA	12 831	22 025	11727	13478	0.91	0.61
KOKRY CENTER	9 139	17 484	0	62	0	0
KONNA	30 442	36 790	3512	12998	0.12	0.35
KOUBAYE	4 268	6 571	3108	5413	0.73	0.82
KOUNARI	11 245	15 487	1520	5712	0.14	0.37
LERE	5 347	17 432	0	0	0	0
MACINA	22 195	36 272	0	2308	0	0.06
MADIAMA	5 350	11 833	0	1864	0	0.16
MATOMO	9 384	15 027	0	2329	0	0.15
NEMA						
BADENYAKAFO	22 805	46 399	1295	34380	0.06	0.74
NIANSANARI	3 907	4 743	0	172	0	0.04
OURO ALI	7 938	10 826	5056	5798	0.64	0.54
OURO ARDO	9 798	10 341	12445	5057	1.27	0.49
OURO GUIRE	6 550	8 142	5326	8945	0.81	1.1
OURO MODI	2 392	3 228	607	1982	0.25	0.61
OUROUBE DOUDE	9 844	12 224	0	153	0	0.01
PONDORI	5 688	9 991	2286	8956	0.4	0.9
SANA	14,590	23 342	0	2606	0	0.11
SASALBE	4 675	5 996	10,945	8677	2.34	1.45

SIO	15 710	24 130	6257	13209	0.4	0.55
SOCOURA	24 821	36 983	3443	20422	0.14	0.55
SOUGOULBE	5 979	9 255	2386	6823	0.4	0.74
SOULEYE	6 691	9 867	0	2364	0	0.24
SOYE	16 312	21 223	11389	22530	0.7	1.06
TENENKOU	7 313	11 274	384	241	0.05	0.02
TOGORO KOTIA	9 045	13 655	25907	10191	2.86	0.75
TOGUE MOURARI	5 481	9 919	5981	11467	1.09	1.16
TOGUERE COUMBE	23,961	27 575	19416	5909	0.81	0.21

An examination of the distribution of cultivated land by municipality and an analysis of the cultivated land/inhabitant ratios will confirm and clarify this point. Although rural municipalities are recent territorial divisions²⁰, their creation was not the result of administrative arbitrariness, but rather of the choice made by villages to group together under a single political and territorial banner. It should also be noted that land management, i.e., the management of land and natural resources, is one of the prerogatives of those municipalities, which justifies our examination of the relationship between population and cultivated areas within the framework of this new unit.

The analysis of the relationship between rice cultivation and population is obtained by comparing, for 1989, the rice-growing area to the population in 1987 and, for 2015, to the population in 2009. The ratio of rice-growing area per capita, compared to the Delta average on both dates (approximately 0.45 ha/capita) shows very different results between the two dates (Table 7 and Figures 10 & 11). A line-by-line reading of the two columns shows very strong fluctuations, sometimes suggesting strong growth in rice cultivation, sometimes indicating a sharp decline.

In 1989, 20 out of 43 municipalities had no rice fields or a very little rice-growing area (ranging from 0.00 ha to 0.06 ha/ per capita). Nine municipalities had very low rates, ranging from 0.07 ha/capita to 0.35 ha/capita, and only three municipalities (Pondori, Sougoulbe, and Sio) had rates close to the average (0.36 ha/capita to 0.59 ha/capita). In contrast, 11 municipalities had rates well above average, with values ranging from 0.60 to 2.86 ha/inhabitant. Among these, three municipalities located in the center of the Delta had particularly high rates: Togoro Kotia with 2.86 ha/capita, Salsalbe with 2.34 ha/capita, and Ouro Ardo with 1.27 ha/capita (Figure 10).

In 2015, 10 out of 43 municipalities had a zero or very low rate (≤ 0.06 ha/inhabitant); 12 had a low rate (between 0.06 and 0.35); 10 municipalities had an average rate (between 0.36 and 0.59 ha/inhabitant) and 11 municipalities had high rates between 0.69 and 1.45. These results, like maps 10 & 11, show that rice cultivation was much more widespread in 2015 and that the highest ratios in 2015 (1.45 ha/inhabitant) were much lower than those in 1989 (2.86 ha/inhabitant for the maximum).

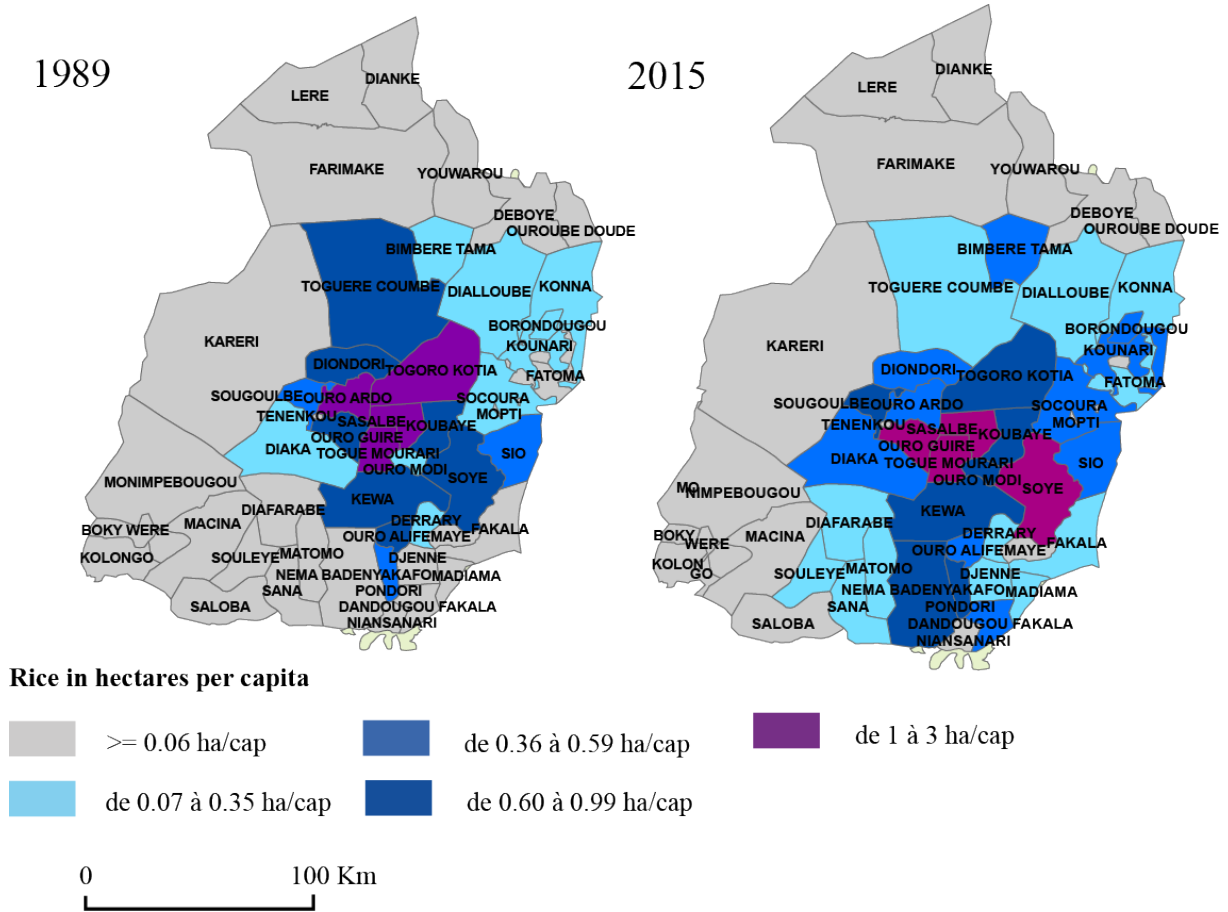
Finally, if we look more specifically at the municipalities of Salsalbé, Togoro Kotia, and Ouro Ardo, which had very high rates in 1989, we see a completely different situation in 2015: Salsalbe went down from 2.34 to 1.45, but more significantly, Togoro Kotia went from 2.86 to 0.75 and Ouro Ardo from 1.27 to 0.49.

These analyses show that rice cultivation is not fixed in municipal territories. The location of rice fields does not correspond to that of the population but seems to shift over long distances, depending

²⁰ They only really came into effect with the establishment of municipal councils in September-October 1999

on the season. Can the mobility of rice fields be explained by relating their location to large hydrological basins?

Figure 10: Ratio of cultivated land per municipality and per inhabitant



3.3.2 – Rice-growing basins and hydrological basins

The mobility of rice fields cannot be understood within the framework of the new rural municipalities. Can it be explained by comparing it with the large hydrological basins of the Delta? (See Delmasig - part 1 - page 21)

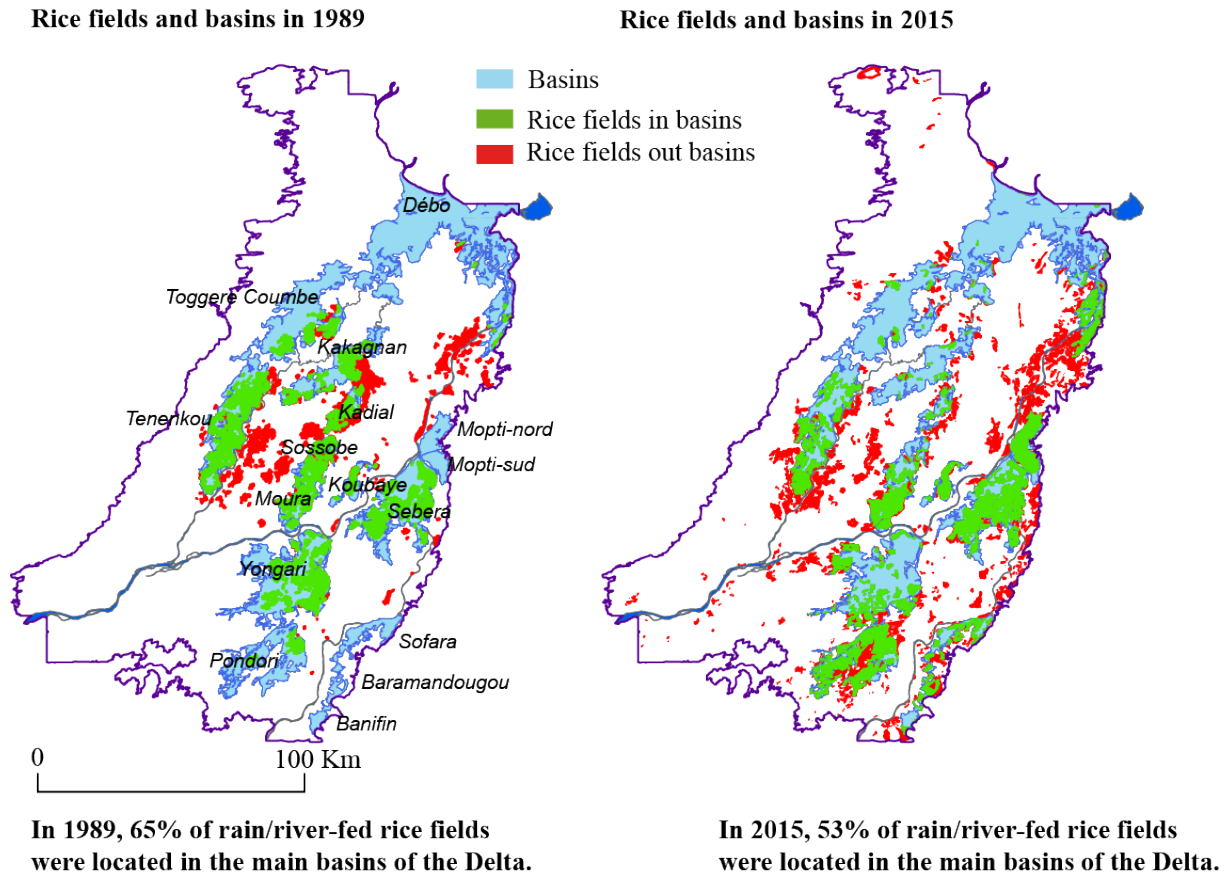
Table 12: land-clearing rates in the main hydrological basins

No.	Name of basin	Total area (in ha)	Area under rice in 1989 (ha)	Percentage of basin under rice cultivation in 1989	Area under rice in 2015 (ha)	% of basin under rice in 2015
1	Debo Walado	120,358	721	0.6	6,838	5.7
2	Togguere Coumbe	51,995	7,482	14.4	2,353	4.5
3	Kakagnan	28,467	9,877	34.7	1,595	5.6

4	Tenenkou	48,357	24,007	49.6	18,241	37.7
5	Kadial	7,227	4,993	66.3	1,417	19.6
6	Sossobe	4,885	3,578	73.2	412	8.4
7	Koubaye	6,815	2,494	36.6	4,277	62.8
8	North Mopti *	8,797	0		7,178	81.6
9	South Mopti *	5,934	0		4,456	75.1
10	Moura	22,242	12,189	54.8	13,829	62.2
11	Sebera	52,357	17,998	34.4	28,487	54.4
11	Yongari Mangari	67,568	17,142	25.4	14,911	22.1
12	Sofara	10,688	0	0	3,418	32.0
13	Pondori	33,620	2,800	8.3	22,788	67.8
14	Baramandougou	4,857	0	0	2,712	55.8
15	Banifin	3,585	0	0	519	14.5
	TOTAL	477,753	103,081	21.6	133,431	27.9

* North Mopti and South Mopti are cultivated in plots established in 1989.

The fifteen main basins of the Delta cover nearly 478,000 ha. In 1989, 65% of rain-fed and river-fed rice fields (103,000 ha out of 157,000 ha) were located in these basins, where the average rate of land clearing reached 21.6%. In 2015, rice fields in the basins accounted for only 53% of the total area of the Delta. At the same time, the rate of land clearing in the basins rose from 21.6% to 27.9%, with most of the growth in rice cultivation taking place outside the hydrological basins.

Figure 11: Rice fields and hydrological basins

This leads us to two observations: between 1989 and 2015, the area of "traditional" rice fields (without water control) almost doubled, in line with population growth, but the location of the rice fields also changed significantly. Although the large basins of the Delta were used more intensively in 2015, this was to a lesser extent than in the Delta as a whole: between 1989 and 2015, pressure on the large basins increased by 30%, while pressure on the Delta as a whole increased by 100%.

The second comment concerns the differences between the basins: in 1989, south of 14°N, the Pondori basin was little cultivated and those of the Bani one (Sofara, Baramandougou, and Banifin) were virtually uncultivated. North of 15°10', there was virtually no land clearing, and the Débo-Walado basin, the largest of all, was not cleared. All of the rice fields were located between latitudes 14° and 15°10' N. In this central strip, the basins were extensively cleared, with a rate of 73% for Sossobé, 66% for Kadijal, (which are, however, quite small basins); 55% for Mourrah, a basin of 22,000 ha, and 50% for Tenenkou, one of 48,000 ha.

The Mopti basins are also heavily cultivated. Developed plots occupy 44% of the northern basin and extend well beyond it to the east, which undoubtedly explains their poor water supply²¹. Thirty-

²¹ This explains why some of the Mopti blocks, whose boundaries are recorded in SAU90, are cut off by LIMITE2 and therefore only appear partially on SAU90_DELTA.

five percent of the Sébéra basin is cultivated with rain-fed and river-fed rice fields (39% with developed plots), and south of Kouakourou, more than a quarter of the Yongari-Mangari basin has been cleared.

The 35% of rice fields that are not located in these main basins are mostly found in three areas: in the medium-depth plains between the Ténenkou and Mourrah basins, in those connecting the Kadiak basin to the northeastern part of Kakagnan, and finally in smaller basins located in the Konna region, along the Niger and Mayo Ranéo rivers. In contrast, the southern basins appear to be little cultivated (8% for Pondori) or not cultivated at all (Sofara, Baramandougou, and Banifin).

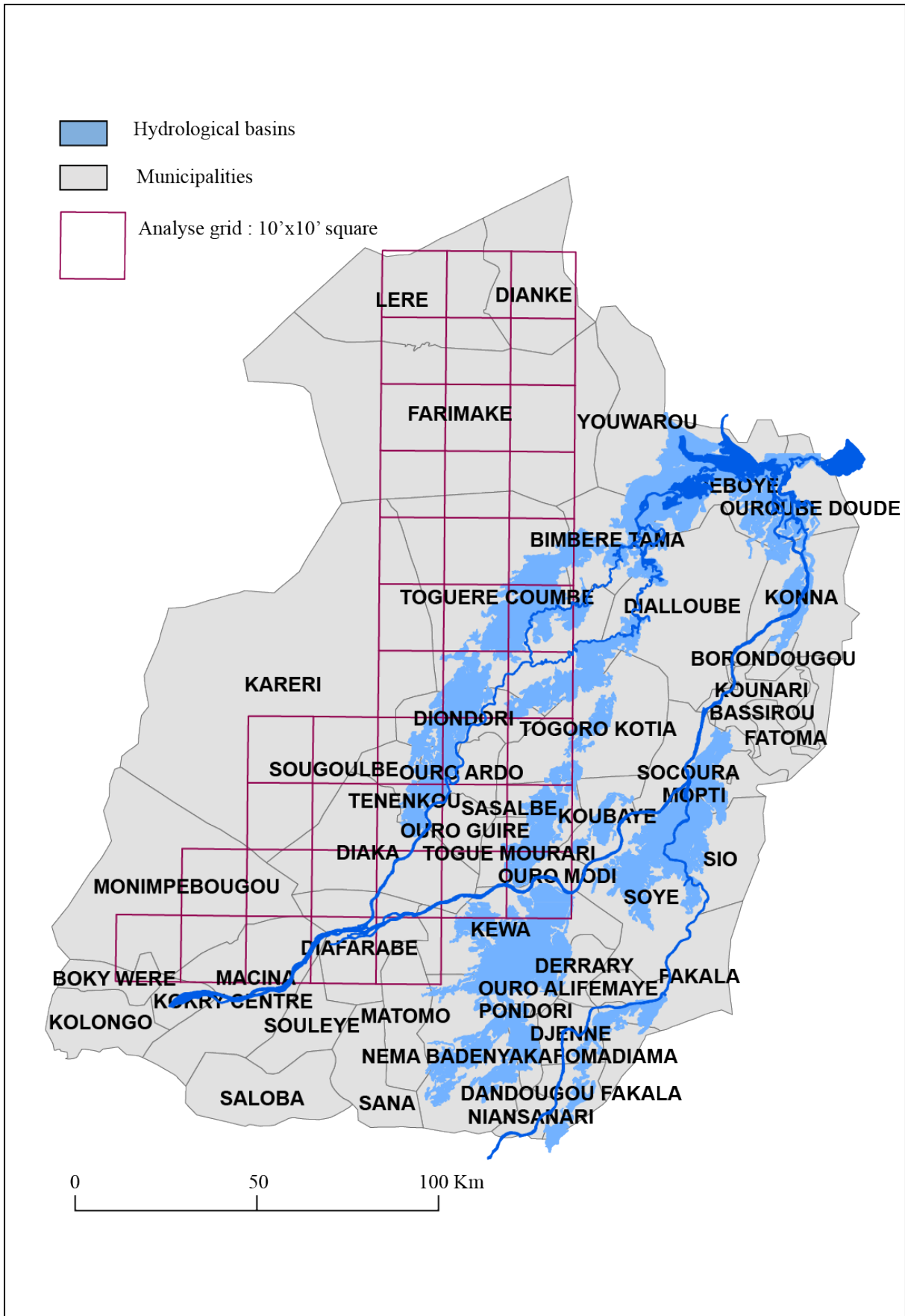
In 2015, the situation is very different: while pressure on all basins has increased from 21.6% to nearly 28%, in directly relation to the growth of cultivated land in the Delta, its distribution between the north and south of the Delta has varied considerably. There has been a sometimes very significant decline in cultivated areas in the northern basins—the deepest ones—and a very sharp increase in the southern basins—the shallowest ones. Thus, Pondori, the southernmost basin, which Jean Gallais described as a "perched basin," saw its rice-growing area increase from 8% in 1989 to 68% in 2015, regaining its status as the rice granary of the southern Delta. Rice fields in the basins on the right bank of the Bani increased from 0% to 32% for Sofara and from 0% to 56% for Baramandougou. On the left bank of the Niger, the Mourrah and Koubaye basins also saw an increase in rice cultivation. Conversely, Tenenkou, the rice granary of the western Delta, saw rice cultivation decline and shift to its outer margins. The change in the central basins is spectacular: Sossobé went from 73% to 8.5%, Kadiak from 66% to less than 20%, and Kakagnan from 35% to less than 6%.

This reveals a dual trend: comparing the mobility of rice fields between 1989 and 2015 across the entire Delta, we see that the geographical layout of the main basins makes the Delta a polycentric space. Rice farmers have been trying to adapt to the significant variations in flooding over the past 50 years by creating veritable "pioneer fronts" in the deepest basins, which are then abandoned when more abundant floods return. These very significant changes are not only achieved by moving rice fields between the Delta's basins and their shallower peripheries. They also result in the abandonment of the shallower basins located between the Niger and the Bani rivers, in favor of the deeper and very sparsely cultivated basins located between the Niger and Diaka rivers. When good floods return, the opposite movement is observed, with the deepest basins being abandoned and the shallower basins, particularly those located between the Niger and Bani rivers, being reinvested. These large-scale movements are detrimental to pastoral areas and contribute to exacerbating land conflicts....

3.3.3. A very ancient form of agricultural nomadism that is still relevant today...

The practices of 1989 were still under the influence of the 1984 flood, the lowest of the century. Do the significant shifts in rice fields in the Delta observed between 1989 and 2015 reflect this catastrophic sequence, or do they also occur in earlier periods? A comparison of the western part of the Delta since 1952 will provide a better understanding of the issue of rice cultivation mobility over the long term.

Figure 12: Analysis grid for rice cultivation in the Delta since 1952



The analysis of cultivated areas in the western part of the Delta was carried out on a 10' x 10' arc grid, north of 14° and west of 4°30'. This grid covers the entire current municipal territories of Diaka, Sougoulbé, Diondiori, and Togue Mourari, and part of those of Diafarabé, Macina, Monimpébougou, and Boky Wéré in the south, as well as Toguere Coumbé, Farimaké, Léré, and Dianké to the north, and only part of Ouro Modi, Salsalbé, and Togoro Kotia in the center of the Delta. The flooded lands of the Delta cover about two-thirds of the grid. Dry crops form a fringe, stretching from Léré in the north (15° 50' N) to Monimpébougou in the south (14°N). The area within the boundaries of the active Delta corresponds to the rice-growing basins of Ténenkou, Toggere Coumbe, Mourrah, and the western part of the Kakagnan basin.

A comparison with the evolution of dry crops provides some insight: from 1952 to 1975, on the western edge of the Delta, the area under dry crops (millet and sorghum) increased from 37,860 ha to 77,070 ha, a 103% increase, which corresponds to a doubling of the area under cultivation. The annual growth rate of cultivated land was therefore 4.5%. The population doubled in the same period – in 23 years – with a growth rate of 3% (it should be noted that the methods of calculation are not the same: the first – cultivated land – is arithmetic, while the second – population – is exponential). Mamadou Nadio (1984)²², indicates a natural population growth rate of 0.43% per year on the western edge of the Delta during this period. We can therefore assume that the sharp increase in cultivated land is linked, to a large extent, to an influx of unregistered populations from the north, following the drought that began in 1969 in the Sahel. Between 1975 (77,070 ha) and 1989 (90,398 ha), the increase in cultivated land was only 1.35% per year, which seems closer to the population growth in this inhospitable area. The year 1984, the driest of the century, also allows us to assume that this margin underwent a complex evolution, with both population arrivals and departures.

The evolution of rain-fed and irrigated rice areas is very different, as shown in the following table:

Table 13: Changes in rice cultivation areas in the western part of the Delta.

Dates	Rice cultivation areas (in ha)
1952	56,960
1975	98,644
1989	76,334
2015	82,352

While the area under dry crops increased over the periods considered, in line with population growth, the area under rice cultivation showed a more chaotic trend. From 1952 to 1975, rice cultivation areas increased from 56,960 ha to 98,644 ha, a rise of more than 73 %, before declining by 23 % between

²² M. Nadio, *The evolution of the inner Niger delta (Mali) 1956–1980. From an underpopulated region to an overexploited region?* Doctoral thesis, ROUEN, 1984, 220 p.

1975 and 1989 (76,334 ha) and increasing slightly (8 %) between 1989 and 2015, while the increase was very strong across the Delta as a whole. Over the 1952-2015 period, the net increase was only 45 % on this western margin, while across the Delta as a whole, the area of rice fields, like the population, tripled during this period of more than 60 years. An analysis of cultivated areas, square by square, will clarify this trend.

Table 14: Cultivated areas per square in 1952, 1975, 1989, and 2015

Name of square	Dry crops in 1952 (ha)	Dry crops in 1975 (ha)	Dry crops in 1989 (ha)	Rice in 1952 (ha)	Rice in 1975 (ha)	Rice in 1989 (ha)	Rice in 2015 (ha)
F14	450	450	947	494	1,466	0	664
F15	100	660	583	798	1,182	0	1053
G13	260	850	976	107	0	0	0
G14	0	0	0	1834	265	778	0
G15	0	0	0	3503	4,299	7,099	1362
H13	390	2,370	768	1022	562	374	432
H14	0	0	0	3780	7,703	9,987	4,703
H15	0	0	0	2439	991	4,022	766
I11	1,050	4,600	8,342	0	0	0	0
I12	3,290	8,550	4,195	100	54	0	92
I13	390	2,100	0	9004	13,796	7,306	9,070
I14	0	0	249	9022	8,699	9,987	6030
I15	0	0	0	1410	2,978	6,563	2,687
J11	1,300	4,600	5,788	0	0	0	0
J12	1,580	3,680	4,627	184	367	0	247
J13	150	200	318	8978	20,988	6,286	17,063
J14	0	0	0	2542	6,006	5,497	5465
J15	0	0	0	1942	10,662	12,711	12,490
K10	6,050	9,080	13,402	0	0	0	0
K11	1,810	2,750	8,703	0	0	0	85
K12	530	1,970	4,638	329	242	0	215
K13	0	0	0	667	3,865	92	3085
K14	0	0	110	761	3,661	362	3,757
K15	0	0	0	3990	10,229	5,269	7,932
L9	9,470	15,000	18,876	0	0	0	0
L10	3,160	5,130	3,398	0	0	0	547
L11	230	620	0	1292	0	0	475
L12	80	0	0	2654	448	0	955
L13	0	0	0	74	179	0	3175
TOTAL	37,860	77,070	90,398	56,926	98,642	76,333	82,350

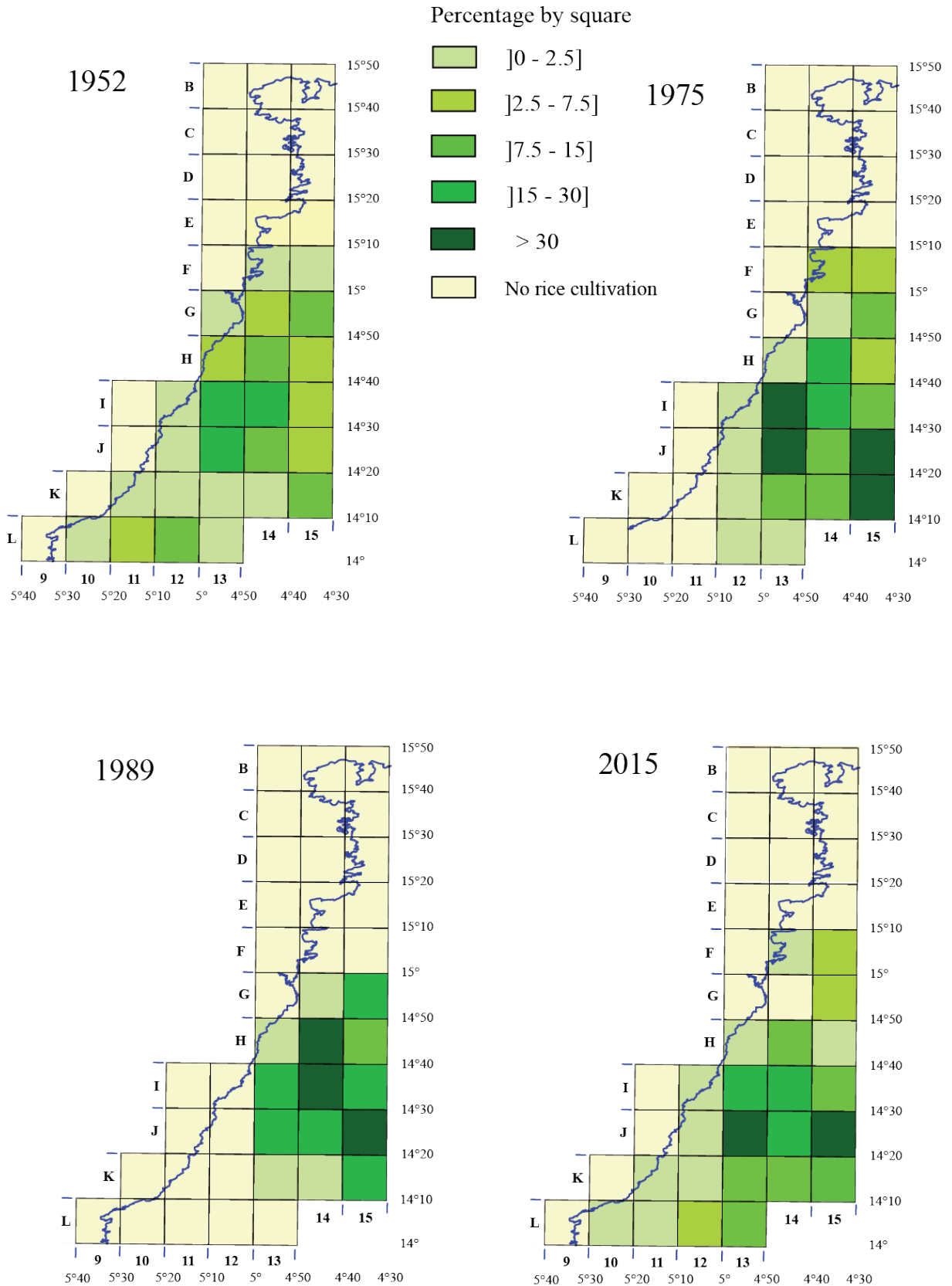
* 34 ha are located outside the squares

** The slight difference in the total is due to rounding

The following four charts show the rates of land use for rice cultivation per 10-minute arc square according to the previous table.

Figure 13: Land use rates for rice fields per 10' square in %

Percentage of land occupied by rain/river-fed rice fields per 10' plot



From 1952 to 1975, rice cultivation was abandoned in four peripheral squares: G13, K11, I10, and I11. At the same time, the rates of land use per square increased sharply, particularly in squares H14, I13, I14, J13, and J14, corresponding to the Ténenkou basin, as well as in squares J15 and K15 (Mourrah basin and northern Yongari). This growth accompanied that of the population in a very classic process.

However, the trend between 1975 and 1989 contrasts sharply with the previous period: rice-growing areas declined sharply (a loss of 22,000 ha), with rice fields concentrated in only 14 squares (compared to 22 squares in 1975), closely linked to the Ténenkou basin. Rice cultivation seems to be disappearing from the southern squares, which correspond to the right bank of the Niger River at the Niger-Diaka confluence.

Between 1989 and 2015, rice-growing areas increased slightly, from 76,000 ha to 82,000 ha, in contrast to population growth. On the other hand, rice fields spread over a larger number of plots (23), bringing this situation closer to that of 1952, but with higher land use rates in 2015.

Between 1952 and 2015, there were significant changes in the rice-growing area, with some squares being abandoned, marking a sharp decline in rice cultivation, and others expanding. At the same time, the land use rate increased in some squares and then decreased, in contrast to population growth. This is the case, for example, in square K15, where the land use rate changed between 1952 and 2015 from 12% in 1952 to 31% in 1975, 16% in 1989, and 24% in 2015.

In order to better understand this contrasting trend in rice cultivation areas, we calculated an index of growth in rice cultivation areas, by period and by square²³, which was then normalized as follows:

$$\text{Growth index Standardized (1952–1975)} = \frac{\text{Rice area in square 'A' 1975}}{\text{Area under rice cultivation 'A'}} \times \frac{\text{Total rice area 1952}}{\text{Total rice area 1975}}$$

In other words, the increase observed between 1952 and 1975 (+65%), which is equivalent to a multiplier coefficient of 1.65, is reduced to 1 by the second term of the formula for calculating the standardized index. The aim is to determine which squares deviate significantly from the norm, whose value is 1. The same calculation is performed for the 1975-1989 and 1989-2015 periods.

²³ It should be noted that each 10' x 10' arc square represents an area of approximately 33,000 ha (specifically 32,936 ha to 33,226 ha depending on the geographical location), or approximately 18 x 18 km.

Table 15: Rice-growing areas per square and normalized index for the 1952-1975 and 1975-1989 periods.

Square	area (ha)				Standardized index		
	Rice_1952	Rice_1975	Rice_1989	Rice_2015	1952-1975	1975-1989	1989-2015
F14	494	1466	0	664	1.71	0	NC
F15	798	1,182	0	1053	0.85	0	NC
G13	107	0	0	0	0	0	0
G14	1834	265	778	0	0.08	3.79	0
G15	3503	4,299	7,099	1362	0.71	2.13	0.18
H13	1022	562	374	432	0.32	0.86	1.07
H14	3780	7,703	9,987	4703	1.18	1.68	0.44
H15	2439	991	4,022	766	0.23	5.24	0.18
I11	0	0	0	0	0	0	0
I12	100	54	0	92	0.31	0	NC
I13	9004	13,796	7,306	9070	0.88	0.68	1.15
I14	9022	8,699	9,987	6030	0.56	1.48	0.56
I15	1410	2,978	6,563	2,687	1.22	2.85	0.38
J11	0	0	0	0	0	0	0
J12	184	367	0	247	1.15	0	NC
J13	8978	20,988	6,286	17,063	1.35	0.39	2.52
J14	2542	6,006	5,497	5465	1.36	1.18	0.92
J15	1942	10,662	12,711	12,490	3.17	1.54	0.91
K10	0	0	0	0	0	0	0
K11	0	0	0	0	0	0	0
K12	329	242	0	215	0.42	0	NC
K13	667	3,865	92	3,085	3.34	0.03	31.08
K14	761	3,661	362	3,757	2.78	0.13	9.62
K15	3990	10,229	5,269	7932	1.48	0.67	1.4
L9	0	0	0	0	0	0	0
L10	0	0	0	547	0	0	NC
L11	1292	0	0	475	0	0	NC
L12	2654	448	0	955	0.1	0	NC
L13	74	179	0	3175	1.4	0	NC
TOTAL	56,926	98,642	76,333	82,350	1	1	1

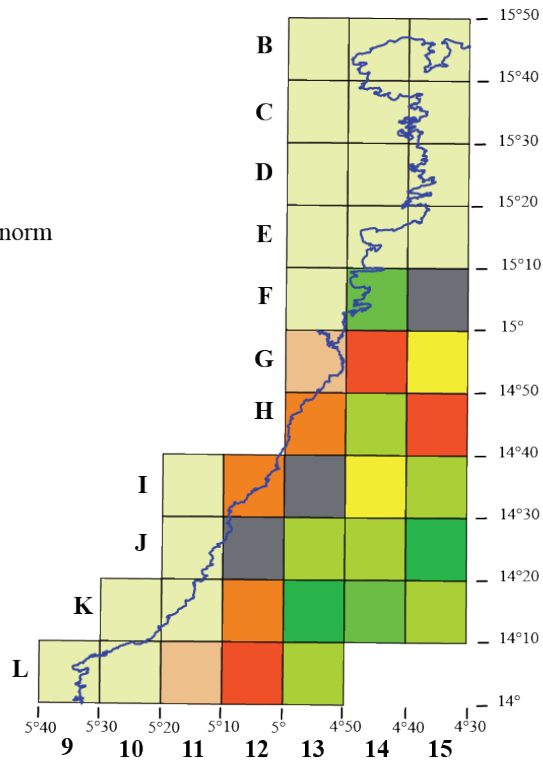
Figure 14: Standardized index of variation in rainfed rice areas per 10' square (western Delta) over three periods

Standardized index of changes in rice-growing areas over three periods

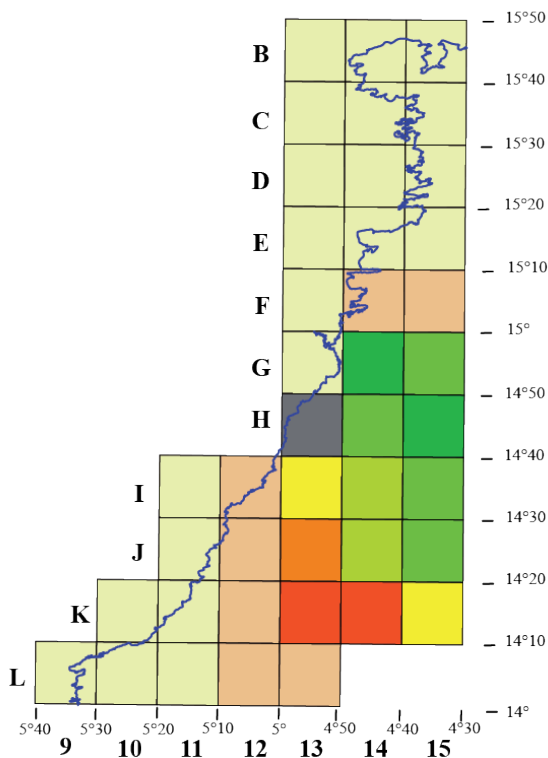
Legend

- 1** Standardized index = NC (not calculated)
Appearance of rice cultivation in year 2
- 2** $SI \geq 3$
Extremely strong increase in rice cultivation
- 3** $1.5 \leq SI < 3$
Very strong positive change compared to the norm
- 4** $1.15 \leq SI < 1.5$
Stronger positive trend than the norm
- 5** $0.85 \leq SI < 1.15$
Situation within the norm
- 6** $0.50 \leq SI < 0.85$
Moderate decline in rice cultivation
- 7** $0.25 \leq SI < 0.5$
Sharp decline in rice cultivation
- 8** $0.01 \leq SI < 0.25$
Decline in rice cultivation to the point of near extinction
- 9** $SI = 0$
Rice cultivation disappeared in year 2
- 10** $SI = 0$
Absence of rice cultivation on both dates

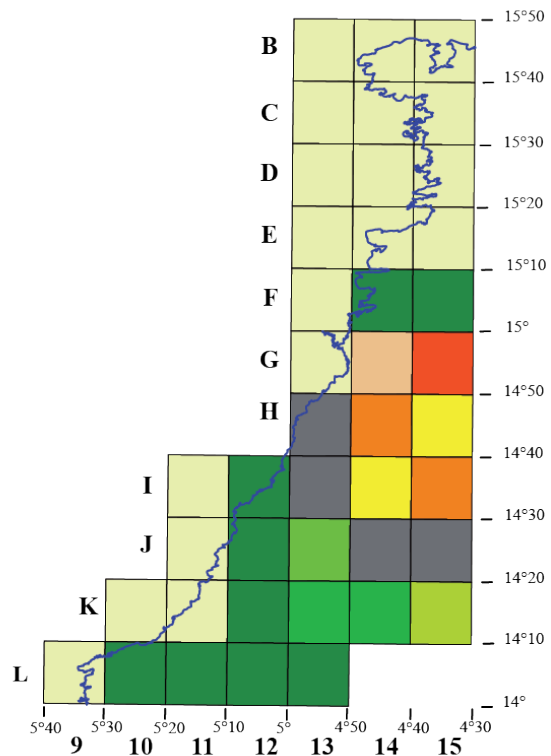
Trend 1952-1975



Trend 1975-1989



Trend 1989-2015



NB:

- A normalized index value of 1, found in the **total areas** for the years considered, means that rice cultivation in a given square has evolved in line with the area as a whole.
- The value 0, depending on the case, means that there is no rice cultivation in the square on both dates or that rice cultivation disappeared from the square in year 2. We distinguish between the two cases in the legend.
- NC: Not calculated because division by zero: rice cultivation appeared in the square in question in year 2, whereas there was none in year 1.

During the period 1952-1975, in a general context of strong growth in cultivated areas, the map shows a decline in rice-growing areas. Ten out of 23 squares show a decline, with rice cultivation disappearing in two of them (G13, L11) and declining to a greater or lesser extent in the other eight (G14, G15, H13, H15, I12, I14, K12, and L12). Most of these squares are located on the periphery of the Delta, and two of them are located towards the center, one south of the current territory of Toguéré Coumbé (H15) and the other in the territory of Diondiori (I14). The squares showing strong growth are located towards the south-center of the area, with the exception of one (F14), located in the northeastern part of the Toguéré Coumbé basin.

During the period 1975-1989, the previous trend was confirmed and reinforced, showing a sharp contraction in the area under rice cultivation. Rice cultivation was abandoned in seven peripheral squares, some of which were already in decline during the period 1952-1975. Conversely, eight of the 23 squares showed strong growth (G14, G15, H14, H15, I14, I15, J14, J15). They form a block in the south-central part of the area, connected to the Ténenkou and Toguere Coumbé basins and, to the east, to the Mourrah and Salsalbé basins. In addition to the abandonment of the western margins of the Delta, the major development is the abandonment of the southern squares, around 14° / 14°10 latitude, located on the Niger-Diaka confluence. It appears that the Diafarabé region and the upper Diaka were abandoned during this second period.

The period from 1989 to 2015 is almost the opposite of the previous period. It is marked by a sharp decline in the central core (G14, G15, H14, H15, I14, I15, and J15), which had recorded the strongest growth between 1975 and 1989, and four squares (H13, I13, J14, J15) located on the periphery of the previous core, which remained virtually stable. Conversely, rice fields were established—or reestablished—in nine squares (F14, F15) in the north and (J12, K12, L10, L11, L12, L13) in the west and south. We observe strong growth in rice cultivation on the periphery at the expense of the center, accompanied by a significant spread of rice-growing areas. In fact, in 1989 compared to 1975, 14 squares (approximately 462,000 ha) were used for rice cultivation, while in 2009 compared to 1989, 22 squares (approximately 726,000 ha) were used.

The 1950s was a period of very high floods, exceeding the reference flood level used in the ecological study (660 cm), with three years exceeding 700 cm (1950, 1951, and 1952). Although the 1975 flood corresponded to the reference flood, the average for the previous five years (1971-1975) was significantly lower, with two very low years (565 cm in 1972 and 568 cm in 1973). The 1989 flood was very low (517 cm), with a five-year average (1985-1989) of 535 cm, which was hardly any better. It followed 1984, which, at 440 cm, was the worst recorded since monitoring of the Niger began in the 1920s. These sudden changes in the river's flow have forced rice farmers to adapt by moving their rice fields. This is clearly illustrated by an analysis of the location of rice fields in 1989 and 2015 in relation to hydrological basins.

Table 16: Floods in Mopti in 1952, 1975, 1989, and 2015

Periods	1952	1975	1989	2015
Flood in Mopti (cm)	719	663	517	618
Average for the previous 5 years	688	619	535	618

* The average is calculated for 2009-2013

An analysis of the evolution of rice cultivation over 63 years in the western Delta shows great instability in the rice-growing area, which contracts or expands significantly, depending on the period, clearly illustrating the "rice nomadism" referred to by several authors.

As previously observed for the years 1989 and 2015 across the entire Delta, the location of rice fields cannot be understood within the municipal framework. With the exception of the municipalities of Diondiori and Ouro Ardo, the map of rice area per capita ratios in 1989 is almost the mirror image of that of population densities in 1987 (see "Population" section). The municipalities with the highest index all have very low or low population densities. These very strong discrepancies for the municipalities of Togoro Kotia, Salsalbe, Togue Mourari, Koubaye, and Kewa, all of which are heavily cultivated and sparsely or very sparsely populated, show that there is no correlation between population density and land use at the municipal level. These phenomena, which reveal the mobility of rain-fed and river-fed rice cultivation, which is not firmly established in territorial frameworks, are well described in the article by M. Kuper and H. Maïga, based on observations made in particular by Kelly (*et al*)²⁴ :

*The main production areas are traditionally Djenneri, Macina, Mourari, and Raneo. Kotia is of particular interest: during droughts, it served as a "granary" or "refuge" for farmers thanks to the presence of low-lying areas. Farmers from neighboring areas (e.g., Raneo, Mourari, and even Mopti) moved there during the growing season to cultivate rice. This colonization is often limited in time, i.e., temporary movements during the growing season, and farmers would have continued to live in their villages of origin [...]. It is very interesting to note that farmers have apparently returned to their former farming areas after the heavy floods of 1994 and 1995.*²⁵

We fully share this view, but would like to add a few comments: the temporary movements of rice farmers attempting to adapt to flood conditions are not completely overlooked by population censuses. The municipality of Togoro Kotia, where rice cultivation developed very rapidly before 1989, is also—along with Salsalbé—the area in the Delta which, while maintaining low population densities that are inconsistent with its land use, experienced one of the highest population growth rates between 1975 and 1989 (+4.73% for Togoro Kotia, +3.50% for Salsalbé), a growth that is unrelated to natural increase. After the 1994 flood that submerged the farming hamlets located in low-lying areas²⁶, a large number of the farmers left. The 1998 census shows that for the period 1987-1998, the growth rates of these two territories were below the regional average.

The long-term location of rice fields in the Delta cannot therefore be explained by the location of the population. It can only be explained in part by the location of large hydrological basins. In particular, the expansion of rice fields correlated with population growth (the per capita availability

²⁴ S. Kelly (et al.), Niger River Interior Delta. Mission report, November 10-23, 1998. Bamako: IRD, 1998

²⁵ M. Kuper & H. Maïga, *op. cit.*, p.9

²⁶ There are few *toggere* suitable for permanent settlement in these central regions.

remains constant at 0.45 ha/inhabitant over 60 years!) does not occur through an increase in land use on the periphery of the hydrological basins. In fact, there is a real alternation between the northern basins, which are deeper, and the southern basins, which are less well supplied, depending on flood patterns.

In 1957-58, during a period of heavy and very stable flooding, Jean Gallais estimated that rice fields had shifted by around ten kilometers, painting a picture of "*village lands destabilized by the relentless search for the best possible location for rice fields, sliding up and down the plain in order to align with the expected floodwaters.*" The shifts reported by M. Kuper and H. Maïga, as well as our analysis, are of a different scale, and imply true agricultural nomadism. The comparison of the location of rice fields between 1989 and 2015, and the analysis of the evolution of the western edge of the Delta since 1952, correspond to very contrasting flood regimes that determine this nomadism of rice fields. **This leads us to wonder whether the very notion of a rice-growing terroir makes sense, or whether we should instead consider the Delta as a whole as a single agricultural migratory space.**

However, the constant movement of rice fields in the Delta is not random: we will therefore seek to understand the strategies of rice farmers, starting with their relationship with the natural environment.

4 - RICE FARMERS' STRATEGIES: RICE FIELDS AND VEGETATION.

Rice farmers in the Inner Delta move their rice fields, sometimes over long distances, in the hope of adapting to variations in flooding. However, the choice of location for a new rice field is not random. What criteria do rice farmers use to choose the location they consider most suitable? We postulate that two major factors should be taken into account: plant formations and the soils associated with them are the first guiding criterion. The second, more conjectural, is the expected height of the flood.

The information discussed in this chapter is derived from shapes representing the areas of rain-fed and river-fed rice fields Riz52, Riz75, Riz89_ouest, Riz2015_ouest for the western part of the Delta, as well as Riz_89 and Riz_2015 for the entire Delta. The relationship between rice fields and the vegetation is established by using spatial operators to cross-reference the areas cultivated with rice with Veg7_ouest for the western part or all cultivated areas of the Delta in the case of Riz_89 and Riz_2015 with Veg7_15°10 showing vegetation formations. This operation makes it possible to "read" the vegetation formations included within the boundaries of the rice fields, i.e., the formations that existed in that location before they were cleared and became temporary rice fields, followed by fallow land where the original vegetation formations reappeared. Furthermore, we limit our analysis to latitude 15°10. In 1989, with one exception, we found no rain-fed rice fields established north of 15°10. This limit was also confirmed in 2015: the few rice fields mapped north of Farimaké are not rain-fed rice fields but floodplain rice fields on the edge of a lake. We will explain this choice in greater detail later.

For now, let us accept this limit as a fact based on field data. The data resulting from the intersection between rice fields and vegetation formations were then processed as follows: The resulting areas of less than 1 ha were removed, then the intersections between rice fields and vegetation formations corresponding to "*Togge*" (i.e. non-floodable mounds:T-shaped formations - level 1) or combining a floodable formation with a non-floodable one (e.g., PAN/TA) corresponding to levels 21, 31, 41, and 61 were also deleted. The result of these simplifications is presented in **Table 17, which reproduces Table 5 on page 13.**

Table 17: Accuracy of rice-growing areas from 1952 to 2015

WEST DELTA	Gross area	Less than S<1ha	Less non-floodable areas	Confidence percentage
Rice52_Veg7	56,960	56,840	53,812	94.5
Rice75_Veg7	98,644	98,585	95,656	97.0
Rice89_west_Veg7	77,042	76,990	76,308	99.0
Rice2015_west_Veg7	84,824	84,718	82,071	96.8
DELTA 15°10				
Rice_1989	158,767	158,683	156,961	98.6
Rice_2015	304,660	304,277	281,778	92.5

Deriving data from different sources raises a problem of data quality, as explained in section 2.2, page 8. These errors may stem from the inaccuracy of the Veg7 coverage, which allows for errors of up to 300 m, or from errors made in the recording of rice fields. The percentage for the ratio between gross area and net area (*minus non-floodable areas*) in the previous table indicates the level of confidence that can be placed in the quality of the processed data. They are good for 1975, 1989, and 2015 (western Delta), poorer for 1952 and 2015 (Delta 15°10). In 1952, rice fields were mapped using IGN photo coverage, which was less accurate than the data from 1975 and 1989 (IFR aerial photography or satellite data) and precluded the possibility of field checks, as was systematically done in 1975. In 2015, the data came from Google Earth mapping, a medium on which it is difficult to distinguish between a rain-fed rice field, a dry crop located on a *Toggere*, or a garden. There were few "rice fields" located on dry formations in 1975 and 1989, but relatively more in 2015, which explains the lower confidence (92.5%) in the quality of the data.

4.1. - The choices made by rice farmers in the western Delta from 1952 to 2015

Our analysis of rice farmers' choices covers a period of 63 years, during which two major changes had intertwined effects: the population growth on the one hand, and, on the other, significant variations in rainfall and flooding patterns, which each year closely determine the success or failure of rain-fed and flood-irrigated rice cultivation.

This analysis covers the area delimited by the Grille_agri1 shapefile used to record rice fields in 1952 and 1975. The vegetation formations included within the boundaries of this grid cover a total area of 772,665 ha. (Shape Veg7_ouest). This means that the diachronic analysis covers nearly 40% of the Delta's surface area (excluding Farimaké). If we compare the area covered by rice fields to the area of flood-prone vegetation formations (590,100 ha out of a total area of 772,665 ha), we can define the "gross" pressure of rice cultivation on this part of the inner Delta. In 1952, this "gross" pressure was 9.6%, rising to 16.7% in 1975, falling to 13.1% in 1989, and then increasing slightly to 14.4% in 2015.

We will further define a pressure that can be described as "net" pressure, which we believe to be more realistic, by comparing the area of rice fields to that of vegetation cleared by rice farmers.

4.1.1 - Rice farmers' choices in the western Delta in 1952

Table 18: Contribution of the main vegetation formations to rice fields and rate of clearing of these formations in 1952 (western part of the Delta)

Rank of contribution to rice fields	Cleared vegetation formations	Total area cultivated in the formation (ha)	Contribution of plant formations to areas cultivated with rice (in %)	Cumulative percentages of areas cultivated with rice	Total area occupied by the formation	Rate of clearing of the formation in %	Rank of the rate of land clearing
1	O	11,503	21.4	21.4	36,148	31.8	1
2	OP	4,613	8.6	29.9	28,981	15.9	6
3	O/VSP	3,573	6.6	36.6	19,372	18.4	3
4	OP/VOR	3,285	6.1	42.7	30,622	10.7	10
5	B/OP	3,258	6.1	48.7	31,381	10.4	11
6	ESP/VSP	2,714	5.0	53.8	32,162	8.4	15
7	VSP	2,600	4.8	58.6	19,604	13.3	8
8	OP/O	2,539	4.7	63.3	14,449	17.6	4
9	VOR	2,012	3.7	67.1	32,085	6.3	19
10	EOR	1,771	3.3	70.4	12,829	13.8	7
11	ESP	1,325	2.5	72.8	11,007	12.0	9
12	O/ESP	960	1.8	74.6	4,773	20.1	2
13	VH	958	1.8	76.4	9,511	10.1	12
14	VOR/VSP	789	1.5	77.9	16,917	4.7	21
15	AC/VH	771	1.4	79.3	33,434	2.3	25
16	B	734	1.4	80.7	7,845	9.4	14
17	VSP/VH	708	1.3	82.0	14,141	5.0	20
18	MB1	689	1.3	83.3	10,120	6.8	17
19	VH/ZB	655	1.2	84.5	6,794	9.6	13
20	VH/AG	614	1.1	85.6	14,147	4.3	22
21	ESP/VH	595	1.1	86.7	8,255	7.2	16
22	VH/P	585	1.1	87.8	23,201	2.5	24
23	ZB	578	1.1	88.9	3,623	16.0	5
24	VB/O	553	1.0	89.9	8180	6.8	17
25	MB2	519	1.0	90.9	14,469	3.6	23

We limit the cumulative cultivated area to 90% of the total rice field area. The remaining 10% is located on plant formations that account for a very small percentage of rice fields (<1%), and whose occupancy rate is also very low. In this case, it may be a matter of very marginal choices made by rice farmers or... inaccurate data.

These formations are classified according to their contribution to cultivated areas, in absolute terms (in ha) and relative terms (%). Column 5 shows the cumulative percentages of areas cultivated with rice. Columns 6 to 8 contain other information that is interesting to compare with the previous column. Column 6 shows the total area occupied by the plant formation in the part of the Delta under

consideration, and column 7 indicates its rate of clearing. Column 8 indicates the rank of the vegetation formation in terms of the rate of clearing. Thus, formation O, ranked number 1 (column 1 of the table), is the one that contributes most to rice fields, with 11,503 ha, representing 21.4% of rice fields in 1952. This same formation also ranks first in terms of the rate of clearing (column 8), since it is 31.8% cleared.

Thus, a formation such as O can significantly contribute to rice fields (it is ranked 1st in terms of contribution) and be heavily cleared. Another formation—as in the case of O/ESP, which is not very abundant—may only rank 12th in terms of contribution to rice fields (1.8%) but rank 2nd in terms of clearing rate. It is easy to see that the first part of the table provides information on the choices made by rice farmers in terms of clearing at a given period. A plant formation can contribute significantly to the creation of rice fields when it is cleared. In this case, it is considered a land resource. The second part of the table provides information on the competition for the use of this vegetation, among rice farmers of course, if the vegetation is heavily cleared, but also between rice farmers and other users of the same natural environment, particularly livestock farmers, when this vegetation is also sought-after pastureland. In this case, competition no longer takes place over a land resource but over the choice of how to use the natural resource: should it become agricultural land for a time or remain as pasture?

In 1952, rice fields covered 56,960 ha in the western part of the Delta. Six percent of these rice fields were located in "unlikely" positions. Ultimately, we estimate that in 1952, rice fields covered an area of 53,812 ha. In this case, 25 plant formations contributed to 90.9% of the rice fields, with O, OP, O/VSP, OP/VOR, B/OP, and ESP/VSP, being the most significant formations and accounting for 50% of the rice fields (part 1 of the table). The first five of these six formations include rice fields carrying *Oriza longistaminata* and *Oriza barthii*, thus demonstrating the importance of the presence of wild rice in the choice of location for rice fields. However, part 2 provides further information, indicating, in particular, the rate of land clearing and therefore the pressure exerted on each plant formation concerned. In this case, the ranking puts O in first place with more than 30% cleared, followed by O/ESP (20%), O/VSP (18%), and OP/O (17%). These two parts of the table may contain somewhat contradictory information: while the "B" formation (bourgoutière), the best pasture in the Delta, contributes little to the rice fields (1.4%), its level of impact is 9%, which is not insignificant for livestock farmers. The fairly marginal presence of formations that are not prone to flooding, such as AC/VH, VSP/VH (between 30 and 60 cm of water) or VH, VH/P or VH/AG (between 10 and 30 cm) or ZB (between 0 and 10 cm), 16% of which are cleared, may seem curious. The water levels at which the vegetation formations are located were defined by Pierre Hiernaux in relation to a reference flood level of 6.60 m in Mopti. In 1952, the flood reached 7.19 m (7.07 in 1950, 7.12 in 1951, 7.31 in 1953, 1954, 1955). This long "wet" period lasted from 1950 to 1967. These high formations were then under an exceptional 70 to 90 cm of water, compared to the reference flood level. At that time, the shallow formations were perfectly compatible with rice cultivation. Conversely, and for the same reason, the most flood-prone formations (VB/OP and B/VB and, a fortiori, BP/VB) were not used because they were too deep.

At the beginning of this chapter, we indicated a "gross" pressure of rice cultivation on the environment of 9.6%. If we now relate 90% of the rice fields to the 25 plant formations concerned (S = 444,050 ha), the pressure that can be defined as "net" pressure, then stands at 11.0% (instead of 9.6%). This is still very moderate and not very different from the pressure estimated by Jean Gallais at the end of the 1950s for the entire Delta (10%).

4.1.2 – The situation in the western Delta in 1975

Table 19: Contribution of the main plant formations to rice fields and rate of clearing of these formations in 1975 (western part of the Delta)

Rank of contribution to rice fields	Cleared vegetation formations	Total cultivated area in the formation (ha)	Contribution of the vegetation formation to rice areas (in %)	Cumulative percentages of areas cultivated with rice	Total area occupied by the formation	Clearing rate of the formation (in %)	Rank of clearing rate
1	O	21,989	23.0	23.0	36,148	60.8	1
2	OP	12,060	12.6	35.6	28,981	41.6	2
3	B/OP	8,949	9.4	45.0	31,381	28.5	6
4	O/VSP	7,548	7.9	52.8	19,372	39.0	3
5	OP/VOR	7,400	7.7	60.6	30,622	24.2	8
6	ESP/VSP	4,514	4.7	65.3	32,162	14.0	10
7	VOR	3,811	4.0	69.3	32,085	11.9	12
8	OP/O	3,704	3.9	73.2	14,449	25.6	7
9	VSP	3,461	3.6	76.8	19,604	17.7	9
10	B	2,315	2.4	79.2	7,845	29.5	5
11	VOR/VSP	1,892	2.0	81.2	16,917	11.2	14
12	ESP	1,439	1.5	82.7	11,007	13.1	11
13	VSP/VH	1,372	1.4	84.1	14,141	9.7	15
14	OP/EOR	968	1.0	85.1	10,560	9.2	16
15	ESP/VH	963	1.0	86.1	8,255	11.7	13
16	O/VOR	896	0.9	87.1	2,946	30.4	4
17	EOR	874	0.9	88.0	12,829	6.8	19
18	VH/AG	852	0.9	88.9	14,147	6.0	20
19	VH	836	0.9	89.7	9,511	8.8	17
20	MB1	832	0.9	90.6	10,120	8.2	18

In 1975, rice fields covered an area of 98,644 ha. (Rice fallow land covered 94,210 ha). After removing areas smaller than 1 ha and plots located on non-floodable formations, rice fields covered 95,656 ha. Twenty formations accounted for 90% of rice fields (86,675 ha), ranging from 23.0% to 0.9% of rice fields (for a total of 90.6%). In 1952, 25 plant formations accounted for 90% of rice fields. *Oryza* formations (containing O or OP) accounted for two-thirds of rice fields, and the top five (O, OP, B/OP, O/VSP, and OP/VOR) accounted for 60% of rice fields. While the presence of wild rice still guides the choices of rice farmers, we are also seeing the clearing of formations (B and B/OP) of *Echinochloa stagnina*, the most sought-after pasture in the Delta. On the other hand, the rates of clearing of rice fields are remarkably high for O and OP), at 60.8% and 41.6% respectively. O/VSP in 3rd position is 39% cleared and B, the Bourgoutière, in 5th position, is nearly 30% cleared!

In 1975, the situation appeared very different from the conditions that prevailed in 1952. In 1975, the area suitable for rice cultivation was reduced to 363,082 ha (compared to 444,050 ha in 1952), with a land use rate of 23.9% compared to only 11.0% in 1952. On the other hand, pressure on the most sought-after areas reached extremely high levels, while the choices available to rice farmers were reduced, particularly with the abandonment of the least flood-prone vegetation: this clearly illustrates the contraction of rice-growing areas observed in the analysis of the location of rice fields per square. There are two additional causes: on the one hand, the population growth through natural increase over nearly a quarter of a century, but also through temporary immigration linked to the drought affecting the

Sahel, which suffered two catastrophic years in 1973 and 1974, during which the Delta served as a "refuge zone"; and, on the other hand, variations in flooding. Although the flood reached 663 cm in 1975, its average for the period 1971-1976 was only 626 cm, with two very bad years (565 cm and 568 cm in 1972 and 1973), values that are far removed from the very high floods of the 1950s. In the 1970s, as we shall see later, uncertainty about flood levels restricted the choices available to rice farmers, who were forced to exercise caution.

4.1.3 – The situation in the western Delta in 1989

In 1989, rice fields covered 77,042 ha, of which we retain 76,308 ha, after removing areas smaller than 1 ha or those located on non-floodable formations. This area is smaller than that of 1975, illustrating the Delta's role as a refuge linked to the Sahelian crisis of the 1970s. This was not the case in the following decade, which saw the worst drought in the Sahel in 1984, accompanied by the lowest flood level of the century (440 cm), with an average flood level of 538 cm for the decade.

Table 20: Contribution of the main plant formations to rice fields and rate of clearing of these formations in 1989 (western part of the Delta)

Rank of contribution to rice fields	Cleared areas formations in the (ha)	areas cultivated in the formation (ha)	Contribution of vegetation formation to cultivated with rice (in %)	Cumulative percentages of areas cultivated with rice	Total area occupied by the formation (%)	Land clearing rate of the formation (in %)	Rank of clearing rate
1	B/OP	12,241	16.0	16.0	31,381	39.0	4
2	OP	9,297	12.2	28.2	28,981	32.1	6
3	O	9,116	11.9	40.2	36,148	25.2	9
4	OP/VOR	6,762	8.9	49.0	30,622	22.1	11
5	VB/OP	5,295	6.9	56.0	10,036	52.8	1
6	OP/O	4,389	5.8	61.7	14,449	30.4	7
7	VOR	3,781	5.0	66.7	32,085	11.8	15
8	B	2,769	3.6	70.3	7,845	35.3	5
9	O/VSP	2,457	3.2	73.5	19,372	12.7	14
10	VB/O	2,382	3.1	76.6	8,180	29.1	8
11	OP/EOR	2,311	3.0	79.7	10,560	21.9	12
12	ESP/VSP	1,703	2.2	81.9	32,162	5.3	17
13	B/O	1,549	2.0	83.9	6,344	24.4	10
14	O/VOR	1,332	1.7	85.7	2,946	45.2	2
15	ESP	1,280	1.7	87.4	11,007	11.6	16
16	B/VB	1,141	1.5	88.9	6,582	17.3	13
17	B/VOR	1,102	1.4	90.3	2,791	39.5	3

In 1989, only 17 formations accounted for 90% of rice fields. Six formations (B/OP, OP, O, OP/VOR, VB/OP, and OP/O) accounted for more than 60% of rice fields, confirming that the primary criterion for rice farmers was still the presence of wild rice in the vegetation. The rate of clearing of plant formations exceeded 50% for the VB/OP formation, followed by O/VOR (45.2%), B/VOR

(39.5%), B/OP (39.0%), and B (35.3%). Formations including *Echinochloa stagnina*, the *Bourgou* of livestock farmers, therefore appear to be greatly impacted by rice cultivation, a situation that is sometimes the source of very violent conflicts between livestock farmers and rice farmers.

Rice fields cover 90.3% of the total area, or 68,907 ha, within a rice-growing area of 291,491 ha, resulting in a net pressure of 23.6%: this is high and little different from that of 1975, despite a significant reduction in cultivated area. At the same time, the area suitable for rice cultivation has shrunk from 444,000 ha in 1952 to 363,000 ha in 1975 and then to 292,000 ha in 1989, severely limiting the choices available to rice farmers. This contraction in rice-growing area is linked to the low flood levels of the 1980s: 5.16 m in 1989, following 4.40 m in 1984, the lowest flood level of the century.

4.1.4 – The situation in the western Delta in 2015

In 2015, rice fields covered 84,825 ha in the western Delta. After eliminating areas smaller than 1 ha and plots located on non-floodable formations, we arrive at a cultivated area of 82,096 ha for rain-fed and river-fed rice.

Table 21: Contribution of the main vegetation formations to rice fields and rate of clearing of these formations in 2015 (western part of the Delta)

Rank of contribution to rice fields	Cleared vegetation formations	areas cultivated in the formation (ha)	Contribution of vegetation formation to rice cultivation areas (in %)	Cumulative percentage of areas cultivated with rice	Total area occupied by the formation	Land clearing rate of the formation (in %)	Rank of clearing rate
1	O	17,503	21.3	21.3	36,148	48.4	1
2	OP	8,099	9.9	31.2	28,981	27.9	4
3	B/OP	7,970	9.7	40.9	31,381	25.4	6
4	O/VSP	6,568	8	48.9	19,372	33.9	3
5	OP/VOR	6,016	7.3	56.2	30,662	19.6	7
6	VOR	4,034	4.9	61.1	32,085	12.6	10
7	ESP/VSP	3,716	4.5	65.7	32,162	11.6	11
8	OP/O	2,793	3.4	69.1	14,449	19.3	8
9	VOR/VSP	2,453	3	72.1	16,917	14.5	9
10	VSP	2,238	2.7	74.8	19,604	11.4	13
11	B	2,037	2.5	77.3	7,845	26.0	5
12	AC/VH	1,790	2.2	79.4	33,434	5.4	21
13	ESP	1,233	1.5	80.9	11,007	11.2	14
14	O/VOR	1,210	1.5	82.4	2,946	41.1	2
15	OP/EOR	1,174	1.4	83.8	10,560	11.1	15
16	EOR	1,151	1.4	85.2	12,829	9.0	17
17	VSP/VH	1,063	1.3	86.5	14,141	7.5	18
18	VOR/EO	917	1.1	87.7	7,924	11.6	11
19	VH/AG	886	1.1	88.7	14,147	6.3	20
20	VH/ZB	616	0.8	89.5	6,794	9.1	16
21	VB/O	601	0.7	90.2	8,130	7.4	19

In 2015, nearly one in three rice fields was located on O or OP, and the top five formations with the most rice fields all contained O or OP. A total of 90% of rice fields (74,068 ha) were located in 21 plant formations on a "rice-cultivable" area of 391,518 ha. The net pressure on the natural environment reached 18.9%. This varied greatly depending on the vegetation formation, exceeding 48% on O, 41% on O/VOR (a less abundant formation), 34% on O/VSP, and more than 25% on B, OP, and B/OP, which also play an important role as pastureland.

4.2. - The choices made by rice farmers throughout the Delta in 1989 and 2015

4.2.1 – The year 1989 in the Delta

Table 22: Contribution of the main plant formations to rice fields in 1989

Rank of contribution to rice fields	Cleared vegetation formations	Total cultivated area in the formation (ha)	Contribution of the vegetation formation to cultivated areas with rice (in %)	Cumulative percentage of areas cultivated with rice	Total area occupied by the formation South of 15°10	Land clearing rate of the formation (in %)	Rank of clearing rate
1	B/OP	20,887	13.3	13.3	75,008	27.8	6
2	OP/VOR	19,229	12.3	25.6	93,518	20.6	11
3	OP	14,092	9.0	34.5	52,295	26.9	8
4	O	13,063	8.3	42.9	64,650	20.2	12
5	VOR	8,447	5.4	48.2	72,335	11.7	15
6	OP/O	8,344	5.3	53.6	37,226	22.4	9
7	VB/OP	7,932	5.1	58.6	24,408	32.5	3
8	B	6,666	4.2	62.9	31,497	21.2	10
9	BP	5,408	3.4	66.3	19,858	27.2	7
10	O/VSP	5,000	3.2	69.5	51,170	9.8	18
11	VB/O	4,716	3.0	72.5	15,460	30.5	4
12	B/O	4,599	2.9	75.4	13,575	33.9	1
13	OP/EOR	4,331	2.8	78.2	25,360	17.1	14
14	VOR/EOR	4,100	2.6	80.8	22,093	18.6	13
15	ESP/VSP	3,474	2.2	83.0	68,504	5.1	20
16	O/VOR	2,649	1.7	84.7	8,847	29.9	5
17	BP/OP	2,241	1.4	86.1	6,638	33.8	2
18	ESP	2,115	1.3	87.5	20,868	10.1	17
19	EOR	1,988	1.3	88.7	18,392	10.8	16
20	VSP	1,877	1.2	89.9	51,885	3.6	21
21	MB1	1,840	1.2	91.1	32,452	5.7	19

In 1989, 90% of rice fields were located on 21 plant formations among the 120 identified in the Delta. We find the formations already noted in the west, with the exception of B/VB and B/VOR (16th

and 17th positions), which appear throughout the Delta only in 22nd and 23rd positions. The top 15 formations, which account for 87.4% of rice fields in the west, also appear in the Delta, where they account for 80% of rice fields. We can add BP (9th– 3.4%), BP/OP (17th and 1.4%), which are very deep formations and very scarce in the western Delta; as well as VOR/EOR (2.6%) and, at the bottom of the table, EOR, VSP and MB1 with very low contributions (<1.3%), formations which appear in the west in positions between the 18th and 23rd ranks with contributions of less than 1.4% and which do not appear in Table 17 (western Delta).

As a first approximation, we can therefore conclude that the choices made by rice farmers across the Delta do not differ significantly from those identified in the west. They simply appear to be slightly broader while retaining the same fundamentals. However, the rates of land clearing in the most sought-after formations, which are lower than those recorded in the western part, exceed 30%, with formations in *Bourgou* (B/O and B/OP) in the top two ranks.

Flood-prone formations south of 15°10 occupy 1,423,680 ha, representing a **gross** pressure of 11.2%. However, if we compare the area of rice fields to that of the vegetation formations used by rice farmers, we see that 90% of rice fields (142,998 ha) are located on a usable area of 806,039 ha. In this case, the **net** pressure reaches 17.7%, which is high but still lower than the pressure of rice cultivation in the western part (23.6%), linked to the importance of the Ténenkou basin.

4.2.2 – The year 2015 in the Delta

Table 23: Contribution of the main plant formations to rice fields south of 15°10 in 2015

Ranking of contribution to rice fields	Cleared vegetation formations	Total cultivated area in the formation (ha)	Contribution of the vegetation formation to areas cultivated with rice (in %)	Cumulative percentage of areas cultivated with rice	Total area occupied by the formation south of 15°10	Rate of clearing of the formation (in %)	Rank of clearing rate
1	O	31175	11.1	11.1	64,650	48.2	1
2	OP/VOR	28,095	10.0	21.0	93,518	30.0	9
3	B/OP	26,402	9.4	30.4	75,008	35.2	5
4	OP	18,020	6.4	36.8	52,295	34.5	7
5	O/VSP	17,831	6.3	43.1	51,170	34.8	6
6	OP/O	15,942	5.7	48.8	37,226	42.8	3
7	VOR	13,594	4.8	53.6	72,335	18.8	17
8	ESP/VSP	11116	3.9	57.6	68,504	16.2	18
9	OP/EOR	7971	2.8	60.4	25,360	31.4	8
10	VSP/VH	7,760	2.8	63.1	51046	15.2	20
11	VOR/VSP	7496	2.7	65.8	46201	16.2	18
12	VSP	6873	2.4	68.2	51885	13.2	24
13	B	6168	2.2	70.4	31,497	19.6	16
14	VOR/EOR	5,723	2.0	72.5	22,093	25.9	11
15	VB/OP	5,670	2.0	74.5	24,408	23.2	14
16	AC/VH	5,337	1.9	76.4	53696	9.9	26

17	BP	4726	1.7	78.0	19,858	23.8	12
18	VOR/ESP	4258	1.5	79.5	9171	46.4	2
19	O/ESP	4233	1.5	81.0	15740	26.9	10
20	ESP	3126	1.1	82.2	20,868	15.0	21
21	ESP/ZB	3,032	1.1	83.2	15415	19.7	15
22	BP/OP	2814	1.0	84.2	6,638	42.4	4
23	VB	2,722	1.0	85.2	32298	8.4	27
24	VSP/ZB	2701	1.0	86.2	11338	23.8	12
25	ESP/VH	2610	0.9	87.1	17537	14.9	22
26	VH/P	2404	0.9	87.9	48843	4.9	29
27	VH/AG	2344	0.8	88.8	22781	10.3	25
28	MB1	2251	0.8	89.6	32,452	6.9	28
29	VB/O	2,163	0.8	90.3	15,460	14.0	23

90% of rice fields are spread across 29 plant formations (compared to 21 in the western part), confirming the wider choices made by rice farmers across the Delta, a situation already observed in 1989. The six formations that contribute most to rice fields are O, B/OP, OP/VOR, OP, O/VSP, and OP/O, all of which contain *Oryza longistaminata* or *Oryza barthii*. The presence of wild rice still guides rice farmers' choices, as it did in 1952 and 1975, a role that was partly lost in 1989. If we compare the choices made across the entire Delta with those in the western part, we see that the top 13 formations are the same (in a slightly different order) for a cumulative total of more than 70% of rice fields. Nine formations that are sought after in the whole Delta are not sought after in the west: each of them contributes little to rice fields, with rates between 1.5% and 0.8%. Finally, three formations that are little used in the west only appear beyond the 29th rank.

The most cleared plant formations show very high rates of clearing (between 42% and 48% of the plant formation) for the first four (O, VOR/ESP, OP/O, BP/OP). While VOR/VSP is not a highly sought-after pasture, this is not the case for BP/OP (42.4%) and, more generally, for formations with *Echinochloa stagnina* (Bourgou), which are heavily impacted (B/OP 35.2%, BP 23.8%, B 19.6%), suggesting potentially violent conflicts of use between livestock farmers and crop farmers.

90% of rice fields (254,557 ha) are located on vegetation formations that constitute the usable agricultural area in 2015 (1,089,291 ha). The net pressure on the environment reached 23.4%, which is higher than the 18.9% in the western part, and is very high for a cropping system with fallow land representing an area equivalent to the area under cultivation for a given year.

4.3. Conclusion: the choices of rice farmers

A comparison of the choices made by rice farmers in the western Delta in 1989 and 2015 with those made across the entire Delta during the same period shows that the results obtained for a given year do not vary greatly, whether the analysis covers part of the Delta or the entire Delta. However, there are significant differences from one year to the next. The most limited choice was in 1989 with only 17 plant formations, and the widest in 2015 with 29 formations, a situation that appears to be very similar to 1952 with 26 formations.

Between these four periods, a number of commonalities emerge in the strategies of rice farmers. Regardless of the year, 10 formations are systematically sought after and used: O, OP, O/VSP, OP/VOR, OP/O, B/OP, B, ESP/VSP, VOR, ESP. Among these, the formations that contribute most to rice fields

are those containing O or OP, i.e. natural rice fields, confirming that the farmers' first criterion for selection is the presence of wild rice, whose characteristics are very similar to *Oryza glaberrima*, the cultivated species. These 10 formations, covering 567,000 ha, constitute the "heart" of the rain-fed and river-fed rice system of the Inner Delta. Added to these are 6 formations VB/O, OP/EOR, O/VOR, VOR/VSP, VSP/VH, VH/AG (170,000 ha), which appear in the choices three years out of four. In total, these 16 plant formations occupy 737,000 ha and form the basis of rice cultivation in the Inner Delta.

Other formations appear less frequently in addition to the previous ones: VB/OP or BP/OP have only been used since 1989, and some others have only been used in one of the four years, such as B/O, B/VB, B/VOR in 1989, ZB, VOR/VSP, ESP/ZB, VB, VSP/ZB in 1952. These rarely used formations all have in common the fact that they are either very deep or, on the contrary, shallow. An analysis of the relationship between rice fields and flooding will clarify this point.

Another question that can be asked is: what types of soil correspond to the choices of plant formations made by rice farmers?

Table 24: Rice fields and soils (Horizon 1)

Horizon 1 (%)	Western part of the Delta			Entire Delta	
	1952	1975	1989	1989	2015
LA	61.3	66.1	55.1	57.8	68.5
A	17.7	27.2	35.0	27.3	21.9
ALS	17.2	6.7	9.9	14.9	9.6
LAS	3.7				

The majority of rice fields are on a silty-clay horizon (LA), and this proportion remains between 55% and 69%. Next come clay soils (A), accounting for around 30% of rice fields in 1975 and 1989. In 1952, in line with the wider choice of plant formations, clay soils competed with clay-loam-sandy soils (ALS), which are less heavy. The distribution of rice field soils therefore does not correspond to that of the major soil types in the Delta (horizon1) (see "**Ecology/soils**" section), where ALS (clay-silt-sand) and LA (silt-clay) soils predominate, representing 38.9% and 33.6% of the Delta's soils respectively, while A (clay) soils come in only 4th place, with 6.4% of the Delta's surface area.

However, it is difficult to know whether rice farmers choose the type of soil or whether this choice is merely an indirect consequence of the choice of vegetation to be cleared. We can add, however, that the choice of silty-clay and clay soils also corresponds to the choice of the finest soils in the Delta, i.e., (horizon1) established in basins where the currents are weakest. For rice farmers, this weak current offers the hope of slow flooding, with little or no risk of drowning the rice plants during their growth, which can withstand a maximum flooding rate of 5 cm/day. In conclusion, rice farmers choose to plant their rice fields on the finest soils—the most clayey—because of their fertility, but also because, like the wild rice plants they support, they are evidence of slow flooding that poses less of a threat to young rice plants.

A comparison of rice-growing areas over a period of 63 years shows that these areas vary greatly from one year to the next:

Table 25: Rice-growing areas over 63 years

	Western part of the Delta				Entire Delta	
	1952	1975	1989	2015	1989	2015
Rice-growing area (ha)	444,050	363,082	291,491	391,518	806,039	1,089,291
Agricultural pressure (%)	11.0	23.9	23.6	18.9	17.7	23.4

In 1989, the year with the most restrictive choices, the rice-growing area was less than two-thirds of its size in 1952 in the western part. Across the entire Delta, 1989 uses only 74% of the area used in 2015.

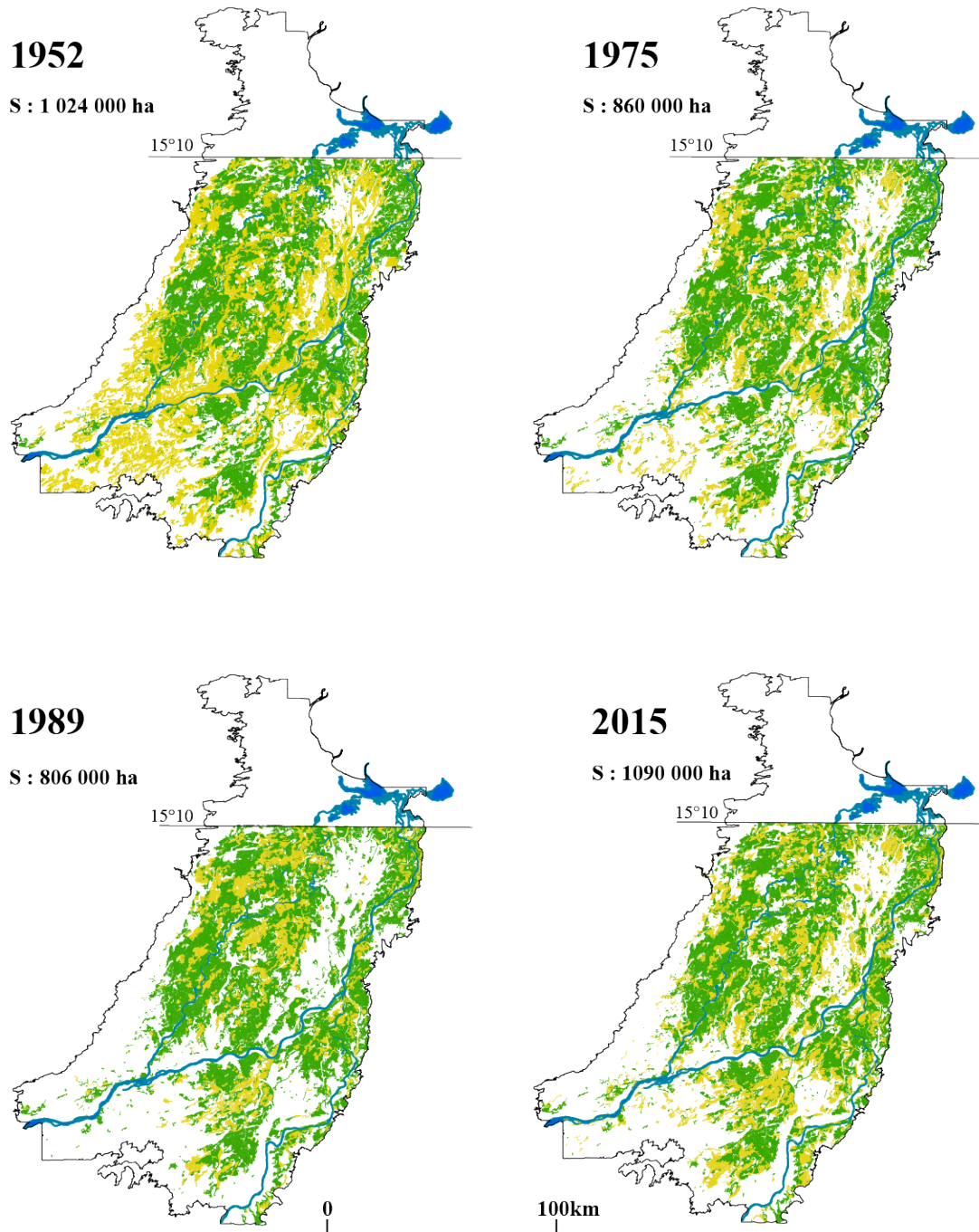
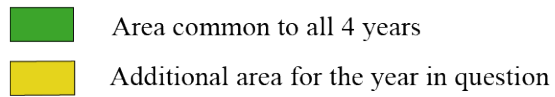
The following four maps highlight the following points:

1/ The area common to all four years (in green) is divided in five large rice-growing areas, each consisting of floodplains and deeper basins. These five areas are composed of plant formations sought after by rice farmers during the four periods of diachronic analysis (1952, 1975, 1989, and 2015) and can be considered the foundation of the Delta's rice-growing area. This area, which covers 567,000 ha, is divided between:

- The western basin of the Delta, the largest of the four. Backed by the Diaka river, it stretches from south of Tenenkou to south of Walado, and is supported by the Tenenkou and Touguere Coumbé basins.
- A central basin along the Mayo Kotya, centered around the Mourrah, Sossobé, Kadiak, and Kakagnan basins.
- The southern basin, which includes the Yongari, Mangari, and Pondori basins. It extends from Kouakourou in the north to south of Djenné.
- The Bani-Niger Mesopotamia, largely developed south of Mopti, encompassing the northern Mopti basin.

Figure 15 : The evolution of rice-growing areas from 1952 to 2015

EVOLUTION OF RICE-GROWING AREAS FROM 1952 TO 2015



- In the northeast of the Delta, the plains and basins of the Konna region, between the eastern border and Pérou Dialloubé.

2/ In addition to these five basins, and depending on the period, complementary areas add to the mobility of rice cultivation in the Delta.

- After 1952, large areas of rice-growing land were abandoned: these areas were mainly located in the southwestern part of the Delta, from Ke Macina to Koa. These were mainly the high plains of Diafarabé. The outskirts of the basins were also abandoned, the most important being located to the west of the Delta, around 15°N (Ouro N'Dia plains).
- In 1975, the mosaic of riverbanks along the Niger, Bani, and main tributaries was heavily exploited. This exploitation subsequently declined significantly.
- In 1989, new areas were cleared. These were all located in the deep basins of the Delta, particularly in the central basins and in Yongari-Mangari, while the medium floodplains were abandoned.
- In 2015, new areas were being used by rice farmers. These were located on the outskirts of the large basins and on the edges of the Pérou Dialloubé. The 2015 map closely resembles that of 1952, with, in particular, a reinvestment in the high plains of Diafarabé in southeastern Niger, even though flood conditions between 1952 and 2015 were very different. We will see later that some plots captured on Google Earth may have been wrongly classified as rain-fed rice fields.

This high mobility of rice fields, as previously observed and confirmed by the analysis of "rice-growing" areas, leads us to question the relationship between rice fields and floods.

5 - STRATEGIES AND CONSTRAINTS: THE ROLE OF FLOODING.

The relationship between rice fields and plant formations has enabled us to highlight the choices made by rice farmers when deciding where to locate their plots. However, the success of these strategies depends on the farmers' predictions of the expected flood level. If the flood is lower or higher than expected, the crops might fail. It is therefore necessary to examine the relationship between rice fields at different periods and the corresponding flood levels. We will also question the validity of the concept of a rice-growing area as defined above, in view of flood variability over this long period of more than 60 years.

Figure 16: The main river network

The main river system of the Inner Niger Delta

● Main stations

The hydrographs cover the period from June (6) to May (5)
They are calculated from monthly averages
over 53 years (1955-2007)

The maximum flood height is the average of all
maximum flood heights over 53 years with the
average date at which this height is reached

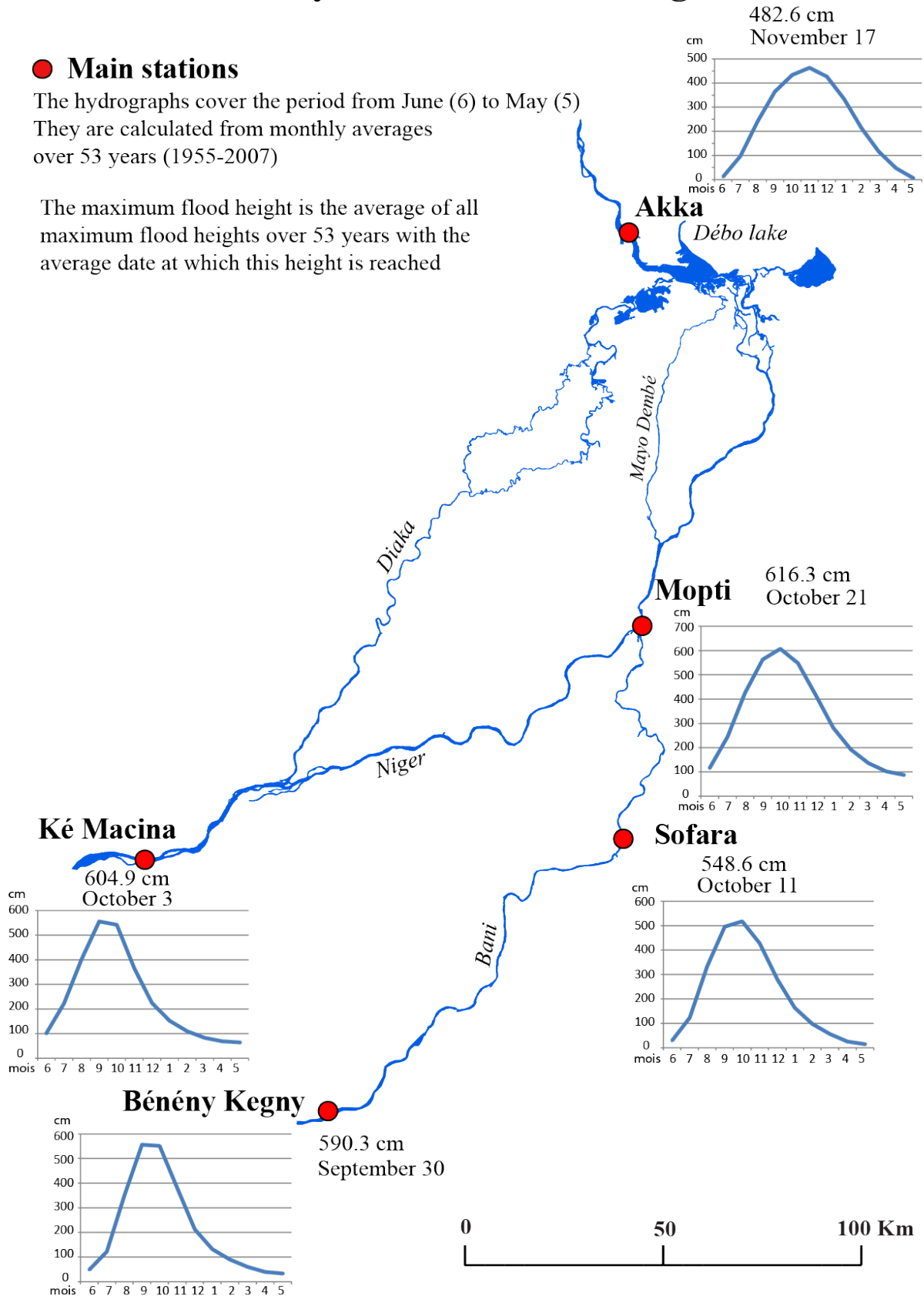


Table 26: Average flood correspondences over 50 years (1955–2005) (Ké Macina, Mopti, Akka reaches)

KE MACINA		MOPTI		Duration (days)	AKKA		Duration (days)	
H (cm)	Date	H (cm)	Date		H (cm)	Date		
699.6	10/12	721.0	11/8	27	602.2	7/12	29	
694.2	1/10	692.8	1/11	31	568.6	4/12	33	
683	6/10	680.0	4/11	29	552.2	4/12	30	
651.6	3/10	656.4	25/10	22	521.2	11/25	31	
636.6	9/26	640.8	10/16	20	494.8	11/16	31	
641.8	11/10	614.6	10/27	16	477.6	11/22	26	
564.6	9/29	576.8	10/13	14	436.4	11/3	21	
548.6	9/26	562.2	8/10	12	421.6	10/31	23	
492	9/30	531.4	10/7	7	394.2	10/30	23	
Average	623.6	10/3	630.7	22/10	20	496.5	11/19	27
Standard								
Deviation	72.5		64.1		8	70.8		4

Table 27: Average 50-year flood recurrence intervals (1955–2005) (Bénégnéy Kegny, Sofara, and Mopti reaches)

BENENY KEGNY		SOFARA		Duration (days)	MOPTI		Duration (days)	
H (cm)	Date	H (cm)	Date		H (cm)	Date		
838.4	10/12	693.2	10/30	18	721.0	11/8	9	
794.2	10/10	667.2	3/11	18	692.8	1/11	4	
763.4	11/10	646.4	10/24	13	680.0	11/4	11	
678.6	9/28	601.2	10/10	12	656.4	10/25	15	
630.8	9/28	581.8	10/5	7	640.8	10/16	11	
490.6	7/10	509.6	17/10	10	614.6	10/27	10	
490.2	9/22	490.6	9/27	5	576.8	10/13	4	
451.6	9/17	462.6	10/1	14	562.2	8/10	7	
433.6	21/9	457.4	9/27	6	531.4	10/7	10	
Average	619.0	1/10	567.8	12/10	11	630.7	10/22	10
Standard								
deviation	157.7		90.6		5	64.1		4

Tables 26 and 27 present a summary (5-year averages) of flood heights over 50 years (1955–2005), ranked from highest to lowest at the Mopti station. H (cm) represents the 5-year average of

flood heights in descending order, Date, the average date corresponding to this 5-year series of floods, and Duration (days), the duration of the flood's propagation over the reach in question. Thus, the five-year average of the five highest floods at Mopti over the period 1955–2005 is 721.0 cm, reached on November 8. This average corresponds to a flood height of 699.6 cm at Ké Macina, reached on October 12, and which reached Akka on December 7 with a flood height of 602.2 cm.

For major floods, the propagation time is 27 days for the Ké Macina-Mopti reach and 29 days for the Mopti-Akka reach. For the Ké Macina-Mopti reach, the propagation time is approximately 30 days, with an average arrival date in Mopti falling in the first half of November, for high flood levels exceeding the reference flood level of 6.60 m. For moderate floods, ranging from 6.50 m to 6.20 m, the propagation time is approximately 20 days, with the date falling in the second half of October. For low floods, below 6.15 m in Mopti, the propagation time from Ké Macina is approximately 15 days, with an average arrival date in Mopti falling in the first half of October. For very low floods (5.35 m), propagation is very rapid (7 days), with an arrival date in the first week of October. This pattern is observed for all reaches with some variations: on the Mopti-Akka reach, the one-month propagation time holds true even for moderate floods, at 6.35 m in Mopti.

The Bénény Kegny–Sofara and Sofara–Mopti reaches (Table 27) show deviations from this pattern. The flood propagation time between Bénény Kegny and Sofara follows the general pattern for high floods (between 8.38 m and 6.79 m at Bénény Kegny). Significant deviations are then observed for moderate and low floods. Similar irregularities are also observed during the Sofara-Mopti propagation. They appear to be linked to the conditions of drainage and flood spreading across the plains, which are complicated by the interconnections between the Niger and the Bani, particularly the tributaries of Lonirdé and Konguéné-Parana (see hydrographic map on page 13).

5.1 - Rice fields and water levels

For each date, we calculated the area of rice fields located within the main water levels defined in the ecological study. This gives us the following table, where the average level of the rice fields is obtained by calculating the average depth weighted by the area occupied by the rice fields at the level in question.

Tableau n° 28 : Rizières et niveaux d'eau

Level	Water heights in Mopti)	Average water heights	Percentage of rice fields in the level			
			In 1952 (western Delta)	In 1975 (Western Delta)	In 1989 (all the Delta)	In 2015 (all the Delta)
2	6.60 m – 6.50 m	6.55 m	0.76	0.0	0.0	0.0
3	6.50 m – 6.30 m	6.40 m	3.78	0.0	0.0	0.0
4	6.30 m - 6 m	6.15 m	20.98	16.35	4.97	9
5	6m – 5.10 m	5.55 m	48.05	46.13	36.27	38.1
6	5.10 m – 3.80 m	4.20 m	26.43	37.52	53.78	49.1
7	3.80 m – 2.60 m	3.20 m			4.98	3.8
		Average level of rice	5.36 m	5.14 m	4.74 m	4.85 m

Between 1952 and 1989, rice fields occupied increasingly lower water levels. Compared to the Mopti gauge, which we use as a reference²⁷, the average level of rice fields fell from 5.36 m in 1952 to 4.74 m in 1989, before rising slightly in 2015 (4.85 m). While nearly 50% of rice fields in 1952 and 1975 were at level 5 (water heights between 5.10 m and 6 m on the Mopti gauge), the majority were at level 6 (3.80 m to 5.10 m in Mopti) in 1989. Level 6, which affected only 26.5% of rice fields in 1952, already characterized 37.5% in 1975. In other words, from 1952 to 1989, rice fields sank in relation to the reference flood level of 6.60 m before rising slightly again in 2015.

5.2 - Rice fields and floods

The relationship between rice fields and floods has been extensively studied by Jean Gallais. Floating rice grows in flooded conditions that must meet the following requirements:

- A maximum submersion of 3 m, which places the lower limit of the rice field at a level equivalent to the flood level minus 3 m.
- A water rise speed of less than 5 cm/day.
- A minimum submersion period of more than 2 months, a condition that determines the upper position of the rice field.²⁸
- The rice field must be flooded no later than 15 days after the last useful rain of the season.

Applying the first three criteria to floods in Mopti since 1950, we obtained the following table, in which "Max height" is the maximum flood height and "Max date" is the day on which this height is reached for the first time. We then used the daily flood database to determine the height corresponding to a minimum of 60 days of submersion ($H \geq 60$) and the date on which this level was first reached. The minimum level corresponds to the maximum flood level minus three meters, and this minimum is limited, in principle, by the deepest formations, which are at -4 m relative to the reference flood level of 6.60 m. The minimum level cannot therefore be less than 2.60 m. A safety water level can thus be defined as between ($H \geq 60$ days and minimum level).

Table 29 : Flood conditions and safety margins in Mopti from 1950 to 2010

Date	Max height	Max date	H \geq 60 days	Start date submersion 60 days	Minimum level (max-3 m)	Safety margin
1950	707	10-nov	668	04-oct	407	261
1951	712	3-Dec	687	23-oct	412	275
1952	719	18-nov	684	11-oct	419	265
1953	731	31 Oct.	685	30-sept	431	254
1954	731	04-nov	701	08-oct	431	270
1955	731	06-nov	692	03-oct	431	261
1956	686	29-Oct.	638	28-sept	386	252

²⁷ It should be noted that water levels where all plant formations are located are calculated in relation to the Mopti gauge. While water levels vary locally depending on flood scales, the water depths of the various plant formations are constant throughout the Delta.

²⁸ The difference between conditions 1 and 3 defines the safety stratum.

1957	730	17-nov	687	13-oct	430	257
1958	703	02-nov	665	05-oct	403	262
1959	697	31-Oct.	650	29-sept	397	253
1960	697	02-nov	657	01-oct	397	260
1961	699	23-Oct.	646	22-sept	399	247
1962	706	07-nov	664	07-oct	406	258
1963	685	15-nov	646	07-oct	385	261
1964	716	01-nov	681	01-oct	416	265
1965	684	01-nov	638	28-sept	384	254
1966	686	9-Nov.	639	06-oct	386	253
1967	720	11-nov	679	07-oct	420	259
1968	651	Oct. 25	610	21-sept	351	259
1969	684	02-nov	658	06-oct	384	274
1970	666	Oct. 22	600	19- Sept.	366	234
1971	650	16-oct	593	13-sept	350	243
1972	565	07-oct	505	9-Sept.	265	240
1973	568	03-oct	489	28-Sept.	268	221
1974	650	18-oct	602	13- Aug	350	252
1975	663	26-oct	605	22-sept	363	242
1976	623	21-Nov.	567	14-oct	323	244
1977	566	10-Oct.	468	11-sept	266	202
1978	620	22-oct	566	18-sept	320	246
1979	645	19-oct	599	15-sept	345	254
1980	592	07-oct	487	02-sept	292	195
1981	628	14-oct	564	07-sept	328	236
1982	551	29-sept	463	31-Aug	260	203
1983	502	10-oct	425	31-Aug	260	165
1984	440	19-oct	388	02-sept	260	128
1985	570	10-oct	484	04-sept	260	224
1986	534	08-oct	409	05-sept	260	149
1987	481	17-oct	410	10-sept	260	150
1988	571	08-oct	478	31-Aug	271	207
1989	516	29-sept	451	05-sept	260	191
1990	510	09-oct	449	28-Aug	260	189
1991	530	05-oct	474	03-sept	260	214
1992	538	07-oct	415	06-sept	260	155
1993	498	06-oct	429	02-sept	260	169
1994	642	29-oct	613	03-oct	342	271
1995	599	28-Oct.	553	27-sept	299	254
1996	593	19-oct	543	18-Sept.	293	250
1997	577	12-oct	529	9-Sept.	277	252
1998	639	25-oct	580	17-sept	339	241
1999	662	26-oct	625	21-sept	362	263
2000	608	23-oct	567	22-sept	308	259
2001	621	18-oct	557	10-sept	321	236

2002	538	08-oct	475	11-sept	260	215
2003	649	15-oct	600	14-Sept.	349	251
2004	560	13-oct	470	06-sept	260	210
2005	571	24-oct	544	7-Sept.	271	273
2006	597	31-oct	553	18-Sept.	297	256
2007	644	15-oct	594	13-sept	344	250
2008	633	23-oct	594	13-sept	333	261
2009	631	17-oct	582	19-sept	331	251
2010	645	01-nov	614	27-sept	345	269

The table above defines a safety water level characterized by its depth, which can vary, but also by its position in relation to the flood level. If rice farmers have placed their rice fields within this water level, they have a good chance of a successful season. On the other hand, placing rice fields outside the safety margin for the year is tantamount to making a bad bet on the flood, and leads to almost certain crop failure. It is clear that other factors, for which we do not have precise data, also come into play. This is the case with the speed at which the water rises, which must not exceed 5 cm/day. The database on daily floods shows us that this condition is almost always met in Mopti for medium or heavy floods. In years with very low floods, the speed of submersion can in some cases exceed 5 cm/day. Years with very low rainfall, during which farmers lack water and have no choice but to flood their rice fields as much as possible, are also years when they run the greatest risk of seeing their rice fields flooded by a sudden rise in water levels.

Figure 17: "The Evolution of the useful water depth in uncontrolled flooded rice cultivation from 1950 to 2010 (based on the Mopti gauge)" shows the position and extent of these safety margins in Mopti between 1950 and 2010 and allows six periods to be identified:

Figure n°17 : Evolution of the useful water level in rain-fed and river-fed rice cultivation from 1950 to 2010 in Mopti

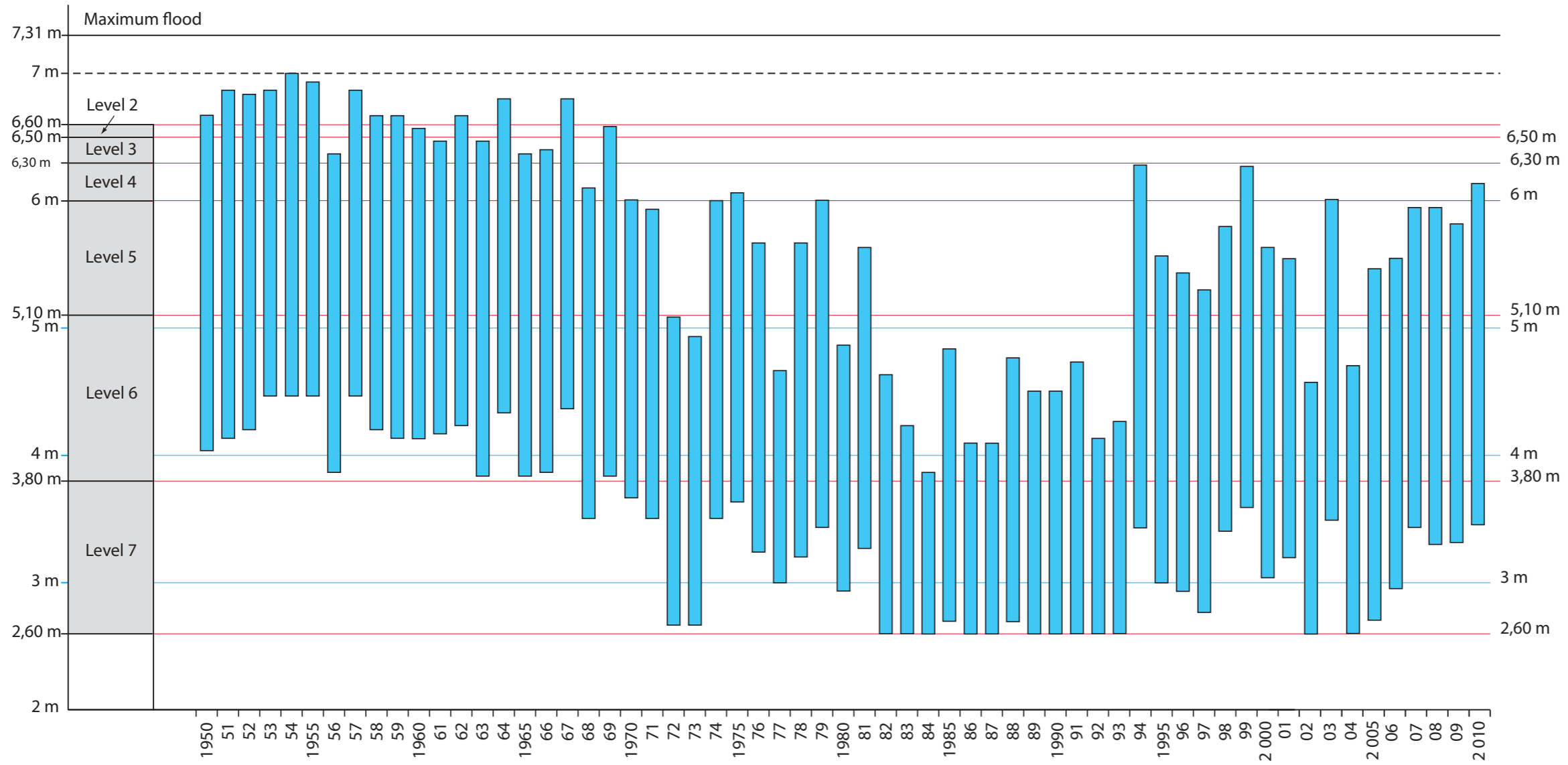


Table 30 : Average safety water levels for six ten-year periods.

Periods	Avg_H_ max	Standard deviation On H_Max	Avg_H_min	H_Submersion >= 60 days	average Effective water level	Usable water
1950–1959	715	16.3	415	676	261	2-3-4-5-6*
1960–1969	693	19.8	393	652	259	3-4-5-6
1970–1979	622	40.8	322	559	237	5-6-7*
1980–1989	538	55.7	271	456	185	6-7
1990–1999	579	58.2	295	521	226	5*-6-7
2000–2009	605	37.9	307	554	247	5-6-7

**Risk levels depending on the position of the rice field in the blade.*

From 1950 to 1959, rice fields could be placed in a high position, between 4.15 m and 6.75 m, and the safety margin was maximum at 261 cm. The risk of rice fields being flooded was level 6 and affected 26% of rice fields. In reality, the risk was low and limited to the lowest rice fields, located between 4.15 m and 3.80 m. During the following period, from 1960 to 1969, conditions remained excellent, with maximum safety margins (259 cm). The following decade (1970-79) saw less favorable hydraulic conditions with a safety margin of 237 cm. In the western part of the Delta, 16% of rice fields were at level 4, which could have led to crop failure. In the 1980-1989 decade, hydraulic conditions became very poor: in order to succeed, rice fields had to be located in low-lying areas (levels 6 and 7) with a rating corresponding to a submersion period of at least 60 days at 4.5 m, i.e., 2.20 m below the rating for the 1950s. The safety margin of 261 cm was reduced to 185 cm. Forty-one percent of rice fields were located in failure-prone situations, at levels 4 and 5. The situation began to improve in the following decade, with a return to near-normal conditions in the 2000-2009 decade, although without reaching the values recorded 50 years earlier. It should be noted, however, that the hydrological conditions of the 1950s were exceptional and corresponded to an abnormally wet period in West Africa.

Flood conditions are not the only parameters that determine rain-fed and floodplain rice cultivation. Jean Gallais²⁹ reminds us that "rain-fed and floodplain rice cultivation in deltas is possible where rainfall is well supplemented by flooding" and that "rice fields must be flooded no later than two weeks after the last useful rainfall."³⁰ The condition relating to the date of the last useful rainfall of the season allows us to understand the significance of the virtual absence of rice fields beyond 15°10 north. This latitude corresponds to that of Dogo. According to Jean Gallais, during the very rainy years of 1950-1956, Dogo received an average of 625 mm of rainfall (compared to 671 mm in Mopti for the same period) and the end of the useful rains most frequently occurred between September 1 and September 15.

²⁹ J. Gallais, *op. cit.*, p. 333

³⁰ J. Gallais, *op. cit.*, p. 220

According to P.A. Gosseye, in the 1980s, the Dogo station received an average of only 310 mm of total rainfall³¹. According to the gradients calculated by P. Hiernaux³², the useful rainfall corresponding to an average of 310 mm does not exceed 220 to 230 mm and, furthermore, the end of the useful rainfall period is in early September.

Two factors may explain why rain/river-fed cultivation rarely extends beyond the latitude of Dogo. On the one hand, given the rainfall patterns of the 1980s, we are considering the minimum rainfall threshold required for rice to begin growing (between 200 and 250 mm of effective rainfall). On the other hand, the flood would need to take over from the rains by September 15 at the latest. We do not have data on floods (heights and dates) for this latitude. However, we can rely on the Mopti station and attempt to extrapolate for an area situated between 15° and 15°15' north latitude. From 1955 to 2005, the date of the maximum flood level in Mopti was on average October 22, with a flood propagation time of 27 days between Mopti and Akka (15°24' N). For areas located upstream of the Débo, between 15° and 15°15', the minimum flood propagation time would be approximately 15 to 20 days, i.e., lasting until the first week of November. There is a very high risk that the flood will arrive too late to take over from the last rains, which must occur, at the latest, in the first days of October; thus, the water levels at Dogo would correspond to those reached at Mopti around mid-September. Under these conditions, Jean Gallais (p. 224) estimates the “safety margin”—which we refer to as the usable water depth—at 0.59 m for Dogo. Our own estimates assign values ranging from 0.35 m to 0.96 m, depending on the annual flood.

Barely acceptable rainfall conditions and flooding that leaves only a very low water depth are factors that increase the risk of crop failure to a level that rice farmers may deem unacceptable. These observations do not claim to account for the northern limit of the rain-fed river system, but they do offer some avenues for further consideration. We can assume that this limit is variable and depends both on the year's rainfall—particularly its timing—and on the annual flood. For low floods, it appears that beyond 15°10' to 15°15', the risk of crop failure becomes too high, and very rapidly increases with latitude. For good flood levels and good rainfall, we have not estimated the risk. A few thoughts nonetheless: if rainfall is better, the end date of the useful rainy season will be slightly delayed, but this delay will not be very significant. The cessation of rainfall linked to the retreat of moist air masses toward the south is always relatively rapid. Good floods are also generally later floods, thus delaying their arrival at the latitude in question. Finally, and this is by no means the least important point, the areas accessible to rice farmers north of 15°10' are primarily located in the deepest basins of the Delta. In years with good floods, the risk of rice fields being flooded by excessively high water levels would therefore be considerable.

6- CONCLUSION

Table 25 and Figure 18 show the evolution of useful water levels in Mopti between 1950 and 2010. This long period began with a series of very good floods (1950-1970), followed by the lowest floods since records began on the Niger at Mopti (1922), particularly in 1984 (440 cm). From the mid-1990s onwards, floods tended to improve again. Using the isoline flood depth model developed in the first part of Delmasig, we can visualize the areas corresponding to different types of floods. The analysis

³¹ See J. Marie, *Le territoire de mare d'Ossolo*, Talence : CEGET Espaces tropicaux no. 11, 1993, pp. 25 et seq.

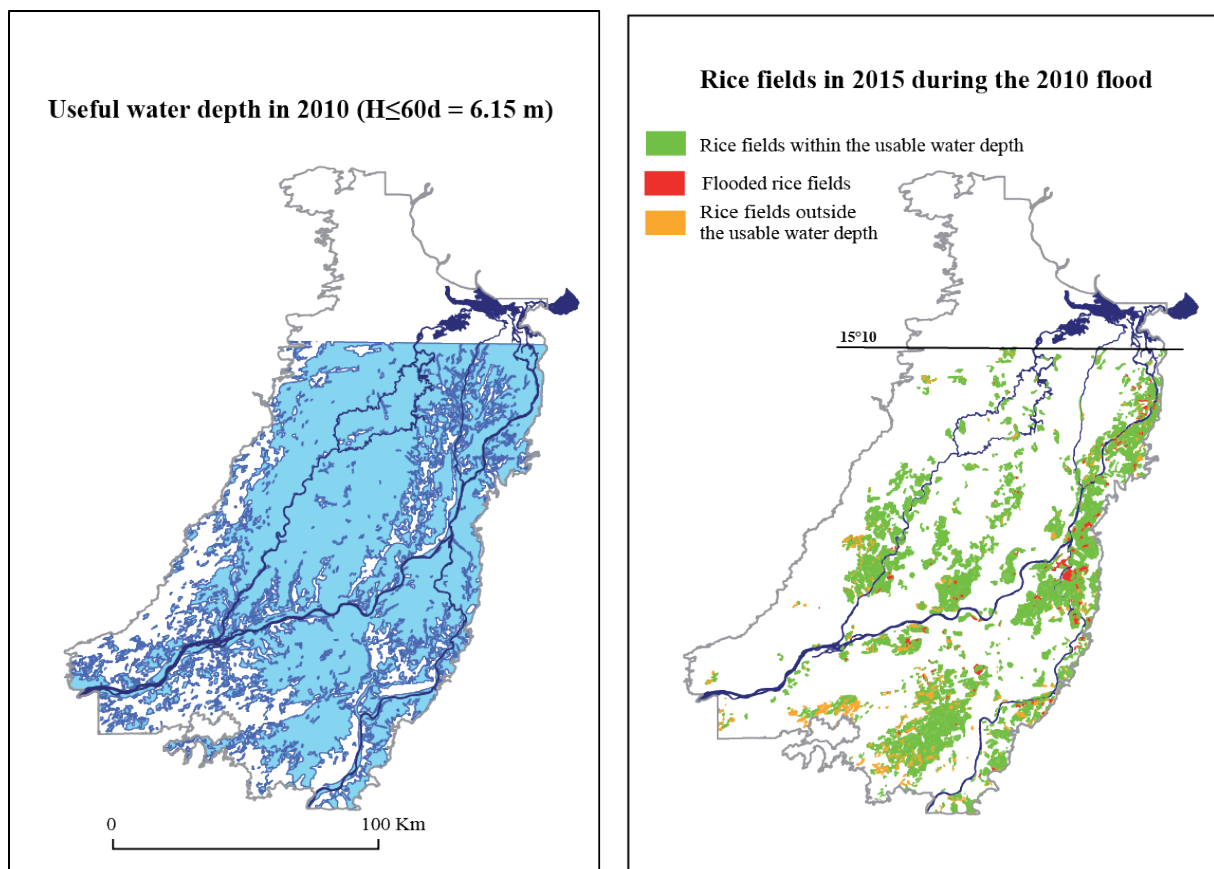
³² P. Hiernaux, Recherche d'une solution aux problèmes de l'élevage dans le Delta intérieur du Niger – Vol 1 : Les pâturages de la zone d'étude, pp.24-26.

of the vegetation formations sought by farmers to establish their rice fields was a first approach to the "rice farmers' space," but it only indicates a "potential space" that we have defined as "rice-growing space." The isoline approach allows us to visualize the useful water table for each year. Cross-referencing the "rice-growing space" with the usable water depth provides a better understanding of the strategies used by rice farmers faced with the risks associated with the unpredictability of flooding. To illustrate this method, we have chosen three years with very different floods: 2010, a good year; 1972, a mediocre year; and 1989, a bad year. *Figures 18, 19, and 20.*

6.1 - 2010, a good year.

The 2010 flood was 6.45 m in Mopti, slightly lower than the reference flood of 6.60 m. However, the height $H \leq 60$ days was 6.15 m. The difference between the flood and $H \leq 60$ d was only 30 cm, whereas the average difference is close to 60 cm. The peak of the flood curve in 2010 is very flat, which contributes to making it a good year. If we cross-reference the usable water space with the rice-growing space as defined in 2015, we see that the safety space for rice farmers reached 900,000 ha in 2010.

Figure 18: Rice fields and flooding in 2010



A simulation based on the location of rice fields in 2015, with the effective water depth of 2010, shows a reduction in the failure rate of rice fields down to 9.6% (approximately 27,000 ha out of 280,000 ha). Some of these are located in areas where the water level is too shallow, while others are at risk of being flooded in areas where the water level is too deep. The rice fields outside the useful water depth (in yellow) also illustrate the fact that the rice field mapping carried out by Leo Zwarts probably includes plots that are not rain-fed rice fields (see comments on page 12 regarding data quality). We had retained

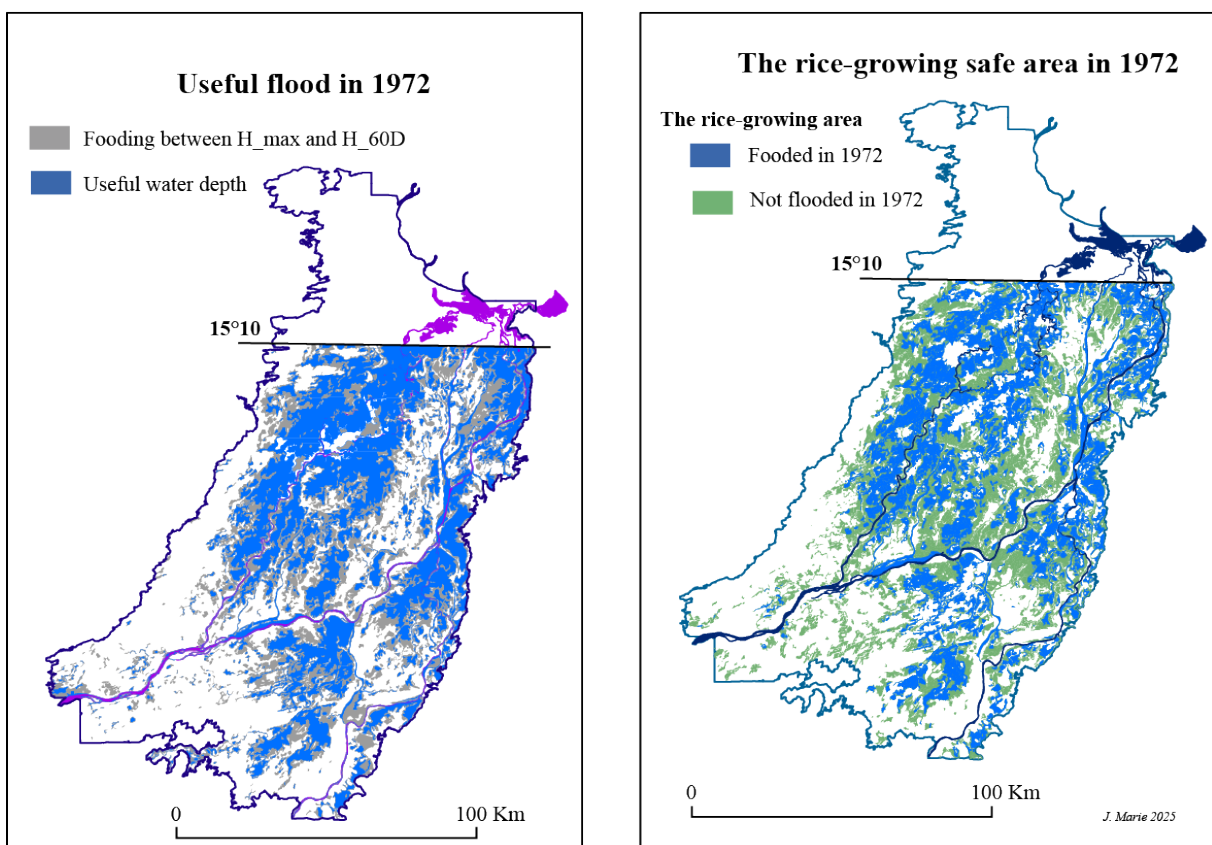
as rice fields plots that could be located on vegetation formations with water levels less than or equal to 30 cm. This was justified in 1952, with floods much higher than the reference flood (6.60 m), but no longer seems to be so in 2015, with floods close to the reference flood, which is the case for the plots marked in yellow.

6.2 - 1972: a mediocre year.

The flood reached 565 cm on October 7, almost one meter below the reference flood level. The flood height maintained for at least 60 days (H_{60d}) was 505 cm, a level reached on September 9. The minimum height (H_{min}) at which a rice field can be planted without being flooded is 265 cm on the Moptigauge, which corresponds to the deepest formations in the delta (-4m), or 260 cm on the scale.

Map No. 20 shows the area occupied by the usable water depth in blue, surrounded by the flood fringe between H_{max} and H_{60J} . The total area of flooded land south of $15^{\circ}10'$ reaches 936,000 ha, and the area occupied by H_{60J} is 629,000 ha. The area suitable for rice cultivation was estimated at 860,000 ha in the 1970s. The intersection of the area suitable for rice cultivation in 1975 with the usable water depth in 1972 shows that only 410,000 ha were flooded. In other words, just under 50% of the rice-growing area would have had good safety conditions in 1972, as shown in the map "Rice safety area in 1972," which differentiates between rice-growing areas flooded in 1972 (shown in blue) and rice-growing areas not flooded (shown in green).

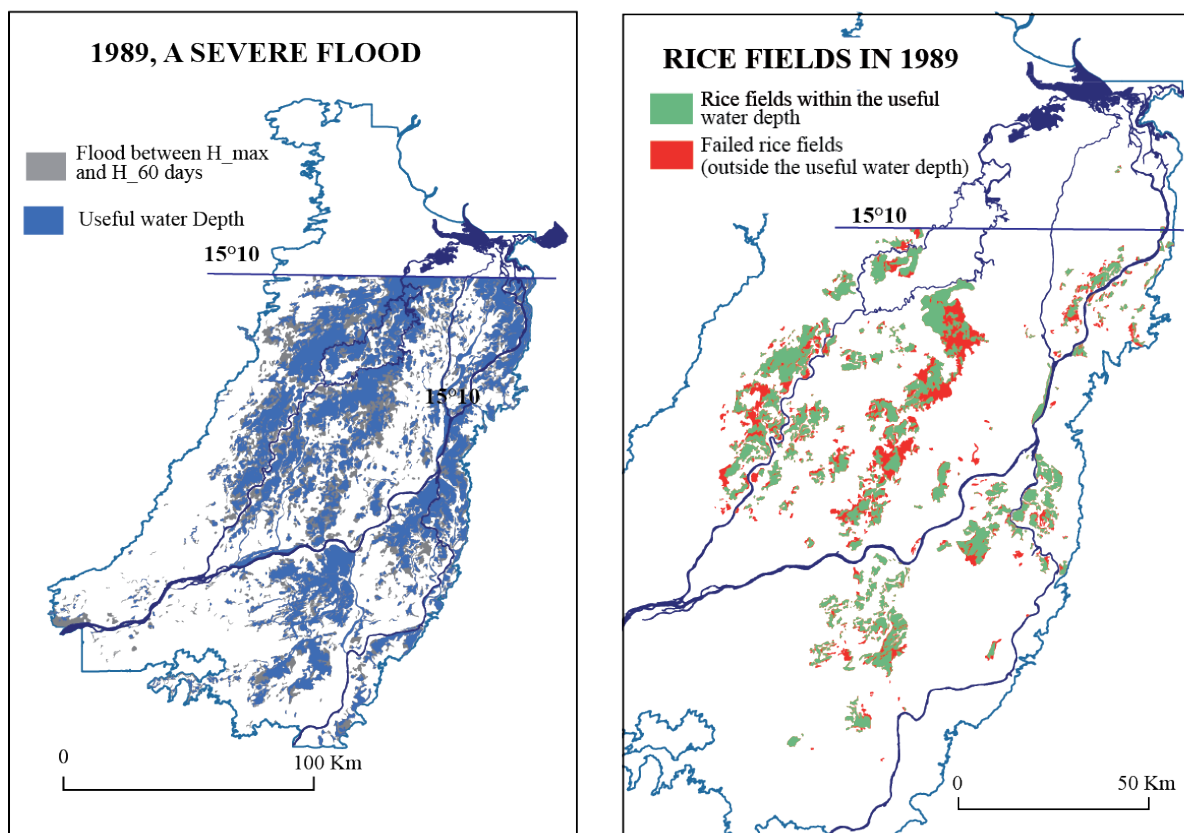
Figure 19: Useful flood and safe area in 1972



6.3 - 1989: a bad year

The 1989 flood reached 516 cm in Mopti, and H_{60J} was only 451 cm with H_{min} limited to 260 cm, the level of the deepest plant formations in the Delta. The flooded area south of $15^{\circ}10'$ is 701,000 ha and the useful water depth is reduced to only 462,000 ha. The intersection of the usable water depth with the rice-growing area is reduced to 370,000 ha, which should be compared with the area of rice fields in 1989 (158,761 ha). Rice farmers' choices are therefore severely limited and the risk of failure appears to be very high, as shown by a more detailed comparison of rice fields in 1989 with the usable water depth: 104,285 ha of rice fields were located in the usable water depth, and 34% of rice fields were very likely to have failed.

Figure 20: The poor flood of 1989



6.4 – What future for rain-fed and river-fed rice cultivation?

The Inner Niger Delta is the third largest wetland on the planet, after the Pantanal in the Amazon and the Sudd on the White Nile in southern Sudan. The Inner Delta is one of the centers of rice domestication, based on the use of a floating rice variety, *Oryza Glaberrima*, which is native to the region. The inhabitants of the Delta practice a very ancient form of rice cultivation that is technically far removed from the sophistication of Asian rice cultivation. The cultivation practices are simple: plowing

followed by broadcast sowing, with the rice starting to grow with the rain. The flood then takes over the floating apparatus that supports the ear as it rises with the flood. Weeding takes place during growth, with harvesting occurring at maturity. The year's crop is often followed by a short fallow period. This type of rice cultivation, without any water control, is characterized by yields of around 700 kg/ha, which are undoubtedly the lowest in the world for this type of crop. The main objective of this rice cultivation is to feed the population of the Delta, which also has resources from fishing and cattle farming. The subsistence nature of this rice cultivation is particularly evident when one looks at the area cultivated per capita – 0.45 ha/capita, or 300 kg of rice per person per year – which does not seem to have changed in sixty years.

This rice cultivation is also characterized by a nomadic lifestyle that Jean Gallais already denounced in 1957/58, highlighting movements of around ten kilometers, which led him to describe rice cultivation in the Delta as a form of "wandering rice cultivation in an imprecise farming area."³³ Subsequent studies have shown larger movements over the long term. Our own work shows that this agricultural nomadism cannot be resolved within the boundaries of the new rural municipalities or even within the organization of the large hydrological basins of the Inner Delta. Admittedly, these basins organize the Inner Delta into a polycentric space, and one might have expected rice fields to move between the basins and the medium-flood plains that border them, which is the case when flood variations remain moderate. When variations are strong, as in the 1980-90 decade, the study shows that this is no longer the case. The displacement of rice fields then takes place between the basins of the north-central Delta—between Niger and Diaka—and the basins of the southern Delta, between Niger and Bani.

This large-scale nomadism leads us to consider the Inner Delta as a single migratory space with, depending on the period and the floods, local or even regional declines and the opening of "pioneer fronts" followed by reverse movements when the floods become more favorable again.

Jean Gallais identified the mobility of rice farming as a factor hindering the technical development of this agricultural system, which is a prerequisite for increasing yields and the highly desirable transition from archaic subsistence rice farming to modern rice farming, the economic basis of farms in the Delta.

In 1957-58, he estimated the Delta's rice-growing area at 800,000 ha and the area actually cultivated with rice at 10%³⁴. He also believed that lack of space was not a constraint on the expansion of this type of rice cultivation: "*The inhabitants of the delta can continue to live off extensive, floating agriculture; space is not a commodity for them...*"³⁵ While this statement could not be disputed in the 1950s, sixty-three years later, things no longer seem so clear-cut. Our own analysis of the "rice-growing space", combined with that of flooded areas depending on the flood level, allows us to clarify this point but also to qualify it significantly. We have defined the "rice-growing space" as that which accounts for 90% of rice fields and reveals the strategies of rice farmers in choosing which vegetation to clear. The "rice-growing area" is organized around a core of 570,000 ha supported by a dozen plant formations. It extends between 800,000 ha and 1,000,000 ha, depending on the period. It peaked in the 1950s, fell to 800,000 ha during the water crisis of the 1980s, and returned to its peak in the 2000s. However, the "rice-growing area" is only a potential area whose effectiveness depends entirely on the flooding hoped

³³ Jean Gallais, *op. cit.* p. 233.

³⁴ Jean Gallais, *op. cit.* p.247

³⁵ Jean Gallais, *op. cit.* p.253.

for by rice farmers. The example of three years with very different floods shows that this potential area can be greatly reduced, thus limiting the real possibilities for rice farmers and placing farms at high risk of failure.

Table 32: The useful area for rice farmers in 1972, 1978, and 1994

Areas	1989 flood = 5.16 m	1972 flood = 5.65 m	2010 flood = 6.45 m
Potential rice-growing	806,000	860,000	1,089,000
Useful water area	460,000	629,000	927,000
Flooded rice-growing	370,000	418,000	900,000
(Flooded rice-growing	2.3	3.0	3.2

In a good year such as 2010, the "flooded rice-growing area" – the area available to rice farmers – exceeds 80% of the potential rice-growing area, this percentage falls to less than 50% in a mediocre year and to 45% in a bad year, while at the same time there are significant constraints on this rice-growing area, which itself is reduced to less than 80% of its maximum extent. In 1989, the area actually usable, at 370,000 ha, represented only 40% of what it was in 2010.

In 1989, the usable area was just over twice (2.3) the size of the rice fields cultivated that year. The possibility of choosing the location of one's rice field was therefore very limited, as shown by the failure rate of rice fields exceeding one-third of the area under cultivation. In 1972, a mediocre year, rice farmers had three times more land available than was actually sown, which somewhat eased the constraints. This ratio of flooded area to cultivated area of 3 was repeated in 2010, but in a completely different context: 2010 was a good year. Placing the cultivated areas in 2015 in a simply mediocre year would mean a catastrophic year with a ratio of less than 1.5!

In 1960, Jean Gallais rightly believed that the extensive and floating rice cultivation practiced in the Inner Delta was not hampered by lack of space. In 2015, with the expansion of cultivated areas keeping pace with population growth, the situation is no longer the same. Rice cultivation, which remains subsistence-based, with a ratio of 0.45 ha/capita, seems to be approaching the limits of its possible expansion. It only provides a certain degree of security in good years and can lead to food shortages when water conditions are no longer optimal. Admittedly, the ongoing global warming could lead to increased rainfall in West Africa and therefore greater flooding of the Niger River. However, this does not protect residents from sudden fluctuations, which also seem to be a hallmark of the changes currently underway.

Since the 1980s, the ever-increasing dominance of rice cultivation has led to a rapid increase in land conflicts over the use of resources, particularly with Fulani herders. The importance of these conflicts was the reason behind the CIPEA/ODEM project, which aimed to propose a new approach to agricultural and pastoral land management, of which our own **Delmasig** project is an extension. Despite the success of two experimental sites, the results of this work were never applied. The conflicts have continued, a situation that is not entirely unrelated to the civil war against a backdrop of jihadism that has been tearing the Delta apart for years.

There seems to be an urgent necessity to move beyond nomadic rice farming with its low productivity and uncertain results. This form of rice cultivation appears to be both predatory in terms of space and uncertain in terms of its impact, and entails many consequences in terms of poverty and

conflicts over the use of space between rice farmers, but also and above all between rice farmers and livestock farmers.

The various attempts initiated since the beginning of the colonial era have failed, whether through the introduction of new varieties that are more productive but also more demanding in terms of water control, or through the development of irrigation systems that are still dependent on the vagaries of flooding. The recent creation of PPIVs might provide the beginning of a solution, but they are closely tied to the Niger and Bani rivers and cannot be generalized. While the development of flood plains remains a desirable objective, its implementation still constitutes a challenge.