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Analysis of water management in the irrigated area of Saga: Rate of satisfaction of water needs, performance indicators, constraints and solutions

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Abstract

This study was carried out on the Saga rice growing area near Niamey. The main objective is to analyze current water management practices and identify improvement opportunities for more efficient and equitable use of water resources. A mixed methodological approach was used, combining surveys of local stakeholders, direct observations and documentary analysis. The results showed that although local management structures exist, they encounter difficulties linked to the coordination of users and the maintenance of infrastructure. Traditional practices, although still in force, are not always adapted to modern challenges, such as climate variability and increasing population pressure. Regarding the satisfaction rate of water allocated to irrigators, we note an average water coverage of the area is estimated at 82% for dry season rice cultivation and 51% for rainy season rice cultivation. Regarding performance indicators, there are low levels of fluctuations in agricultural reinforcement rates, with coverage estimated at 73% during the dry season and coverage of irrigation water demand of 82%, directly at 97%. % during the campaign. Achievable with a coverage rate of irrigation water demand of 51% during the winter season. The agricultural efficiency (Ea) values of irrigation water for all crops are low. Based on these observations, solutions were proposed for good participatory governance, improving infrastructure and integrating innovative approaches to integrated water resources management. These proposals aim to ensure sustainable and long-term management of the irrigated area, while meeting the growing needs of users.

Keywords: Rice Growing Area; Performance Indicators; Water Satisfaction Rate; Water Management and Saga

1. Introduction

The world officially has more than 324 million hectares of irrigated land, out of a total of 1.4 billion hectares of arable land (FAO, 2012). These irrigated areas produce more than 40% of global food production (FAO, 2012). However, water, a crucial element in the productivity of these areas, is often poorly managed. The management of water resources is therefore becoming a major issue, particularly in Sahelian regions such as Niger where the short rainy season characterized by low and random precipitation, as well as interannual variation in production poses a serious challenge (Namata, 2012 ; Mossi, 2005). Indeed, Niger is a Sahelian country plagued by food insecurity.

Thus, he had to look for solutions to face these challenges. Since the 1960s, the Nigerien government has been committed to mobilizing water resources for agricultural purposes, with particular emphasis on the development of hydro-agricultural developments.

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These efforts led to the creation of irrigated areas with total water control, mainly intended for rice cultivation in the Niger River valley, as well as mixed farming in the Tahoua and Maradi regions. Other off-season sites are also devoted to market gardening throughout the national territory, supplemented by runoff water conservation works (Republic of Niger, 2005). The areas with water control are collective and supervised by the National Office for Hydro-Agricultural Developments (ONAHA).

Inefficient water management in irrigated areas can lead to serious problems such as soil degradation, salinization, and overexploitation of water resources. These problems not only undermine the sustainability of irrigated agriculture but also long-term food security in these regions.

Despite the existence of numerous studies on water efficiency in irrigation, there remains a lack of integrated data taking into account technical, economic and social aspects of water management. The objective of this study concerns water management, the rate of satisfaction of irrigation needs, performance indicators, constraints and solutions for good governance of the Saga rice growing area.

2. Materials and Methods

2.1. Materials

2.1.1. Presentation of the study area

Created in 1967 by the national agricultural service of Niamey with the help of Chinese technical cooperation, the hydro-agricultural development of saga (13°27'39.9''N, 002°08.44.1''E) is one of the very first irrigated areas with total water control in Niger. Completely integrated into the urban community of Niamey, it is limited to the north by the village of Saga, to the south by the village Banigoungou to the east by the tarmac road linking Niamey-Kolo and to the west by the Niger River. Since its creation, the irrigated area of saga has only been rehabilitated once in 1987 and today covers a nominal area of 430 ha divided into 7 GMPs including 381 ha dominated by the irrigation network and 49ha for market gardening (TAHIROU et al, 2022). The perimeter is supplied with water by the Niger River

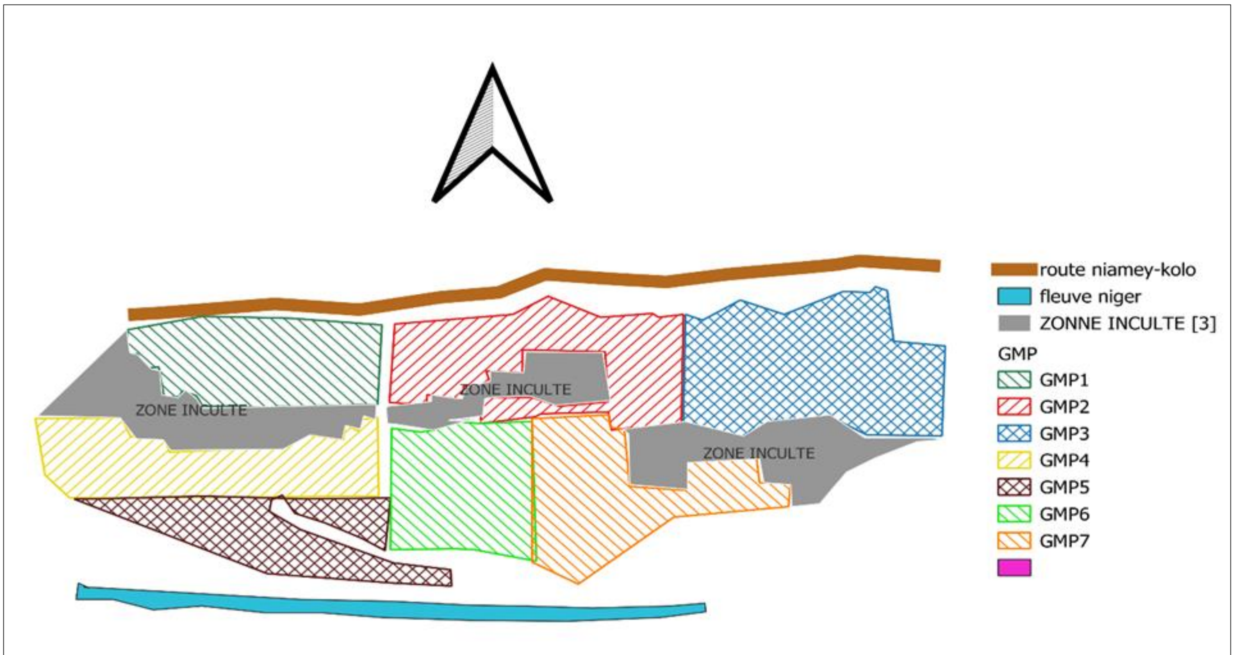

Figure 1 Map of the hydro-agricultural development of Saga

2.2. Methods

The methodology that we adapted for this study is as follows:

2.2.1. Data collection methodology

- Data collection was carried out in two phases

- A first phase of "open" type surveys was implemented to choose the tertiary sector and collect general information on the area (mapping, climate, hydrography, pedology, history)
- A second phase of investigation which took place on the site itself
- The methodology proposed for this last phase is based on intensive field work aimed on the one hand at collecting information on technical, social and organizational management not only from the cooperative but also from water managers. and among the operators. The data collected comes from interviews, questionnaire proposals, interviews and direct observations in the field.
- The surveys of the cooperative aimed to obtain information on the organization and technical management of the area (the technical sheets of the rice growing area);
- The surveys of water managers in the area aimed to assess the effectiveness of their water management system;
- The surveys among farmers aimed to evaluate: to identify their irrigation practice, to evaluate their satisfaction in terms of accessibility to water resources and finally to evaluate the satisfaction of the water needs of rice through the use of cropwat software.
- Facing farmers, the sampling choice process was based on a random method, the farmers are chosen directly on the site. The perimeter has 576 irrigators including 471 men and 105 women. In the field 48 men and 5 women were surveyed
- To process the field data obtained, the following equipment was used: The Climwat 2.0 and Cropwat 8.0 (FAO) software respectively made it possible to obtain the climatic data of the study area and to calculate the water requirements of the rice. The Microsoft Excel 2016 spreadsheet was used to calculate the different flow rates and other variables studied.

2.2.2. Data analysis methods

General analysis method

The data was analyzed in line with previous studies and courses taken on the management of irrigated areas during my university career.

- **Method of analyzing the perimeter water satisfaction index**

The rate of satisfaction of water needs (TSB) is assessed by the work of the International Institute of Irrigation Management (IIMI).

A TSB value ≈ 100% is a good indication of water management. A value greater than 100% or less than 100% respectively reflects either water waste or a water shortage.

The TSB was calculated by the following formula:

TSB = VP (m3 /ha) / BEI (m3 /ha) with:

TSB: rate of satisfaction of water needs on a perimeter during a growing season.
VP: total volume of water pumped and consumed during a growing season in m3/ha
BEI: water requirements of plants theoretically estimated for a growing season in m3/ha

The theoretical volume of water pumped on the perimeter per dry season and winter season is calculated by the calculation method used by (Mossi et al, 2016)

$$\mathbf{VP\ (m^3) = Qp\ (m^3/s)\ x\ Nbh\ (s)}\ \text{Avec}$$

VP : total volume of water pumped and consumed during a growing season in m3/ha
Qp : total flow rate of the pumps having operated in m3 /s. Nbh : number of pump operating hours in seconds**.**

Rainfall efficiency coefficient (er) is determined by the FAO formula :

Pe = 0.8*P - 25 if P> 75 mm/month Pe = 0.6*P - 10 if P< 75 mm/ month

Agronomic data relating to the plant and the soil were considered to calculate water requirements. These include:

- Crop coefficient (Kc) which varies according to the vegetative stage ;
- The efficiency of the irrigation system network estimated at 72%

The performance of the Saga hydro-agricultural development was assessed according to three efficiency indicators retained during this study.

Table 1 Performance indicators used

Indicator	**Expression**
Rate of agricultural intensification	Ti (%) = (Scult / Sirrig) x 100
Crop satisfaction rate	Ts (%) = (Vdist / Vth) x100
Agronomic efficiency of irrigation water	Ea (kg/m3) = Rt / Ceau

Vdist : volume distributed respectively, Scult : irrigated cultivated area, Sirrig : irrigable area of the perimeter, Vth : Theoretical volume, Rt : average crop yield, Cwater : quantity of water consumed per cultivated hectare.

3. Result

3.1. Management of water distribution on the perimeter

Managing water distribution in the area is essential to guarantee the viability of agricultural activities. However, frequent power cuts provided by Nigelec further disrupt the regular distribution of water on the irrigated areas (ONAHA, 2011).

At level (GMP) 2 and 3, water distribution is theoretically ensured by the water workers, but the task is now shared between the delegates, due to the modifications brought about by cooperation with the water workers. However, the silting of the canals and the lack of constant maintenance limit the effectiveness of the irrigation system. The pumps become tired, and a significant amount of water is lost. Another factor affecting good water distribution is non-compliance with the crop calendar by farmers. Due to numerous delays, irrigation extensions are negotiated, which increases electricity consumption and puts more wear on the pumps.

Some operators also have gardens of 1 to 3 hectares or plots outside the perimeter, not planned during the design, which require additional pumping. This makes water management even more complex.

The "water tower" system, in place since the design of the perimeter, has been improved and adjusted in consultation with producers. Each water intake was once marked with colors indicating irrigation days, a practice which has now disappeared. The water workers, under the supervision of the perimeter supervisors, ensure that this water tower is respected, ensuring that each irrigation day, all the secondary ones are in water and that the rotation between the sprinklers is respected.

However, several factors disrupt this system : uncontrolled water pumping by garden cultivators outside the perimeter, the poor efficiency of the distribution network, the low flow rate of pumping stations and frequent power cuts. The downstream part of the perimeter, representing approximately 30 hectares, is not served by water, and 120 plots have been abandoned in the GMP 3 zone, made up of veterans and small producers. These plots were replaced by high value-added market gardens, operated by spontaneous market gardeners, mainly senior executives. In other parts of the perimeter, water is supplied on demand and the valves are operated by water workers. Although technical management tools, such as the irrigation calendar and pumping station logbooks, are in place, there is a lack of means to properly archive, store and interpret this data in order to improve the technical management of the perimeter.

3.2. Analysis of constraints and proposals for sustainable water management

3.2.1. Perimeter water satisfaction index

Nb : Given the lack of data on the last 3 years' campaigns due to flooding, data from the 2021 campaign was used for this part.

Volumes of water pumped for the hydro-agricultural development of Saga

These available data from the main Saga station made it possible to evaluate the theoretical volumes of water pumped per year and per season.

The results are summarized in the following Tables.

Table 2 Monthly pumping time Dry and wet season for the 2021 campaign**.**

		Pomp N°1	Pomp N°2	Pomp N°3	Pomp N°4	Total
Pumping time in hours	SS	910	825	1085	948	3768
	SH	716	743	851	1008	3318

The results of the theoretical pumped volume on the perimeter during the dry season and the wintering season are summarized in Table 2.

Table 3 Theoretical volume pumped on the perimeter by dry season and wintering season

Period	Number of hours (s)	Pump flow (m^3/s)	Volume of water pumped (m^3)
Saison Sèche	13 564 800	0,3	4 069 440
Saison Hivernale	11 944 800	0,2	2 388 960

Considering the areas developed during these different seasons, table 4 presents the theoretical volumes of water received per hectare on the Saga perimeter.

Table 4 Volumes of water pumped per hectare dry and wet season in 2021

Period	Volume of water pumped (m^3)	Areas developed (ha)	Volume of water pumped per hectare(m^3/ha)
Dry Season	4 069 440	280.78	14493,33
Winter Season	2 388 960	371.81	6425

The results obtained in Table 4 shows that the volumes of water pumped during the wet season remain low compared to the volumes of water pumped in the dry season. On average, the volumes of pumped water are 14493.33 m3 / ha for the dry season and 6425 m3 / ha for the wintering season.

- Irrigation water requirements

The estimation of rice water requirements was made following the standard standards of the Cropwat 8.0 software. Tables 6 and 7 evaluate the irrigation water needs of rice for the two growing seasons in the Dry Season and the Wet Season in the Saga area.

Table 5 Assessment of rice irrigation water needs in the dry season at the Saga irrigated area in 2021

	Nov.	Déc.	Jan	Fév.	Mars	Avril	Mai	Total
Reference Evapotranspiration (ET0) mm	357.1	346.5	367.4	386.9	504.5	489.5	494.8	
Crop coefficient (Kc)	0.8	0.9	1.2	1.2	1.0	0.9	0.6	
Water requirement (ETcult. = Kc x ET0) mm	285.68	311.85	367.4	464.28	605.4	489.5	445.32	2979.43

Pre-irrigation (S) and mud (mm)	150	150	0	0	0	0	0	150
Infiltration (In) (1mm/Jr clay soils) mm	10	10	10	10	10	10	10	10
Total Water Need (ETcult. + S + In) mm	445.68	471.85	377.4	474.28	615.4	490.5	455.32	3330.43
Average ten-day rain(P)	0	0	0	0	0	0	0	0
Rain efficiency coefficient (er)	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Pluie efficace (Pe = P x er) mm	0	0	0	0	0	0	0	0
Net Need for Irrigation Water (I Net = ETcult. + S + In - Pe) mm	445.68	471.85	377.4	474.28	615.4	490.5	455.32	3330.43
Efficiency of the Irrigation System (ep)	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
Gross Irrigation Water Need (I brut = Inet / ep) mm	619	655.34	524.16	658.72	896.38	681.25	632.35	4367.2
Gross irrigation water requirement in m^3/ha m^3/ ha	2315.26	2288.43	2026.08	2470.98	3249.6	2653.57	2494.64	17498

From Table 5, the total irrigation requirements for rice cultivation amount to 17498 m3/ha. So ; the need for irrigation water during the dry season resulting in a total volume of 4,913,088.44 m3 of water over an area of 280.78 ha.

Table 6 Assessment of rice irrigation water needs in the rainy season at the Saga irrigated area in 2021

	Juin	**Juil.**	**Aout**	**Sept.**	**Oct.**	**Nov.**	**Déc.**	**Total**
Reference Evapotranspiration (ET0) mm	399.6	164.3	245.7	269.5	374.4	357.1	346.5	2150.1
Crop coefficient (Kc)	0.9	0.9	1.0	1.2	1.2	1.0	0.6	2080.49
Water requirement (ETcult. = Kc x ET0) mm	359.64	147.87	247.5	323.4	440.88	357.1	207.9	2979.43
Pre-irrigation (S) and mud (mm)	100	100	0	0	0	0	0	100
Infiltration (In) (1 mm /Jr clay soils) mm	10	10	10	10	10	10	10	10
Total Water Need (ETcult. + S + In) mm	469.64	257.87	255.7	333.4	450.88	367.1	217.9	2352.49
Pluie décadaire moyenne (P)	43.2	172.7	177.4	50.9	0	0	0	444.2
Rain efficiency coefficient (er)	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Effective rain (Pe = P x er) mm	34.56	138.16	141.92	40.72	0	0	0	355.36
Net Need for Irrigation Water (I Net = ETcult. + S + In - Pe) mm	435.08	119.71	113.78	292.68	450.88	367.1	217.9	1997.13

Efficiency of the Irrigation System (ep)	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
Gross Irrigation Water Need (I brut = Inet / ep) mm	604.27	166.26	158.02	406.5	626.22	509.86	302.63	2773.76
Gross irrigation water requirement in m^3/ha m^3/ha	2458.41	1279.29	1350.74	1729.82	2348.98	1970.78	1304.95	12439

The analysis of table 6 shows that the total irrigation needs for rice cultivation amount to 12,439 m3/ha. Thus, the need for irrigation water for the winter season results in a total volume of 4,624,944 m3 of water on a developed area of 371.81 ha.

- Needs satisfaction rate (TSB)

From the results obtained for the volumes of water pumped and the irrigation water needs, the rates of satisfaction of rice water needs per season are calculated for the Saga rice growing area. Figure 2 shows the rate of satisfaction of mobilized water needs according to the growing seasons

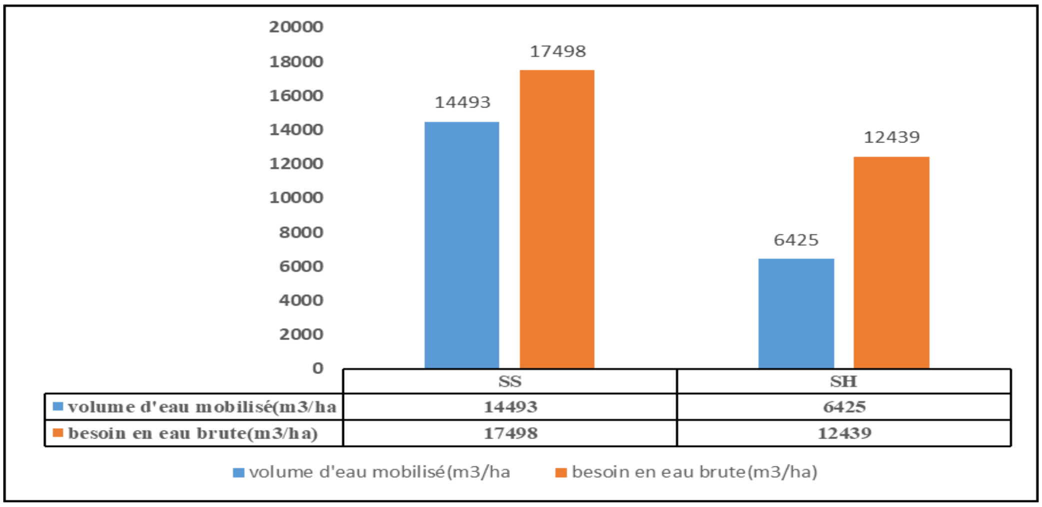

Figure 2 Rate of satisfaction of water needs on the Saga perimeter in the dry season and wintering season of 2020-2021

The average water coverage of the area is estimated at 82% for dry season rice cultivation and 51% for rainy season rice cultivation. Figure 2 shows that the amount of water supplied around Saga does not meet the water demand for rice grown during the season.

- Summary of performance indicators for the Saga irrigated area

The performance of the scope was analyzed based on the performance indicators (table 1) cited above.

Table 7 Summary data of Saga perimeter performance by season.

Parameter	**Performance indicator**	
Rate		
	Dry Season	Winter Season
Rate of agricultural intensification	73%	97%
Crop satisfaction rate	82%	51%
Agronomic efficiency of irrigation water	45Kg/m3	116Kg/m3

Table 7 shows low levels of fluctuations in agricultural reinforcement rates, with an estimated coverage of 73% during the dry season and coverage of irrigation water demand of 82%, directly to 97% during the campaign. Achievable with a coverage rate of irrigation water demand of 51% during the winter season. The agricultural efficiency (Ea) values of irrigation water for all crops are low. Indeed, in the dry season, rice/water production is 0.45 kg/m3 (compared to 1.16 kg/m3 in the rainy season). The Saga perimeter faces several problems related to water management, governance and finance.

3.2.2. Constraints linked to water management, governance and finance at the saga perimeter level

The Saga perimeter encounters several informal water users: The operators of informal plots, in particular market gardeners, take large quantities of water from irrigation canals without paying fees, which represents an anarchic use of water resources. Likewise, households, carters and shepherds use the canals for domestic needs or for watering livestock, but their withdrawals are less significant.

- Brick makers: Installed along the canals, these brick makers also draw water, although the quantities are not precisely measured.
- Governance problems : The perimeter cooperative, although it has an administrative structure, suffers from a lack of democratic dynamism. The current office has been in place for decades, limiting self-management capacity and transparency.
- Weak financial management : Collection of fees is incomplete, with some users escaping payment. Finances are poorly managed, with unbalanced spending, including compensation for elected officials that exceeds maintenance expenses. The diversion of water for informal activities such as gardening has also become common.

These problems reflect poor management, both in terms of the use of water resources and that of administration.

3.3. Proposed solutions for Sustainable Water Management in the Irrigated Perimeter

3.3.1. On the hydraulic level

- Modulation of water volumes : Set up a system for modulating the volumes of water provided to adjust supplies according to the actual needs of the crops and thus save water ;
- Formal distribution for market gardeners: Create a formal water distribution system for market gardeners in order to ensure effective collection of fees and avoid water shortages in irrigated plots;
- Training of GMP managers : Train managers of Development Groups (GMP) on the maintenance and management of the irrigation network, in order to improve the performance of the system and the sustainability of the infrastructure ;
- Compliance with irrigation standards : Ensure compliance with technical irrigation standards to optimize water use and guarantee good crop yield;
    - Strengthening resources at GMP3 : Increase the number of sprinklers within GMP3 to improve coverage and distribution of water in the plots served;
    - Sustainability of infrastructure : Establish a regular maintenance plan for hydraulic infrastructure in order to guarantee their long-term sustainability.

3.3.2. On the organizational level

- Distribution of tasks: Structuring a better distribution of tasks between the members of the cooperative for more efficient management and avoiding overloading certain actors;
- Respect for the cultural calendar: Strengthen adherence to the agricultural calendar to optimize the use of available resources and harmonize production cycles;
- Decentralization and strengthening of GMPs : Decentralize responsibilities and strengthen the capacities of GMPs to encourage greater involvement and accountability of producers ;
- Dialogue between the State and producers : Establish transparent and regular discussions between public authorities and producers to align the objectives and priorities of the Agricultural Hydraulic Agency (AHA).

3.3.3. On a social level

- Community mobilization : Encourage strong participation of farmers in community work in order to guarantee better social cohesion and proper functioning of the cooperative ;

- Raising awareness of water management : Promote equitable and rational management of water, while taking into account the social dynamics and behaviors of users ;
- Information dissemination channels : Create effective means of communication between the actors involved, in particular by facilitating access to information on water management and strategic decisions linked to the irrigated area.

4. Discussion

The results of this study show that the Saga perimeter suffers from several technical and organizational dysfunctions which compromise the efficiency of irrigation. On the one hand, the dilapidated state of irrigation and drainage infrastructure leads to significant water losses, limiting the quantity available for crops. Which confirms the study by N'Guessan et al. (2019) on irrigated systems, particularly on the performance of the Nanan irrigated rice perimeter in Ivory Coast, by demonstrating that dilapidated infrastructure and lack of maintenance are recurring problems in many irrigated areas, confirming our observations in Saga .However, in their study, the pumping systems were often broken down, whereas in the case of Saga, the pumps are modern and allow good extraction of water from the river but it is mainly the power cuts and the defective valves which disrupt water distribution Institutional management in Saga, marked by poorly defined responsibilities between ONAHA and the cooperative, recalls the conclusions of Tonneau et al. (2013), who showed that clarifying the roles of actors in irrigated areas is crucial to improving coordination but these roles are poorly played. However, while these authors recommend further decentralization and a transfer of management to cooperatives, our study suggests that the involvement of local actors is limited and that decentralization alone is not enough to resolve the problems if it is not accompanied strengthening management capacities. In addition, uncontrolled water withdrawals by informal actors, such as market gardeners and brick makers, increase pressure on water resources, further weakening the efficiency of irrigation. Regarding the seasonal variation in water needs, our results corroborate the work of Houndénou et al. (2016), who noted that water requirements for irrigation are higher in the dry season. However, unlike their study where irrigation systems partially met these needs, in Saga we found an even lower coverage rate, highlighting the urgency of improving the efficiency of the system. Still in relation to the efficiency and performance of Saga's perimeter, our results match those obtained by Nicolas (2016) in Morocco at the level of the perimeters of the Triffa plain. According to this author, these two parameters depend on the use effect, which depends on the farmer's management, is formulated as a function of this management.The results obtained by this author show that farmers are not 100% satisfied when gravity irrigation is practiced. Regarding satisfaction with irrigation water, our results corroborate the work of SIMON (2016) in Haiti. The author showed that for five (5) of the ten (10) plots studied, an average of 90% of the water that arrives is used to satisfy the needs of the crops and the needs of the five (5) other plots are covered. only 73% on average.

On the perimeter, the volume of water measured during the study period only meets 37% of the water needs of the crops grown. On the other hand, in relation to the performance indicator, the results obtained by Donkora (2019) in Burkina Faso are contrary to those we obtained on the irrigated area of Saga. The results of the evaluation of the technical performances of the irrigated areas of Savili and Mogtédo show that the efficiency of water application is less than 20% in Savili and between 41 and 55% in Mogtédo. Finally, in terms of solutions, Martin et al. (2007) showed that modernizing infrastructure and more inclusive governance are essential to ensure sustainable water management. We share this vision, but our study also emphasizes the regulation of uncontrolled withdrawals and the regular maintenance of infrastructure as specific priorities for the Saga perimeter.

5. Conclusion

This study provided a better understanding of the dynamics and challenges of water management in the rice growing area of Saga, Niger. It revealed that despite the institutional structures in place, such as ONAHA and the rice farmers' cooperative, water management remains largely ineffective, largely due to poor coordination between actors, unregulated informal practices, and the lack of active participation of farmers in decision-making processes. Unauthorized water withdrawals and inequitable distribution make it even more difficult to optimize the use of this crucial resource.The results of this study highlight the importance of reforming water governance by further involving local communities and strengthening the application of existing rules. Practical solutions were formulated to improve water management, including better cooperation between stakeholders and more inclusive decision-making. Furthermore, it would be beneficial to conduct future research on the introduction of technological solutions to improve irrigation efficiency.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed

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