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REALIZATION OF A LAYOUT AND MANAGEMENT PLAN FOR THE SADIOLA BOTTOMLAND IN THE KOUTIALA CERCLE IN SOUTHERN MALI

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ABSTRACT

The region of Sikasso in southern Mali has a large potential for bottomland, the working rate of which is very low except in the wet season. Their enhancement as a strategy to reduce the dependency of the agricultural sector on climatic instability will allow us to reinforce the food self-sufficiency of the rural world of this locality. However, to make the choice of the type of water mobilization infrastructure and an adequate management plan for a bottomland, it is necessary to accomplish technical studies. It is in this context that this research was conducted, the objective of which is to contribute to the technical study of the development of the Sadiola bottomland by offering a type of layout and a plan of management for its efficient working. The Quick Diagnosis of Pre-Development (QDPD) procedure was applied based on soil, topographic and hydrological data. The type of adequate infrastructure selected is "Contour bunds with flood discharge structure". Finally, the plan of management was drawn up thanks to the analyses of the satellite pictures of the occupation of the bottomland and of the cultural aptitude of different types of soil that compose this studied bottomland.

Keywords: bottomland, layout, plan of management, cultural aptitude

INTRODUCTION

Agriculture constitutes the main activity of rural populations in African countries, with 55% having active jobs. It contributes 32% on average to the training of the African gross domestic product (GDP) (WB, 2014). Despite the growth of agricultural production in recent decades (NEPAD, 2013; ADB, 2021), the African continent remains an important importer of cereals (wheat, rice, corn) because this growth did not follow the rhythm of that of its population, which doubled in the last 30 years (NEPAD, 2013).

Traditional agriculture is very impacted by climatic hazards and the deterioration of lands (SWAC, 2010; UNCCD, 2014; Diawara et al. 2019), and Sahel farmers are perpetually looking for new lands for cultivation. States also, in the search of food self-sufficiency, are increasingly moving toward the search of funding for the exploitation of seasonal wetlands, notably from the bottomlands (Albergel et al., 1993).

The estimated area of bottomlands in Africa is approximately 1.3 million km² (Raunet, 1985), which is from 4 to 5% complete areas of the continent, or 17.3% of farmland according to data from *the* "Center for Sustainability and the Global Environment (SAGE)" (Roudart, 2010). However, this agricultural potential of bottomlands at the continental scale is not sufficiently exploited. Nevertheless, agriculture in the bottomlands gives numerous advantages. Indeed, the concentration of (superficial and underground) flow in the bottomland favors the bringing under cultivation on the one hand of more demanding varieties in water, such as "*Sorghum bicolor*" (sorghum) and "*Oryza sativa*" (rice), and on the other hand, of varieties with longer cycles but with stronger output (Raunet, 1991; Albergel et al., 1993). Bottomland favors the development of arboriculture and off-season market gardening.

Since the droughts of the early 1970s that led to a very large cereal deficit followed by famine and the death of tens of thousands of people in the Sahel (Bonnecase, 2010), Mali has undertaken efforts to develop lowlands and small floodplains, particularly in the southern part of the country (Ahmadi et al., 1994; Ahmadi et al., 1998), where the 1200 mm rainfall isohyet has disappeared for 30 years (Diawara, 2019). According to data from the Woody Resources Inventory Project (WRIP), the areas of bottomlands and small floodplains in southern Mali are estimated at 300,000 ha (Ouattara, 2009). However, less than 10% of this potential had been developed through development until 2015 according to the project "Initiative for Reinforcement of Resilience through Irrigation and Appropriate Resource Management (IPRO-IRRIGAR)" (DNGR, 2015).

The bottomlands of the South-Mali, done up or not, and their immediate areas are used for various agricultural activities, including rice growing, market gardening and arboriculture (Ahmadi et al., 1994). The village of Sadiola (village of Kapala, cercle of

Koutiala) in the region of Sikasso in southern Mali has a bottomland of 166.57 ha. The population of this locality (village of Kapala), which saw only agriculture, is often confronted with partial vulnerability. The proportion of the vulnerable population in this village in 2014 was 15.0% according to the figures of the Statistical Directory of the Ministry of Rural Development (MDR/CPS-SDR, 2014). The development of this bottomland would undoubtedly allow the population to exploit it better to produce more for home consumption and to generate incomes and to diminish socioeconomic vulnerability, notably that of women and young people.

Aware of these stakes, the village of Sadiola expressed a need motivated by the development of its bottomland, which was worth being registered in the National Program of Near Irrigation (PNIP) of Mali. At its request, the village solicited a threshold pouring out as a type of development to be accomplished. However, it was necessary to conduct studies to make a choice regarding the type of adequate development according to the characteristics of the bottomland.

The bottomland layout and management plans are the result of multidisciplinary studies (Ahmadi et al., 1994). These studies indeed include hydrological, topographical and pedological aspects at the same time, as well as socioeconomic aspects. This allows us to define not only the type of adequate water mobilization infrastructure but also land use patterns for production.

Furthermore, there are few studies that make it possible to propose both the type of layout to be carried out in the bottomland and its management plan. For example, Hounkpetin (2003) was able to identify constraints related to the layout of the Okeita bottomland in the Commune of Pobè (in Benin) and to propose an appropriate layout for its sustainable exploitation without indicating a plan for its use. Additionally, Souberou (2013) and Kindjinou (2013) evaluated the development potential of the bottomlands of the commune of Materi in Benin and those of Togo, respectively, without proposing a layout plan. Finally, Akassimadou et al. (2014), in their study on the determination of the real agronomic potential of bottomlands in the agroecological zone of the Guinea savannah of Côte d'Ivoire for sustainable agriculture, did not make a layout proposal that better corresponds to the bottomland. Thus, our study aims to propose a layout and management plan for the Sadiola bottomland to allow its efficient use.

PRESENTATION OF THE STUDY AREA

With its sudanian tropical climate, the region of Sikasso is the most watering of Mali (Diawara, 2019). Therefore, it is one of the most important agricultural regions of the country, with a proportion of the workforce practicing this activity above the national average and households being relatively more equipped (INSTAT, 2021). Specifically, it is the main cotton pool of the country, with more than 70% national production (Nkuingoua et al., 2022). Moreover, in addition to cotton, they produce very large quantities of cereals, tubers and vegetables in the region.

The village of Sadiola is located 25 km from the capital of the rural commune Kapala (cercle of Koutiala) in the northeast of the Sikasso region (Fig. 1).

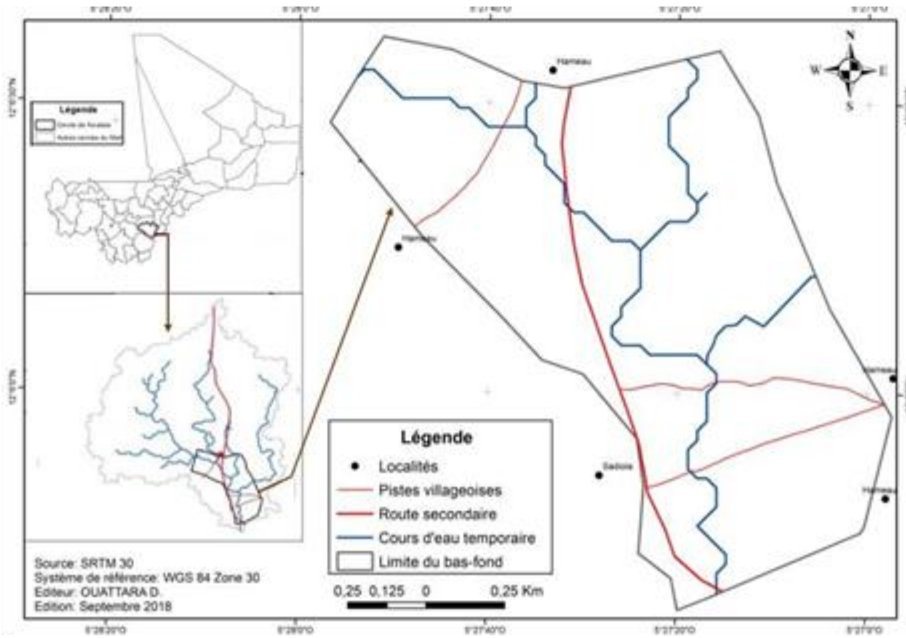

Figure 1: Map of the Sadiola bottomland location.

Its population is estimated at 2,700 inhabitants during the 4th general population and housing census (RGPH) of 2009, according to data from INSTAT (2012). As in the entire region, the main population activity of Sadiola village is agriculture. Off-season market gardening, which used to be widely practiced, no longer exists there due to the early drying up of the surrounding water reservoirs.

Sadiola has a bottomland with an estimated area of 166.57 ha at the outlet of the Sadiola River watershed, the development of which could revive market gardening. It is crossed by a seasonal stream fed by rainwater.

METHODOLOGICAL APPROACH

Data and processing tools

Description of the data used

Geographic (satellite and drone images and administrative boundary shapefiles), climatic, soil and socioeconomic data were used in this work. The main characteristics of these data are presented below:

- *Geographic data:* they are two types. It is files of forms of the administrative borders under *format* « *shp* », coming from the database of Decentralization Mission and from Institutional Reforms (MDRI) in 1998 in Mali, which were used to locate the zone of study, and satellite pictures « *raster* » SRTM and LandSat OLI of 01/04/2017 of 30 m of space resolution, which served, respectively, for the demarcation of the shoal and for the analysis of its occupation. The satellite pictures come from the archives of *the United States Geological Survey (USGS), https://earthexplorer.usgs.gov/*. The pictures of the drone, also in the format « *raster* », are from 2018 and were collected to the Office of study *"Engineering Consulting Service 96 (ECO-96 SARL)*".

- *Climatic and soil data:* they are composed of the temperature of air and annual rainfall from 2007 until 2017, on the scale of the village from which the overturning basin and the bottomland were extracted. The source of these data is NOAA, notably ARC2 for rainfall.

The Soil Database for the bottomland dating of 2019, also under format « *shp* », was also gathered to ECO-96. It contains information on the types and permeability of the soil of the bottomland.

- *Socioeconomic data:* socioeconomic indicators harvested to 13 farmers of the bottomland, among whom seven (7) men and six (6) women mainly concern the social organization around the bottomland, modes of acquisition of plots in the bottomland and their work.

Processing tools

Different tools were used for the collection of data, their treatments and analyses. The collection of socioeconomic data was accomplished with the Kobo Toolbox application.

Moreover, for treatment and analyses, Grass GIS 7.4 and ArcGIS 10.2.1 software were used for demarcation and estimation of the parameters of the watershed and of the bottomland and for the realization of thematic maps. Envi 5.1 software served for the analysis of the picture LandSat to assess different units of occupation and use of the soil of the bottomland. Finally, the Mobile Topographer tool on smartphone was used to collect the GPS coordinates of some points in the bottomland, which served for the validation of the occupation and soil use map.

Treatments and analyses of data

Treatments and analyses of data were made in some stages.

Satellite pictures

The automatic ridge and thalweg extraction method (Aoulmit, 2016) was applied to the SRTM image to analyze the toposequence to delimit the watershed and to extract the main morphometric characteristics (including the longitudinal slope bottomland average) and geomorphological units, including bottomlands, through the topographic position index (TPI) (Ouattara, 2009).

For the identification of bottomland land cover and land use units, we proceeded to the colored composition of the Landsat image in Envi 5.1, followed by the classification technique supervised by maximum likelihood (N' Da et al., 2008; Kouassi, 2014).

The results obtained from the cartographic analyses were corrected and validated during the field visit coupled with the socioeconomic surveys. Thus, the GPS coordinates of some points in the shallows and their occupations were recorded for comparison with those of the map for validation.

Soil types and hydroclimatic characteristics

The types of soil on which the cultural aptitude of the bottomland is identified are dependent on the analysis of samples of soil taken in holes by the soil team of the Office ECO-96 Mali. The cartography of the soil units was then accomplished.

Temperatures served only for the presentation of the zone of study, while rains, on top of that, were also aggregated on the scale of the basin overturning and used in the estimate of the debit of flood of the watercourse feeding the bottomland. The latter was obtained by the ORSTOM method (FAO, 1996; Berthé et al., 2021).

Choice of layout and management plan

The type of layout (bunds, thresholds, etc.) from the bottomland defined by the multicriteria method of the Quick Diagnosis of Pre-Development (QDPD) (Lidon et al., 1998), founded on valuation and on a combination of stocks of seven indicators (soil, topographical and hydrologic) of the middle.

Finally, for plan management of the bottomland, we crossed the cards of occupation of the soil and soils to whom the cultural aptitude of soil is known defined in the database of ECO-96.

RESULTS AND DISCUSSION

The main results obtained in the course of this study are regrouped into five (5) categories below:

Main characteristics of the watershed and hydrographic network

Estimates of the main characteristics of the watershed of the Sadiola River and its hydrographic network are introduced in Table 1.

Table 1: Main characteristics and hydrographic network

Features	Parameters	Symbols	Units	Values
Watershed morphometry	Area	A	km^2	18.70
	Perimeter	P	km	31.64
	Compactness index	K_G	-	2.05
	Length of the equivalent rectangle	Léq	km	14.66
	Equivalent rectangle width	*l*éq	km	1.28
Landform	Maximum altitude	Hmax	m	355
	Minimum altitude	Hmin	m	321
	Median altitude	Hmed	m	338
	Elevation	D	m	22
	Total elevation	DT	m	34
	Overall slope index of the watershed	Ig	m/km	1.50
	Average slope of the watershed	Imoy	m/km	2.32
Hydrographic network	Main stream length	L	km	2.41
	Elevation of the main watercourse	ΔHmax	m	0.15
	Average slope of the main watercourse	Pmoy	m/km	2.07
	Drain density	Dd	m/km^2	1.20
	Hydrographic density	Dh	$1/km^2$	1.12
	basic time	Tb	s	1194.7

The watershed of Sadiola, with an area of only 18.70 km^2, is a small pool pouring (FAO, 1996) for a 31.64 km perimeter. The indication of density is 2.05; what classifies him among basins mountainsides of form lengthens (Melle, 2011). As a result, the time of concentration is rather long; otherwise, its hydrological response to rainfall transformation is slower.

All the Sadiola watersheds are between altitudes of 321 m and 355 m. Its median altitude is 338 m. The medium slope of the overturning basin, which is estimated at 2.32 m/km or 0.23%, and its overall slope index of 1.50 m/km (or 0.0015) indicate that its relief is very weak according to the classification of ORTSOM (Souadi, 2011).

Occupation of the soil of the bottomland of Sadiola

The analyses of satellite pictures combined with investigations during ground visits led to the cartography of the occupation of the soil of the bottomland of Sadiola. Five (5) different units of occupation and use of the soil were identified, as introduced in Fig. 2.

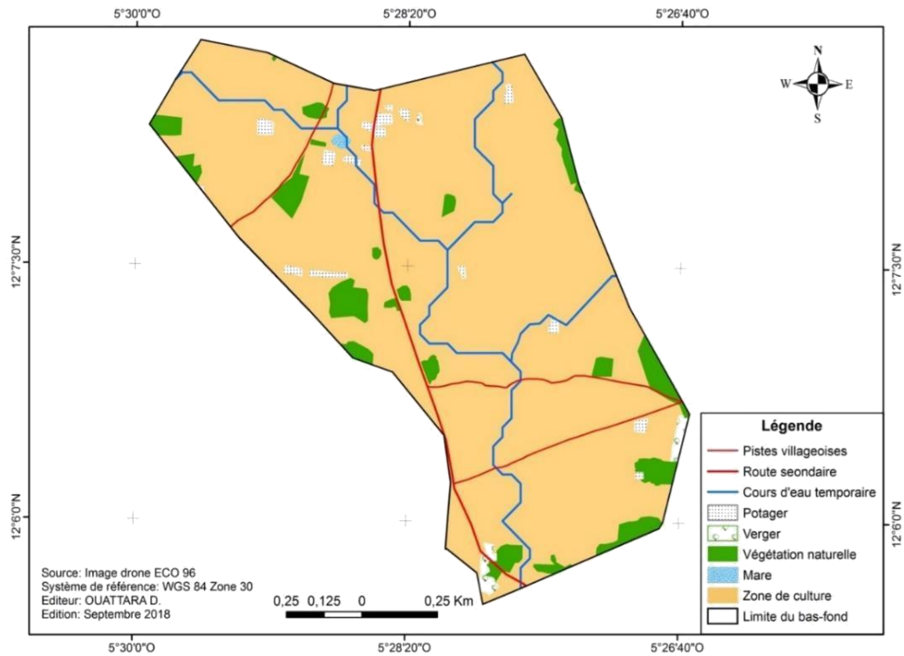

Figure 2: Units and use of the soil of the bottomland of Sadiola.

Five (5) localizable units in the bottomland across this map are the « kitchen garden », « orchard », the « natural vegetation », « the water (the pond) » and the « culture zone ». The main unit is from a distance from the "culture zone", occupying more than 91.35% of the bottomland. Four (4) others are little representative in area terms but are widely dispersed inside the "zone of culture", where it is principally produced of pluvial rice. Market gardening at the level of kitchen gardens, which occupy 1.36% of the bottomland, is generally played in enclosures to prevent the animals from entering there. It shows the weak use of the bottomland of Sadiola after the wet season because of the small pool of 0.22 ha (or 0.13% of the bottomland), the maximum depth of which is 1 m, which generally dries up before January according to the exploitation of the bottomland. The plant cover (6.45% of the bottomland) is slightly dense and principally composed of wood and bushes. They meet some kinds, such as the "*néré*", the "*rônier*", and the "*baobab*".

Finally, in the bottomland, there are some small orchards (0.71%), generally close to natural vegetation.

Modes of acquisition and use of plots in the bottomland of Sadiola

From testimonies obtained during interviews with users of the bottomland, it was confirmed that the bottomland statutorily belongs to the village of Sadiola. In other words, he belongs to the village group and cannot make the object of sale, and any use change is supervised by the usual leader to whom the management of lands is entrusted. He makes decisions after consultation with his advisers.

There are two (2) modes of acquisition of plots in the bottomland: inheritance for 46.15% and donation for 53.85% of investigations. Farmers can use it as well during the wet season for production (generally of rice) as during the dry season for market gardening. In contrast, this last activity mainly compelled the precocious lack of watering water, including in wells, which made market gardening not develop much this day. Regarding the use of harvest, 84.62% of farmers maintain that they are only intended for home consumption, compared to 15.38% who commercialize a part to assure some expenses of their household.

Agropedological characteristics of the bottomland

Grace in the data of analysis of the soil samples raised by the office Eco-96 in the bottomland of Sadiola, we accomplished the soil map of the bottomland (Fig. 3) by introducing three (3) types of soil (or soil units).

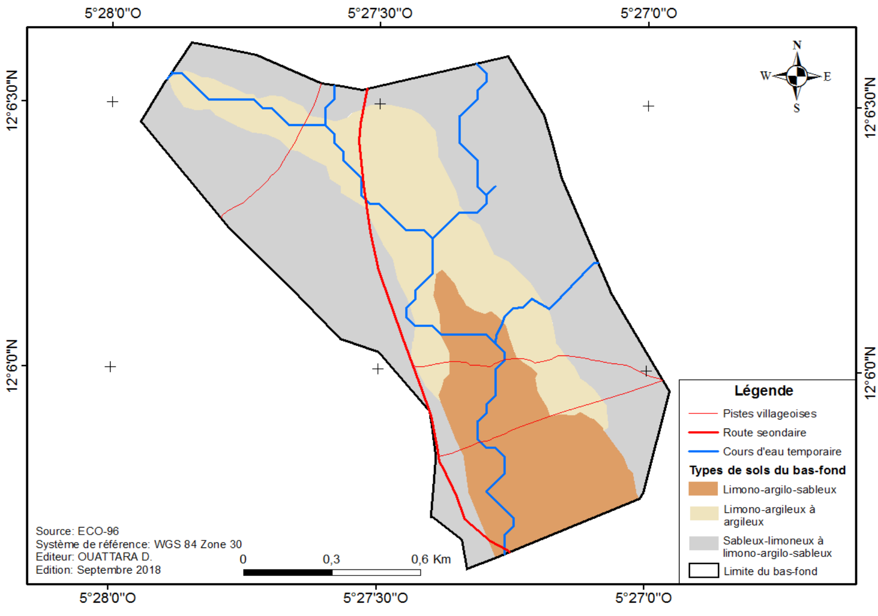

Figure 3: Soil map of the bottomland of Sadiola.

The three soil units in the Sadiola bottomland are loam-clay–sandy (D-M), loam-clay to clay (D-A) and loam-sandy to loam-clay–sandy (G-M). They fit together in the same order and extend along the main watercourse from the outlet. Thus, the permeability of the bottomland as a whole is average. The statistics (areas, levels of permeability and cultivation suitability) of these soils are given in Table 2.

Table 2: Statistics (areas, permeabilities and aptitude for cultivations) of soil units in the bottomland of Sadiola. Source of data: ECO-96 Mali office, (2018)

Type of soil		Area		Permea-bility level	Cultural aptitude
Scientific names	**Vernacular names**	**(ha)**	**(%)**		
Limono-clay–sandy (D-M)	Ŋakanfalacɛn-cɛndugukolo	32.40	19.45	Mean	Flooded rice and market gardening in the off-season
Loamy clay to clayey (D-A)	Ŋakanfaladugukolo to faladugukolo	41.85	25.13	Low	Irrigation of food crops, rice in the rainy season and market gardening in the off-season
Sandy loam to sandy clay loam (G-M)	Dabacɛncɛn to dabacɛncɛnfala-dugukolo	92.32	55.42	Mean	Irrigable marginally suitable for rice. Moderately suitable for market gardening and undemanding arboriculture, reforestation with good water control
Total		166.57	100.00		

The first unit (D-M), of a 32.40 ha area, is 19.45% complete areas of the bottomland and is favorable to the culture of flooded rice and to market gardening in the against season. The second unit (D-A) has favorable subsistence crops in the pluvial season and market gardening there against season. His 41.85 ha area represents 25.13% of the bottomland. Finally, the last unit (G-M), the largest area of which is 92.32 ha (55.42% of the bottomland), can be used for polyculture (corn, sorghum, market gardening) for forested nursery gardens; however, it is not very capable of irrigated rice growing.

In the second column of this table, the vernacular (or indigenous) names of the different morphopedological units are given to facilitate the consideration of the results of this study by the local populations in the field. Indeed, the importance of ethnopedological knowledge is no longer in question for the resolution of soil management problems and sustainable agriculture (Diallo et al., 2016).

Layout plans and plans of management of the bottomland of Sadiola

The choice of the type of development to be accomplished in the bottomland of Sadiola was made on the basis of the multicriteria analysis of QDPD. The soil indicators and topographical and hydrologic estimates are given in Table 3.

Table 3: Estimate of the indicators of the choice of the type of development of the bottomland of Sadiola

Indicators	Parameters and units	Values
Soil	Permeability (m^3/s)	$5.10^{-7} < 10^{-4}$
	Depth of an impermeable layer (m)	Indifferent
Topographic	Mean longitudinal slope of the lowland (%)	0.21% < 1%
Hydrological	Flow axis	With or without marked flow axis
	Flood flow per linear meter of lowland width (l/s)	25.34 l/s
	Depth of the lowland interflow sheet	Indifferent (not compulsory)
	Minimum duration of coverage of irrigation needs by base flows (months)	Indifferent (not compulsory)

It emerges from the crossing of these indicators that “contour bunds with flood discharge structure” proves to be the most appropriate development for the bottomland of Sadiola (Lidon et al., 1998), different from the initial choice expressed by the village. Indeed, this type of development is adapted to bottomland, not filters such as ours, where the soils are weakly to moderately filterable (Tab. 2), with a low flow, without a marked flow axis and whose average longitudinal slope of the lowland is less than 1%. Contour bunds with flood discharge structures are intended for rice cultivation. They allow water to be stored in the traps and allow excess water to pass over the dikes (Wopereis et al., 2008).

To arrive at the land use bottomland management plan, the land cover and use maps of the bottomland (Fig. 2) and the soil units (Fig. 3) were crossed. whose cultural aptitudes are defined in Table 2. The map resulting from this crossing summarizing the bottomland management plan is shown in Fig.4 below.

Analysis of this map shows that the “natural vegetation”, “vegetable gardens”, “orchard” and “pond” units that already exist are maintained in the new bottomland management plan. In addition, the "cultivation zone" unit, which was the largest and mainly reserved for rainfed rice cultivation, was divided between zones (1) of flooded rice cultivation where market gardening can also be practiced in the off-season, (2) submerged crops such as upland rice, maize or cotton, the latter of which were not grown there, and (3) arboriculture. Ballo (2019), in his thesis on bottomlands in the Mali-South zone, proposed practically the same types of land use in the bottomland of Bamadougou (a locality located in the cercle of Sikasso, slightly more than 100 km south of the commune of Kapala), according to their cultural aptitudes.

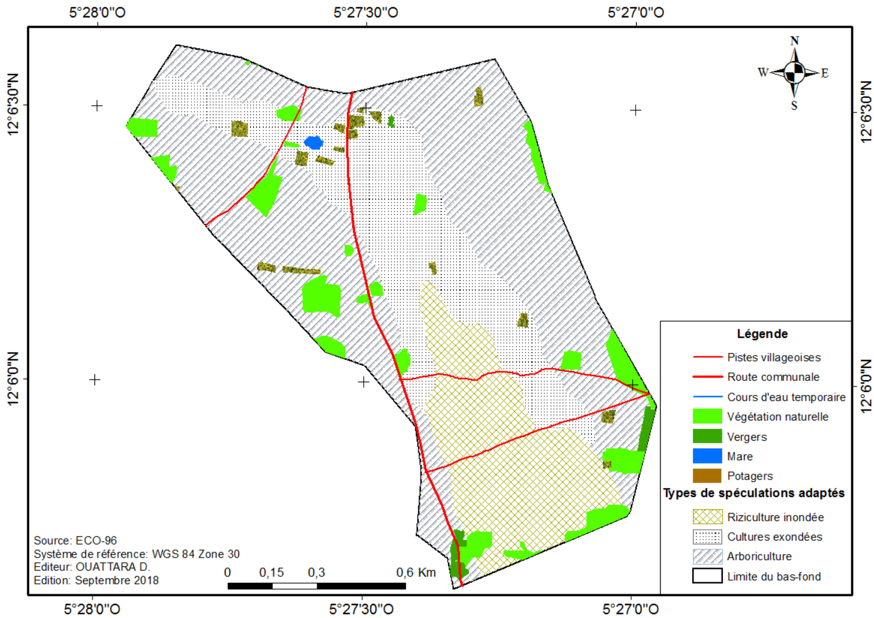

Figure 4: Plan of management of the bottomland of Sadiola.

The distribution by area of these different types of use to be planned in the Sadiola bottomland through this management plan is shown in Fig. 5.

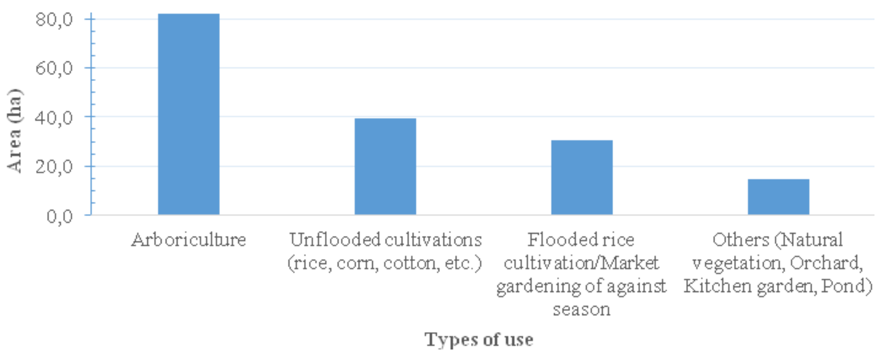

Figure 5: Distribution by area of the types of use in the Sadiola bottomland management plan.

Thus, according to this new configuration, arboriculture should occupy more space in the bottomland of Sadiola, with an area of 82.15 ha, in addition to the already existing orchards. Exposed crops can be practiced on 39.37 ha during the rainy season. The flooded rice-growing area represents 30.64 ha, which can also be used in the dry season for market gardening thanks to the remaining humidity.

This new management plan should make it possible both to increase agricultural production in the Sadiola bottomland and to diversify it and contribute significantly to the food self-sufficiency of the population. Additionally, with the practice of arboriculture and market gardening, the bottomland of Sadiola could allow a very significant additional contribution of income to households in general and to women and young people in particular.

CONCLUSION

This study on the realization of a layout and management plan for the Sadiola bottomland has contributed to a better knowledge of it and the activities that are practiced there. The layout and management plan produced by the QDPD multicriteria method has highlighted the agricultural potential of this bottomland. Thus, the construction of contour bunds with a flood discharge structure would allow prolonged exploitation of the bottomland beyond the rainy season along with an active practice of market gardening and the development of mixed farming adapted to the types of soil. who compose it. In addition to cereal crops and market gardening, the Sadiola bottomland will be able to shelter fruit trees over almost half of its surface. The loss of cereal production area in the rainy season in favor of arboriculture will be offset by the increase in off-season production. This new management plan would therefore not only reduce food insecurity by increasing food production but also reduce the poverty level of bottomland farmers thanks to income from market gardening and fruit.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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