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Use of Multi-Method Approach for a Gravity Irrigation Network Diagnosis: Case of Karfiguela Paddy Field in Burkina Faso

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Abstract

Burkina Faso is an agricultural and landlocked country whose agriculture is dependent on climatic hazards. Irrigated agriculture therefore appears as an alternative to secure, intensify and sustainably increase agricultural production. However, irrigation systems in Burkina Faso suffer from numerous technical, organizational, land and structural problems, which strongly undermine their performance. This is the case of the irrigated perimeter of Karfiguéla which since its development in 1977, has experienced insufficient water. This research has contributed to the reflection on the performance and operation of gravity irrigation networks on the irrigated perimeter in Burkina Faso and the contribution of satellite images in the mapping of irrigated perimeters. Then, an approach based on a mapping of hydraulic networks and on four main diagnostic methods were used: 1) mapping of hydraulic networks, 2) a detailed visual inspection of hydraulic infrastructure, 3) estimation of canals' hydraulic efficiency, 4) surveys of the various actors involved in the management of the perimeter. These methods lead to the same results concerning the state of degradation and the functioning of irrigation networks in wet seasons. In terms of results, Karfiguéla perimeter has a net area of 360 ha and is supplied by a network made up of a supply canal, a primary canal, four (4) secondary canals, 37 tertiary ones, and quaternary ones for plots of water supply, all in ordinary concrete except the quaternary which are in rammed soil. The efficiency of the canals in the rainy season, greater than 100%, shows that the irrigation network during this period functions as a drainage network while the real drainage network is disorderly and non-functional. The damage to the irrigation network, siltation, grassing, erosion, overturning, large cracks and many others are all the more severe as we advance toward the Quaternary. The Strickler roughness coefficient values of the order of 68 for the feeder, 47 for the primary, between 32 and 52 for the secondaries and 31 for the tertiaries also reflect a high degradation of the channels. Upkeep and maintenance are rare and generally poorly executed. Improving the performance of irrigation on the perimeter requires a complete rehabilitation of the hydraulic network, the reinforcement of the management and maintenance capacity of the operators' works and the search for a water resource complementary to the Comoé River to support irrigation, for example, the exploitation of the alluvial aquifer which unfolds under the perimeter and is easily accessible through rudimentary wells and sumps. All this is essential to ensure the sustainability of the rice-growing activity, which has a concentration of nearly 1200 farmers.

Keywords

Irrigated Perimeter, Hydraulic Network, Rice Cultivation, Water Management, Remote Sensing

1. Introduction

Agriculture is a major component of Burkina Faso's economy, a landlocked country in West Africa [1]. However, it's completely dependent on the weather hazards which greatly influence agricultural production [2] [3]. For this, irrigated agriculture has emerged as an adaptation solution to the effects of climate change, specifically by permitting compensating rain-fed production deficits and by promoting off-season production [4] [5] [6]. This mode of production is extremely important for national production to ensure food and nutritional security. For West African countries meeting the food needs necessarily requires an increase in irrigated areas [5] [7]. However, for several years, the situation in Burkina Faso in terms of sustainable management of water resources has been in deficit: 1750 m^3/year/inhabitants in 1998, then to 852 m^3/year/inhabitants in 2001 and finally 703.4 m^3/year/inhabitants in 2017; the shortage threshold being set at 1000 m^3/year/inhabitants [8] [9]. Water consumer demand, mainly distributed over three (3) sectors which are irrigation (51% in 2005), domestic water and livestock (46%), is only increasing. Irrigation already represents more than half of the country's water demand, mainly satisfied by surface water which is threatened by drying up [9]. In the context of the scarcity of water resources, irrigated systems are called upon to reduce their water consumption while producing more; in other words, it's important to improve irrigation performance [3] [5]. Thus, water efficiency and productivity are topical issues about the performance of irrigation systems and specifically gravity systems [8] [9]. The poor agronomic and economic performances of irrigated perimeters in Burkina Faso have been highlighted by several studies and associated with factors such as the inadequacy of speculations, non-compliance with itineraries and good irrigation practices and techniques, and many other reasons [3] [6] [10]. However, there remains a factor that is rarely discussed, but it is as important: aspects related to efficiency and water management in the irrigation network and at the plot [3] [11] [12]. Yet the irrigation systems in Burkina Faso, for the most part gravity, are plagued by enormous problems both structural and functional which lead to enormous water losses during transport in the irrigation network and the water application in the plots [3] [13]. This model of system, when degraded, becomes an obvious handicap for agricultural production [5] [13]. This is the case of the Karfiguéla's irrigated perimeter, which since its construction suffers from insufficient water resources [12]. Certainly, a few diagnostic studies of performance have been carried out [12] [14]. But for the most part, the diagnosis hasn't been approached systemically and the solutions proposed are generally unsustainable or insufficient. It's in this context that the present study is conducted to assess the impact of the current network on the supply and management of the irrigated perimeter by adopting cartographic, physical, hydraulic and participatory methods.

2. Study Area

The study area (**Figure 1**) is in the southwest of Burkina Faso, in the "Cascades" region and more precisely in the province of Comoé. It extends between the longitudes 4˚49' and 4˚48' West and the latitudes 10˚38' and 10˚41' North in the alluvial plain of Karfiguéla. The "Cascade" region is one of the best watered places in the country with annual rainfall between 1000 and 1200 mm. It also presents one of the most rugged reliefs, which stands the highest peak in the country, Mount Ténakourou rising to 747 m [15]. It's crisscrossed by lakes, perennial ponds, waterfalls and many rivers including the Comoé and the Léraba [16].

The perimeter is also built a few meters from the minor bed of a transborder river in Burkina Faso and Ivory Coast called Comoé and has a gravity network, supplied by a water intake on this river. Out of 750 ha of planned development, only 350 has been developed from 1973 to 1977 for rainfed rice cultivation only, due to 1) rationing of the water supply in the perimeter dictated by the new sugar company of Comoé (SN SOSUCO), main users and guardian of the resource, and to 2) the lack of a master plan for the development of Karfiguéla perimeter. Its operation in the dry season was introduced in 1992 with the construction of the Moussodougou dam [14].

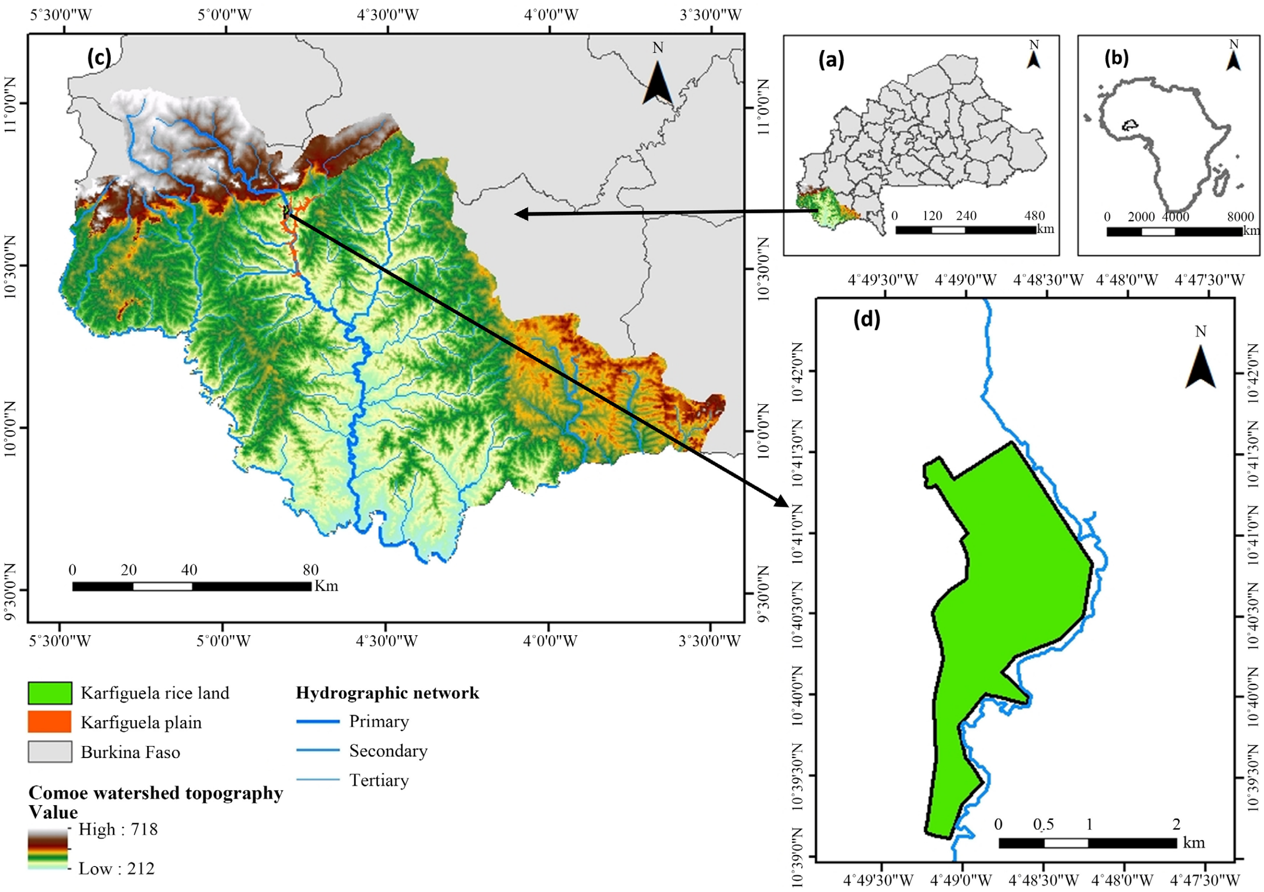

Figure 1. Location of the study area: (a) in Burkina Faso (b) country of the African continent, (c) the Comoé watershed and location of the irrigated area of Karfiguéla in the Comoé watershed (d) Global view of the irrigated perimeter and its hydraulic network.

3. Methodology

The diagnosis of the network was both quantitative and qualitative. The methodology adopted is based on a participatory multi-method approach in four (4) steps: 1) mapping of the hydraulic network 2) a detailed visual inspection of the hydraulic infrastructure 3) estimation of the canals' hydraulic efficiency 4) surveys of the various actors involved in the management of the perimeter. Before carrying out any diagnosis, it's important to have a recent and reliable map of the network which will serve as a basis not only for the diagnostic work, but also for the planning of interventions on the network.

3.1. Hydraulic Network Mapping

The network mapping was carried out base on high resolution Google Earth images ranging from 30 m to 60 cm depending on the satellites and sensors used (SPOT, Quickbird, Ikonos, etc.) [17]. The use of those images is generally done online on the platform Google Earth. The import of the images on another GIS software is only possible by screenshots [17]. The images used for this study are provided by CNES SPOT satellites dating from November 2019. As presented in Figure 2, the mapping method used has six (6) steps [17] [18]:

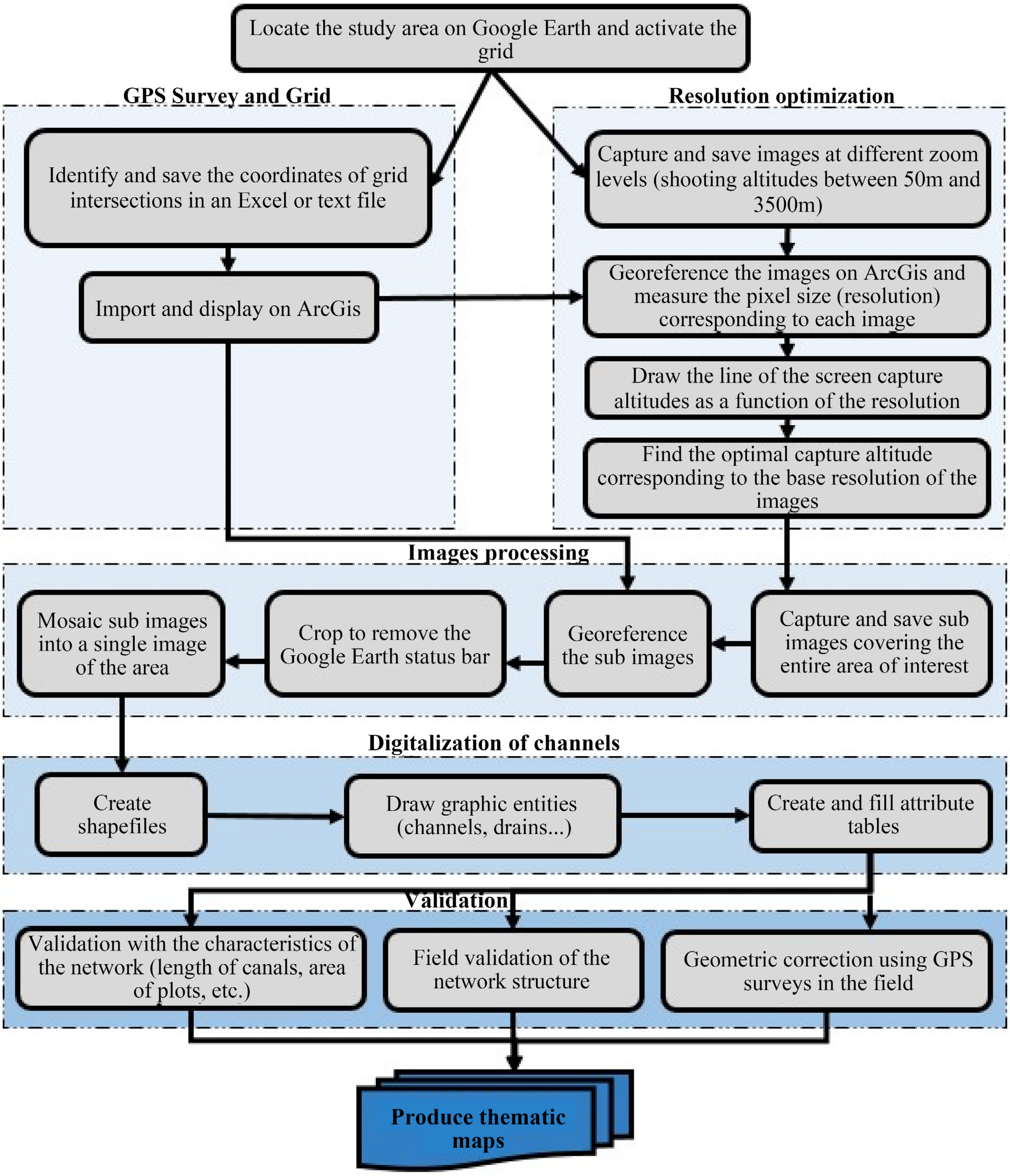

Figure 2. Flowchart of the mapping methodology.

1) The first step consists in making a grid of the area to record and materialize the geographical coordinates of the benchmarks on ArcGis.

2) The second step concerns the optimization of capture resolution by determining a linear function between the zoom and the resolution of the images.

3) The third is devoted to the collection and processing of images on ArcGis

to get at the end a single georeferenced image covering the entire study area.

4) In the fourth step, it involves visually digitizing the various infrastructure (canals, plots, drains, structures, etc.) visible on the images and providing information on their typology and characteristics.

5) The fifth step is a field validation of the cartography carried out at three levels: first, the coordinates of some landmarks (contours of the perimeter, position of certain valves, large trees) were taken by Garmin GPS and imported on ArcGis for a geometric validation/correction, then the location and the arrangement of the canals and the different infrastructure were checked visually in the field and finally the dimension values of the canals and plots were compared with the data collected from the Provincial Directorate of Agriculture and Hydro-Agricultural Development (DPAAH).

6) The last step consists of the production of thematic maps.

3.2. Hydraulic Detailed Visual Inspection of the Hydraulics Infrastructures

Visual diagnosis is the most used method in diagnostic operations for irrigated areas in Burkina Faso [12] [13]. It's a field phase that has for principle to analyze in detail each element of irrigated perimeter infrastructure and its use by the users [3] [13] [19].

Thus, elements such as the physical boundaries of the perimeter, the irrigation channels (feeder, primary, secondary, tertiary and quaternary), the drainage network, flow regulation infrastructure, plots and engineering infrastructure (bridges, slabs, roads…) have been visited in detail. Inspection made it possible to identify and inventory, using field files, the various malfunctions and degradations on each infrastructure inspected as well as their gravity. The visual diagnosis also has the advantage of constituting a validation's step of the mapping based on satellite images and of understanding the difficulties encountered during the mapping (grassing, filling or interruption of canals, absence of canals, and the extension of irrigated areas, etc.).

3.3. Hydraulic Efficiency of Channels

3.3.1. Flow Estimation

Network efficiency is its capacity to transport a defined quantity of water from point A to B. Flow measurements is therefore necessary to determine this efficiency. In the literature, several methods have been developed to estimate the flow rates of free surface water [20]. From methods by velocity field exploration to the approach by the general equations of hydraulics, through volumetric (gravimetric) methods, tracer dilution, gauging channels and calibrated weirs, the choice of approach to use is an important exercise [20] [21]. Many factors can guide the choice of appropriate method: flow rates, channel size, type of flow, flow velocity, required accuracy, safety considerations… [20] [21]. For this study, the current meter gauging and the float gauging methods with two types of floats (weighted bottles and stick) thrown on the two banks and the middle of the channel was used. Indeed, these methods, which are simpler in their implementation, are adapted to this study and have already been used for flow measurements on several irrigated perimeters in Burkina Faso (perimeter of the Kou Valley, Bagré, Mogtedo, etc.) [13] [22]. To study the functioning of the irrigation network in a wet campaign, the flow rates were measured twice during the wet campaign of the year 2020: at the beginning (July) and the middle of the campaign (August). A dozen measurement sections were retained in total on the channels. 1) For the feeder, a section at the start and the end were retained. 2) For the primary channel, the measurements concerned the start of the primary channel and that of the secondary channels. 3) For the secondary channels, the measurements concerned only the S2 at its entrance and at the level of the tertiary outlets. In this study, the section is defined as any portion of the network where there is no water intake, no service on the way and no water supply. According to the continuity equation, the sum of the incoming flows must be equal to the sum of the outgoing flows plus or minus the losses [23].

Thus, for a section:

$$\text{Inflow} = \text{outflow} + \sum \text{losses} \tag{1}$$

$$\text{eff}\left[\%\right] = \frac{\text{outflow}}{\text{Inflow}} \times 100 = \frac{\text{Qdownstream}}{\text{Qupstream}} \tag{2}$$

3.3.2. Channels Roughness

This method, based on general hydraulic equations, has permitted us to compare the current roughness of the channels with that of new channels and assess the current quality of the channel. In this study, the Manning and Strickler equation was used to determine the channel roughness parameter, using the measured flow rates as input data. For greater reliability, on the same reach, the calculation was made on the basis of two flow measurements.

$$U = K_S R_H^{2/3} \sqrt{I} \Rightarrow K_S = \frac{Q}{R_H^{2/3} S \sqrt{I}} \tag{3}$$

$$R_H = \frac{S \text{ wetted}}{P \text{ wetted}} \tag{4}$$

I: slope of the canal;
S: wetted section [m^2];
P: wet perimeter [m];
R_H: hydraulic radius [m];
Q: flow rate [m^3/s];
K_s: Manning's roughness coefficient [m$^{1/3}$/s].

3.3.3. Survey of Stakeholders Involved

From the first phases of this study, the various actors involved in irrigated perimeter management were consulted in the development of methodological protocols and their applications. In this dynamic, surveys were carried out to collect quantitative and qualitative data on the operation and management of water and structures in the perimeter. The investigation mainly targeted four entities, including institutional managers through the Provincial Directorate of Agriculture and Hydro-agricultural Development (DPAAH) and the Cascades Water Agency (AEC), local cooperatives and operators. Thus, three types of surveys were administered according to the target group in French and in the local language (Dioula) according to the preferences of the interviewee: 1) semi-structured interviews with the chief of the perimeter and the operation's technicians, 2) structured interviews with each of the farmers' cooperatives at a meeting organized for this purpose and 3) questionnaires with eighteen (18) farmers of all sex, age and position on the perimeter. The questions addressed revolve about several points, namely the administrative and institutional situation of the perimeter, the historical and physical description of the irrigation system, the dynamics of villages in irrigation, the functioning of cooperatives, the water and infrastructure management mode, and the difficulties encountered by management, technicians, cooperatives and operators in the efficient operation of the perimeter.

4. Results and Discussion

4.1. Structure of the Hydraulic Network

4.1.1. Irrigation Network Mapping

Validated mapping (**Figure 3**) determined that the irrigation canals have varying lengths (**Table 1**) depending on the geometry of the area they serve. The irrigated perimeter of Karfiguéla has a gross area of 400.4 ha and a net area of 360 ha. It's served by a gravity network supplied by a feeder located on the Comoé River far of 2.230 km from the perimeter.

Table 1. Nature and length of the different irrigation canals in the perimeter.

Channels	Type of coating	Symbols	Number	Length [m]
Feed	Ordinary concrete	CA	1	2451
Primary	Ordinary concrete	CP	1	1654
Secondary 1	Ordinary concrete	S1	1	792
Secondary 2	Ordinary concrete	S2	1	797
Secondary 3	Ordinary concrete	S3	1	1568
Secondary 4	Ordinary concrete	S4	1	3883
S1 tertiary	Ordinary concrete	T1-i	5	320 - 612
S2 tertiary	Ordinary concrete	T2-i	4	612
S3 tertiary	Ordinary concrete	T3-i	10	110 - 410
S4 tertiary	Ordinary concrete	T4-i	18	190 - 585
Quaternaries	Clay	Q	-	87 - 332

The hydraulic district, called "block" on the perimeter, generally has an area of 15 ha which may vary depending on the configuration of the network (Table 1). The block has 30 plots of 0.5 ha. Each farmer generally divides his plot into ten boxes of 25 m by 20 m each. The hydraulic districts are grouped into four large blocks representing the areas dominated by the secondary canals as presented in Figure 3.

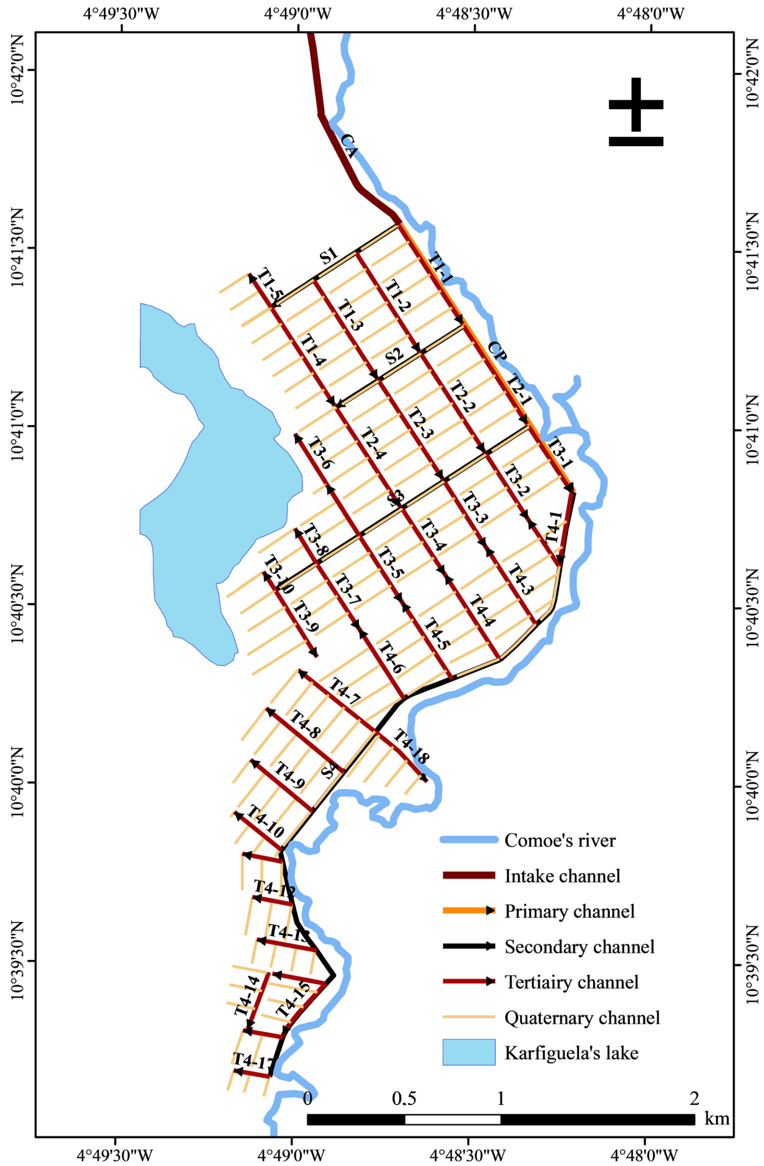

Figure 3. Architecture of the irrigation network of the Karfiguéla perimeter.

Karfiguéla irrigation network is made of the feeder, primary, secondary and tertiary channels of trapezoidal shape with an ordinary concrete coating and by quaternaries in clay. The supply channel has two stairs and a reading scale for the water level. The primary channel has four valves and stairs installed at the entrance of each secondary and three coupled control valves to lateral weirs, installed after the intakes of the secondary channels S1, S2 and S3. The secondary channels are each supplied by an intake valve located on the right bank of the main channel. Right at their intersections with the tertiary sectors they supply, tertiary intake valves and flow control valves are installed. The tertiary sectors are equipped with quaternary intake and flow regulation valves. The quaternaries directly supply the plots and are scoured and traced in an archaic way in each campaign by the farmers who depend on them. Their shape and number are undetermined.

4.1.2. Drainage Network Mapping

The perimeter sanitation network consists of two main drains and an outfall, all of clay and which drain the excess water from the irrigation canals and the various blocks of plots through secondary drains towards Karfiguéla Lake (**Figure 4**).

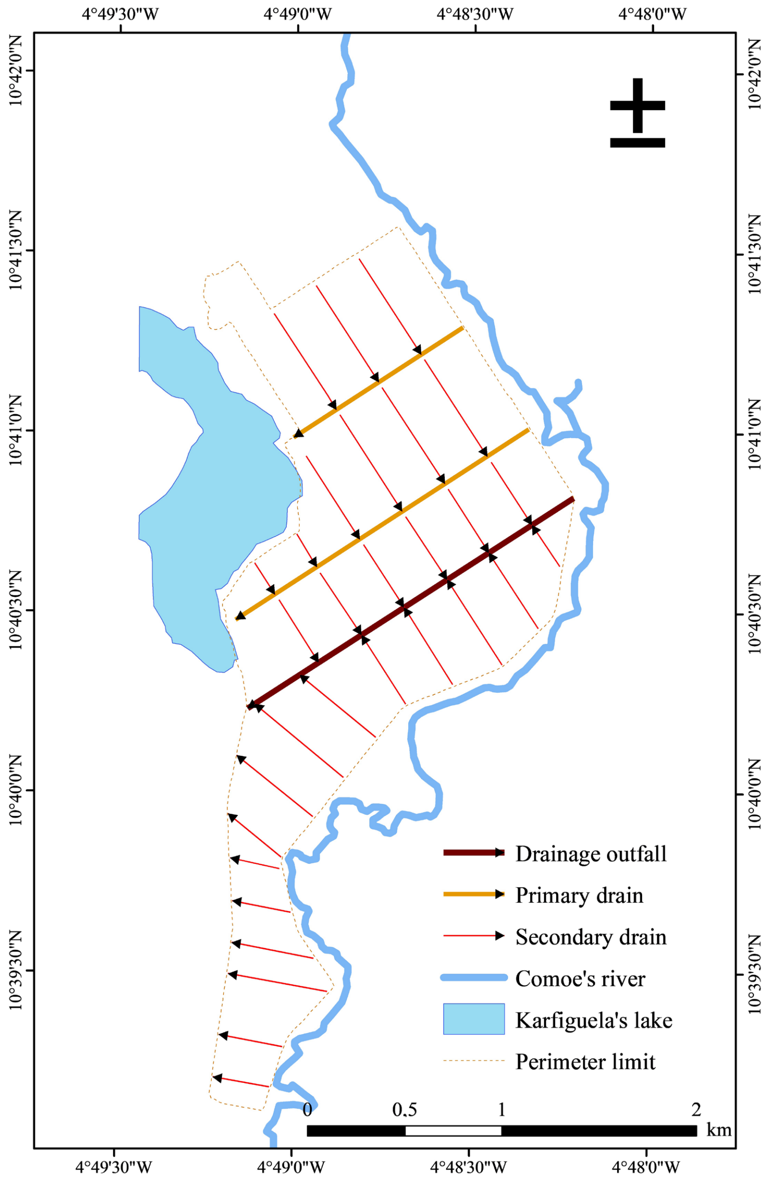

Figure 4. Mapping of the drainage network.

The first primary drain collects water from tertiary T1-i and from the blocks irrigated by these tertials. The second main drain drains the water from T2-i and the plots are located to its right through secondary drains. The outfall collects drainage water from the tertiary sectors and blocks served by the secondary canal S3 and the upper part of the secondary S4. As presented in **Figure 4**, the drainage of the lower part of the perimeter isn't really assured. The secondary drains aren't connected to any collector, thus making drainage non-existent.

Also, during the mapping, interruptions on several secondary drains were noticed. The results of the visual inspection, presented below, explain these remarks and validate the map.

4.2. Current Physical Condition of the Irrigation Network

4.2.1. Hydraulic Infrastructures Functionality

Infrastructure is said to be functional when it achieves the objective for which it was installed [24]. It's therefore qualified as non-functional when it's no longer suitable or used for its primary function. However, the functionality doesn't attest to the quality of the work because it can be functional, but qualified as poor when it doesn't fully play its role [24]. Inventory results in **Table 2** show a rate of functionality of the infrastructure of 79%. The main malfunctions encountered are the breaks or landslides of the stairs and weirs (ii) the valve mechanism problems or the total lack of valves at the level of the tertiary and quaternary canals and the total lack of scuppers on the entire perimeter.

Table 2. Inventory and functionality of hydraulic infrastructure on the perimeter of Karfiguéla.

Channels	Type of work	Total visited	Functional	Non-functional	Functionality rate
Feeder	Intake valves	2	2	0	100%
	Stairs	2	1	1	50%
	Bridge	1	1	0	100%
Primary	Valves	4	4	0	100%
	Bridges	3	3	0	100%
	Lateral weirs	4	4	0	100%
	Stairs	3	3	0	100%
Secondary	Valves	50	37	13	74%
	Road bridges	50	50	0	100%
	Lateral weirs	50	39	11	78%
Tertiary	Intake valves	37	18	19	49%
	Regulating valves	-	0	-	0%
Total			162	44	79%

4.2.2. Physical State of Irrigation Network

In general, the feeder and the primary channel suffer from some minor slight pathologies ranging from grass cover to cracks in the panels, including silting up. As for the secondary and tertiary canals, the damage is greater (**Figure 4**). The eight (8) main impairments observed on the different channels can be summarized as follows (**Figure 5**): 1) transverse, vertical, oblique or any other cracking of the majority of the panels; 2) complete degradation of the panels joints on all the channels and grassing of these joints; 3) settlements and overturning of certain canals; 4) advanced erosion of the canals lining, especially in the tertiary canals; 5) erosion of the backfill of canals and weirs (intake infrastructure) certainly due to overflows caused by improper handling of valves; 6) presence of shrubs and large trees in close proximity of the canals leading to serious cracks and even overturning of the concrete modules over a length of several meters for the secondary and tertiary canals; 7) significant siltation and grassing of the various canals and 8) intentional filling of the last sections of certain tertiary canals with a view to redirecting all the water towards the plots upstream. The state of deterioration of the channels can be explained by the old age of the network, built more than 45 years ago.

Figure 5. Some of the most recurring degradations on the irrigation network of the perimeter.

4.2.3. Physical State of the Drainage Network

The drainage network is traced in each campaign by the producers, but in an anarchic and disordered. Several malfunctions hamper its proper functioning (Figure 6). These are: 1) the interruption of the drainage network in certain places, by some producers who by this sabotage hope to gain a few additional square meters of irrigable area; 2) voluntary widening of drains in order to engage in fishing activities; 3) rejecting the rice straw directly inside the drains after threshing; 4) the diversion of drainage water for the irrigation of plots outside the consensus irrigation schedules.

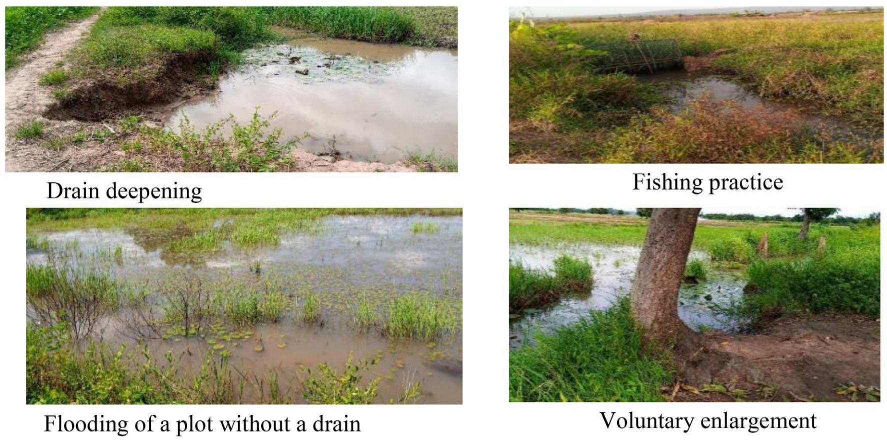

Figure 6. Some malfunctions of the perimeter drainage network.

4.3. Irrigation Network Efficiency

4.3.1. Water flow Transport Efficiency

Current meter and float gauging were carried out in the feeder, in various sections of the primary canal and secondary canals (Table 3) during the July and August months (peak rainfall) of the 2020 year. Between July and August in the feeder, there is very little variation in water flow. In other words, the water quantities entering the network are practically constant. In addition, these values of water flow in the feeder are consistent with the flow measurements carried out on the feeder during 2018 dry season [22]. In which the efficiency of the network was estimated at 52%. On the other hand, the water flow values in the primary, secondary and tertiary networks vary enormously depending on the period. Indeed, this is explained by the variation in the crop's water requirement in the rainy season, due to rainfall variability. The distribution of flows in the network depends on rainfall episodes and the crops vegetative stage. The specific case of the large variation in the flow of the secondary channel S4, whose flow goes from 0.053 m^3/s in July to 0.24 m^3/s, is explained in particular by the downstream position of this channel in the network. Indeed, S4 being a continuity of the primary channel (Figure 3); it therefore constitutes a drainage channel for unused flow of the primary channel. During August month, the month of high rainfall, the irrigation water needs are very low or even non-existent, S4 drains almost all water entering the network.

For the 2020 wet season, at first glance, the efficiency during the month of July in the feeder and primary channel seem quite good for an old gravity network. The efficiency during August months (all greater than 100%) suggests the water unforeseen inflows into the canals from 1) surface water runoff in the secondary and tertiary coming from unplanned plots, and the strong degradation of canals, 2) the drainage of plots which are flooded or caused by the presence of large cracks in the canals serving as drainage corridors during irrigation, 3) the drainage of surface water. The general observation is that during the wet season, the role of irrigation network is reversed; it receives more water into the different channels than it supplies. Instead of participating in the water distribution, it turns into a drainage network. This situation was also noted during surveys with operators and the visual inspection.

Table 3. Value of flow rates and efficiency of canals in wet season.

Channels	July 2020		August 2020	
	Float gauging		Current meter gauging	
	Q upstream [m^3/s]	Efficiency [%]	Q upstream [m^3/s]	Efficiency [%]
Feeder	0.231	88%	0.26	123%
Primary	0.121	89%	0.25	167%
S1	0.083	124%	0.07	136%
S2	0.033		0.05	
S3	0.01		0	
S4	0.053		0.24	

4.3.2. Channel Roughness

The aim of estimating the roughness coefficients is to assess, with relative magnitudes, the level the channel degradations. The values K_{s1} and K_{s2} (**Table 4**) represent the Strickler roughness coefficients, calculated using two flow measurements in July and August 2020. An average K_s is calculated when the variation between K_{s1} and K_{s2} is acceptable and if not, the measurements are repeated. Thus, the variation values between the K_{s1} calculated with the July 2020 flow measurements and K_{s2} taken from the August 2020 measurements also permitted us to validate the values of the measured flows. In this study, the maximum variation in roughness is 8 $m^{1/3}/s$, the flow values are therefore good. With regard to the roughness values, the general observation is that the roughness of channels increases in the network and that all the values of Strickler coefficients of channels are lower than that of the estimated new concrete at about 70 $m^{1/3}/s$ [25] except the feeder which has a K_s of 68 $m^{1/3}/s$. This situation is explained, on the one hand, by the increase in the solid load and water pollution (organic and chemical) as one as moves forward in the network and, on the other hand, by human intervention level in the network which creates mechanical and chemical erosion of channels which are closest to the plots. Indeed, the operators use clay mixed with herbs to plug leaks in the valves and to replace the non-existent valves at the tertiary level. Thus, the channel roughness results illustrate very well the level of degradation of channels on the perimeter. They're consistent with the results obtained during the visual diagnosis.

Table 4. Values of the current roughness coefficients of the canals of the irrigated perimeter of Karfiguéla.

Channels	K_{s1} [$m^{1/3}/s$]	K_{s2} [$m^{1/3}/s$]	Average K_s [$m^{1/3}/s$]
Feeder	64	72	68
Primary	44	49	47
S1	36	35	35
S2	31	32	32
S3	43	43	43
S4	51	52	52
Tertiary	32	31	31

4.4. Organizational Dynamics on the Perimeter

4.4.1. Grouping Methods

The perimeter is used by about 1200 producers coming from eight (8) villages: Karfiguéla, Banfora, Tingréla, Lémouroudougou, Kiribina, Sibiéna, Tiékouna and Nafona [14]. They're grouped into five (5) cooperatives each managing one block with the exception of cooperatives n˚4 and 5 which share only block IV (**Figure 7**).

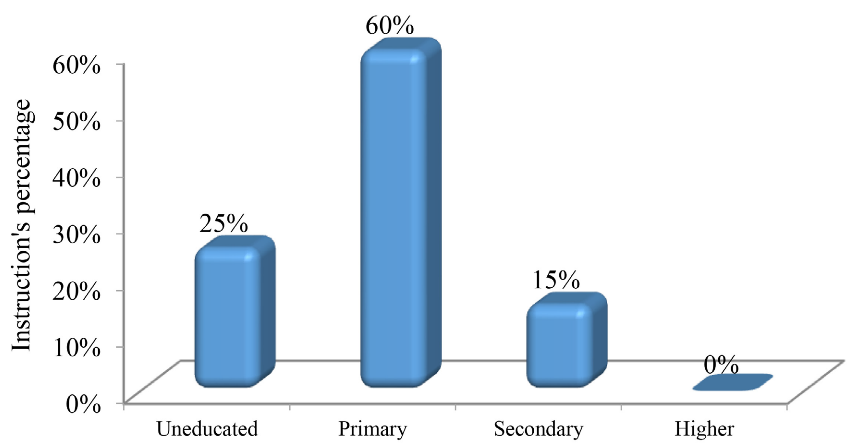

Figure 7. Educational level of the cooperative office.

Each cooperative is managed by an office made of a president, a treasurer, a secretary all unpaid except for the water worker who has a monthly salary between 15.19 Euros and 22.78 Euros. The cooperatives are grouped into a union called the Union of Karfiguéla's Perimeter Operators (UCEPAK). It benefits from the regular support of technicians from the DPAAH for better management of water, fertilizers, infrastructure and marketing. In theory, UCEPAK has internal regulations and includes three bodies: the general assembly, the management board and the control committee. Unfortunately, despite the relatively high level of education of cooperative members, namely 75% of which 60% are at the primary level and 15% at the secondary level and 25% are uneducated members (Figure 8), it's clear that the organization of cooperatives and the union leaves something to be desired.

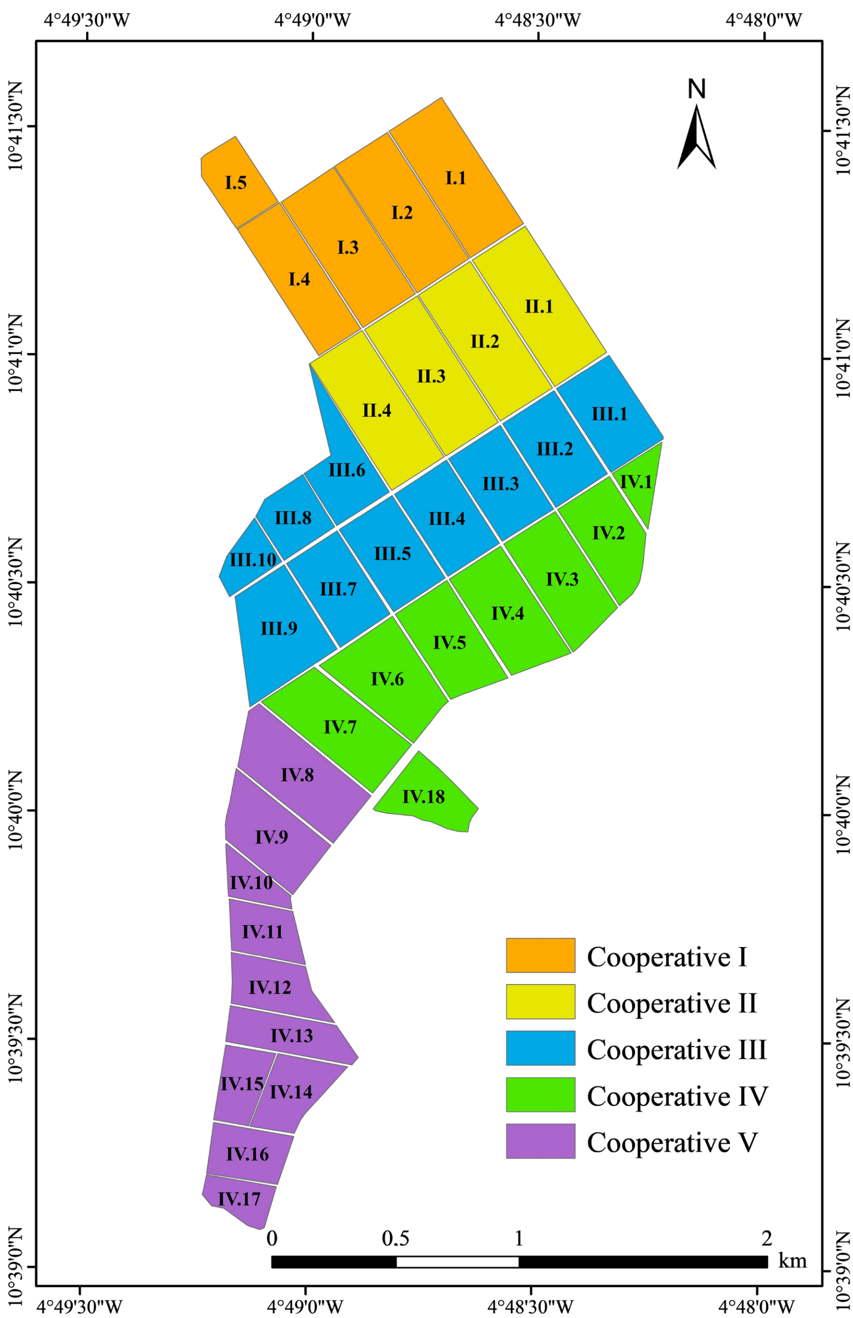

Figure 8. Division of the administrative management of the perimeter into cooperatives.

While the internal regulations are almost non-existent, for some social considerations, no punitive measure is taken in the event of non-compliance with the rules. No clear and formal task or responsibility is assigned to each member of the union and cooperatives, thus leading to poor management and organization of cropping campaigns. Also, it should be noted that the ignorance of principles and regulations of cooperatives and the UCEPAK by the farmers create a climate of mistrust, individualism and even conflicts within the perimeter. The most explicit situation encountered during field trips is non-compliance with the crop calendar proposed by the DPAAH, leading to crops cycle differences of up to 2 months.

4.4.2. Exploited Areas

In the dry campaign, the irrigated perimeter of Karfiguéla is divided into two parts: the first part is made up of blocks I, II and III and the second is made up of blocks IV and V [4]. Water problems are such that a system of alternating seeding of each part of the perimeter has been adopted. Thus, only one part of the perimeter is exploited in dry campaign. Even under these conditions, the water deficit is still present on the perimeter and also persists in wet seasons.

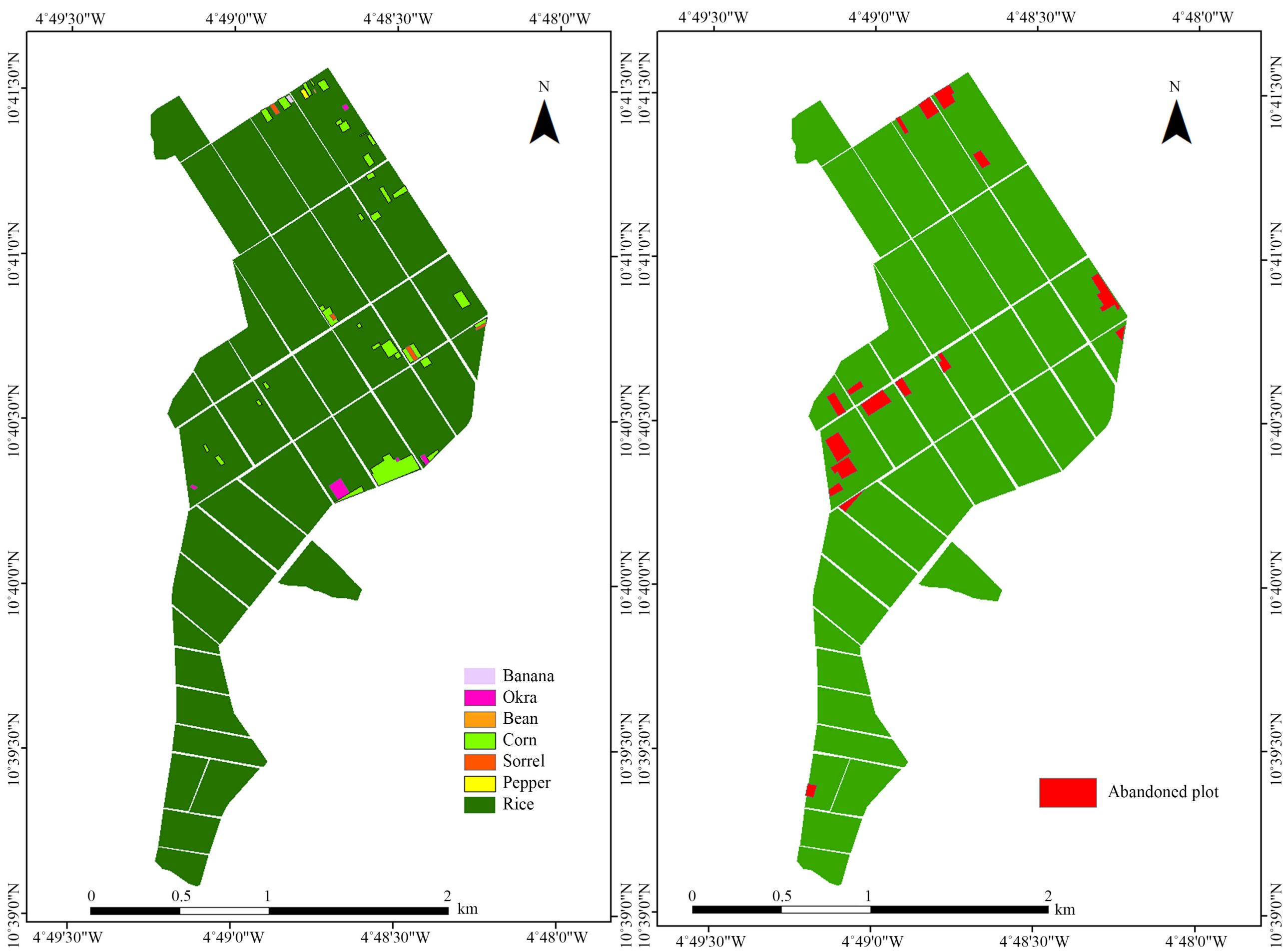

Figure 9. Land use maps in the humid campaign (a) middle of the campaign (28/08/2020) (b) End of the campaign (18/11/2020).

In theory, the entire perimeter is seeded during the wet campaign. However, for several years, some plots have received other crops than rice, which is the main vocation of the perimeter, or have been abandoned for hydraulic, topographical or pedological reasons. Already in 2002, there was a land loss rate of 8.2% and 7.3% in 2003. In 2018, the abandoned area was about 25 ha [14]. In the middle of a wet season in the year 2020 (**Figure 9**) speculations other than rice were recorded over an area of 10.8 ha, the rest of the plots seeded with rice. These speculations were put in place from the first rains and mainly concern corn, okra, beans, sorrel, chili and bananas. At the end of the wet season, before the harvest period, the abandoned area was about 10.6 h (**Figure 9**). For the majority of abandoned plots, it was noticed that crops from nearby plots have wilted stems and empty panicles thereby indicating a water problem in this area.

4.4.3. Water Management and Maintenance of Hydraulic Infrastructure

On Karfiguéla irrigated perimeter, collective activities are programmed in advance on cropping calendars by a collaboration between farmers, technicians who support them and the DPAAH. Unfortunately, the schedule is rarely respected especially during the wet season because of rainfall delays. In 2020, for example (**Table 5**), cycle deviations of up to two (2) months were noted on the perimeter, complicating the management of water, fertilizer inputs and crop diseases on the perimeter.

Table 5. Calendar of cultural activities for the year 2020.

Activities	Execution period	Execution period
	2019/2020 dry campaign	2019/2020 dry campaign
Main channel cleaning	18-23/12/2019	13-16/06/2020
Secondary channel cleaning	24-30/12/2019	17-20/06/2020
Pre-germination	02-05/01/2020	21-23/06/2020
Establishment of nurseries	06-10/01/2020	24-26/06/2020
Mud	01/07/2020—02/12/2020	06/25/2020—07/31/2020
Transplanting	01/15/2020—05/02/2020	09-21/07/2020
Water stops	05/10/2020	10/15/2020
Harvest	15-31/05/2020	20/10/2020

✓ **Management of water turns and cultural calendar**

The distribution of water in the plots during dry campaign is done by water turns on the secondary canals. As for the application of water to the plot, it's mainly done by submersion basins for rice, and by short lines for vegetables. The water release program on the perimeter during dry campaign provides a water volume per cycle of 8000 m^3/ha for the part of the perimeter that will be developed and considering the efficiency of 0.6 for the irrigation system. However, the problems linked to climatic hazards (increased evapotranspiration), topography, degradation of canals and possibly the diversity of speculations make this resource insufficient and don't always facilitate the strict application of water turns.

In the wet campaign, the water in the irrigation network comes exclusively from the natural flow of the Comoé River. There is no water release operated by SN-SOSUCO, the main controller of valve openings at the dam. There is no precise watering schedule in the wet season, because the irrigation water supply depends on the quantities of rain that has fallen. This situation causes the same inconvenience as in the dry campaign, especially during periods of delayed rainfall or pockets of drought. To these problems are added anarchist and disorderly manipulations of flow control valves by farmers which lead to water deficits on certain plots and floods on others, consequently generating latent and real conflicts between farmers.

✓ **Upkeep and Maintenance of Infrastructures**

The maintenance and upkeep of hydraulic infrastructure remain a central component in the management of irrigated areas [13]. These operations allow better management of water distribution while strengthening the sustainability and efficiency of the infrastructure. On the perimeter, channel maintenance operations generally consist of weeding and cleaning (**Figure 10(d)**). For a synergy

(a) (b) (c) (d)

Figure 10. upkeep and maintenance operations of the canals: (a) rehabilitation of S3 by cooperative III; (b) rehabilitation of a tertiary canal by an operator; (c) rehabilitated tertiary channel which has failed; (d) tertiary canal weeded and cured.

and staggering of maintenance tasks, the roles are distributed as follows: the feeder and the primary channel are maintained by all the cooperatives, the portion of the canal which directly feeds its block and the secondary canals are maintained by each cooperative, the tertiary canals are maintained by the irrigators concerned and finally, the quaternary canals are traced at each campaign. The weeding and cleaning works are carried out with archaic materials such as hoes and manual shovels.

Rehabilitation such as the rebuilding of degraded, cracked or overturned canals (a) and b), are often carried out by farmers on the irrigation canals. These maintenance or rehabilitation works are made possible through water charges (10 Euros/ha) paid at the end of each season by the operators. The rehabilitation is controlled by the office of the cooperative concerned with the repairs. Unfortunately, it's clear that this work is often botched and the rehabilitated infrastructure fails quite frequently (**Figure 10(c)**). As for the drainage network, it is not frequently rehabilitated and the malfunctions only accumulate.

5. General Discussion and Recommendations

As all large developed and irrigated perimeters with partial or total water control (Banzon, Bagré, Vallée du Kou, etc.), Karfiguéla paddy rice perimeter should help boost national rice production in terms of quantity and quality in order to meet consumer needs and requirements. Indeed, rice has become for several years in Burkina Faso, a staple food in cities where three-quarters of the supply is ensured by imports [26]. A current national production which barely covers 47% of the current population needs to oblige the government to a tripling (1998 to 2006) and quadrupling (2006 to 2019) of rice imports from 137,185 tons in 1998 (39.44 million euros) to 305,180 tons in 2006 (57.35 million euros) against 510.9 tons in 2019 (105.08 million euros) [26] [27] [28]. The main constraint to development of irrigation is the availability of water which is a direct cause of the low percentage of development of irrigable areas, namely 33% of effective development on the potential of 233,500 ha with a percentage of 26% of not exploited areas from these developed perimeters [3]. The reasons for this non-exploitation are associated with water scarcity and faulty irrigation systems. Karfiguéla perimeter is a typical example of paddy fields reality in Burkina Faso. With an irrigated land potential of 750 ha, only 370 ha have been currently schemed, due to the availability and distribution of the Comoé River water use. Even more, nowadays, only a small part of perimeter is developed during each dry season because of the insufficiency of the resource, and even in the event of pockets of drought, productivity remains mediocre. These problems are linked to the insufficiency of water resources and to major dysfunctions hampering, on the one hand, the local increase in the production of rice and, on the other hand, the effective and substantial improvement of farmers' incomes. However, in 2019, a case of over-irrigation of rice was observed on Karfiguéla perimeter in dry season: 15,404 m^3/ha per cycle against a maximum of 9500 m^3/ha recommended by the FAO [29]. He also denounces a low efficiency of the water use with a value of 0.26 kg/m^3 against a minimum recommended by the FAO of 0.51 kg/m^3. This situation seems contradictory to the water deficit situation observed on the perimeter during this study and reported by previous inventory studies [3] [14] [18] [30] [31].

The different methodological approaches used in this study prove to be complementary in the process to explain the situation of water management on the perimeter with a view to purpose solutions and appropriate action plans for improving water productivity of the perimeter. The mapping results constitute a basis for the management and intervention planning of the perimeter, highlight dysfunctions in the water drainage of the perimeter. The advanced degradation of the irrigation network highlighted not only by flow measurements but also by roughness values lower than the roughness of concrete and approaching that of clay are so many indicators that show the inaptitude network for the effective and efficient distribution of water. Thus, the insufficiency of water on the perimeter isn't justified only by the distribution of the resource from Comoé River but also by a waste of water obvious which finds its explanation in the defective state of the irrigation network, but also in the water management [32]. This causes an uneven distribution of water on the perimeter. Indeed, this study reveals problems of efficient and equitable management of water allocation between irrigators of the same block, sub-block or agricultural plot: the quantities of water allocated can't be known because of the state of network failure, leading to uncontrolled distribution through fractures and cracks in the channels. While some plots further downstream dry out from lack of water, others die from excess water due to an uncontrollable supply of water and an inefficient drainage system. Thus, beyond the rehabilitation of the perimeter, an establishment of sophisticated and adequate water information and management systems is necessary for better management of the resource, which remains very precious. Studies in this direction have already been carried out within the framework of research projects on the efficient management of water in the perimeter of the Kou, Bagré basins, etc. Thus, many authors' perimeters [29] [33] [34] [35] show that easy-to-use, routine and financially accessible management tools could be applied and used by agricultural administrations in irrigated. Agricultural water management using free remote sensing, decision support tools such as CropWat, Google Earth Engine, and communication platforms such as WhatsApp have been proposed. The mapping results presented in this study are therefore presented as a primary step that could follow the development of a consolidated and complete database for water management, inputs, upkeep operations in order to create tools and frameworks for monitoring and water and productivity management in general for Karfiguéla perimeter and his hydraulic infrastructure. Also, it would be necessary to integrate flow determination devices such as water-level gauges and to carry out effective training/awareness-raising of farmers in general, cooperative managers in particular in order to promote efficient and coordinated management irrigation on the perimeter.

Indeed, the results show that the management of the agricultural and hydraulic infrastructure of Karfiguéla perimeter is disastrous and marked by non-compliance with cropping schedules, a lack of upkeep and maintenance of hydraulic infrastructure, the main causes of the poor quality of crops yield. These situations for which the main persons in charge are the offices of the cooperatives and UCEPAK which for social considerations can't manage with firmness the finances, the operations of upkeep and maintenance of works and the management of water distribution on the perimeter. This incapacity is also the cause of latent and real conflicts between farming groups. The difficulties to which the Karfiguéla perimeter is confronted are common to the irrigated perimeters of Burkina Faso: Lémourdougou in the Cascades Region, Bagré, Boulbi, Zimtanga, Savili, Manga aval in the Center, Center East, Center North, Center West and Center South Region, Lantaogo in the East, Kou Valley in the Hauts Basins Region, Mogtédo and Zorgondo in the Central Plateau Region, Rassondé in the Northern Region, Ourou Noma in the Sahel Region, Dano Moutouri in the South-Western Region and Fara and Débé in the "Boucle du Mouhoun" Region.

6. Conclusion

At the end of this study, the current state of the hydraulic network and the structural, technical and organizational weaknesses which hinder its proper operation has been studied. The multi-method approach has permitted to highlight the poor quality of the irrigation channels, the non-application of activity programs and poor maintenance of infrastructure and hydraulic works. These factors undermine the good functioning of the hydraulic network and the good management of water resources on the perimeter. Surveys lead to the stakeholders showing insufficient water from the source (Comoé River) both in the dry and wet agricultural campaigns. Investigations by hydraulic and visual approaches on the irrigation network and its ancillary infrastructure during the dry campaign show that the network is no longer efficient. In the wet season, the irrigation network doesn't transport water efficiently to the plots; on the contrary, it drains the water from the perimeter. The drainage network is completely messy and non-functional. Complete rehabilitation of the network is therefore necessary for better water management in the perimeter, but the insufficiency of the water resource remains a problem. Considering the favorable geographical, climatic and hydrogeological contexts in which the Karfiguéla perimeter is located, its total rehabilitation of the perimeter is necessary, but it's also important to find an alternative water resource to fill the water deficit. The shallow groundwater, which is deployed under the perimeter, could be a good alternative to the water needs of irrigators.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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