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An integrated methodology for energy use optimisation: The case study of Ben Nafa Kacha irrigation scheme, Burkina Faso

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ABSTRACT

The increasing awareness of regional climate and water-cycle changes are putting under pressure the efficient water use in agriculture. In developing countries, a reliable supply of energy is the key factor to enhance agricultural productivity and water efficiency. A neat water resources management is required for building flexibility, adaptable water distribution and reducing the extra amount of energy used. The “water-energy nexus” is a fundamental aspect for future planning and policy. The paper sheds the light on the application of an integrated methodology based on a DSS knowledge, aiming at improving the water delivery service, energy and costs optimization. The hydraulic simulation modelling is combined with an economic analysis, related to the yearly cost of energy, crops profitability and the impact of energy savings to the cost production. The analysis revealed that the application of this methodology focus on irrigation schemes critical aspects, providing optimized solutions for future policies.

1. Introduction

In developing countries, climate change in temperatures, rainfall patterns, extreme events and rising competing demand for water is continuously affecting the water cycle (Molobela and Sinha, 2010). Therefore, there has been a growing need of integrating energy use in irrigation schemes (Siddiqi and Diaz Anadon, 2011). In African countries, a reliable supply of energy is one of the requirements for the growth in agricultural productivity and irrigation. The energy use relies on system's design, the way it is operated and maintained (Belaud et al., 2020). It was stated that energy is globally consumed in pumped irrigated agriculture in a range of 23% - 48% and the steady increase of energy use is being a major issue for irrigated wter supply (Zhao et al., 2020). A continuous monitoring is becoming significantly common, in order to assess the effective use of energy and identify the policy to reduce energy consumption and costs. One possible strategy for lower energy bills deals with the reduction of water supply, since water savings produce energy savings. The policy involves several actions that build together the “water demand management” (Pardo et al., 2013). The efficient use of water in agriculture represents an important aspect for future planning and policy considerations, since water and energy are linked in the “water-energy” nexus(Staupe-Delgado, 2019).. In Sub-Saharan countries, the projected water use efficiency for the year 2050 is 25%, significantly lower than the world average value, approximately the 45% (Forslund and Mouel, 2017). Furthermore, as reported by the World Bank, many irrigation infrastructures are affected by inflexible water delivery services and are not able to reach farmers' needs (Wold Bank, 2006). Poor performance of irrigation infrastructures and low profitability are due to unconceiving use of water, poor farmers skills and lack of know-how (Malanco et al., 2018), rather than to water scarcity events. A deft water resources and energy management is becoming more urgent, since it build resilience, sustainability and it intensifies the agricultural productivity (Odo, 2017). thus producing energy recovering instead of extra-costs to high energy costs (Cabrera et al., 2015) (Pérez-Sánchez et al., 2016). In these perspectives, a Decision Support System (DSS), which is a dedicated software-based system, integrates hydrology, irrigation, energy and various aspects of small and large scale irrigation schemes, with the following objectives: providing valuable assistance to policy makers for improving guidelines in agriculture (Jawale and Vaidya, 2016), (Asaolu et al., 2009); improving irrigation planning and management practices (Mira Da Silva et al., 2001). A DSS was developed for semi-arid agriculture, with the purpose of enhancing crops productivity and providing assistance to smallholder farmers in taking more strategical decisions (Churi et al., 2013). Moreover, in the Middle Rio Grande area, a DSS was developed for the monitoring of the water delivery service and water demand within the scheme, in order to precisely and efficiently meet the water demand, for further irrigation performance improvement (Zhai et al., 2020). An assessment of the direct and indirect economic effects of

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policies subsidizing agriculture, targeting 'water-saving' techniques, has been conducted in Morocco and Syria (Doukkali et al., 2015), (Aw-Hassan et al., 2014). Results showed that the access to energy increases the water use management in irrigation, water use efficiency and productivity. A large-scale hydrological model was developed as an integrated DSS, in the main stem of Tarim river, (Yu et al., 2015), aiming at simulating new irrigation strategies, land use scenarios and possible effects in water savings. Results of the study revealed that a DSS scientific basis is an opportunity for decision makers to deal with agricultural water consumption issues and water allocation in the study area. In Egypt, a research study was conducted to demonstrate the use of DSS by the Egyptian government, in rationalizing decision-making process and better manage water resources with real-time operations, thus for socio-economic development purposes (Kamel, 1997).

Agricultural production in Burkina Faso is mainly extensive and dominated by small holder farmers, who own average land size (3–6 ha), characterized by low productivity (Combary et al., 2017). Surveys conducted among local farmers and Water User Associations (WUAs) proved that the Ben Nafa Kacha scheme is frequently over irrigated and water distribution is not adequate to the cropped areas, due to rigid irrigation rotation. Local farmers are not well equipped to use drainage systems, therefore the amount of water oversupplied is conveyed back to the river. This results into wastewater events, meaning extra-costs. As local WUAs confirmed, the energy cost is currently the most critical expense, raging from the 30% to the 60% overall. Effective water pricing is policy makers affected, frequently debated in developing countries with subsistence-driven agriculture (Wellens et al., 2013). Since farmers are price takers, any variation in energy prices cannot be managed and they have to accept any increase. As in small-scale irrigation schemes, farmers agree and cooperate to adjust the water rate, duration and the frequency of irrigation (Wang et al., 2013), local WUAs are responsible for irrigation water management up to the secondary canals. Conversely, local farmers agree at the lower levels and since farmers have a little knowledge of crop water requirements, this may lead to inequity in the scheme. These gaps in knowledge prove that a knowledge-based DSS is a real need for the context, towards enhances policies in agriculture and water resources management (Zingaro et al., 2017), (Asaolu et al., 2009).

The paper was carried out with the following objectives: i) deploy the knowledge-based DSS to the Ben Nafa Kacha scheme for constraints and performance assessment ii) evaluate a first improved scenario from the water-energy nexus perspective, aiming at monthly energy savings and more flexible water delivery service iii) develop a second improved scenario, to assess the impact of energy savings per crop.

The paper is organized in four sections. The *Material and methods* which describes the study area, the knowledge-based DSS in a comprehensive overview, the hydrological and climate data availability. The *Case study* which refers to the data collection: the pumping station and water supply, the cropping pattern and crop factors, the costs of operations and energy, farms economics (crop production, costs and profit). The *Results* giving evidence of the DSS application to the current conditions (baseline scenario), alternative and improved scenarios (energy use and costs optimization, impact of energy saving on crops profitability). *Conclusions* of the conducted research.

2. Material and methods

2.1. Study area

The Ben Nafa Kacha irrigation scheme is located in Sourou Valley, in the north - western part of Burkina Faso (Fig. 1), a land locked country. The irrigation scheme is currently undergoing a FAO conducted pilot project to enhance crop water productivity and to increase the water use efficiency in small-scale irrigation schemes. Two-thirds of Burkina Faso belong to the Volta Basin, particularly 183,000 Km^2 of the country area are located within the basin. The study area is affected by a unimodal rainfall pattern, which comprises the alternation between two seasons: a long dry season and a short raining season. The wet season starts in May and it ends in September. The wettest months are July, August and September. In the dry season, crops' yield can be increased because of the abundant sunshine the country enjoys. The major constraint of water resources management is the high evaporation, which increases continuously from the South to the North of the country, with average values of 3020 mm in the North (Dori), 2720 mm in the center (Ouagadougou) and 2356 mm in the South (Bobo-Dioulasso).

Sourou River is the main water resource of the irrigation scheme. The river crosses the border from Mali to Burkina Faso and it is about 65 Km length. It becomes the tributary of Mouhoun River, which is the most important and permanent water flow in the country. Sourou Valley is known for its hydro-agricultural installation of dam valves at the junction of Sourou and Mouhoun rivers in 1984. This led to a relevant increasing of the water level in Sourou river, which corresponds to an overall volume of 600,000,000 m^3, through the valley (Rosillon et al., 2012). Thanks to the dam valves installation in the river irrigated perimeters, the Sourou valley became one of the most important wetland in the country. The valley represents the most significant agricultural production zone, the so-called food basket of Burkina Faso (Savadogo et al., 2013). The area considered in the pilot project is 275 ha, which is distributed among 247 farmers, comprising paddy rice, maize, onions, green beans and tomatoes. The distribution of cultivated hectares among farmers comes from the cropping pattern survey, which was conducted by FAO in December 2018. Results showed that the majority owns 1 ha; 2 ha belong to some of them and only very few of them hold 0.25 ha of cultivated land. Each irrigation provides water simultaneously to 2 ha, via tertiary canals. The irrigation scheme is not under water scarcity condition, but the poor practices in water

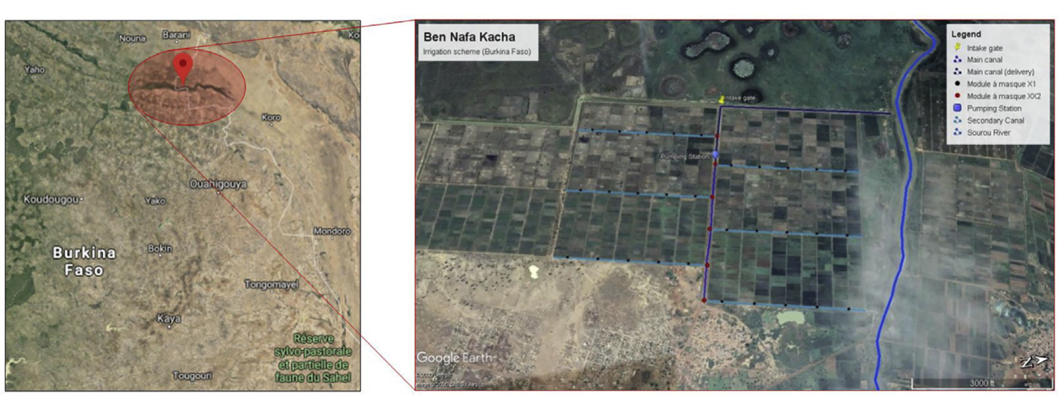

Fig. 1. Pilot Area of the Ben Nafa Kacha irrigation scheme, Burkina Faso.

resources management result in an inefficient water distribution in the scheme. Farmers rely on a single water access: surface water resources are used for agricultural purposes, while groundwater is for urban utilization.

2.2. Decision support system

The knowledge-based DSS methodology, previously deployed to the Mubuku scheme (Uganda) (Bettili et al., 2019), is briefly described (Fig. 2) for its application to the Ben Nafa Kacha scheme. The DSS consists on the deployment of a versatile and flexible model, integrating the FAO MASSCOTE approach with the hydraulic simulation modelling, MIKEHydro Basin. The MASSCOTE is a step-by-step methodology applied to generate optimal strategies for irrigation management practices, aiming at providing more effective water management and water delivery service (Renault et al., 2007). The first step of the MASSCOTE is considered, namely the Rapid Appraisal Procedure (RAP), which consists on spreadsheets, compiled with data gathered in the field and data obtained from the modelling. Three main objectives of the RAP are: i) assessing the overall performance thorough relative indicators; ii) identify constraints in the schemes, for modernization strategies considerations; iii) define options for performance improvements. Internal indicators (the field flow rate capabilities, reliability, flexibility and equity) provide a comprehensive understanding of the processes that affect the water delivery service and the overall performance. Each indicator is weighted from 0 (least desirable) to 4 (the most desirable). Conversely, external indicators compare input and output of the scheme, expressing the efficiency from the perspectives of the water use efficiency, crop yield and budget. These are used as benchmark for monitoring the results of improved operations delivered to the scheme. MIKEHydro Basin is implemented with required input data, in order to provide the total amount of crop water demand, according to the irrigation scheduling and cropping pattern (Fig. 2). Lastly, the RAP was integrated with irrigation data, obtained as output from the simulation modelling, in order to estimate the key performance indicator. Moreover, the Participatory Rural Appraisal (PRA), as defined in the MASSCOTE, represents the framework of the DSS implementation. It was carried out through FAO surveys conducted in the field in 2018. The PRA starts with the identification of the actors to be involved (local farmers, WUAs, technical expertise), the organization of local and remote activities, samples preparation, for further enhancements of management models and lastly supporting stake holders in decision making. It is proved that a participatory approach is the key factors to fill the gap between theoretical and practical requirements (Lindblom et al., 2016). Since energy is the most critical expense and local farmers face inadequate water supply and distribution, the research is developed in this perspective. Recent studies stated that the high cost of diesel fuels and electric have a relevant impact on decision makers, when considering the need to meet water and energy requirements for crops (Pardo Picazo et al., 2018). Performance indicators are a fraction of the irrigation water supply and they are generally expressed as percentage values (Burt et al., 1997. The Field Irrigation Efficiency (IE) is chosen as the target indicator, since it is necessary to evaluate improvements in water management practices and it is the primary value affecting water delivery service and the scheme performance overall. The IE indicator is computed as here below:

$$IE = 100 \cdot \frac{CM\ of\ Total\ Net\ Water\ Irrigation}{CM\ of\ Total\ Irrigation\ Water\ Delivered\ to\ Users} \quad (1)$$

In formula (1), the total net water irrigation is computed from the crop water requirements, taking into account evapotranspiration at the field level and special irrigation practices (the amount of water needed for land preparation of specific crop, i.e. paddy rice); the total irrigation water delivered to users represents the difference between the amount of water supply and water losses through the estimated conveyance efficiency (80%).

The DSS approach represents the starting point to analyze the inefficiencies of the scheme, from both hydrological (available water resources, irrigation scheduling flexibility and irrigation efficiency) and energetic points of view (energy savings and operating costs reduction).

2.3. Hydrological and climate data

The climate module in *MIKEHydro Basin* model accepts inputs data (Taechatanasat and Armstrong, 2014) (rainfall time series, temperatures, relative humidity, wind speed, solar radiation, irrigation data and soil properties) to compute the reference evapotranspiration (ET_o), expressed in millimeters of water. It represents an important component of the hydrological cycle, which significantly affects crop water requirements and water resources management (Lopez-Moreno

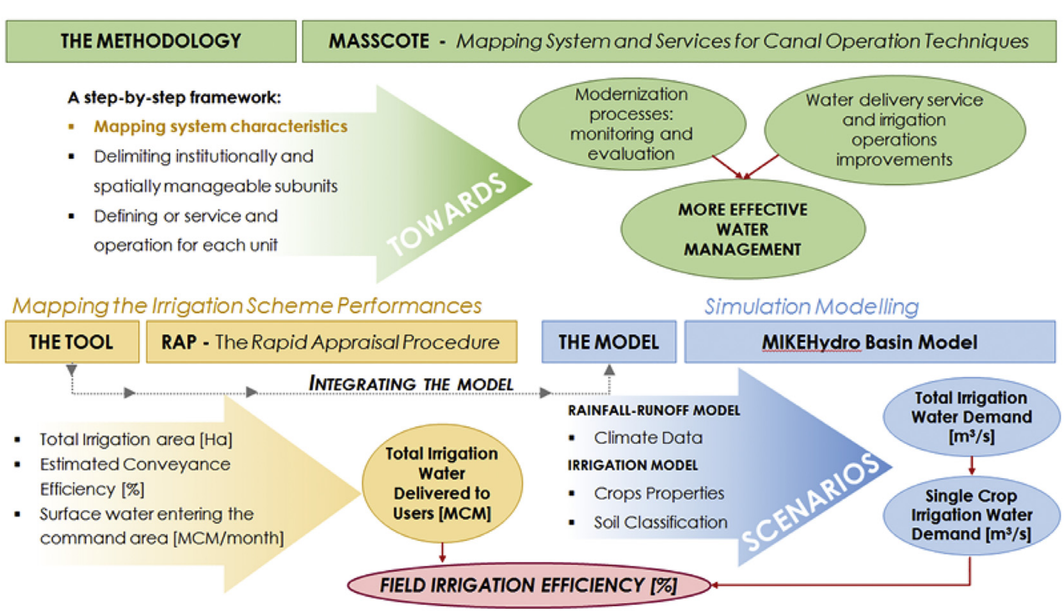

Fig. 2. The knowledge-based DSS applied to the Ben Nafa Kacha irrigation scheme for performance assessment.

et al., 2009). The standard *FAO-56 Penman-Monteith Method* is applied to compute the reference evapotranspiration, (ET_o) over time (Allen et al., 1998). Finally, the evapotranspiration ET_{crop}, related to specific crop type, is computed following the FAO56 Model Dual Crop Coefficient, internationally accepted and inbuilt in MIKEHydro. The quantity is expressed by the formula (2) and it is influenced by the dimensionless K_c crop factors (Yu et al., 2015), which were computed by means of data fields:

$$ET_{crop} = K_c \cdot ET_o \tag{2}$$

Climate data were provided by the local Meteorological Station Dori, which is the closest meteo station to the Ben Nafa Kacha irrigation scheme, located 12 Km north-western distance from it (Lat. 14.3, Long. -0.03), in the northern "Sahel Region" Daily rainfall time series cover a period of 5 years, from 2012 to 2017. The hyetograph is plotted on a monthly basis representation (Fig. 3). The quality of data is good: on a time range of 14 years daily observation, it encompasses the 82% on the entire year and 80% in the wet season. Therefore, it is a reliable source of data (Dembélé and Zwart, 2016). It can be observed a rainfall amounts on average yearly basis of approximately 800 mm. It exceeds 150 mm in July and August. In conclusion, the rainfall peak-period is from June to September, while in the rest of the year precipitations are sporadic, particularly in winter, when it hardly ever rains.

3. Case study

3.1. Pumping station and discharge

The Ben Nafa Kacha is rainfed in the humid season (May–September) and under pumping irrigation during the irrigation campaigns (October–April).

The pumping station is composed by three electric Archimedes screws, operating from the low-lying level of Sourou to the main canal, with a height of 4.30 m and 300 l/s discharge of each. The pumps are simultaneously used in order to obtain the maximum discharge of 900 l/s. Each pump works for 4380 h/year. The main canal is connected to 6 secondary canals (SC_i) (Fig. 4), each providing water by rotation to 5 tertiary canals. Even though the cost of energy is higher, 2 ha are under 12 h of pumped irrigation, per 5 days. Discharge measurements were conducted by FAO in the field, under an irrigation campaign. Discharge values plotted (Fig. 5) reflect the amount of water supply on a monthly basis, which is diverted into secondary canals via six *modules à masques* installed into the main canal. The standard type is the model XX2, installed in SC1, SC2, SC3, SC4, SC5. The amount of water discharge is diverted by $XX2_{150}$, with a nominal flow rate per unit of width of 150 l/s. Conversely, in SC6 the discharge is diverted by $XX2_{90}$, with a nominal flow rate of 90 l/s. Results of discharge measurements peak in April, May and December. SC1 and SC2 have the highest discharge values. In the dry season (October–April) SC1 shows approximately 155,000 m^3/month on average, conversely SC2 provides an average value of 125,000 m^3/month per season. The rest SC_i have a discharge of 91,000 m^3/month, on average. The time period from May to September has the lowest discharge values, since it represents the humid season, where rainfalls peak (Fig. 3). SC1 and SC2 have an average value of 115,000 m^3/month, equally to SC3 and SC6, with an average discharge of 70,000 m^3/month.

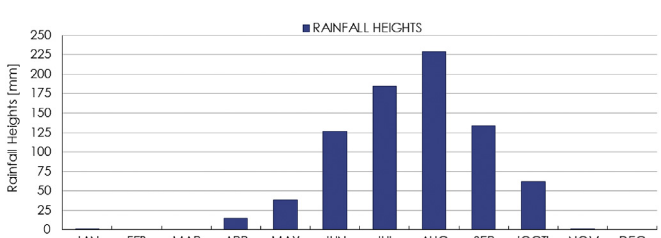

Fig. 3. Global Rainfall Hyetograph.

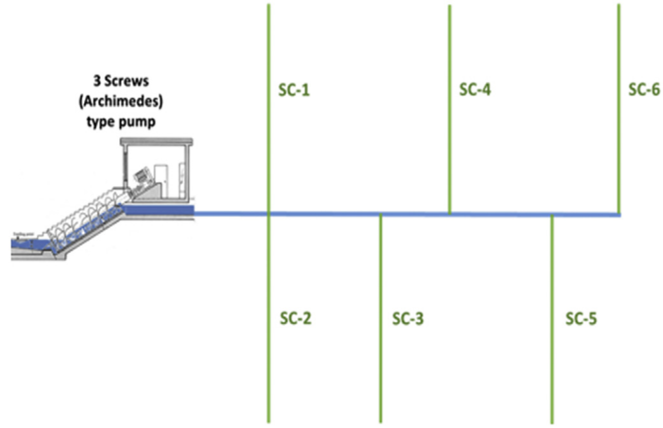

Fig. 4. The design of the Ben Nafa Kacha irrigation scheme (Source: FAO).

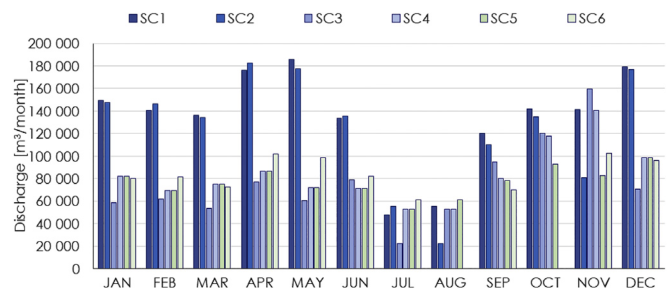

Fig. 5. Discharge measurements from the secondary canals.

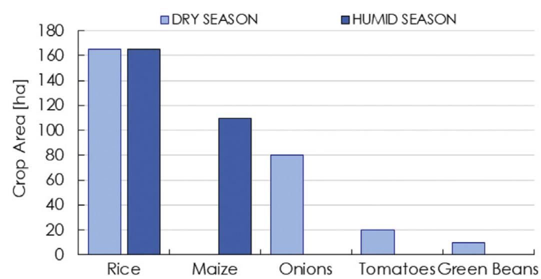

Fig. 6. Cropping pattern.

3.2. Cropping pattern and crop factors

FAO measurements were conducted in the command area to understand the cropping pattern and K_c. More than 90% of the scheme is cropped with paddy rice, onions, maize, tomatoes and green beans. Only rice is produced in monoculture. There are two growing seasons: the humid and the dry season (Fig. 6). The pilot area is divided into one area devoted to the lowland rice (165 ha of paddy flooded rice) and one to the horticultural crops (110 ha). In the horticultural area, during the rainy season, almost 100% is devoted to maize and during the dry season the main crop are onions, tomatoes and green beans.

In the horticultural area, during the rainy season, almost 100% is devoted to maize and during the dry season main crops are onions, tomatoes and green. Crop water requirements (ET_{crop})is the amount of water needed to meet the water losses via evapotranspiration of a disease-free crop, which grows under non-restricting soil water, achieving full production potential under given environmental conditions (Doorenbons et al., 1997). The parameters included in the model (Table 1) are sowing days, root depth (RD), the maximum vegetation height (MH), K_c coefficients, the length of crops initial growing (INI), development (DEV), middle (MID) and late stage (LAT). The nursery (NR) consists in the 5–10% of the total planted area (Brouwer et al., 1985).

3.3. Operating costs

The irrigation scheme was installed decades ago and the only significant modern aspect occurred in 2017, when the diesel pumps were changed into electric, supplied by the SONABEL organization. According to the WUAs, the composition of costs have been investigated per humid and dry seasons (Fig. 7). A comparison between pumps types was made (Table 2) in energy use and costs, on irrigation campaign basis, assessing an increase in the total cost of 1000 USD on a yearly basis.

Since farmers are price-takers, they cannot control the commodity prices and this is reflected on their welfare purely dependent on external factors. An increase in energy prices over time will have a high impact on farmers, who cannot deal with prices. The irrigation turns are scheduled between 6:00 am and 4:00 pm, with 10 h of operating pumps, while the peak tariffs occur in the range of 10:00 am – 2:00 pm and 4:00 pm – 7:00 pm. The peak tariff is 118 CFAF/kWh, conversely the off-peak tariff is 54 CFAF/kWh. The cost of electricity is high, because the water consumption for irrigation mostly occurs in the peak time range. Therefore, it is required to reschedule the irrigation period to the off-peak, including new rules for irrigation operations, without any variation in the irrigation pattern.

3.4. Crops production and farm economics

The average yields per relevant crop were considered in the analysis (Table 3). Local communities do not have storage areas for the harvested facilities and farmers using inappropriate means to quantify products. Surveys were conducted in the field by FAO, among 60 farmers occurred via collective samples, divided in three sections addressed four topics: water use efficiency, crop water productivity, irrigation management, farmers' socio-economic.

The aims of the surveys are identifying the water use and energy nexus, improving water delivery service, providing guidelines to enhance agricultural practices, evaluating the overall costs of irrigation and farm economic key factors. Farms economics' aspect was carried out through a quantitative analysis, with questions related to the percentage of crops produced per farmers, each crop; the amounts of crops produced for self-consumption and addressed to the commercial production. Rice, onions and tomatoes are considered. Results revealed that 100% of crops are produced in multi-cropping system, 100% of rice and maize are used for household consumption, 50% of onions and others are addressed to commercial purposes. Data were provided according to the off-season, pre-harvesting and harvesting period (Tables 4–6), Recent studies have demonstrated that economic factors (market prices, natural resources availability and agricultural subsidies) led farmers' behavior towards a better water management in agriculture (Wiggering and Steinhardt, 2015), (Gebrehiwot et al., 2016).

4. Results

4.1. Baseline scenario

The total amount of water demand (*WD*) and the total amount of water supply (*WS*) were plotted into a single graph, in order to assess the current water balance in the scheme (Fig. 8). The model application revealed that, in spite of June and July, where crops are river basin irrigated and rainfed, the overall irrigation scheme is not affected by water scarcity conditions, even though farmers rely on one single water access. Where little water shortage events are observed, the cause is found in the inadequate water distribution. The field irrigation efficiency computed via the RAP results in 25%, a poor value if comparing to the 40%, considered a reasonable efficiency for irrigation canal systems, by the “Irrigation water management training manual N.4” (Brouwer et al., 1985).

The table below (Table 7) provides crop areas [ha] and crop water requirements for the two seasons. Once the hydrological aspects are evaluated, in order to assess the fluctuation of energy costs yearly, the monthly water supply the monthly water supply is estimated in terms of energy cost per month (Fig. 9).

Data taken into account were the total energy costs of the pumping station, equal to 55,837 USD yearly and the overall amount of water supply equal to 6,791,931 m^3.

Results were obtained according to the current operating hours of the pumping station, which is equal to 4380 h/year. The graph shows a peak of energy cost in April equal to 5502 USD, where the amount of water supply exceeds the water demand. This means that the energy costs can be reduced if the water service is rescheduled according to the crop water demand, in order to avoid any wastewater events. The energy costs sharply decreased from May to August, where the humid season occurs and crops are rain-fed too. A minimum value of 1895 USD is reached in August. Lastly, according to the beginning of the dry season, it is clear the spread observed in the graph in terms of energy costs, peaking with 5573 USD in December.

Table 1
Irrigated, crop factors and growing stages.

Dry season

Crops	Length [Days]				RD [mm]	MH [m]	Kc [−]		
	INI	DEV	MID	LAT			INI	MID	LAT
Paddy rice	15	25	50	20	500	1.00	0.80	1.20	0.60
Onions	10	15	45	30	400	0.50	0.60	1.10	0.80
Green beans	10	20	35	10	700	0.40	0.60	1.10	0.90
Tomatoes	15	20	40	20	700	0.60	0.40	1.20	0.80

Humid season

Crops	Length [Days]					RD [mm]	MH [m]	Kc [−]		
	NUR	INI	DEV	MID	LAT			INI	MID	LAT
Paddy rice	15	15	25	55	20	500	1.00	0.80	1.20	0.60
Maize	–	15	30	55	30	700	1.80	0.70	1.10	0.40

The initial stage of paddy rice includes the land preparation and nursery phases (sowing and transplanting). In the first one, a huge amount of water is required: the root zone needs to be saturated and lands have to be flooded. Indeed, the percolation quantity has to be included in the model.

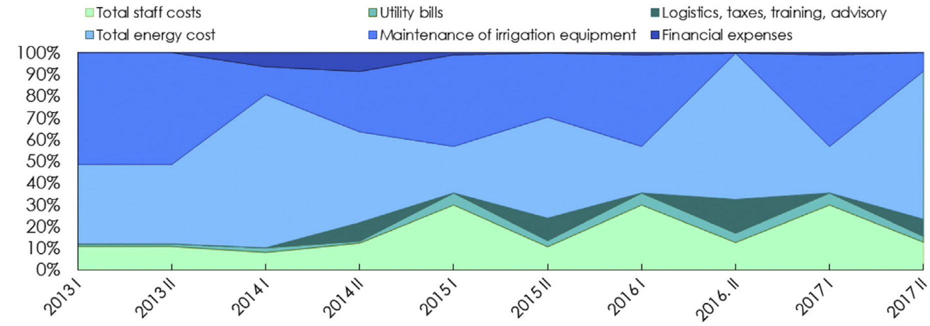

Fig. 7. Estimated costs per humid and dry season (Source: FAO data collection in the field).

Table 2
Energy used and cost per campaign (Source: bills of service providers).

Energy used per irrigation campaign	Diesel	Electric
Energy tariff of energy source [XOF/l]	675	64,387
Energy use of pumping station [l]	22,000	240
Total energy cost of pumping station [XOF]	14,850,000	15,452,880
Total energy cost of pumping station[USD]	27,770	28,897

Table 3
Crops and average yields (Source: FAO data, 2018).

Crop	Yield [t/ha]
Rice	4–6
Tomato	40–50
Onion	15–20
Maize	2–4

Table 4
Farms economics of rice (Source: farmers surveys, FAO 2018).

Rice	Off-season	Pre-harvesting period	Harvesting period
Yield [t/ha]	4	5	6
Farmers Price [XOF/t]	150,000	150,000	150,000
Cost [XOF/ha]	617,453	617,453	617,453
Income [XOF/ha]	600,000	750,000	900,000
Profit [XOF/ha]	−17,453	132,548	282,548
Profit [USD/ha]	−26	199	424

Table 5
Farms economics of onions (Source: farmers surveys, FAO 2018).

Onions	Off-season	Pre-harvesting period	Harvesting period
Yield [t/ha]	20	20	20
Farmers Price [XOF/t]	326,923	246,154	96,154
Cost [XOF/ha]	1,444,590	1,444,590	1,444,590
Income [XOF/ha]	6,538,461	4,923,077	1,923,077
Profit [XOF/ha]	5,093,871	3,478,487	478,487
Profit [USD/ha]	8660	5913	813

Table 6
Farms economics of tomatoes (Source: farmers surveys, FAO 2018).

Tomatoes	Irrigation season
Yield [t/ha]	50
Farmers Price [XOF/t]	60,000
Cost [XOF/ha]	1,032,255
Income [XOF/ha]	3,000,000
Profit [XOF/ha]	1,967,745
Profit [USD/ha]	2952

As mentioned, farmers are price-takers meaning that if the energy spreads owing to market trends variations, farmers must accept them at market risk and the WUAs transmits the increases to the water fees. Therefore, a flexible water service is required to decrease energy costs and traduce them into savings, in order to provide guidelines to develop appropriate management policies. The *baseline scenario* assessment, from both hydrological and energy costs perspectives, provides the basis for further analysis in terms of energy use, costs optimization and more appropriate distribution of water supply. Indeed, according to recent studies, it was proved the importance of maintaining good performance levels in irrigation systems, since low irrigation water reliability is needed to improve crop productivity (Lakmali et al., 2015). The aim is to tackle energy savings and provide flexible water service in the scheme, for proper management guidelines, policies and performance improvements. The analysis on the energy costs required per crop will assess the effective energy saving and its impact on the total profit.

4.2. Energy use and costs optimization

Small-scale irrigation schemes are putted under pressure to produce more with less water supply, in order to reduce also the cost of energy used (Levidow et al., 2014). The agricultural sector, in the major part of sub-Saharan countries, linked to the direct and indirect energy supply. Therefore, policies are required to consolidate the relationship between the most important economic sector in Africa and the use of energy, in order to meet farmers' welfare. This second scenario focuses on the energy use optimization, with the objective of decreasing the total operating expenses, according to the high impact of the costs of energy as mentioned by the WUAs and plotted in the graph (Fig. 7). Previous guidelines provided, in view of a more flexible water service, recommended an irrigation rescheduling, in order to save the amount of pumped energy, thus reducing the total cost of operations.

The exact amount of water needs to be supplied according to the quantity required by crops to grow up, since farmers are facing high fees on pumped water. The water service was rescheduled mostly to the off-peak period range and decreasing the duration of irrigation from 10 h/day to 7 h/day. The amount of water supply is stored in the on-peak period of water tariffs, in order to turn off the water pumps. Field analysis conducted in 2018 revealed that the main canal is wide and deep enough to store water in the on-peak period, for a range of time equal to 4 h per day. The water pumps are turn on again, from 2:00 pm – to 5:00 pm, as a second functioning time period on a daily basis. Results (Fig. 10) show the comparison between the amount of water supply and water demand, after rescheduling the irrigation duration and water distribution. It was monthly assessed an appropriate amount of water supply according to the water demand, in spite of the humid season where some deficits can be observed, since these deficits are covered by rainfalls distribution. Therefore, only 4 h/day under irrigation are sufficient to meet crops water needs. Discharge in excess, pumped in 3 h/day related to the rescheduling irrigation period is better

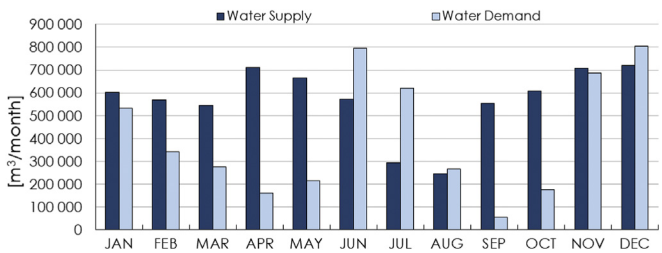

Fig. 8. Overall Monthly Water Demand and Water Supply, Baseline Scenario.

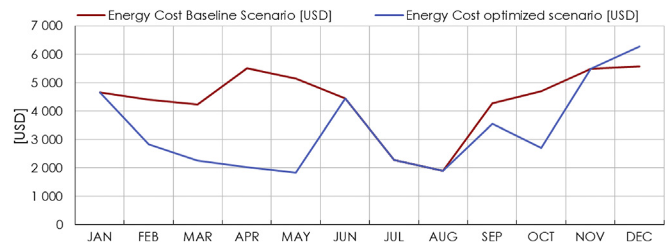

Fig. 11. Energy cost trends per scenario, over time.

Table 7
Crop Water Requirements, Dry and humid seasons.

Crop	Dry season	Area [ha]	CWR [m^3]	CWR [m^3/ha]
Paddy rice	October–April	165	2,180,374	13,214
Onions	October–April	80	464,471	5806
Tomatoes	October–April	20	119,743	5987
Green beans	October–April	10	49,196	4920
Crop	**Humid season**	**Area [ha]**	**CWR [m^3]**	**CWR [m^3/ha]**
Paddy rice	May–September	165	1,779,782	10,787
Maize	May–September	110	331,987	3018

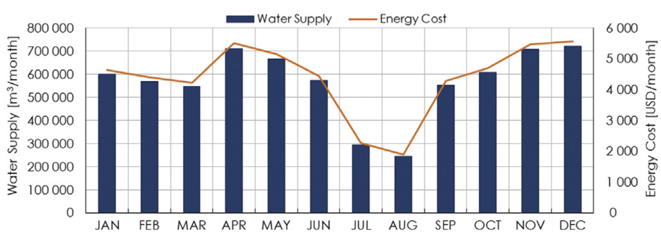

Fig. 9. Energy cost fluctuation over time and overall monthly water supply.

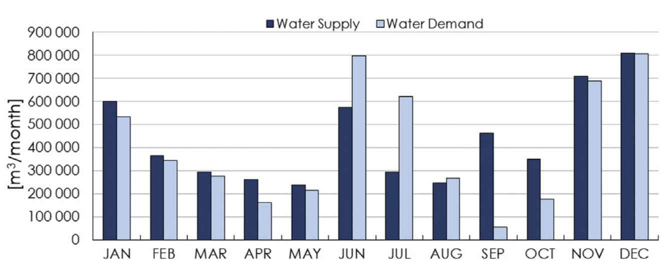

Fig. 10. Overall Monthly Water Demand and Water Supply, Energy use optimization Scenario.

allocated to satisfy the water balance. The field irrigation efficiency reaches higher value of 38%. The overall amount of water supply exceeds the water required of 5%. This value can be accepted as an opportunity to reallocate the amount of extra water supply in the rainy season, in case rainfalls are not sufficient to cover the crop water demand. Moreover, the excess of water supply occurred in the months of September and October can be accepted also if considering that the initial land preparation phase of paddy rice takes place and the fields need to be flooded by water supplied by the irrigation system itself, since the dry season takes place. On a yearly basis, the total water discharge to be supplied to the scheme is equal to 5,189,893 m^3/year, with 3347 working hours of the pumping station. The monthly amount of water discharge was evaluated in terms of energy costs supply, for both baseline and optimized scenario (Fig. 11). From data comparison, it was assessed a sharply decrease of 37% from January to June. Also, values reached with this alternative scenario are reduced by the 19% than the *baseline scenario*. The overall costs reduction assessed with the optimized scenario reached the value of 24%, since the overall water demand decreased and the number of working hours per year was reduced too.

These results led to the computation of the amount of energy saved per month, as plotted (Fig. 12). It can be observed that two peaks were reached in April and May, accounting for 3500 USD and 3000 USD, respectively. Indeed, according to the water balance assessed in the baseline scenario, a huge amount of water supply is delivered to the scheme, even though the water demand was significantly lower. A negative value could be observed in December, meaning a little increase of energy costs of approximately 800 USD. The energy costs recovered with the optimized scenario was about 12,400 USD on a yearly basis.

This meant that a flexible water service in terms of water adequately distributed and consequently a more appropriate use of pumping station have a significant impact on the energy costs over time (Fig. 7).

4.3. Impact of energy saving on crops profitability scenario

As stated previously, an efficient use of energy, both non-commercial energy (seed, manure and animate energy) and commercial (diesel, electricity, fertilizers) provides support to achieve increased productivity, contributing to profitability and competitiveness of agriculture sustainability (Canakci et al., 2005). In this scenario, the energy costs were evaluated in percentage, per main crops cultivated in the dry season (rice, onions, tomatoes), in order to identify which one has the highest impact on energy costs (Fig. 13). It was assessed rice has the major impacting crop, since it requires the highest amount of water (Table 7).

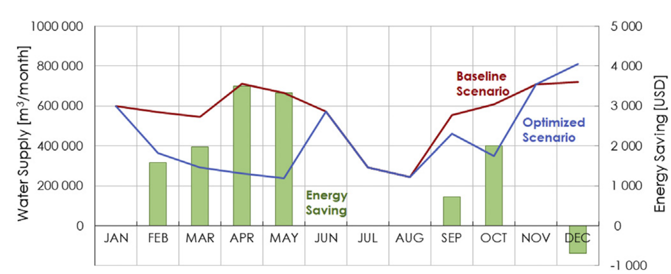

Fig. 12. Energy cost recovered by the optimized scenario, over time.

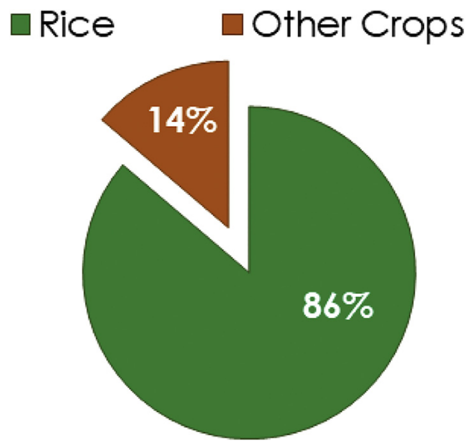

Fig. 13. Energy costs distribution per main crop.

Data related to the farm economics (Tables 4–6) are used to compute the percentage of total costs and profit, per crop (Fig. 14). The graph shows an evidence of significant higher costs and low profit of rice. This means that, for local farmers, producing rice for commercial purposes does not provide significant advantages.

Farmers confirmed that rice production represents the bottleneck of the cropping pattern, since it consumes the highest amount of water, thus it encompasses the lowest profitability value. Indeed, it is addressed to self-consumption, rather than for commercial purposes. Rice represents the key staple crop in the western Africa (Ouedraogo, 2015): increasing its production in a profitable way is critical to ensure food security and the growth of a sustainable economy (Katic, 2014). Conversely, onion and tomato require lower costs for the production, approximately the 30% and 65% of profit, on average. Therefore, it is convenient to deliver the half production of these two crops to the commercial purpose. Definitely, rice revealed to be the one with 82% of profit.

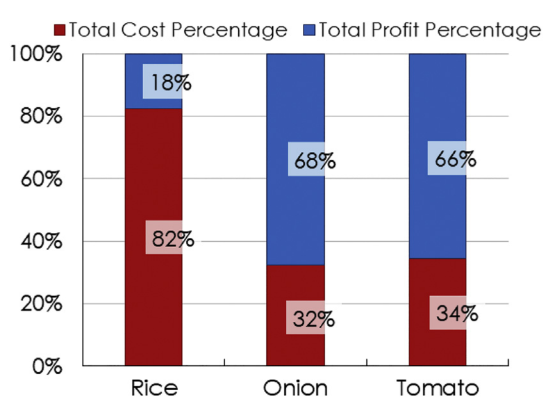

Fig. 14. Total profit compared to the total costs, per main crop.

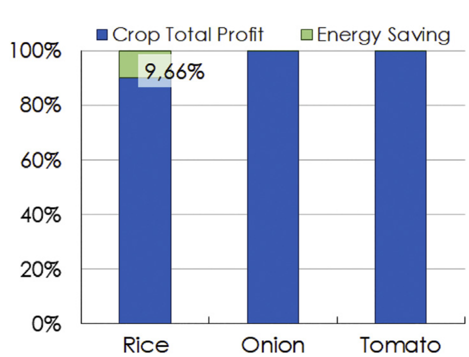

Fig. 15. Total profit per crop rated to the total cost.

Table 8
Results in percentage, per crop.

Results	Rice	Onion	Tomato
Total Cost [%]	82	32	34
Total Profit [%]	18	68	66
Energy Saving [USD]	11,924	396	45
Impact on Profit [%]	9.66	0.03	0.07
Crop Total Profit [%]	90.34	99.97	99.93
Energy Saving [%]	9.66	0.03	0.07

Conversely, onion and tomato reach the values of 32% and 34%, respectively. Lastly, the overall profit was compared to the percentage of energy saving within the improved scenario, per crop (Fig. 15). The impact of energy saving is higher wherever crops have lower profitability. Rice provided an evidence of 10% as the total amount of energy saved. It is clear in the graph below, that the amount of energy saved is paltry if considered in terms of onion and tomato overall profitability (Table 8).

5. Conclusions

A knowledge-based DSS is the starting point to assess the existing constraints within an irrigation scheme. As local farmers confirmed over water supply conditions, in terms of duration, frequency of irrigation and inadequate water distribution among upstream and downstream levels, a DSS is required. Indeed, the RAP application to the baseline scenario provides a poor field irrigation efficiency of 25%: water supply is significantly higher if compared to the water demand. As WUAs confirmed that the energy costs are the highest among the operating expenses, water delivery service needs a rescheduling process, mostly during the off-peak period of water tariffs, for lower energy costs and enhanced flexibility. The improved scenario results into higher field irrigation efficiency (38%) and overall reduction of energy costs (24%). Moreover, the second alternative scenario proved that rice, with the highest water requirement, needs the highest cost for its production (80%), for the lowest profit (18%). A result of 10% of energy saved from rice production is obtained. Therefore, it is confirmed that rice production is more convenient for self-consumption, rather than for commercial purposes.

However, some limitations occur in the study. The methodology provides reliable results if surface irrigation schemes are taken into account. Data availability for the model implementation plays an important role in results' accuracy. The hydraulic modelling is not an open source software and the support of technical experts is required.

The research significantly contributes to science advance: it is based on an integrated methodology, that can be rapidly implemented, reproducing real-time results and further scaled up to larger irrigation schemes. Moreover, the methodology is target oriented: it introduces the concept of "citizen science", which refers to the participation of local people to the methodology development. Indeed, local farmers, WUAs and technical experts are involved through appropriate surveys within the "Participatory Rural Appraisal (PRA)". They can provide the existing gaps in knowledge, immediate feedback of the applied model, data collection and obtained results validation and lastly, strengthening Sustainable Development Goals through smarter water management and operations at local and regional level.

Declaration of competing interest

The authors declare no conflict of interest.

References

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. Irrigation and drainage paper no. 56, crop evapotranspiration - guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper No 56. Food and Agriulture Organization (FAO), Rome 56 (97):e15.

Asaolu, O.S., Ogbemhe, J., et al., 2009. A decision support tool for basin irrigation in northern Nigeria. Maejo Int. J. Sci. Technol. 3 (2), 295–305.

Aw-Hassan, A., Rida, F., Telleria, R., Bruggeman, A., 2014. The impact of food and agricultural policies on groundwater use in Syria. J. Hydrol. 513, 204–215. https://doi.org/10.1016/j.jhydrol.2014.03.043.

Belaud, G., Mateos, L., Aliod, R., Buisson, M.C., Faci, E., Gendre, S., Ghinassi, G., Gonzales, Perea R., Lejars, C., Maruejols, F., et al., 2020. Irrigation and energy: issues and challenges. Irrig. Drain. 69, 177–185.

Bettili, L., Pek, E., Salman, M., 2019. A decision support system for water resources management: the case study of Mubuku irrigation scheme, Uganda. Sustainability 11 (22), 1–19. https://doi.org/10.3390/su11226260.

Brouwer, C., Goffeau, A., Heibloem, M., 1985. Irrigation Water Management Training Manual N.1: Introduction to Irrigation. Food and Agriculture Organization (FAO), Rome, pp. 102–103.

Burt, C.M., Clemmens, A.J., Strelkoff, T.S., Solomon, K.H., Bliesner, R.D., Hardy, L.A., Howell, T.A., Eisenhauer, D.E., 1997. Irrigation performance measures: efficiency and uniformity. J. Irrig. Drain. Eng. 123 (6), 423–442. https://doi.org/10.1061/(ASCE)0733-9437(1997)123:6(423).

Cabrera, E., Gomez, E., Cabrera Jr., E., Soriano, J., Espert, V., 2015. Energy assessment of pressurized water systems. J. Water Resour. Plan. Manag. 141 (8), 04014095. https://doi.org/10.1061/(ASCE)WR.1943-5452.0000494.

Canakci, M., Topakci, M., Akinci, I., Ozmerzi, A., 2005. Energy use pattern of some field crops and vegetable production: case study for Antalya region, Turkey. Energy Convers. Manag. 46 (4), 655–666. https://doi.org/10.1016/j.enconman.2004.04.008.

Churi, A.J., Malongo, R.S.M.I., Mahoo, H., Tumbo, S.D., 2013. A Decision Support System for Enhancing Crop Productivity of Smallholder Farmers in Semi-Arid Agriculture 3.

Combary, O.S., et al., 2017. Analysing the efficiency of farms in Burkina Faso. Afr. J. Agric. Resour. Econ. 12 (3), 242–256.

Dembélé, M., Zwart, S.J., 2016. Evaluation and comparison of satellite-based rainfall products in Burkina Faso, West Africa. Int. J. Remote Sens. 37 (17), 3995–4014. https://doi.org/10.1080/01431161.2016.1207258.

Doorenbons, J., Pruitt, W.O., Aboukhaled, A., et al., 1997. Crop water requirements. Irrigation and Drainage Paper no 24. Food and Agriculture Ogaization (FAO), Rome.

Doukkali, R., Lejars, C., Mengoub, F.E., El Ghandour, A., 2015. What Are the Indirect and Direct Effects of Irrigation Policy on Energy Costs? A Social Accounting Matrix Assessment in Tadla (Morocco) CIDConference, Special Session 'Irrigation and Energy' Montpellier, France.

Forslund, C., Mouel, A., 2017. How we can feed the world in 2050? A review of the responses from global scenario studies. Eur. Rev. Agric. Econ. 44 (09). https://doi.org/10.1093/erae/jbx006.

Gebrehiwot, K.A., Gebrewahid, M.G., et al., 2016. The need for agricultural water management in sub-Saharan Africa. J. Water Resour. Protect. 8 (09), 835–843. https://doi.org/10.4236/jwarp.2016.89068.

Jawale, M.A.P.S., Vaidya, D.R., 2016. Decision support system for irrigation canals. Int. J. Sci. Eng. Res. 7 (9), 854–858.

Kamel, S., 1997. DSS to Support Socio-Economic Development in Egypt Proceeding of the Thirtienth Annual Hawaii International Conference on System Sciences. Vol. 3. IEE, pp. 329–336.

Katic, P.G., 2014. Improving west African rice production with agricultural water management strategies. Global Water Issues Insights https://doi.org/10.22459/GW.05.2014.06.

Lakmali, W.A.S., Gunawardena, E.R.N., Dayawansa, N.D.K., 2015. Comparative performance assessment of major irrigation systems in Upper Deduru Oya Basin. Trop. Agric. Res. 26 (2), 343–354. https://doi.org/10.4038/tar.v26i2.8097.

Levidow, L., Zaccaria, D., Maia, R., Vivas, E., Todorovic, M., Scardigno, A., 2014. Improving water-efficient irrigation: prospects and difficulties of innovative practices. Agric. Water Manag. 146, 84–94. https://doi.org/10.1016/j.agwat.2014.07.012.

Lindblom, J., Lundstrom, C., Ljung, M., 2016. Next Generation Decision Support SYSTEMS FOR FARMERS: Sustainable Agriculture IT. Conference Paper. Vol. 1. IFSA Europe, Berlin, pp. 49–57.

Lopez-Moreno, J.I., Hess, T., White, S., 2009. Estimation of reference evapotranspiration in a mountainous mediterranean site using the penman-monteith equation with limited meteorological data. Pirineos Rev. Ecol. Mont. 164, 12. https://doi.org/10.3989/pirineos.2009.v164.27.

Malanco, J.A., Makurira, H., Kasese, E., Gumindoga, E., 2018. Water management challenges at Muschandike irrigation scheme in Runde catchment. Zimbabwe 378, 73–78. https://doi.org/10.5194/piahs-378-73-2018.

Mira Da Silva, L., Park, Jr, Keatinge, J.D.H., Pinto, P.A., 2001. A decision support system to improve planning and managementin large irrigation schemes. Agric. Water Manag. 3 (51), 187–201. https://doi.org/10.1016/S0378-3774(01)00124-X.

Molobela, I.P., Sinha, P., 2010. Management of water resources in South Africa: a review. Afr. J. Environ. Sci. Technol. 5 (12), 993–1002.

Odo, A.O., 2017. Agricultural water management in sub-Sahara Africa: options for sustainable crop production. Green. J. Agric. Sci. 6 (4), 151–158. https://doi.org/10.15580/GJAS.2016.4.022616046.

Ouedraogo, S., 2015. Technical and economic efficiency of rice production on the irrigated plain of Bagre (Burkina Faso): a stochastic frontier approach. J. Econ. Sustain. Dev. 6 (14), 78–85.

Pardo Picazo, M.A., Juarez, J.M., Garcia-Marquez, 2018. Energy consumption optimization in irrigation networks supplied by a standalone direct pumping photovoltaic system. Sustainability 10 (11), 4203. https://doi.org/10.3390/su10114203.

Pardo, M.A., Manzano, J., Cabrera, E., Garcìa Serra, J., 2013. Energy audit of irrigation network. Biosyst. Eng. 115 (1), 89–101. https://doi.org/10.1016/j.biosystemseng.2013.02.005.

Pérez-Sánchez, M., Sanchez-Romero, F.J., Ramos, H., Lopez-Jiménez, P., 2016. Modeling irrigation networks for the quantification of potential energy recovering: a case study. Water 6 (234). https://doi.org/10.3390/w8060234 8.

Renault, D., Facon, T., Wahaj, R., 2007. Modernizing Irrigation Management—The MASSCOTE Approach. The Food and Agricultural Organization, Rome, p. 63.

Rosillon, F., Savadogo, B., Karboe, A., Bado-Sama, H., Dianou, D., 2012. Attempts on the origin of the high nitrates concentrations in groundwaters of the Sourou Valley in Burkina Faso. J. Water Resour. Protect. 4 (8), 663–673. https://doi.org/10.4236/jwarp.2012.48077.

Savadogo, B., Kaboré, A., Zongo, D., Poda, J.N., Bado, H., Rosillon, F., Dianou, D., 2013. Problematic of drinking water access in rural area: case study of the Sourou Valley in Burkina Faso. J. Environ. Prot. 4 (1), 31–50. https://doi.org/10.4236/jep.2013.41004.

Siddiqi, A., Diaz Anadon, L., 2011. The water-energy nexus in Middle East and North Africa. Energy Policy 39 (8), 4529–4540.

Staupe-Delgado, R., 2019. The water–energy–food–environmental security nexus: moving the debate forward. Environ. Dev. Sustain. 22 (7), 6131–6147. https://doi.org/10.1007/s10668-019-00467-5.

Taechatanasat, P., Armstrong, L., 2014. Decision support system data for farmer decision making. Proceedings of Asian Federation for Information Technology in Agriculture. AFIDA, pp. 472–486.

Wang, X., McIntosh, C.S., Watson, P., Zhang, H., Lu, Q., 2013. Technical Efficiency in Small-Scale Irrigation Cooperative and its Determinants from the Perspective of Social Capital Heterogeneity–the Case of northwestern China. Annual Meeting, August 4-6, 2013. Washington, D.C. https://doi.org/10.22004/ag.econ.148070.

Wellens, J., Thaoré, F., Diallo, M., Tychon, B., 2013. A framework for the use of decision-support tools at various spatial scales for the management of irrigated agriculture in West-Africa. Agric. Sci. https://doi.org/10.4236/as.2013.48A002 (accesse: May 26, 2013–July 16, 2013).

Wiggering, H., Steinhardt, U., 2015. A conceptual model for site-specific agricultural land-use. Ecol. Model. 295, 42–46. https://doi.org/10.1016/j.ecolmodel.2014.08.011.

Wold Bank, 2006. Reengaging in Agricultural Water Management: Challenges Opportunities and Trade-Offs. The International Bank for Reconstruction and Development. Water for Food Team, Agriculture and Rural563 Development Department (ARD), Washington, DC.

Yu, Y., Disse, M., Yu, R., Yu, G., Sun, L., Huttner, P., Rumbar, C., 2015. Large-scale hydrological modeling and decision-making for agricultural water consumption and allocation in the Main stem Tarim River, China. Water J. 7 (6), 2821–2839. https://doi.org/10.3390/w7062821.

Zhai, Z., Martinez, F.J., Beltran, V., Martinez, N.L., 2020. Decision support systems for agriculture 4.0: survey and challenges. Comput. Electron. Agric. 170. https://doi.org/10.1016/j.compag.2020.105256 105256.

Zhao, Y., Wang, Q., Jiang, S., Zhai, J., Wang, J., Guohua, H., Haihong, L., Zhang, Y., Zhu, Y., et al., 2020. Irrigation water and energy saving in well irrigation district from a water-energy nexus perspective. J. Clean. Prod. 267 (122058). https://doi.org/10.1016/j.jclepro.2020.122058.

Zingaro, D., Portoghese, I., Giannoccaro, G., 2017. Modelling crop pattern changes and water resources exploitation: a case study. Waster J. 9 (9) 685. https://doi.org/10.3390/w9090685.