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Irrigation Efficiency in the Large Irrigated Perimeters: Case of Upper Cheliff Perimeter (Northwestern Algeria)

大型灌溉周邊的灌溉效率：以阿爾及利亞西北部 Cheliff上游周邊為例

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ABSTRACT

This study concerns the irrigation perimeter of Upper Cheliff (Plains of El Khemis and El Amra-Abadia, located in northwestern Algeria), it deals with the main indices related to the exploitation of Large Irrigated Perimeters of the Cheliff valley which has its main adductor, the Cheliff wadi, with over a length of 730 km. Through the results of applying indices measuring both network efficiency (E1) and parcel efficiency (E2) for the period 2010-2019 for the plains of the Upper Cheliff perimeter, the Irrigation Water Use Efficiency Index (WUE = E1*E2) tracks water-saving efforts. It is in the order of 38% and 36% for the plains of El Khemis and El Amra-Abadia respectively. This figure remains low and strongly influenced by the losses from direct releases in long-distance wadis, water thefts, inefficient and poorly maintained networks, lack of counting, and wastage. Indeed, reducing leakage in irrigation systems could generate a considerable volume of water that would reduce the pressure on the existing resource and reduce the water deficit until 2030. Saving much of the lost or wasted water is technically feasible and would cost far less than the cost of producing water to meet additional future water needs. Also, the area under cultivation changed during the period 2011-2019. Potato, cereal, and fruit trees have shown a significant evolution in the upper Cheliff area. Finally, the challenges to be taken in the coming years are considerable. On the one hand, it is a question of dealing with the constraints of climate change and on the

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other hand, making a considerable effort to improve the yields of our irrigation systems.

Keywords: Upper Cheliff, Northwestern Algeria, irrigated perimeters, WUE, efficiency, climate change.

摘　　要

本文針對阿爾及利亞西北部Cheliff山谷上游(El Khemis和El Amra-Abadia平原)的灌溉周邊進行研究，探討Cheliff山谷大型灌溉周邊開發關聯的主要指標，Cheliff乾河谷全長逾730公里。通過應用指數測量2010-2019年期間Cheliff上游平原周邊的網絡效率(E1)和地塊效率(E2)的結果表明，灌溉用水效率指數(WUE = E1*E2)可用以追蹤節水力度。El Khemis和El Amra-Abadia平原的結果分別為38%和36%。這個數字仍相當低，並且嚴重受到長距離乾河直接釋放、水盜竊、效率低下和維護不善的網絡、缺乏統計和浪費等損失的影響。事實上，降低灌溉系統的滲漏可以節省大量的水，從而減輕對現有資源的壓力，並減緩缺水的現象直到2030年。節省大部分損失或浪費的水於技術上具備一定可行性，並且成本遠低於為滿足日益加劇的用水需求而需額外產水的成本。此外，種植面積在2011-2019年期間發生了變化。 馬鈴薯、穀物和果樹在Cheliff上游地區表現出顯著的進化。然而因氣候變化帶來的壓力，以及需要努力提高灌溉系統下的產量，未來幾年仍需要面臨不小的挑戰。

關鍵詞：Upper Cheliff，阿爾及利亞西北部，灌溉周長，水分利用效率，氣候變化。

1. INTRODUCTION

In the world, 70% of the freshwater withdrawn is used to irrigate 25% of the cultivated land that provides 45% of the world's food (Thenkabail *et al.*, 2011).

The Mediterranean basin has been identified as one of the most vulnerable regions to "water crises" due to limited water resources, significant climate change and increasing anthropogenic pressures (Plan Bleu, 2013). In this context of climate and anthropogenic changes, the exploitation index of renewable water resources is expected to deteriorate by 2050 (Plan Bleu, 2012). Algeria is one of the southern countries of the Mediterranean basin that suffers from water scarcity from one season to another, and from one year to another. The water potential is globally estimated at 19 billion m^3/year (corresponding to about 600 m^3/inhabitant/year) and Algeria is in the category of countries poor in water resources regarding the scarcity threshold set by the World Bank at 1000 m^3/inhabitant/year (UN, 2002). Water flows are characterized by significant seasonal and inter-annual irregularity, violence, and rapidity of floods. The climate in Algeria is semi-arid (200 mm to 500 mm) from which resources are increasingly limited and difficult to exploit (Kettab *et al.*, 2004).

The West of the country has experienced several major droughts during this century, in the 1940s and the 1980s until today (Khaldi, 2005). The most recent one, characterized by the decrease in rainfall associated with a significant increase in temperature during the last two decades, has been influenced by its spatial magnitude, its intensity and by its major impact on the decrease of water resources (Errih, 1993; Meddi and Hubert, 2003; Habi and Morsli, 2011; Meddi and Talia, 2011; Taibi *et al.*, 2015; Zeroual *et al.*, 2017; Hallouz *et al.*, 2019; Hallouz *et al.*, 2020). Indeed, regardless of the importance of these infrastructures, surface resources remain closely dependent on rainfall, where the drought has significantly affected the level of water reserves that has reached a critical threshold and no longer allows for improvement and proper distribution. This situation has severely penalized all sectors (population, agriculture, and industry) (Hamlat, 2014).

The country during the period of 1973-2000 certainly experienced a succession of periods of severe and persistent, particularly in the western regions before expanding to the whole country, resulting in a rainfall deficit of 30% and reducing the mobilizable potential by 11% (ANRH, 2001).

From this perspective, water demand management is a key focus undertaken before moving on to supply management. Each territory is experiencing an imbalance between water demand and available resources. Water management must be improved to limit leakage, one of the major causes of water shortage. Reducing leakage in irrigation systems could generate a considerable volume of water that would reduce the pressure on existing resource and reduce the water deficit until 2030. Saving much of the lost or wasted water is technically feasible and would cost far less than the cost of producing water to meet additional future water needs (Chabason, 1998). For this reason, the mobilization and optimal use of water are the foundations of agricultural hydraulics, which has been under the remit of a Ministry of Water Resources since 1999. Algeria covers an area of almost 2.4 million square kilometers divided into two climatic zones (Guemraoui and Chabaca, 2005):

- The northern zone accounts for 14% of the territory, its climate is sub-wet to semi-arid;
- The southern zone accounts for 86% of the territory, its climate is Saharan;

The potential for good quality irrigable soil exceeds 1.5 million hectares according to studies conducted by the National Agency for Hydraulic Resources (ANRH, 2001). The future irrigation targets chosen by the various national development plans are 1 million hectares, 40% of which are in large irrigation areas (Guemraoui and Chabaca, 2005).

Thus, the total irrigated areas throughout the National territory represent less than 6% of the useful agricultural area (AAU), however, the commercial value of irrigated agricultural production represents according to the years almost 50% of the total amount of land's products (ONID, 2012a).

This clearly shows the importance of irrigation in the development of agricultural production. To address these challenges, in coordination with the Ministry of Agriculture and Rural Development (MARD, intervention on water systems to increase their performance is one of the indispensable and urgent solutions advocated in the new water policy (Water Act, 2005) to improve the resource economy (JORA, 2005; PNE, 2005).

According to the Ministry of Water Resources (2019), annual water needs by 2030 will have to be 12.9 billion m^3 for a population of around 50 million people, compared to 10.4 billion m^3 currently. The annual requirements for 2030 are as follows:

- 4 billion m^3 for The Drinking Water Supply (compared to 3.3 billion m^3 currently);
- 8.3 billion m^3 for agriculture (compared to 6.8 billion m^3 currently);
- 0.6 billion m^3 for industry (compared to 0.3 billion m^3 currently)

In agriculture, two extreme scenarios (Algeria) arise:

- One with little change in the efficiencies, an average extension of irrigated areas and the maintenance of current crops, the demand for irrigation water would be 15.4 billion m^3;
- On the other with improved efficiencies (80%), an extension of the area to 2,000,000 ha and the development of cereal and forage crops, the demand for irrigation water would exceed 20 billion m^3.

Also, the existing large irrigation perimeters, supplied mainly from dams, have twenty-five (25) and a total area of around 206,404 hectares, as well as nearly 164,000 ha (79%) irrigable (ONID, 2012b). Of this area, about 120,000 hectares operate as a gravity. Pressurized irrigation systems cover about 86,000 hectares and cover recent perimeters. They are managed by the National Office of Irrigation and Drainage (ONID) and the wilaya offices (OPIW). This study concerns the irrigation perimeter of Upper Cheliff (Plains of El Khemis and El Amra-Abadia) (State of Ain Defla, north-west Algeria), built-in 1941 and rehabilitated in 2011 (Fig. 1). The Upper Cheliff region and its plains are part of the northern part of the Cheliff watershed in northern Algeria, which is characterized by a semi-arid climate. The overall approach to water resource management of this perimeter incorporates three levels: reservoir dam management, management of the irrigation network, irrigation management at the parcel.

It is, therefore, necessary to introduce the efficient management of water resources that are already scarce. To do so, a concept called water use efficiency, or more simply called irrigation efficiency. This concept is widely used throughout the world (Wang *et al*., 1996; Multscha *et al*., 2017; Koech and Langat, 2018; Nini and Mebarki, 2020). Technically, it is based on a volumetric or hydrological approach, i.e. the part of the water distributed for irrigation that is used to increase productivity. This definition is mainly used for field projects inherent to irrigation water management. It is also valid at the scale of a watershed or basin scale (Qureshi *et al*., 2011; Koech and Langat, 2018). Water efficiency is one of the objectives of the Mediterranean Strategy for Sustainable Development of the Blue Plan (Blinda, 2012).

In Algeria, the size of the volumes of water used in agriculture shows that the potential for water savings can be realized in this sector and can be in the range of 20 to 25%. With a saving of 20%, i.e. 1.4 billion m3, half of the Algerian population could be supplied with drinking water at present. These recoverable volumes could irrigate 300,000 hectares of additional planted land, or 30% of the total irrigated area, according to the Ministry of Water Resources.

Total efficiency calculations have focused on irrigation campaigns from 1990-2019 at the El Khemis plain and the 2006-2019 campaigns at the El Amra-Abadia plain.

In this study, the operating diagnosis and the analysis of the hydraulic performances will be used to assess the level of achievement of the objectives of valorization, water saving, and improvement of the efficiency of use of the resource in the agricultural sector through the implementation of modern irrigation systems.

2. ANALYSIS OF IRRIGATION USES

The use of irrigation in Algeria is very old as shown by the remains of the Roman era (basins, aqueducts...). Ancient irrigation techniques are still working to this day. These different techniques (foggaras, seguias, wells...) are adapted to a potential of greater diversity (coastal plains, foothills, high plains, steppes, oases...). The construction of the current Algerian perimeters began during the colonial period (ONID, 2012a).

Irrigation perimeters can be categorized into two (02) categories:

- The ancient perimeters: inherited from colonization with traditional gravitational irrigation (channels and seguias).
- Recent perimeters: made after independence where modern irrigation techniques dominate sprinkling and localized irrigation.

3. STUDY AREA

The Cheliff Valley, crossed by the Wadi Cheliff, is located in the northern part of the Cheliff watershed, which occupies 22% of the area of northern Algeria (ONID, 2006).

The Upper Cheliff perimeter is both the oldest and most extensive of the Algerian irrigable perimeters, created in 1941, it is 40 km from the sea. It stretches along the wadi Cheliff valley on the right and left banks from the municipality of Djendel in the east to the municipality of El Attaf in the west, a length of about 75 km (fig. 1). The perimeter is composed of the plains of El Khemis

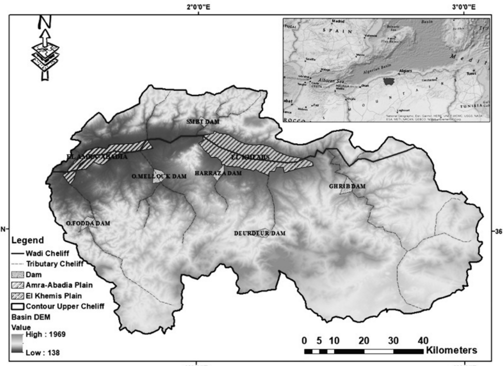

Fig. 1. Location of Upper Cheliff plains.

and El Amra - El Abadia. The average width of the perimeter is eight (08) km. The climatic conditions are harsh (very hot summers, very irregular rainfall around 470 mm), but the alluvial soils are of very good quality, and the region benefits from several developments carried out on a wadi whose hydrological regime was very irregular (BRL, 2007).

The Wadi Cheliff, over a length of 730 km, is the main adductor carrying water dropped from the dams to the stations. The bed of Cheliff's wadi has lost its original shape with the phenomenon of carriage and erosion due to the transport of materials. The Cheliff wadi regime is characterized by extreme irregularity, which has led to the construction of several regulatory structures for irrigation water needs (BRL, 2007).

a. Climatology

The climate of the Upper Cheliff of Mediterranean type is relatively homogeneous on the whole with hot and dry summers and cool and rainy winters. It is characterized by light winds of less than 10 km/h and high average sunshine, varying between 60 and 80% of the day's duration depending on the season (ONID, 2006). In the study of the National Water Plan (1997), for the period 1910-1983 the weather stations showed two more pronounced areas of precipitation around Ain Defla: the Dahra massif and the Ouarsenis with a maximum of 800 mm. Between these two reliefs reigns the Cheliff valley which corresponds to a minimum rainfall of 350 mm.

- Winter rains (October-January) account for 50% of the average annual rainfall.
- Summer rains (June-September) account for only 10%.
- The remaining 40% is the period from February to May.

Indeed, the climate is a limiting factor for plant production and essentially in the Mediterranean region with contrasting seasons. It intervenes through its main components, which are precipitation, temperature, insolation, wind, frost, relative humidity, fog, sirocco, and evaporation. In our area, we note that precipitation is low, irregular, and random with a high interannual variability with an average of about 480 mm. A maximum of 627.1 mm of rainfall, relative to the observation period considered (1975-2017), was recorded in 2008/09, while a minimum of 192 mm was recorded in 1978/79. Note that 80% of rainfall is concentrated between November and February (Madi *et al*., 2018). Maximum temperatures exceed 30 degrees from May to October and imply a fact that evaporation exceed 1500 mm/year (Madi *et al*., 2018). This climate is qualified by climatologists by the tell oven, or a portion of the Sahara strayed into the tell (Madi *et al*., 2018). On the other hand, the Thornthwaite water balance is established month by month, over the period 1975-2017, from rainfall (P), evapotranspiration (ETP) and the readily usable reserve (RFU) taken equal to 100 mm (Thornthwaite and Mather, 1955). It allowed us to estimate the annual agricultural deficit at 615.5 mm, with a maximum value of 170.80 mm recorded in July. Depending on the results of this assessment, irrigation is required from April to October.

b. Water resources

At the El Khemis plain, a classified area of 37,020 ha with a total area of 20,300 ha (Tab. 1),

Table 1. Upper Cheliff Irrigation Perimeters (Water Areas and Resources) (ONID, 2012b)

Perimeter	Plain	Creation date	Wilaya	Area (ha)		Water Ressources
				Equiped	Irrigables	
Upper Cheliff	El Khemis	1941	A. Defla	20300	19746	Ghrib/Deurdeur/ Harraza/ Borehole
	El Amra-Abadia	2006	A. Defla	8495	7220	Sidi M'Hamed Bentaiba/Ouled Mellouk
	Total			28795	26966	

the dam policy can be summed up in two distinct periods. The first dates back to the colonial period with the construction and reception of the Ghrib Dam (Tab.1) (1939, located in Wadi Chorfa, the initial capacity of 280 million m^3, Drinking Water Supply + irrigation), initially with a capacity of 280 million m^3 (Perennes, 1987), which underwent major work in 1995, namely the preparation of the upstream slope coating, two elevations of the dike in 1995 and 2003, and works to raise the spill threshold in 2007 by achieving a device consisting of twenty (20) fuse increases to reinforce the dam's useful capacity from 115 million m^3 to 185 million m^3. The latter is heavily silted up, yet the little attention paid to the protection of watersheds. As for the second period, it corresponds to the impetus given to the large hydraulic sector during the 1980s, which resulted in the receipt of new reservoirs on the tributaries of the Cheliff. These are the Deurdeur (1984, located in the municipality of Tarek Ibn Ziad, an initial capacity of 115 million m^3, intended for the Supply of Drinking Water + irrigation) and the Harraza (1984, in the municipality of Djelida, with a capacity of 75 million m^3, intended for irrigation) which regulate respectively 44 and 23 million m^3 (Tab.2) (Perennes, 1987).

The El Amra-El Abadia Perimeter, with an equipped area of 8,495 hectares, with an irrigable area of 7.220 hectares (Tab. 1), is located on the right bank of the Wadi Cheliff. The water resources that feed this Great Irrigated Perimeter has their origin from the Sidi M'Hamed Ben Taiba dam (2006, located in the municipality of Arib, the initial capacity of 75 million m^3, intended for Drinking Water Supply + irrigation) and the Ouled Mellouk dam (2005, in the municipality of Rouina, with an initial capacity of 127 million m^3, intended for drinking water supply + irrigation) (Tab. 2).

c. Water systems

The plain of El Khemis presents, between the municipality of Djendel in the east and the municipality of Arrib in the west, the shape of an elongated spindle of east-west direction with a

Table 2. Operating dam (regular volume and assignment) (ONID, 2012b)

N	Dam	Wilaya	Type of Dam	Year commissioned	Initial capacity 10^6 m^3	Capacity according to latest survey 10^6 m^3	Regularized volume 106 m^3/Yr	Assignment
1	Deurdeur	A. Defla	Earth Dam	1984	115	105.12	40	Mixed
2	Harraza	A. Defla	Earth Dam	1984	70	76.65	23	Irrigation
3	Ghrib	A. Defla	Earth dam	1939	280	115.32	105	Mixed
4	S.M.B. Taiba	A. Defla	Earth dam	2005	75	75	21	Mixed
5	O. Mellouk	A. Defla	Earth Dam	2003	127	127.00	38	Mixed
	Total				667	499.09	227	

length of 35 km, the average width is about eight (08) km. The Cheliff wadi divides the perimeter into two (02) banks: A right bank with a geographical area of 11,305 hectares divided into five sectors and a left bank with an overall geographical area of 9,730 ha (ONID, 2012a).

The El Khemis plain has (03) three pumping stations and five (05) reprise stations and three (03) storage and control tanks. These three stations have undergone a complete renovation of the hydromechanical part. The dominant irrigation methods are sprinkling and gravity (ONID, 2005).

As for the plain of El Amra- El Abadia, the installation of the network is very recent. Its commissioning dates back only to 2006, it has three (03) pumping stations including one (01) reprise station and three (03) storage and control tanks (ONID, 2007).

d. Network diagnosis

In the case of the plain of El Khemis, these are works dating back to the 1940s. The first development concerned the right bank, which was equipped with a low-pressure network powered in the head by the Djendel station (formerly), the low pressure mainline that crosses the perimeter from east to west, two compensation tanks distributed along its course and an extensive network of low-pressure pipes (Cherfaoui and Hallouz, 2008). Designed at the end of the 1960s, the modernization and extension of the facilities of the Upper Cheliff perimeter aimed at an extension of the irrigation networks by densification on the right bank and the creation of specific infrastructure on the left bank. Similarly, new developments have been planned to replace gravity irrigation with sprinkler irrigation for, among other things, intensive crops (Cherfaoui and Hallouz, 2010).

The modernization and extension of the infrastructure of the right bank-led (BRL, 2007) (fig. 2):

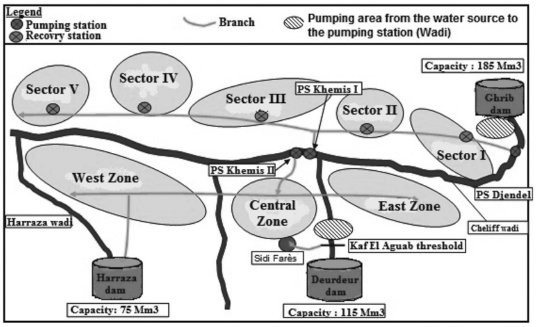

Fig. 2. Diagram of the irrigation network of the El Khemis plain (BRL, 2007).

- To the reinforcement of dewatering pumping consisting of : (i) the Djendel pumping station and its 40,000 m^3 regulation-compensation tank, (ii) the construction of the Khemis I pumping station and its 10,000 m^3 regulation tank; the latter was connected to the existing main pipe which was initially powered by the load breeze of El Khemis.
- In a second step, the modernization and extension of irrigation infrastructure were carried out by dividing the right bank into, with a geographical area of 11305 ha, into 5 sectors (Sector n°01 Djendel: 1610 ha, Sector n°02 Ain Chaiba: 920 ha, Sector n°03 El Khemis: 3190 ha, Sector n°04 Sidi Lakhdar: 2885 ha and Sector n°05 Arib: 2700 ha). The developments included construction:
- 5 pressure pumping stations,
- 3 basins to supply the pressure pumping stations in the Ain Chaiba, Sidi Lakhdar, and Arib sectors, with Djendel and Khemis being supplied directly by the drainage basins,
- 5 regulation tank,
- a sector-specific pipeline network.

The development of the left bank, with a geographical area of 9,730 ha, are divided into three (03) sectors: Sector West: 4,717 ha, East sector: 1,950 ha, and central sector: 3,063 ha, differs from that of the right bank by the adoption of a pumping system by direct discharge, the regulation being ensured by an elevated tank located at the place called Sidi Farès, at the end of the branch qualified as discharge. This tank is associated with a 40,000 m^3 ground compensation basin that has been planned to prevent the irrigation network drainage in the event of a stop pumping, considering the on-demand distribution method selected (BRL, 2007). The diagnosis showed that the old network is partly functional: it is well adapted to gravity irrigation and serves areas where the new network has shown failures (frequent breakage of certain sections). The maintenance of the functional branches of this network at the lowest cost is an option desired by the manager, the investments will consist of renewing the old equipment that leaks or is inoperative. The branches of the old non-functional network will not be rehabilitated; they are permanently replaced by the new network. The network of the left bank is a new network (1975), the old network concerned only a small surface and is abandoned. This network is fed by the Khemis II station, the distribution back-up pipeline to the Sidi Farès reserve and the elevated regulation tank. The diagnosis of the network showed that the failures were mainly due to the head system which operates in a situation of shortage of inputs in the wadi Cheliff at the station Khemis II. Consequently, the number of pumps in operation is limited by the flow available in the wadi. Since the station discharges into a distribution discharge pipeline, if the flow called by the network exceeds the flow of the pumps, they operate outside their normal range of operation and there is premature wear of the pumps due to cavitation. These failures have occurred several times. Doubling the discharge pipeline is evaluated as a solution to this problem (BRL, 2007).

This description shows that the initial design of the irrigation infrastructure and its reinforcement leads to significant pumping, each cubic meter delivered is raised over 100 m: 110 m for the left bank and 120 m for the right (50m for drainage and 72 m for recovery (BRL, 2007). In the face of this state of gravity distribution, the mode of gravity distribution has once again become the rule for the right bank; the practice of sprinkling mainly for the potato is obtained by thermal pumping downstream of the outlet. The extension of the orchards was accompanied by the promotion of localized irrigation.

Finally, and in order to strengthen the water resource and reduce pumping heights, rehabilitation projects were carried out in 2008 (BRL, 2007), namely:

i) a direct water supply from the Deurdeur Dam to the eastern and central zones,
ii) irrigation of the western zone from the Harraza dam.

e. Irrigation regime and frequency

First of all, the plain of El Khemis has benefited from a long experience in terms of irrigation where, the INRA station of Khemis - Miliana served as a place of experimentation for the irrigation trials in the 1960s. This allowed farmers to have an annual irrigation plan. A technical reference sheet has been established and determines the periodic doses of water required per unit area for each crop. A cooperative effort has been made with OTAM-France and the INRA station in Khemis-Miliana. This was not the case for El Amra-El Abadia, which does not have an experimental station. A foreign consultancy firm has been approached by the Algerian State to study the irrigation project of the El Amra-El Abadia plain. However, a major problem arises in the case of irrigation doses with climate change. The use of drip irrigation is not very efficient. In addition, farmers in the El Amra-El Abadia plain did not wait the National Office of Irrigation and Drainage (ONID) for the issue of irrigation. Indeed, before the switch to large-scale hydraulics (LSH), farmers in this region have resorted to the Small and Medium Hydraulics. And to this day, farmers still use the Small and Medium Hydraulics (SMH) in order to use a surplus of water per hectare. This makes it possible today to think that the "SMH and LSH" MIX is the most widely used in the region. In fact, irrigation on the Office's perimeters takes place in a relatively permanent context of water scarcity. The problem for the National Office of Irrigation and Drainage (ONID, 2006) is not commercial (irrigators are generally ready to buy more water than the National Office of Irrigation and Drainage can supply) but technical; it must ensure that the available water is brought to the plots with the minimum amount of water loss available and it must organize its distribution.

As a result, irrigators do not have the choice of the doses to be applied to crops. It is the Board that sets the annual volumes distributed, according to the needs of the crops. The National Agricultural Policy (priority to strategic crops) and the water resource quotas that are allocated to it. First, (currently in January-February) the user must submit the irrigation request to the National Office of Irrigation and Drainage, formalized by signing a subscription on which he indicates the location of the plot to be irrigated, the surface area of each crop, as well as any additional information: irrigation method, flow rate demand for the Upper Cheliff perimeter and etc.

The annual volume per hectare for each crop is then fixed before the beginning of the campaign by the National Office of Irrigation and Drainage according to the resources allocated based on the level of the dams, the transit capacities of the network, and the subscriptions recorded (Table 3). The National Office of Irrigation and Drainage then informs the irrigators of the volumes allocated for the campaign on the parcels requested. In doing so, it undertakes to deliver a given annual volume according to a schedule corresponding to the needs of the declared crop. The forecasts at the beginning of the campaign made it possible to determine the volume that should be delivered to each parcel for the duration of the entire campaign. As distribution is generally processed by water tower, the National Office of Irrigation and Drainage then

Table 3. Irrigation water requirement (per plant) (in mm per month or per year)

	10	11	12	1	2	3	4	5	6	7	8	9	Total
Wheat					22	55	77	96	43				293
Grain barley					22	51	58	17					148
Early Bersim	35	5			19	51	64	25			20	57	236
Late season sorghum	65								106	185	212	110	678
Oven Sorghum -early	49	15				7	63	143	106	185	212	81	861
Alfalfa	46	2			17	34	70	135	174	200	150	89	917
Cauliflower	66	5								103	140	143	457
Early potatoes						25	102	141	76				344
Late potatoes	74									62	148	160	444
Melons							49	135	187	200	85		656
Peppers							58	135	206	215	170	57	841
Artichokes	65	10			14	34	64	48	98	150	159	120	802
Tomato, fresh or frozen						12	83	134	152	175	74		630
Grainy corn							46	135	228	225	112		746
Industrial Tomato							40	127	204	175	148	50	744
Citrus	46				8	26	59	97	141	162	138	96	773
Apple trees	50					16	59	133	217	250	235	133	1092
Pear trees	39					26	59	84	194	223	189	120	934

* Built from operating balance sheets OPIC/ONID. Khemis-Miliana.

sets the volume allocated to each parcel per week. The staff in charge of organizing the distribution has a theoretical schedule for the distribution of weekly doses which gives them (unless otherwise requested by the user, which is satisfied according to the possibilities of the network) the volume to be delivered for such crop and area for the week under consideration. The user is informed at the end of the week for the following week(s) by a document, giving the characteristics of the water turn. The water turn is most often kept the same or with few changes over four consecutive weeks, it is established by the managers and calculated based on a theoretical schedule of doses per crop and per month (Table 3).

In the event of a water shortage, these rates are revised annually by the board based on the water resources allocated to it and the forecasting crop plan. Moreover, this irrigation schedule does not correspond to the modulations of calculated needs. There seems to be a consolidation of irrigations over the summer months, irrigation is essential and theoretically easier to organize during this period. It seems essential to extend the duration of the irrigation campaign to start as early as March if necessary and to be ready to provide supplemental irrigation during a dry winter even if the irrigation campaign has not really started and the demand only concerns certain crops.

In general, it can be noted that even if the farmers are free to choose the crops practiced in the case where there is no strong restriction due to the state of the network or the insufficiency of the resources of the perimeter, they could not master the choice of the doses to be brought according to the stage of development of his crop (except modification of the water turn at his request, however, the possibilities remain limited).

He is also not in control of the flow that is allocated to him, which the gravity network corresponds to the average water hand allocated to all the farmers in the area.

Finally, famers are not in control of the frequency of irrigation, which is generally once a week and can only be increased in exceptional cases. To the farmer, the choice of irrigation method remains. On the Upper Cheliff, there is generally the possibility of using medium pressure sprinkler equipment, localized irrigation equipment or simply pipes leading to the parcel irrigated by gravity (rays for market gardening, basins for arboriculture) (Table 4).

Table 4. Evaluation of linear structures

Upper Cheliff perimeter		Units	Linear
1. El Khemis plain		ha	20300
Equipped area			
1.1. New network			
Pipes	Main	Km	189
	Secondary	Km	113
	Branch	Km	475
Drains	Main	Km	88
	Secondary/Tertiary	Km	-
Tracks		Km	300
1.2. Former network			
Pipes	Main	Km	99
	Secondary	Km	58
2. El Amra-Abadia plain			
Equipped area		ha	7220
Pipes	Main	Km	30
	Secondary/Tertiary	Km	127
	Branch	Km	-
Drains	Main/Wadi	Km	61
	Secondary/Tertiary	Km	149
Tracks		Km	57

* Built from operating balance sheets OPIC/ONID. Khemis-Miliana.

4. REHABILITATION OF HYDRO-AGRICULTURAL INFRASTRUCTURE ON BOTH PLAINS

4.1 El Khemis Plain

Given the potential for agricultural land and water resources in the Wilaya of Ain Defla and the equipment already in place since 1941, a complementary development for the comfort of existing structures to enable the new system rehabilitated and completed to respond effectively to the existing irrigation needs of the Upper Cheliff perimeter (BRL, 2007).

The works that make up the project are as follows:

1 - Achieving the Kaf El Agab diversion threshold.
2 - Construction of an adduction pipe connecting the Kaf El Agab threshold to the existing tank Sidi-Fares over 15 km, ND 1200 mm, PN 16 bars.
3 - Achieving Djendel's diversion threshold.
4 - Realization of the bypass threshold of the Khemis pumping stations (I and II).
5 - Rehabilitation of the civil engineering of the STP (Khemis I, II, and Djendel).
6 - Construction and equipment of the Harreza pumping station, capacity 2 $m^3.s^{-1}$.
7 - Construction of the 1750 m^3 Harreza elevated tank.
8 - Construction of the Harraza water pipe over 1.5 km in FTI DN 1200 mm PN 16 bars.

Since the total flows required are approximately 9.5 $m^3. s^{-1}$, it will be necessary to distribute the demand for water in two or three days. Taking into account the maximum capacity of the main pipe, the distribution in three days was adopted. It should be noted that the left bank of Upper Cheliff is divided into three distinct zones: East, Central and West zones (ONID, 2006). Maximum demands for irrigation water are recorded in July. Total applications are 3.3 $m^3. s^{-1}$ for the East Zone and approximately 3.1 $m^3. s^{-1}$ for the West and Central Zones (BRL, 2007). The different impacts of this achievement on the physical, biological and human environment as well as the proposed mitigation measures can be summarized as follows (BRL, 2007):

- Improved performance of the existing irrigation system by about 60% for the left bank and about 65% for the right bank.
- Preservation and improvement of existing ecosystems such as filling the Harraza tank, maintaining an ecological flow in the Deurdeur wadi, etc.
- Relief of Khemis II Pumping Station.
- Reducing electricity consumption by about 50%.
- Job creation and improved economic conditions for the people of the area.

4.2 El Amra-Abadia Plain

Due to the lack of structures (adductors), linking the dam to the perimeter, irrigation of the perimeter of El Amra-Abadia is done from releases on the Wadi Ebda from the Sidi M'Hamed Ben Taiba (SMBT) dam to the threshold of El Amra (ONID, 2007).

Also, the illicit piquing carried out in an anarchic manner on the Wadi Cheliff, makes it difficult if not impossible to use the waters of the SMBT dam in a rational and controlled manner for agricultural purposes following their destination.

This has led to a significant decrease in the volume of water used to irrigate the El Arma and Abadia perimeters. Therefore, the choice of routes and the definition of an adduction mode are among the major concerns.

Thus, the study of the adduction variants consists of retaining the solution which will make it possible to channel the water from the dam to the two stations (El Amra - Abadia) over a line of about 36 km (Fig. 3) (ONID, 2007).

It will also involve the rehabilitation of the two existing pumping stations by connecting them to the pipeline to be planned. The water intake will be at the level of the Hollow Jet, with an available load of 4.3 bars that correspond to the normal retention level (ONID, 2007).

5. CONCEPT OF EFFICIENCY AND TOTAL WATER LOSS IN IRRIGATION SYSTEMS

The amount of water needed for crops varies

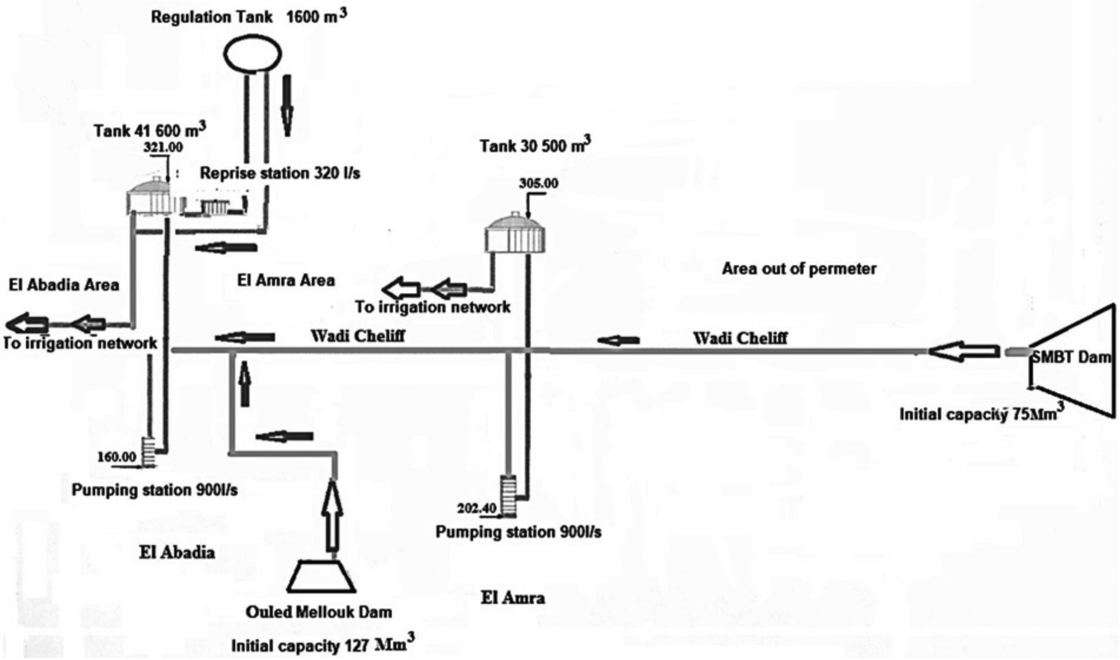

Fig. 3. Diagram of the irrigation network of the El Amra-Abadia plain (ONID, 2007).

according to plant species and climatic conditions, but they cannot be reduced without also reducing agricultural production: to maximize the investment, water supplies close to maximum evapotranspiration (ETM) are often made to do high production (Granier and Deumier, 2013).

In addition to improving plant water efficiency through genetic progress, there is room for improvement by seeking better control of water losses at all levels. These losses are largely related to the irrigation techniques used, and the indicator that allows us to assess them is the efficiency of irrigation water (Granier and Deumier, 2013).

Indeed, the concept of irrigation efficiency, which was still limited to the ratio of water consumed in the root zone to that used before the Second World War, in the 1950s, became a factor used in engineering for the design and operationalization of irrigation technologies (van Halsema *et al.*, 2012). Beginning in the 1990s, the concept of efficiency expanded to include studies of the technical and economic performance of irrigation and water accounting at the water resource scale, incorporating the concept of productivity (Lankford, 2012). This index tracks water and makes it possible to monitor the efforts made in terms of water savings through demand management by reducing losses and waste during transport and use.

The fundamental objective of saving water in a perimeter is to try to reduce overexploitation by reducing losses and removals. There are generally three levels of irrigation water efficiency: course efficiency, distribution efficiency, and total efficiency of the irrigation system (Granier and Deumier, 2013).

5.1 Methods for estimating water use efficiency

5.1.1 Water Use Efficiency (WUE)

Irrigation water efficiency depends on irrigation methods and technologies at the parcel and is expressed without units (i.e. percentage) (Machibya *et al.*, 2004). The method of calculating water efficiency was adopted as part of the Mediterranean Strategy for Sustainable Development (MSSD) du

Plan bleu (Blinda, 2009, Nini et Mebarki, 2020, Blinda, 2012). It represents the product of the efficiency of the transport and distribution systems of irrigation water by the efficiency of the parcel (Expósito and Berbel, 2017):

$$WUE = E1 \times E2 \tag{1}$$

This index tracks water savings efforts through demand management by reducing losses and wastes in transportation and use (Perreira, 2005; Hsiao *et al*., 2007; Blinda. 2012; Koech and Langat, 2018; Nini and Mebarki, 2020).

5.1.2 Global Network Efficiency (E1)

It is the efficiency of the irrigation water transport and distribution networks upstream of the agricultural parcels, measured as the ratio between the volume of distributed water Vd at the top of the parcels (m^3) and Vl the volume of water dropped from the dam (water source) upstream of the networks (m^3), including losses in the networks (FAO, 2003; Blinda, 2012).

$$E_1 = Vd/Vl \tag{2}$$

The efficiency of irrigation networks (E1) can be estimated by the management structures when measuring instruments are available on the networks (counters, use of satellite images, etc.). It is specific to each network. However, it would be possible to assess a national average efficiency by averaging the efficiencies of each network, weighted by the volumes transiting each year (Thivet and Blinda, 2007, El Amri, 2014).

5.1.3 Parcel irrigation efficiency (E2)

Some of the water brought to the head of the parcel is lost, either because it infiltrates deep into the ground without benefit to the plants, or because some of it evaporates directly (period of high heat), either it runs off the ground and reaches the ditches of the wastewater system (PNE, 1997).

Indeed, the efficiency of irrigation to the parcel defined as the sum of the efficiencies (to the parcel) of each irrigation method (surface irrigation, sprinkler irrigation, micro-irrigation, other irrigation modes), weighted by the respective proportions of the different methods in the country and estimated as the ratio between the quantities of water efficiently consumed by the plants and the quantities of water brought to the parcel (Louhichi *et al*., 2000; Machibya *et al*., 2004; Blinda , 2012):

$$E_2 = \sum_1^n \frac{S_m \times E_m}{S} \tag{3}$$

Where:

n : number of irrigation methods used.

S_m : irrigated surface (ha) by irrigation method (gravity irrigation, sprinkling, micro-irrigation, other irrigation methods).

E_m : water efficiency (%) in different irrigation methods.

S : total irrigated area (ha) according to all methods

The actual average irrigation efficiency at Parcel E2 is difficult to measure on the ground, given the difficulty in accurately estimating the amount of water consumed by plants and a large number of parcels. E2 will be estimated. Each country has its own estimates of the average efficiency of different systems, based on pilot experimental sites. The E2 value, thus better reflects the structure of the distribution of irrigated water by major irrigation modes at the national level (Thivet et Blinda, 2007, Blinda, 2012, Granier and Deumier, 2013).

As a first approximation, and in the absence of precise data on the real efficiency of the different irrigation modes, the indicator can be calculated with a theoretical average efficiency estimated at 60% for gravity, 80% for sprinkling, and 90% for localized irrigation (Thivet and Blinda, 2007).

5.1.4 Distribution and delivery efficiency (network) (Er)

Network efficiency (from the dam to irrigation hydrant) as a ratio of the volume of water at the outlet of the irrigation hydrant Vd (m^3) to that pumped to the dam (source) Vp (m^3). This efficiency is estimated by Japanese experts at 0.90, which is to say, that the rate of loss in the distribution network and supply is about 10% (Rinaldi and Ubaldo, 2007; Bhouri Khila *et al*., 2015).

$$Er = Vd/Vp \qquad (4)$$

5.1.5 Course Efficiency (Ep)

It is determined as a report of the volume of water received at the pump station (pumped) Vp (m^3) to that dropped from the dam Vl (m^3) (Bhouri Khila *et al*., 2015).

$$Ep = Vp/Vl \qquad (5)$$

6. PERIMETER-WIDE EFFICIENCY RESULTS

6.1 Changes in water volumes in favor of irrigation in Upper Cheliff

We have the entire data perimeter of the National Office of Irrigation and Drainage-Regional Directorate of Cheliff (ONID-DRCH) on the evolution of water volumes over the periods 1990-2019 and 2006-2019 for the plains of El Khemis (Fig. 4) and El Amra-Abadia (Fig. 5) respectively: Allocated volume, the volume of dropped water from the dam, volume at the head of the network and distributed volume.

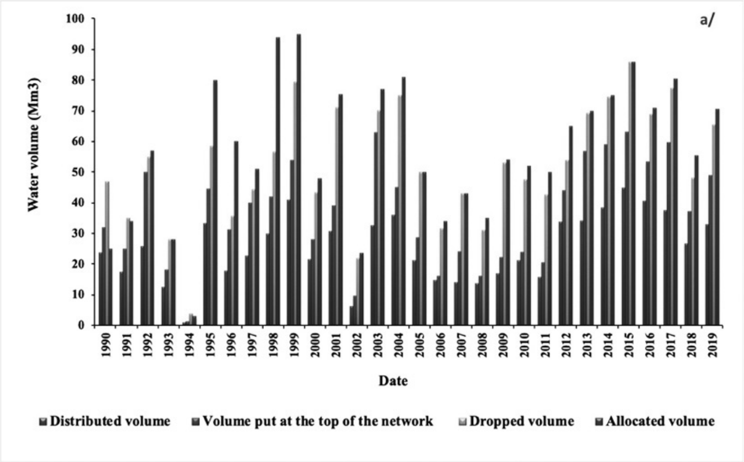

Fig. 4. Evolution of water volumes in the El Khemis Plain.

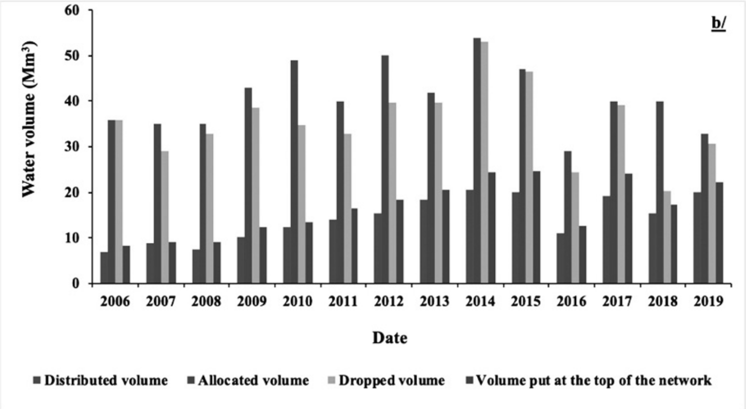

Fig. 5. Evolution of water volumes in the El Amra-Abadia Plain.

For large irrigation areas, the low water supplies of these drought years are fixed for each irrigation campaign by a ministerial circular, usually, in March, even April; and are in any event not comparable to the volumes requested (ONID, 2012a). This approach is doubly penalizing because it makes the revenue base of the managing organizations random (ONID, 2014).

During the 1990-1999 decade, a theoretical water volume of 95 million m^3 was allocated to the perimeter of the Upper Cheliff (El Khemis Plain) in 1999, whereas it was fixed at 25 million m^3 in 1990. Only one exception was made in 1994 with an allocated volume equal to 3 million m^3 and this is due to the Ghrib dam, which was empty because of the repair work of the upstream siding of the said dam.

The period 2000-2009 saw a volume of 81 million m^3 allocated in 2004, compared to a low allocated volume in 2002 equal to 23.50 million m^3.

For the decade 2010-2019, the volumes of water allocated were higher compared to other periods, with a minimum of 50 million m^3 in 2011 and a maximum of 86 million m^3 in 2015. Note that a volume of more than 70 million m^3 was allocated to the perimeter during the year 2019 (Fig. 4).

The volume dropped reached a maximum of 85.88 million m^3 in 2015 and a minimum of 3.82 million m^3 in 1994 due to the Ghrib dam, which was empty because of the repair work of the upstream siding of the said dam. The volume puts at the head of the network ranges from 1.20 million m^3 (the year 1994) to 63.16 million m^3 (the year 2015). The volume of water distributed varies from year to another in an interval between 0.9 million m^3 (the year 1994) and 54.83 million m^3 (the year 2015). The differences between the dropped and distributed volumes reflect the water losses during each irrigation campaign, which vary from year to year (Fig. 4). In inter-annual average value (1990-2019), the dropped volume is 52.24 million m^3 while the volume at the head of the networks is 36.54 million m^3 and finally, the average volume distributed is 32.94 million m^3 (Fig. 4).

In the El Amra-Abadia perimeter, the lowest volume was 29 million m^3 allocated in 2016 (very dry year), and a maximum volume of 54 million m^3 allocated in 2014. Also, the theoretical volume of water allocated to the perimeter was revised downwards (33 million m^3) in 2019 (Fig. 5).

The dropped volume reached a maximum of more than 53 million m^3 in 2014 and its lowest value 20.32 million m^3 was recorded in 2018. The volumes at the head of the network were very low during the first three years of exploitation of the perimeter (approximately 9 million m^3) compared to the volumes dropped. These volumes ranged from 8.33 million m^3 (year 2006) to 24.60 million m^3 (the year 2015). The volume of water distributed varies from year to year in a range of 7.04 million m^3 (the year 2006) to 20.6 million m^3 (the year 2014). In fact, the minimum value of the volume distributed was observed in 2006, which can be explained by the fact that it was the first year of operation and launch of this new perimeter, less subscription of irrigators and this campaign began during the off-season (from September 2006) it was, above all, a year of awareness of farmers for irrigation from the irrigation network established. The differences between dropped and distributed volumes explain the annual water losses, which vary from one campaign to the next (Fig. 5).

As an inter-annual average value (2006-2019), the dropped volume is approximately 35.6 million m^3 while the volume at the head of the networks is 16.67 million m^3 and finally, the average volume distributed at the head of plots (irrigation hydrants) is reduced to 14.32 million m^3 (Fig. 5).

6.2 Total efficiency

a. El Khemis Plain (1990-2019)

Water drops from the dams occurred in wadis. In addition to the natural losses associated with this type of water supply, illicit pumping constitutes a very important part of the loss of route. If efforts have been undertaken to improve parcel efficiency, special attention should be given to improving the course and distribution efficiencies (Messahel *et al*., 2005).

During the 1990-2019 period, the average network efficiency reached 78% (or 22% losses between the volume distributed and the volume at the head of the network (pumped)) (Table 5). The lowest efficiency recorded in 2007 came with 58% (or 42% loss), and the year 2006 gave the best efficiency (92%) with only 8% loss on the network. The loss of the course (33%) between the dam and the entrance to the perimeter, is attributable to the dropped water from the dam in the Cheliff wadi, taken over further downstream by pumping stations serving the perimeter. Considerable losses are recorded for each campaign (evaporation and infiltration) at the level of this adductor, which are

Table 5. Values of efficiencies in the El Khemis Plain

Date	Volume (10^6 m^3)			Efficiency Course (%) (2/1)	Efficiency Network (%) (3/2)	Total Efficiency (%) "Perimeter" (3/1)
	Dropped (1)	Pumped (2)	Distributed (3)			
1990	47.00	32.00	23.70	68	74	50
1991	35.00	25.00	17.38	71	70	50
1992	55.00	50.00	25.76	91	52	47
1993	28.00	18.20	12.50	65	69	45
1994*	3.82	1.20	0.90	31	75	24
1995	58.50	44.50	33.20	76	75	57
1996	35.70	31.20	17.70	87	57	50
1997	44.40	40.00	22.74	90	57	51
1998	56.70	42.00	29.90	74	71	53
1999	79.47	53.83	40.96	68	76	52
2000	43.26	28.04	21.61	65	77	50
2001	71.13	39.04	30.70	55	79	43
2002	21.79	9.59	6.26	44	65	29
2003	70.16	62.95	32.58	90	52	46
2004	74.99	45.05	36.04	60	80	48
2005	50.00	28.74	21.25	57	74	43
2006	31.66	16.04	14.76	51	92	47
2007	43.00	24.00	14.00	56	58	33
2008	31.00	16.00	13.76	52	86	44
2009	53.00	22.28	16.94	42	76	32
2010	47.58	23.95	21.16	50	88	44
2011	42.60	20.48	15.69	48	77	37
2012	53.86	43.98	33.86	82	77	63
2013	69.22	56.79	34.12	82	60	49
2014	74.54	58.99	38.33	79	65	51
2015	85.88	63.16	44.82	74	71	52
2016	68.91	53.37	40.57	77	76	59
2017	77.47	59.69	37.54	77	63	48
2018	48.10	37.16	26.67	77	72	55
2019	65.44	48.91	32.97	75	67	50

*Empty dam (repair work on the dam's upstream siding).

estimated at 30%–35% compared to the allocated quota, thus, the realization of forced pipe remains essential, which will allow to control the discharges well, the rational exploitation of hydromechanical equipment, and ensure the irrigation dose at the right time (ONID, 2005). Direct releases into the wadi posed a positive effect on the support and recharging of the underground reserves in the Cheliff Valley. Also, the supply losses, sometimes significant, are not completely lost or unused, since a part is recovered by farmers (outside the perimeter).

One should note that during very dry years, pumping samples in the wadi are suspended, following the significant decrease in the reserve of the dam which prohibits all releases in favor of irrigation. These restrictive measures emanating from the central authorities are dictated by the priority of covering the needs of the drinking water supply (Nini and Mebarki, 20020). In the absence of upstream resource protection devices (definition of an ecological flow over the wad, continuous control of the level of the aquifer, etc.), the regulation of water withdrawals does not directly related to the sustainable management of aquifers (Nini and Mebarki, 2020).

Moreover, the average efficiency of the course is estimated at 67%. Apart from the year 1994 when the dam was empty (efficiency 31%), the year 2009 shows an efficiency of 42% (i.e. a significant loss of water along the course and equals 58%). Note that during the period 1990-2004, the efficiencies of the course recorded at very acceptable values (91% in 1992 or 8% of water losses) but from 2005 until 2011, the efficiencies are revised downwards, and this is probably due to the redevelopment work launched at the perimeter level. Note that from 2012, water losses along the course ranged from 18% to 26%.

The total efficiency of the irrigation system on the El Khemis plain reached 49% (51% of water loss between the volume at the dam outlet (water source) and the volume distributed (up to the irrigation hydrant). The year 2002 showed a total efficiency of 29% that is 71% of water losses in the irrigation system of the perimeter. On the other hand, efficiency in 2012 was around 63% or 27% of water losses in the irrigation system only, this is probably due to the climatic conditions during this period from which this year recorded a rainfall of about 590 mm (Wet Year).

The total losses of the irrigation system, from the dam to the irrigation hydrant, amount to 25.69 million m^3 per year: the overall losses of the networks represent about 10 million m^3 (or 38.9% of the total losses) and the losses of the course are 15.70 million m^3 (61.11%).

b. El Amra-El Abadia Plain (2006-2019)

Moreover, over 14 years (2006-2019), the average efficiency of the network is in the order of 86%, this can be explained by the fact that this perimeter is newly installed, after one year of operation, this efficiency was equal to 98%, after 10 years of operation, it is in the order of 87%.

The total efficiency that represents the volume distributed within the network is remarkably low during the first years of operation of the El Amra-Abadia Perimeter (2006-2010) (Table 6), but from 2011, the average efficiency is 44%, which means that 46% of the volume dropped has been lost. The maximum total efficiency was observed in 2018 (76%), this year was a surplus from which a significant rainfall was recorded (>700 mm).

To reduce these losses, the volumes used outside the perimeter were considered when calculating total efficiency ((Inside the perimeter (IP) + Outside the perimeter (OP)), which increases the total efficiency within the perimeter and subsequently being able to invoice.

Moreover, the major problem of losses remains in the course and the irrigation system. The average total efficiency of the irrigation system is 41%, that is to say, that over 42 km of water flows from the dam to the pumping station, 59% of the dropped

Table 6. Efficiency values in the El Amra-Abadia Plain

Date	Volume (10^6 m^3)			Efficiency Course (%) (2/1)	Efficiency Network (%) (3/2)	Total Efficiency (%) "Perimeter" (3/1)
	Dropped (1)	Pumped (2)	Distributed (3)			
2006	36.00	8.33	7.04	23	85	20
2007	29.00	9.01	8.83	31	98	30
2008	33.00	9.09	7.58	28	83	23
2009	38.56	12.48	10.22	32	82	26
2010	34.92	13.48	12.38	39	92	35
2011	32.84	16.48	13.98	50	85	43
2012	39.83	18.49	15.34	46	83	39
2013	39.80	20.54	18.49	52	90	46
2014	53.09	24.53	20.60	46	84	39
2015	46.55	24.60	20.04	53	81	43
2016	24.48	12.70	11.10	52	87	45
2017	39.14	24.15	19.25	62	80	49
2018	20.32	17.22	15.52	85	90	76
2019	30.75	22.27	20.16	72	91	66

volume is lost. The highest losses volumes of the course were recorded during the first year of operation of the network (77% in 2006), while the lowest losses are recorded in 2018 (15%), this can be explained by:

- Degradations of the wadi bed following the extraction of aggregates for the needs of the dam works and local needs.
- Additional degradations of the Wadi bed by farmers through the realization of storage basins.
- Loss of course (infiltration - evaporations).
- Very frequent power failure.
- Lack of electrical power for the operation of the groups at the time of irrigation generally causes a disturbance at the level of the program of water distribution to Irrigators.
- The instability of the electrical network in some cases causes the wear of certain electrical parts at the control.
- Siltation of the Thresholds which negatively affect the compensation.

6.3 Water use Efficiency (WUE)

a. El Khemis plain (2010-2019)

In the absence of data, it was considered useful to take a common period (2010-2019) to estimate the different values in the two plains (El Khemis and El Amra-Abadia).

In inter-annual average values (2010-2019), the dropped volume is 63.36 million m^3 while the volume at the head of the networks is 46.65 million m^3 and finally, the average volume distributed at the head of parcels (irrigation hydrants) is reduced to 32.57 million m^3 (Tab. 7).

Over the 2010-2019 period, the overall average efficiency of transport and network distribution reached 51% (or 49% of losses between the volume at the outlet of the dam and the distributed volume) (Tab. 7).

Also, the average parcel efficiency (E2) estimated over the period 2010-2019 for the El Khemis plain is 74%. Given the lack of data, we were unable to calculate this parameter, year by year, over the entire study period.

The water use efficiency (WUE) of the El Khemis plain has reached 38%.

b. El Amra-Abadia plain (2010-2019)

Table 7. Average annual volumes and irrigation water use efficiency in the El Khemis Plain (2010-2019).

Allocated volume (Va) (10^6 m^3)	Volume of dropped water from the dam (Vl) (10^6 m^3)	Volume at the head of the networks (Pumped) (Vp) (10^6 m^3)	Distributed volume (Vd) (10^6 m^3)	Total efficiency (E1) (%)	Efficiency Parcel (E2) (%)	Water Use Efficiency (WUE) (%)
67.55	63.36	46.65	32.57	51	74	38

At the scale El Amra-Abadia plain, for an overall dropped volume of 36.17 million m^3, the volume pumped is 19.44 million m3 and the volume distributed across the plain is reduced to 19.49 million m^3, for a total loss of networks of 21.27 million m^3 (Tab. 8).

Table 8 presents the results of the total average efficiency estimated at 46% and the average efficiency at the parcel (E2) equal to 79%. Finally, the product of these two efficiencies resulted in an average irrigation water use efficiency (WUE) of around 36%.

Besides, the average irrigation water use efficiency (UES) values for both plains remain low in the Management Organization Specific System (ONID).

To increase this efficiency, the management Body (ONID) has adopted a new strategy that consists of accounting for the volumes dropped from the dams and collected along the course upstream of the pumping stations (outside the irrigation perimeter), this is done by authorizing the farmer to subscribe to these areas as crops to be irrigated.

Moreover, the new average Irrigation Water Use Efficiency (WUE) takes into account the volumes (dropped and distributed) and areas irrigated by the pumping ways of the organism and those of farmers.

The water use efficiency (WUE) of the plain of El Khemis reached 36% and that of the plain of El Amra-Abadia is around 38%.

Thus, to increase this efficiency, the managing body (ONID) has adopted a new strategy which consists in accounting for the volumes dropped from dams and collected along the course upstream of the pumping stations (outside the irrigation perimeter), and this, by authorizing the farmer to subscribe these areas in crops to irrigate. In addition, the new average efficiency of the use of irrigation water (WUE) considers the volumes (dropped and distributed) and areas irrigated by the means of pumping of the organization and those of the farmers, i.e., the volumes distributed outside the perimeter. From table 9 shows that the values of average Irrigation Water Use Efficiencies (WUE) have increased from 38 to 48% for the El Khemis plain and from 36 to 47% for the El Amra-Abadia plain (an increase of more than 10% for each plain).

If efforts had undertaken through the National Fund for the Development of Agricultural Investment (FNDIA) to improve efficiency at the parcel, special attention must be paid to improve the course and distribution efficiencies.

This efficiency is currently, on average,

Table 8. Average annual volumes and irrigation water use efficiency in the El Amra-Abadia Plain (2010-2019).

Allocated volume (Va) (10^6 m^3)	Volume of dropped water from the dam (Vl) (10^6 m^3)	Volume at the head of the networks (Pumped) (Vp) (10^6 m^3)	Distributed volume (Vd) (10^6 m^3)	Total efficiency (E1) (%)	Efficiency Parcel (E2) (%)	Water Use Efficiency (WUE) (%)
42.39	36.17	19.45	16.69	46	79	36

Table 9. Average water use efficiency for the two (02) plains (inside and outside the perimeter)

Plain	Distributed volume (Vd) (10^6 m^3)			Total efficiency (E1)	Parcel efficiency (E2)	Water Use Efficiency (WUE)
	(IP)	(OP)	Total	(%)		
El Khemis	32.58	8.41	40.99	65	74	48
El Amra-Abdia	16.69	3.6	20.28	59	79	47

IP: inside the perimeter, OP: outside of perimeter.

around 65%. Reducing it to 85% would result in a significant annual volume gain.

The situation of irrigation in Algeria can be summarized as follows:

- 60% of the area is equipped in gravity;
- Popularization of new irrigation techniques very insufficient;
- Cost of energy and equipment to the relatively high plot;
- Derisory water pricing.

All these factors mean that there is no real incentive to practice water-saving irrigation techniques.

7. IMPACT OF THE RECEPTION ON THE EL AMRA PLAIN ON THE EVOLUTION OF EQUIPPED SURFACES

The reception of the El Amra-Abadia plain allowed for an increase of more than 1/3 of the equipped areas (Cherfaoui and Hallouz, 2010). Undoubtedly, this additional potential in surfaces irrigated from large scale hydraulics will allow irrigation from surface water. This will reduce the use of water from the groundwater.

What about the impact of receiving the El Amra-Abadia plain on the evolution of irrigated surfaces from large scale hydraulics?

8. RECEPTION OF THE EL AMRA-ABADIA PLAIN AND ITS IMPACT ON THE EVOLUTION OF IRRIGATED AREAS

According to Table 10, the average area irrigated in the plain of El Khemis during the period 2010-2019 was not very significant in terms of the equipped surfaces, which are of the order of 20,300 hectares.

It appears that during the 1990-2004 period, the utilization rate of equipping areas was slightly

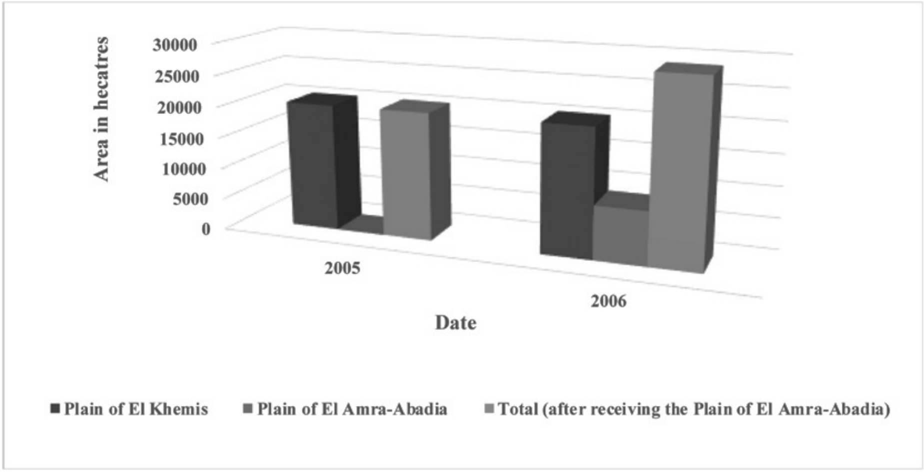

Fig. 6. Evolution of equipped surfaces.

Table 10. Evolution of irrigated areas

Unit: Ha

Irrigation campaigns	El Khemis Plain (1)	El Amra -Abadia Plain (2)	Upper Cheliff (1+2)
1990	3758	-	3758
1991	3573	-	3573
1992	5251	-	5251
1993	3515	-	3515
1994	1782	-	1782
1995	4066	-	4066
1996	3444	-	3444
1997	3366	-	3366
1998	3014	-	3014
1999	4130	-	4130
2000	3264	-	3264
2001	3774	-	3774
2002	1907	-	1907
2003	3638	-	3638
2004	3953	-	3953
Average 1990-2004	3681	-	3496
2005	2565	-	3125
2006	2087	1268	3355
2007	2819	1567	4386
2008	2257	1207	3464
2009	1391	1496	2887
Average 2005-2009	2224	1385	3443
Variation (%) 1990-2004 / 2005-2009	-40.00	-	-1.52
2010	1728	1996	4996
2011	1640	2368	4096
2012	3024	2741	4381
2013	4609	2989	6013
2014	5425	3699	8308
Average 2010-2014	3285	2759	5559
Variation (%) 2005-2009 / 2010-2014	+47.71	+99.21	+61.46
2015	6654	3795	10449
2016	5321	2040	7361
2017	5760	3359	9119
2018	4642	1928	6570
2019	5311	3343	8654
Average 2015-2019	5538	2893	8431
Variation (%) 2010– 2014 /2015– 2019	+68.58	+4.86	+51.66

* Built from operating balance sheets. OPIC/ONID. Khemis- Miliana.

higher than that of 2005-2009 (Figure 7). Indeed, it was 18%, while it is slightly above 11% in the last considered period. Three major constraints explain this state of affair, on the one hand, an almost chronic drought that prevailed during the reporting period, the illegal withdrawals of water dropped upstream of the perimeter, and the transfer for the drinking water supply of surface water. The encouragement of small and medium hydraulics under the National Agricultural Development

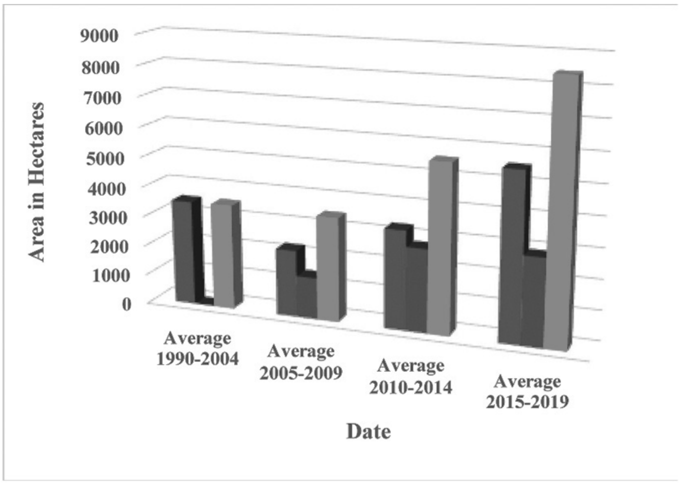

Fig. 7. Average use of irrigated surfaces.

Program has certainly had an impact on the use of surface water. The annual balance sheets of the agricultural sector confirm this finding.

Let's see now, the impact of the reception of the plain of El Amra-Abadia on the evolution of the irrigated surfaces, from the large hydraulics system for the whole perimeter of the Upper Cheliff. As a reminder, the plain of El Amra-Abadia is also competing for its lack of irrigation water by the needs in Drinking Water Supply, from the large hydraulics. Indeed, the dams of Ouled Mellouk and Sidi M'Hamed Ben Taiba also serve the urban areas of the plain in drinking water (Cherfaoui and Hallouz, 2010).

If on reading the operating balance of the two perimeters, the irrigated areas at the level of El Amra-Abadia plain are almost half as low, the yield in terms of the utilization rate of the equipped areas is to the advantage of the latter. Indeed, for the period 2015-2019 the plain of El Khemis, this yield is in the order of 27%, while for that of El Amra-Abadia plain, it is 14% (Fig. 7).

9. IMPACT OF THE TRANSITION TO LARGE SCALE HYDRAULICS ON THE EL AMRA-ABADIA PLAIN ON WATER AVAILABILITY

The substitution of large hydraulics to the small and medium hydraulics on the El Amra-Abadia plain has affected, on the one hand, of preserving the water resources available at the groundwater and on the other hand of reducing somewhat the abusive practice of drilling on the plain (Tab. 11).

The gradual extension of water use from the large-scale hydraulics will undoubtedly allow the recharge of the groundwater, which has long been overworked by the uncontrolled use of underground waters (Cherfaoui, 2012).

As for the effect of receiving the El Amra-Abadia plain on the volumes of water distributed throughout the Upper Cheliff, it is clear from the reading of table 5 that, although the quantities delivered are comparatively lower than those of El Khemis plain, the results are much better. The volumes of water distributed represent 50% of those delivered to the perimeter of El Khemis (Fig. 8), while the perimeter equipped with the latter is 2.4 times greater than that of El Amra-Abadia.

10. IMPACT OF THE PERIMETER EXTENSION ON THE IRRIGATION MODULE

Table 12 shows that for the period 1990-2005,

Table 11. Evolution of distributed water volumes

Unit: 10^6 m^3

Irrigation campaigns	El Khemis plain	El Amra -Abadia plain	Total volume
1990	23.70	-	23.70
1991	17.38	-	17.38
1992	25.76	-	25.76
1993	12.50	-	12.50
1994	0.90	-	0.90
1995	33.20	-	33.20
1996	17.70	-	17.70
1997	22.74	-	22.74
1998	29.90	-	29.90
1999	40.96	-	40.96
2000	21.61	-	21.61
2001	30.70	-	30.70
2002	6.26	-	6.26
2003	32.58	-	32.58
2004	36.04	-	36.04
Average 1990-2004	23.46	-	23.46
2005	21.25	-	21.25
2006	14.76	7.04	21.8
2007	14.00	8.83	22.83
2008	13.76	7.58	21.34
2009	16.94	10.22	27.16
Average 2005-2009	16.14	8.42	23.28
2010	21.16	12.38	33.54
2011	15.69	13.98	29.67
2012	33.86	15.34	49.2
2013	34.12	18.49	52.61
2014	38.33	20.60	58.93
Average 2010-2014	28.63	16.16	44.79
2015	44.82	20.04	64.86
2016	40.57	11.10	51.67
2017	37.54	19.25	56.79
2018	26.67	15.52	42.19
2019	32.97	20.16	53.13
Average 2015-2019	36.51	17.21	53.73

* Built from operating balance sheets OPIC/ONID. Khemis- Miliana.

fruit arboriculture and potato cultivation accounted for almost 75% of the irrigated areas on the El Khemis plain.

What about the impact of the extension of the perimeter with the reception of the plain of El Amra-Abadia?

Overall, there is a similarity in terms of the strong presence of potatoes on both perimeters. In terms of differences, there is an almost insignificant weight of arboriculture in the El Amra-Abadia plain, while it occupies more than half of the irrigated area on the El Khemis plain.

It appears from the exploitation balance sheets of the El Khemis and El Amra-Abadia plains that a considerable gap separates the achievements in terms of rotational crop rotation against the expected

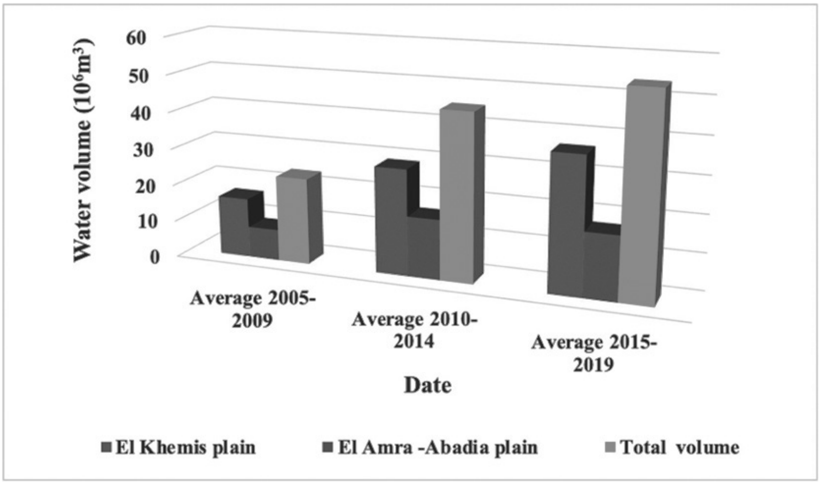

Fig. 8. Average allocation of water volumes.

objectives (Cherfaoui and Nasri, 2018).

Except for potato cultivation, the bulk of the crops grown do not have an impact on the added value of the national economy, given the import food bill. The Agricultural Economic Renewal Program is part of the perspective of better social development of irrigation water.

DISCUSSION

Algeria currently imports a large part of its food consumption. We can mention cereals, milk, tomato concentrate and etc. Therefore, some crops or products have been declared strategic in particular, such as wheat, milk, red meat, industrial tomatoes, pulses, and potatoes.

The application of this policy of strategic crops development, on the irrigated perimeters, could give:

- intensification of wheat through irrigation;
- development of fodder for both meat and milk production;
- development of industrial tomatoes and potatoes.

Since the early 2000s, the Algerian government has taken important steps to overcome the water shortage situation that was affecting the country. The hydraulic issue has been prioritized on the political agenda and large-scale measures have been taken to mobilize new conventional and non-conventional water resources.

The new water policy is thus been structured around two strategic axes

- the development of hydraulic infrastructure: dams, transfers, seawater desalination plants, water treatment plants, etc.
- the institutional reform of the water sector which aims to promote better resource management.

The Upper Cheliff perimeter includes the El Khemis plain and the El Amra-Abadia plain. The irrigation infrastructures of the El Khemis plain (equipped area) are made up of two pressurized networks, separately sited on the right and left banks of the Cheliff wadi. (See map and hydraulic diagram of the upper Cheliff).

Both networks are served by pumping stations on the Cheliff wadi, (one for the left bank and two for the right bank), which operate by level regulation on control tanks and compensation tanks (maintaining water in the networks). In addition, the left bank station pumps wild water in winter to the Harraza dam. Eventually, an additional station is installed at the Harraza dam to ensure the supply of a part of the left bank network.

Lastly, the pressurization for sprinkler

Table 12. Evolution of average land use

Cultures	1990-2005		2006-2010						Variations 1990-2005/2006-2010		2011-2019						Variations 2006-2010/2011-2019	
	El Khemis Plain		El Khemis plain		El Amra-Abadia plain		Total				El Khemis plain		El Amra-Abadia plain		Total			
	Hectares	%	Hectares	%	Hectares	%	Hectares	%	Hectares	%	Hectares	%	Hectares	%	Hectares	%	Hectares	%
Citrus	356	10	62	2	35	2	97	2	-259	-73	242	4	110	4	352	4	+255	+263
Various Fruit Trees	1573	43	1002	35	103	7	1105	25	-468	-30	1791	26	148	5	1939	20	+834	+75
Olivier	48	1	36	1	0	0	36	1	-12	-25	257	4	0	0	257	3	+221	+614
Potato	1184	32	1360	47	935	62	2295	52	+1111	+94	3464	51	1006	34	4470	46	+2175	+95
Cereals	66	2	10	0.35	63	4	73	2	+7	+11	561	8	434	15	994	10	+921	+1262
Industrial culture	94	3	0	0	0	0	0	0	-94	-1	178	3	0	0	178	2	+178	+178
other cultures	361	10	398	14	371	25	769	18	+408	+113	360	5	1220	42	1580	16	+811	+105
Total	3682	100	2868	100	1507	100	4375	100	+693	+19	6853	100	2918	100	9770	100	+5395	+123

* Built from operating balance sheets OPIC/ONID. Khemis- Miliana.

irrigation is ensured on the right bank by five (5) booster pumps (1 per sector) which are fed from 3 new compensation tanks and 2 existing ones. The left bank conveyance scheme is being redesigned to ensure direct conveyance of water from the Deurdeur dam to the eastern and central zones, the western zone being irrigated by the pumping station located at the foot of the Harraza dam (BRL, 2007).

Improving the efficiency of irrigation water use is key to effective water demand management. In addition, the total efficiency of the irrigation system of the El Khemis plain reached 49% (i.e., 51% of water loss between the volume at the outlet of the dam (water source) and the volume distributed (up to the irrigation hydrant). The year 2002 showed a total efficiency of 29%, i.e., 71% of water losses in the irrigation system of the perimeter. On the other hand, the efficiency in 2012 was around 63%, i.e., 27% of water losses in the irrigation system only. The total losses of the irrigation system, from the dam to the irrigation hydrant, amount 25.69 Mm^3 per year: the global loss of the networks represent about 10 Mm^3 (38.9% of the total losses) and the losses of the course are 15.70 Mm^3 (61.11%). In the plain of El Amra-Abadia, the total efficiency in which represents the volume distributed within the network is remarkably low during the first years of operation of this perimeter (2006-2010) (Table 4), but from 2011, the average efficiency is 44% i.e. 46% of the volume dropped was lost.

Moreover, the major problem of losses remains at the level of the course and the irrigation system. The average total efficiency of the irrigation system is 41%, i.e. over 42 km of water flow from the dam to the pumping station, 59% of the volume released is lost. The most important losses of the route were recorded during the first years of operation of the system (77% in 2006), while the lowest losses are recorded in 2018 (15%).

Indeed, the study focuses on the effects of agricultural water valorization actions (Water Act 2005) through the application results of indices measuring both the global efficiency of the networks (E1) and parcel efficiency (E2) for the period 2010–2019 of the plains of El Khemis and El Amra-Abadia in the perimeter of The Upper Cheliff. The Irrigation Water Use Efficiency Index (WUE) makes it possible to monitor the efforts made in terms of water-saving. For both plains, the WUE (38% El Khemis plain and 36% El Amra-Abadia plain) is strongly influenced by transport losses, while the distribution efficiency (>70%) reflects the positive impacts of the network rehabilitation actions on the scale of the plains.

Besides, water efficiencies in the plains of the Upper Cheliff perimeter remain low compared to those found by other researchers, Nini and Mebarki (2018), in their study of large irrigated perimeters in north-eastern Algeria, found water use efficiency value equal to 61.5% and an average of 52% in the Bouchegouf area (Eastern Algeria) (Nini and Mebarki, 2020). In Tunisia, Bhouri Khila *et al.* (2016) found an average water use efficiency value of about 50% in its study on water use efficiency from durum wheat crop. Also, in the report prepared by Thivet and Blinda, (2007), the value of irrigation water use efficiency (WUE) in Algeria is the lowest in the Mediterranean basin, it was equal to 36% in 1995 and 2005, it is estimated at 34% in 1995 and 48% in 2005 in Morocco, 70% in 1995 and 2005 in France.

Blinda (2012), in its Blue Plan report on the water efficiency performance of Mediterranean countries (2005-2010), found that the majority of countries (Algeria, Tunisia, Syria, Egypt, Morocco) fall into Category 2 (48% ≤ Country Efficiency < 72%) which represents an average water use efficiency, three countries (Turkey, Italy, Lebanon) are in Category 3 (Country Efficiency < 48%) which indicates low efficiency and three others (Malta, Cyprus, France) in Category 1 (Country Efficiency ≥ 72%) representing high efficiency.

Also, the Blue Plan's findings (Blinda, 2012), for the Mediterranean regions, have enabled the synthesis of information and to propose the value of 74% as a target figure by 2025 for total water use efficiency and the value of 50% for the average total efficiency from 2005 as the reference year. This led to the establishment of three categories relating to countries' water use performance:

- Total Efficiency ≥ 74% ....High efficiency
- 50% ≤ Total efficiency < 74%..... Average efficiency
- Total efficiency < 50%............... Low efficiency

Efficiency at the level of both plains is classified as Low. Therefore, a considerable effort must be made to improve the efficiency of our irrigation systems.

There is also a positive gradient between gravity irrigated areas and total irrigated areas. This is because in Algeria the mode of gravity irrigation is still dominant in the area, despite the progress already made by the country in terms of equipping for modern irrigation systems.

Consequently, water savings will become increasingly essential for all water uses, particularly in the agricultural sector, with crop irrigation accounting for 70% of total water demand (Thenkabail *et al.*, 2011; Blinda, 2012). The implementation of water demand management policies, which promote the establishment of irrigators' associations, water-saving awareness campaigns, concerted management of irrigated perimeters and adapted water pricing, while increasing production, will help to limit water consumption in the agricultural sector, including the following measures:

- Choose crops based on water consumption and climatic conditions: focus on water-efficient crops;
- Grouping irrigation together by setting up a collective irrigation system;
- Choose the right equipment to limit water loss;
- Start irrigation when necessary, i.e. taking into account the water state of the soil and climatic conditions;
- Obtain a better distribution of water so that only the parcel is watered, not the surrounding paths;
- Check equipment to detect water leaks and repair them systematically; Recover rainwater.

Finally, the challenges ahead at the level of the Upper Cheliff and in general, for all the perimeters of the large hydraulics in Algeria are of two orders (Cherfaoui and Hallouz, 2010):

- ➢ The induced consequences of various erosions on watersheds may undermine efforts in the development of large-scale hydraulics. The recent awareness among decision-makers that resulted in the implementation of the Rural Renewal Program "PRR". An axis that deserves to be sustained and on an ongoing basis.
- ➢ The other challenge facing large hydraulics is without context, the iterative nature of the droughts in our regions. Only the widespread use of techniques allowing to rationalize and/or integrate water savings can make the best use of the heavy investments made in large-scale hydraulics.

CONCLUSION

The efforts made by public authorities in recent years to invest in mobilization and water supply in the agricultural sector are real. It is also necessary to mention the various support measures for farmers to ensure better efficiency of the water resource.

It is clear from our contribution that the renovation and extension have begun nearly three decades ago of the Upper Cheliff perimeter, in this case, the plains of El Khemis and El Amra-Abadia to the northwest of the latter, have produced mixed results. Also, the reduction in resources allocated from dams has meant that annual loss rates are 35% on average for various reasons, including losses from direct releases in the long-distance wadi, water thefts, inefficient and poorly maintained networks, billing, and no counting problems. Waste or overconsumption encouraged by low water costs accounts for only 1% to 10% of crop costs, while water is the basic but pivotal factor in the production and increased yields.

As we have seen before, the challenges we face in the coming years are considerable. On the one hand, it is a question of dealing with the constraints related to climate change, and on the other hand, of carrying out the policy of upgrading management. It is also clear from the operating balances of the Upper Cheliff perimeter that efforts must be made to reconcile micro and macro-economic interests. Large-scale hydraulics must contribute to efforts to reduce external dependence on food. The crops as a whole, is very voracious in water and having a very low impact on the country's trade balance. A mode of exploitation, through the choice of crop - rotation that risks worsening the degradation of humus, in a context where forage crops and livestock remain the poor relative of the choices made.

A development model that excludes industrial and forage crops yet limited to food crops, at the same time, is out of step with essential food needs.

For this:

- An action plan is needed for the increased development of agricultural hydraulics and the establishment of modern irrigation systems for water-saving and increased yields:
- Upgrading of existing perimeters (support operations and major repairs) to improve performance and reduce losses, which will save the equivalent of several medium-volume dams.
- Encourage water-saving irrigation techniques in conjunction with Agriculture and adapt projects accordingly.

Finally, through these spaces, it is expected among other things:

- ➢ Better exploitation of existing potential;
- ➢ The identification and proposal of local development programs (by wilaya) for a better coherence between the availability of the resource and irrigation objectives (readjustment of wilaya programs);
- ➢ The adaptation of production systems to the agronomic characteristics of each region to better enhance the hydraulic potential;
- ➢ The valorization and generalization of the use of non-conventional water (treated wastewater).

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