Precision Irrigation with Cost-effective and Autonomic IoT Devices using Artificial Intelligence at the Edge

D1.1

Report on techno-economic analysis of the proposed irrigation solution

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PART I

ANALYSIS OF THE TECHNICAL, ECONOMICAL AS WELL AS ENVIRONMENTAL REQUIREMENTS OF THE IRRIGATION SYSTEM

1. INTRODUCTION

Tunisia is a semi-arid to arid country over three quarters of its territory with rainfall amounts varying between 1500 mm in the northern regions to less than 100 mm in the south.

The total hydraulic resources are estimated at 4.875 billion m^3 /year divided into surface water (2.7 billion m^3 /year) where the northern basins provide 82% of these resources and groundwater (2.175 billion m^3 /year) where 29% of these resources come from deep non- renewable fossil aquifers in the South.

The demographic growth, the urbanization of the population and the economic development push the demand for water upwards so that water becomes an increasingly scarce resource and almost reaches the critical threshold (ITES, 2014). Indeed, the scarcity and low potential of natural water resources is reflected in the low quota of the Tunisian inhabitant which does not exceed 470 m^3 /year, well below the FAO standard of 1000 m^3 /inhabitant/year.

In Tunisia, according to the Ministry of Agriculture, Hydraulic Resources and Fisheries, agriculture absorbs 80% of water resources, representing the major part of the available water, which is used in irrigation, whose irrigated areas extend over 435.9 thousand hectares. Taking into account all these factors, Tunisia will be in the nearest future, called to solve the most paradoxical equation of its history: to make irrigated agriculture produce much more than today to meet the population's while using less water.

To address this objective, we propose the OSIRRIS project, with the goal to offer a cost-effective, simple and semi-autonomous precision irrigation system which is highly adapted to the local farming context in Tunisia. We will apply cutting-edge technologies such as Internet of Thing (IoT) and Artificial Intelligence (AI) in order to improve the issues on irrigation. The OSIRRIS project is composed of (06) working packages touching different aspects of the agricultural system.

In the following document, we will treat two tasks from the first working package (WP1) which is "Techno-economic analysis of the proposed irrigation solution":

The first part will discuss the analysis of the technical, economical as well as environmental requirements of the irrigation system. The second part is about the creation of KPs to be measured before and after the implementation of the OSIRRIS system.

2. WATER RESOURCES IN TUNISIA: STATE OF ART

Tunisia is subject to the influence of two climates, the first is Mediterranean in the North and the other Saharan in the South, which are at the origin of a spatio-temporal variability of water resources.

The annual average of rainfall in Tunisia is around 231.6 mm, varying from less than 100 mm in the extreme south to more than 500 mm in the north of the country.

The total water resources in Tunisia are estimated at 4,875 M̄ m3/year distributed in surface water with a volume of 2.7 M̄ m3/year where the northern basins provide 82% of these resources and in groundwater estimated at 2.175 M̄ m3/year, of which 29% comes from the non-renewable fossils of the South

The table below summarizes the surface water in Tunisia by sector, detailing the number of basins and their average inputs:

Table 1: Surface water in Tunisia by sector

Sector	Average input Mm^3 /year	Percentage (%)
Extreme North and Ichkeul	960	36
Cap Bon, 0. Miliane and North Sahel	250	9
Méjerdah-Ghar elMelh	1000	37
Sebkhat Kelbia-Sidi el Hani	212	8
Sahel of Sousse and Sfax and the wadi Lebben	63	2
Chott elGharsa and Sebkhat Naouel-Sidi Mansour	95	4
South	120	4
Total	**2700**	**100**

(Source: Ayadi, 2017)

The distribution of water resources according to regions in Tunisia is shown in Figure 1:

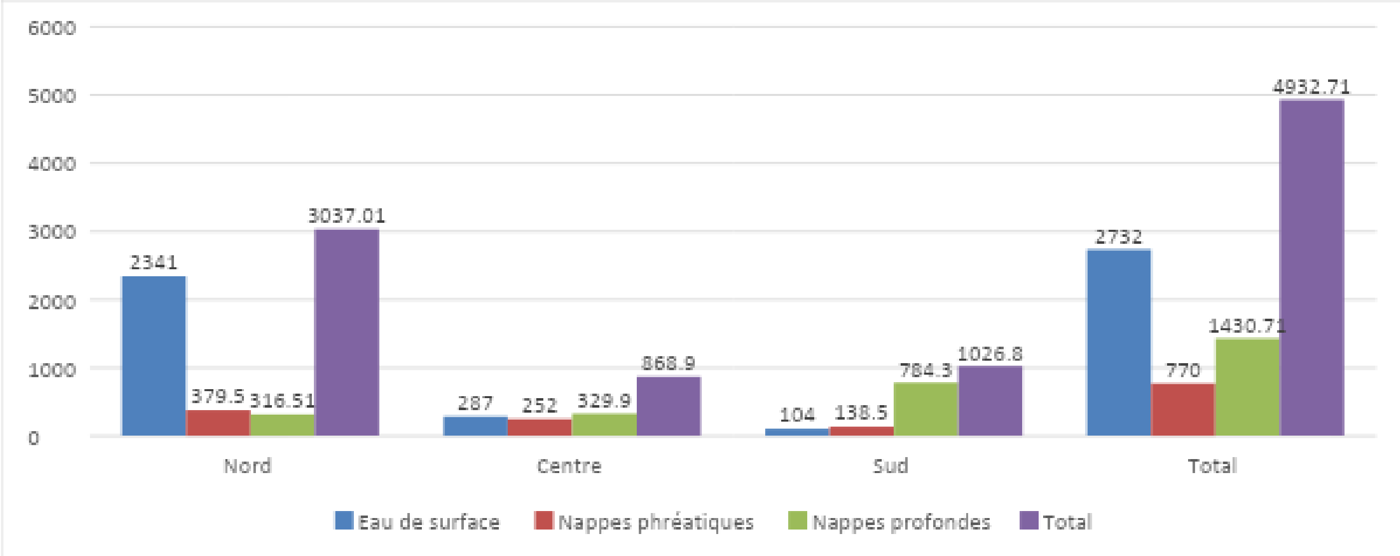

Figure 1: Distribution of conventional water resources in Tunisia (in Mm3)

(Source: African water facility, 2017)

Conventional resources are formed by surface waters with a potential equal to 2732 Mm3 which represent 55.39% of the global potential of resources and groundwater with a potential of 2200.7 Mm3 which represent 44.61%. The variability of rainfall means that 61.6% of resources are located in the north of the country, 17.6% in the center and 20.8% in the south. (Water, Environment and

Business for Development et Raoudha Gafrej, 2022).

The shortage of the resources in terms of volume are increasingly fragile because of pollution and overexploitation by the proliferation of illegal drilling which results in the degradation of quality. Indeed, according to the 2020 National Water Sector Report, 85% of all groundwater resources have salinity levels exceeding 1.5 g/l. At the surface water level, in the northern zone, more than 70% of the resources have a salinity below 1.5 g/l, in the center only 50% of the resources have a salinity below this value and in the south only 5%.

Water stress has increased by 66% in 2000 (National Water Sector Report, 2020) as a result of a set of factors linked in particular to the hydrometeorological characteristics of the hydrological year, the volumes mobilized by irrigated perimeters and their illegal extensions, the mode of water resources management adopted, etc.

In 2020, 75.56% of renewable resources are exploited by the irrigated agricultural sector, which covers 435,000 ha and represents only 8% of the utilized agricultural area, 20.6% for drinking water needs and 3.84% for other uses (tourism, industry, groundwater recharge, wetlands and irrigation of green spaces and golf courses).

Groundwater resources are estimated at 746 Mm^3/year. The exploitation of the resource has clearly evolved, it was estimated in 2015 at 903 Mm^3/year. This exploitation was done through 151850 surface wells less than 50 m deep of which 111431 wells were equipped (Ayadi, 2017).

Concerning deep water resources, they are estimated at 1429 Mm^3/year. The use of this resource has experienced a remarkable progression, it was estimated in 2015 at 1705 Mm^3/year. This exploitation was done through about 21675 drillings during 2015, half of which are illicit (Ayadi, 2017). Table 2 presents the evolution of the volume of water mobilized.

Table 2: *Evolution of water resources mobilization*

Resource in Mm^3	**Potential-Balance Sheet 2005- in Mm^3**	**Mobilizable resources in Mm^3**	**Operation/Mobilization in Mm^3**			
			2004	**2006**	**2008**	**2015**
Surface water	2700	2500	2200	2300	2400	2500
Dams	--	2170	1927	2000	2080	2170
Hill dams	--	195	160	180	188	195
Hillside lakes	--	135	113	120	128	135
Groundwater	2175	2175	1867	1978	2034	2608
Deep water	1429	1429	1127	1171	1227	1705
Groundwater	746	764	740	807	807	903

(**Source**: Ayadi, 2017)

More than half of Tunisia's water wealth (55%) comes from renewable surface water which is closely linked to the climate. These resources are mobilized through 3 types of works: large dams (37), hill dams (234) and hill lakes (800). The rest is covered by groundwater.

Based on the data of the Tunisian branch of non-conventional water and artificial recharge, the use of water resources is characterized by a remarkable and frightening increase. In fact, the use of surface water was predicted in 2015 by 2500Mm^3/year, which is approximately the total amount of water surfaces that can be mobilized, while the exploitation of groundwater has exceeded the mobilized amount judged 2608Mm^3 (Ayadi, 2017).

As of 01/30/2023, the cumulative inflows to the dams reached 210 Mm^3. They were significantly lower than the average for the period (883.5 Mm^3) and the inflows recorded at the same period of the previous year (792.4 Mm^3). Therefore, the water reserves in all the dams reached 700.2 Mm^3 against 1145.6 Mm^3 recorded on the same date of 2022 and an average recorded over the last three years of 1256.9 Mm^3, as a deficit of 556.7 Mm^3. For all the dams, the filling rate reached 30.2% (ONAGRI, 2022).

Water is crucial for agricultural activity, especially in areas frequently affected by drought or water shortage. The uses of water resources in Tunisia are illustrated in Figure 2.

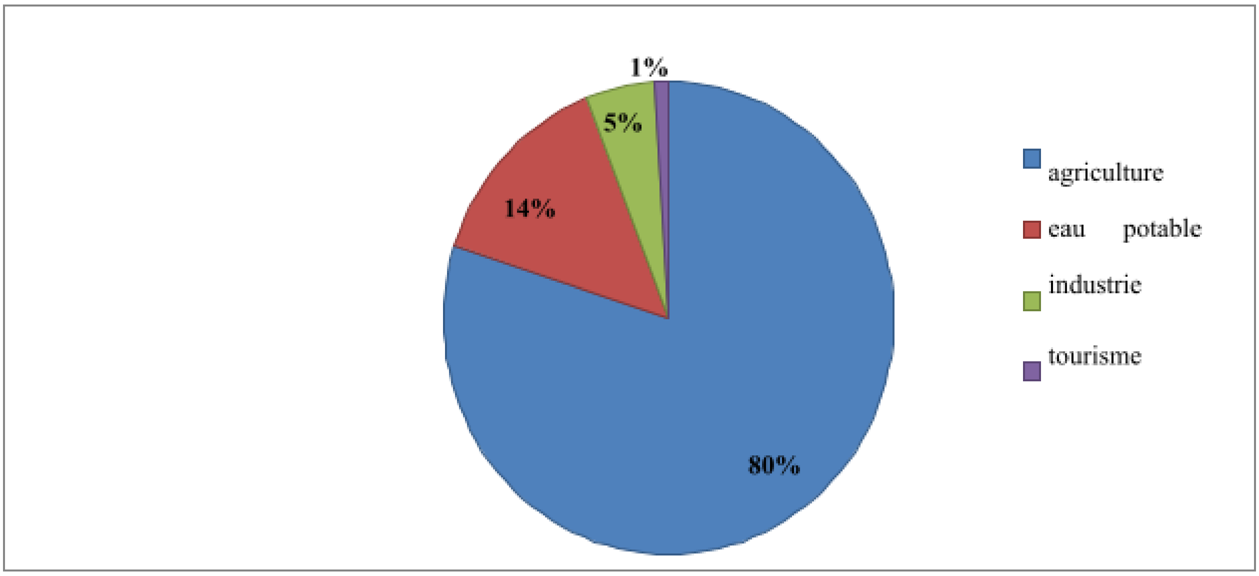

Figure 2: Use of water resources in Tunisia by sector

(**Source:** MARHP, 2014)

In Tunisia, the agricultural sector uses most of the available water. It consumes nearly 80% of water resources for irrigation of irrigated areas assessed by 425900 ha (MARHP, 2016).

Groundwater is the main source of water for irrigation, irrigating 50% of the irrigated area, while deep groundwater and surface water irrigate 26% and 21% respectively, and marginal water (treated wastewater, brackish water) represent 3% (Besbes et al, 2012).

The potential for non-conventional water is formed by treated wastewater in plants of treatment of ONAS, desalinated seawater and drainage water. Water production desalinated from brackish groundwater are not new resources since raw water is already counted in conventional water potential.

3. SITUATION OF THE IRRIGATED SECTOR IN TUNISIA

3.1. Evolution of the sector

Over the last thirty years, more than a third of public investment efforts have been allocated to irrigated agriculture. These means have made it possible to mobilize most of the water resources and to reach nearly 350,000 ha of developed irrigated areas. The extension of irrigated areas was possible thanks to the mobilization of most of the inventoried water resources (90%) and the allocation of most of them to irrigation (80%). Given the limitations of national water supplies, the extension of irrigated areas cannot be continued.

The irrigated areas occupy only 8.2% of the useful agricultural surface, but they contribute by 37% in value of the production, hence the important role they play in ensuring the country's food security. Arable land is estimated at 5 million ha including 440,000 ha irrigable area in 2020, divided into public irrigated PPI perimeters over an area of nearly 248,000 ha (56%) and private perimeters covering 192,000 ha PIP (mainly on surface wells and boreholes).

The prospects for the evolution of the areas actually irrigated under total control on the one hand, and the demand for water on the other, are as follows

Table 3: Evolution of irrigated areas and irrigation water demand

Year	1995	2010	2015	2020	2025	2030
Area actually irrigated (ha)	335 000	436 000	417 000	433 000	450 000	467 000
Water demand (Mm3)	2115	2140	2110	2085	2058	2035
Unit volume m3/h	6300	5300	5000	4800	4600	4400

Source: "Water 21" study, 2010

From these forecasts, it can be concluded that the areas actually irrigated are growing exceptionally well. However, a decrease in unit volumes per hectare can be observed. This can be explained by the adoption of irrigation water saving technologies. (Jamel ben Nasr, 2015)

3.2. Background and water resources

The total rainfall resources over the whole country are estimated at 36 billion m^3 /year, of which 13 billion m^3 /year are allocated to arable land (5 million hectares), thus constituting the total average potential of "green water" usable for rainfed agriculture. This potential increases to nearly 19 billion m^3 /year if we add the evapotranspiration of plants on rangelands estimated at 5 million hectares (Besbes &al. 2008).

Regarding the potential 'blue water' resources, they are estimated at 4,855 million m^3 /year, of which 2,700 Mm^3 /year constitute surface water (56% of mobilizable resources) and 2,165 Mm^3 groundwater (44% of mobilizable resources). These average values hide, in reality, wide regional disparities and some groundwater resources are already either subject to overexploitation or of a quasi-fossil nature located in the South (MADD/ANPE, 2009).

Non-conventional resources are essentially limited to the use of treated wastewater. According to ONAS, in 2019, in Tunisia, 62 million m^3 of treated wastewater were reused (22% of the total volume supplied by treatment plants) of which 21 million m^3 were reused directly in the irrigation of 4114 hectares among 9815 hectares developed to be irrigated by treated wastewater.

3.3. The irrigable land in Tunisia

In Tunisia, as both water and soil resources for irrigation are limited, the potential of irrigable areas under total control or intensive (with permanent water resources) is about 410,000 ha in 2010 (425,000 ha in 2015), or 8% of the useful agricultural area.

Semi-intensive or supplementary irrigation as well as flood spraying (with random water resources) constitutes a potential estimated at about 150,000 ha. On the whole, the irrigated perimeters are scattered over the whole territory with particular concentrations in the Medjerda valley in the North, Kairouan in the Centre and the oases in the South.

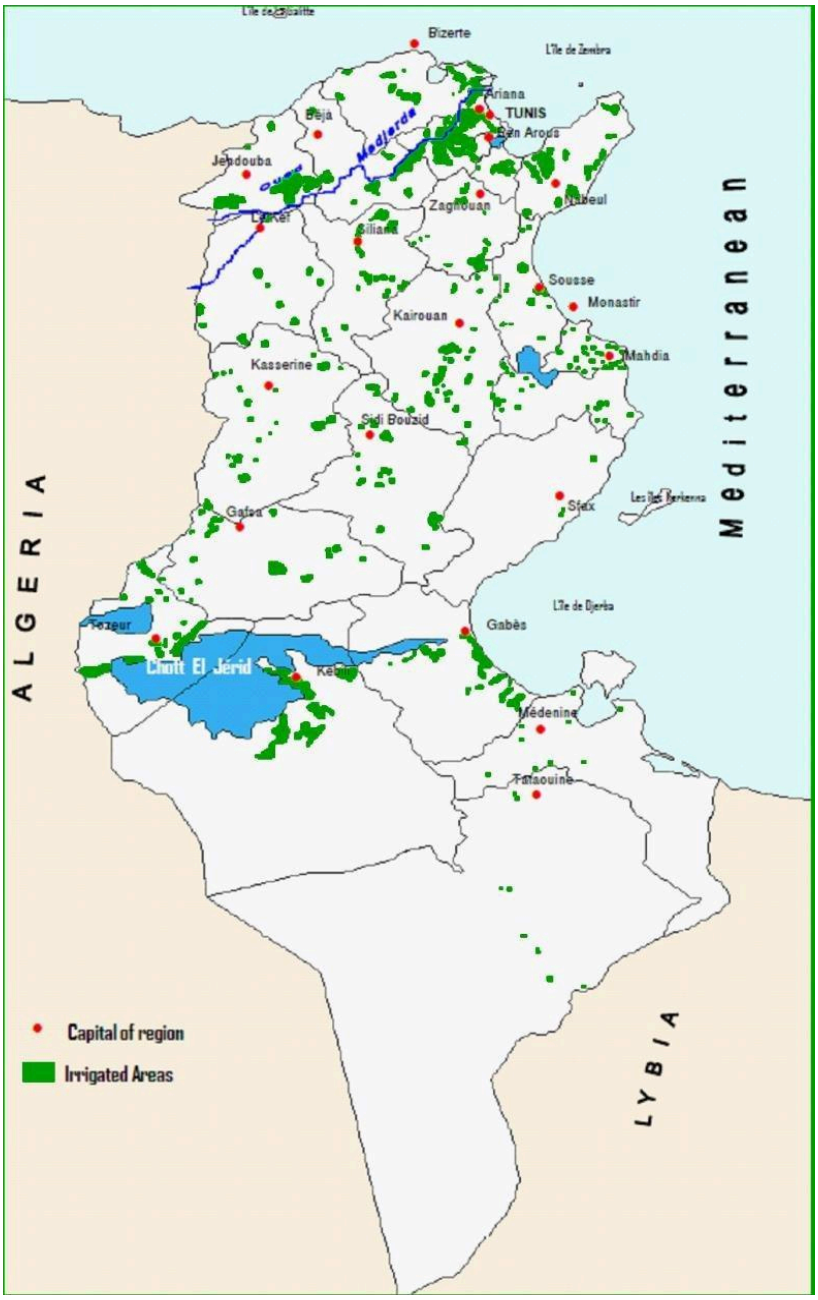

***Figure 3**: General map of irrigated areas in Tunisia* **(Source:** DGGREE)

From a dynamic point of view, the surface area under total control developed for irrigation reached about 60,000 ha at the end of the 1960s and is currently approaching 410,000 ha. It is divided into "public irrigated perimeters" (PPI) which are developed by direct investment by the State through collective infrastructures estimated at 216,000 ha, 90% of which are managed by 1,253 GDAs, and 10% managed directly by the CRDAs; and "private perimeters" which are made up of individual systems supplied most often by surface wells and carried out thanks to the initiative of the farmers themselves (194,000 ha) with significant financial incentives from the State reaching 25% of the private investments overall. (Hamdane A, 2021)

The PPI are equipped with several types of structures and hydraulic networks including: 1358 pumping stations, 90 large pumping stations, 20,000 km of irrigation networks, 10,500 km of sewerage-drainage networks, 8,000 km of agricultural tracks. These structures require significant financial resources for their maintenance.

Private irrigated schemes (PIPs) are developed by private funds and managed by farmers and generally benefit from indirect state funding in the form of subsidies. Public perimeters in the North are generally irrigated from surface water while private perimeters rely on groundwater. In the Centre, irrigation is mainly based on shallow groundwater or from dams. In the South, irrigation is done from deep aquifers with very little renewables (National Water Sector Report, 2020).

Regarding the nature of irrigated areas, fruit trees occupy first place with nearly 49% of irrigated areas, come in second place vegetable crops with 26%, field crops and fodder with 24% and industrial crops with 1%.

4. TECHNIQUES AND MODES OF IRRIGATION IN TUNISIA

In order to choose a specific irrigation method, a number of factors are involved in the selection process:

- Natural conditions: soil type, slope, climate, water availability, water quality
- Crops: Surface irrigation is applied to all crops. Sprinkler and drip irrigation methods, due to the high investment costs, are mainly adopted for the irrigation of high value crops such as vegetables and fruit trees.

They are rarely used for staple crops with low financial value. Drip irrigation is highly recommended for the irrigation of individual plantations, trees and row crops. It is not used for irrigation of dense plantations such as rice fields.

- Technology: The level of sophistication required to install and operate an irrigation method affects its selection in a given case. The techniques of sprinkler and drip irrigation methods are more complex than those of surface irrigation.
- Irrigation tradition: the choice of an irrigation method is linked to the traditions of irrigators in the region or country. The introduction of a new irrigation method may cause unexpected difficulties. Generally, farmers are reluctant to adopt new irrigation techniques. The management of the equipment will be uncertain, and the costs will be too high compared to the benefits. Often it is more profitable to rehabilitate and improve the operation of a traditional irrigation system than to introduce a new irrigation method.
- Labor requirements: Labor requirements for the development, operation and maintenance of surface irrigation schemes are always higher than for sprinkler and drip irrigation schemes.

Surface irrigation requires fairly careful site preparation (grading), regular maintenance and good irrigation management to ensure proper operation of the system. In contrast to sprinkler or drip irrigation techniques, land preparation work is very minimal, and labor requirements for network operation and maintenance are lower.

- Costs and benefits: an estimate of the costs and benefits of each irrigation method should be made before choosing one

Types of irrigation systems

An irrigation is suitable if it wets the surface and the area around the plant so that the water is absorbed by the roots. And as a result, the plant receives all the appropriate nutrients.

Nevertheless, for every need and form of planting, there is a suitable type of irrigation system.

Surface irrigation system

This type of irrigation is widely used in the cultivation of cereals. The system is in fact formed by irrigation channels where the water flows by gravity with the highest central part for the plants. The water flows at the top of a main channel that feeds all the others.

Surface irrigation systems are similarly called gravity irrigation systems because the water is applied directly to the soil surface and, due to the effect of gravity, moves and infiltrates the soil.

This type of system has the highest percentage of irrigated area in the world compared to pressure systems.

The main advantages of surface irrigation systems are their low installation cost, simple equipment, low energy consumption and no impact from wind.

Localized irrigation system

This system applies localized and controlled water to the plant, thus reducing the soil surface that becomes wet, exposed to evaporative losses. As a result, application efficiency is much higher and water consumption is lower.

Localized irrigation is usually used as a fixed system with as many lateral lines as necessary to supply the entire area. In this way, there is no movement of the lateral lines.

But, only a certain number of sidelines should work at a time to minimize capacity and better control.

Drip irrigation is a controlled and specific irrigation method that has the property of saving water resources.

This is particularly due to the proximity of the water source to the plant's roots while avoiding wasteful evaporation and increasing overall water and nutrient use.

The advantages of drip irrigation systems include strict control over the amount of water delivered to the plants. In addition, semi-automated or automated systems require less work to

manage the system. This system reduces the incidence of pests and diseases and weed development and allows cultivation in areas with rocky outcrops and/or steep slopes while ensuring excellent uniformity of water application.

Micro irrigation system

The micro-sprinkler system is a commonly used method of irrigation for high profitability and is characterized by the application of water and nutrients in a fraction of the soil volume covered by the plant roots.

It is a localized irrigation system that uses self-compensating or regular micro-sprinklers, with disc or sieve filters. Moreover, it is completely modular and suitable for orchards and the various species that are born and grow in greenhouses.

It is easy to install, operate and maintain, plus it saves water and labor.

Sprinkler irrigation system

Sprinkler irrigation is an irrigation technique that simulates artificial rainwater in which a sprinkler expels the air in a jet of water that, as it travels, becomes small droplets of water that fall on the soil and plants.

Sprinkler irrigation systems are classified into two main groups: conventional and mechanized systems.

Conventional irrigation systems

The conventional sprinkler system is considered the basic sprinkler irrigation system. It uses tubes throughout the area with manual sprinkler exchange.

In other words, after the first watering, the grower must enter the wetland, remove the sprinkler and place it in the next area to be irrigated.

The conventional sprinkler is called the basic irrigation system, consisting of a catchment system, a pumping system, a discharge or main line and a branch or sideline with sprinklers.

Mechanized irrigation system

The main objectives of a mechanized irrigation system are to irrigate large areas where it would be technically and economically impossible to use conventional systems, to increase the efficiency of water application and to reduce labor costs.

Irrigation system	Benefits	Disadvantages
Surface irrigation	✔ Low capital investment in equipment and operating costs. ✔ Energy-efficient.	□ Causes water stagnation and soil salinization High water losses due to evaporation and infiltration
Sprinkler irrigation	✔ Does not require ploughing or land leveling system	□ Energy intensive □ Water loss due to droplet evaporation and wind
Drip irrigation	✔ Evenly distributes small amounts of water Reduces workload	□ High investment and operating costs □ Difficult maintenance □ Clogging □ Salt accumulation in emitters
Underground irrigation	✔ No water loss by evaporation ✔ Applies the water directly to the necessary place of the plant	□ Problems are not immediately visible

For movement to occur, the sprinkler (or set of sprinklers) is mounted on a mechanical system with wheels.

Table 4: Advantages and disadvantages of irrigation system

The Buried Diffuser

The Buried Diffuser is a revolutionary new technique for optimal irrigation water management and 100% water conservation. The buried diffuser can be used for the irrigation of fruit and forest trees and shrubs as well as for vegetable crops and ornamental plants placed in pots, containers, vases and tubs.

Thanks to the Buried Diffusers, CHAHTECH the inventor has developed two new concepts: the Anticipated Irrigation and the injection and storage of water in the deep layers of the arboricultural exploitations. In fact, the Buried Diffuser, in addition to the conventional irrigation during the hot and dry seasons, can be used in rainfed and irrigated agriculture, both for arboriculture and for some annual crops with tap roots (corn, turnips, cucurbits, etc.).

The Buried Diffuser is, without a doubt, the most efficient irrigation system to bring water to the roots.

Smart irrigation in Tunisia

Unsustainable use of water resources and climate change will exacerbate the existing tensions surrounding resources, especially in the Mediterranean context. Despite investments in costly modern equipment, the performance of irrigated agriculture remains below expectations, notably because of the lack of available water data and the limited use of decision support tools. Although a variety of soil moisture sensors are available on the market, they are not widely used by the agricultural community because of their high cost and complexity. Access to information at an unprecedented level, via easily accessible low-cost and low-tech sensors, may be a major lever for improved identification of achievable gains in performance, and to guide actors toward efficient water management. An open source wireless soil moisture sensor, low-energy and economically and technically accessible, was developed. The tool was designed according to water users' requirements and applied to a Tunisian irrigation scheme subject to major water use efficiency issues. The functioning of the wireless sensor network was tested on pilot plots over a growing season and compared with commercial sensors. A single parameter calibration can be performed in either the laboratory or the field. This low-cost sensor can be used for real-time irrigation monitoring and as a decision-making tool for water management. (P. Vandome et al, 2023)

Smart farming involves the integration of advanced technologies into existing farming practices to increase production efficiency and quality of agricultural products. The evolution of IoT and UAVs has enabled the vision of sustainable smart farming, where these smart technologies have proven to increase the quality of crop yield and reduce the environmental footprint from the agricultural sector. Faris A. Almalki et al (2021) shows a low-cost platform for comprehensive environmental parameter monitoring using flying IoT. The proposal is based on experimental work to fulfill the requirements of automated and real-time monitoring of the environmental parameters using both under- and aboveground sensors. These IoT sensors devices on a farm collect vast amounts of environmental data, where it is sent to ground gateways every 1 h, after which the obtained data are collected and transmitted by a drone to the cloud for storage and analysis every 12 h. This platform is deployed and tested in a real scenario on a farm in Medenine, Tunisia, in the period of March 2020 to March 2021, covering open-field and greenhouse cultivation. This low-cost platform can help farmers, governmental, or manufacturers to predict environmental conditions data over the geographically large farm field, which leads to enhancement of crop productivity and farm management in a cost-effective, and timely manner. Obtained practical results indicate that automated and human-made sets of actions have been applied and/or suggested that are smart actions for precision agriculture, which, in turn, dramatically boost crop productivity and help in saving natural resources.

Smart Soft PRO is an engineering company specialized in the development of tailor-made technological solutions, which has just initiated an information system dedicated to the agricultural sector by integrating IoT. The founder indicates that the Smart Farm system was designed for the collection, processing, storage and dissemination of data in a suitable form to help the management of farms; especially spatial and temporal variability to improve economic performance. Smart Farm also integrates decision support systems in order to optimize the exploitation of resources (electricity, water, time, ventilation, heating, air conditioning, human resources, etc.). With regard to smart irrigation, Smart Farm is a controlled system that allows the farmer to control and manage water resources in an efficient, ecological and intelligent way according to sensors that are located in each area and that provide indicators on the moisture of the soil.

With the depletion of natural resources, today, modern agriculture tends to focus on new techniques such as precision agriculture that brings together techniques to optimize yield and reduce the excessive use of natural resources and energy. It is in this configuration that was given the launch signal of the Tunisian satellite "One Challenge", Tuesday, March 22, 2022, for its use in smart agriculture, cereal cultivation and rationalization of the use of irrigation water. This experiment, the first of its kind in Africa and the Arab world, was conducted in one of the agricultural estates of Boussalem, in the governorate of Jendouba in coordination with the company Telnet, specialized in engineering and technology, and the National Institute of Field Crops. This pioneering experiment involves linking farms belonging to the National Institute of Field Crops to the intranet of objects, where data on moisture, heat, sunshine and plant diseases are detected through sensors installed on agricultural land and which will then be transmitted to the "One Challenge" satellite. Subsequently, instructions will be issued to remotely control agricultural equipment to treat or irrigate the land.

4.1. Total equipped areas in Tunisia

The DGGREE data on the follow-up of the total surfaces equipped with water saving equipment (subsidized or not) accumulated during the period 1995-2014 show 127,255 ha equipped at the beginning of 1995, and 375,547 ha equipped at the end of June 2014, i.e. 248,292 ha equipped over the period and a rapid conversion towards the most water saving equipment.

In 2014, the relative share of the different equipped areas are estimated as follows: 24% of the areas are equipped by the improved gravity irrigation technique, 31% are developed by the sprinkler irrigation technique and the remaining area (45%) are equipped by the localized technique (DGGREE, 2015).

The attached map shows the relative share of these different facilities in 2014 and the equipment rate of irrigated perimeters by governorate (DGGREE - DGEDA).

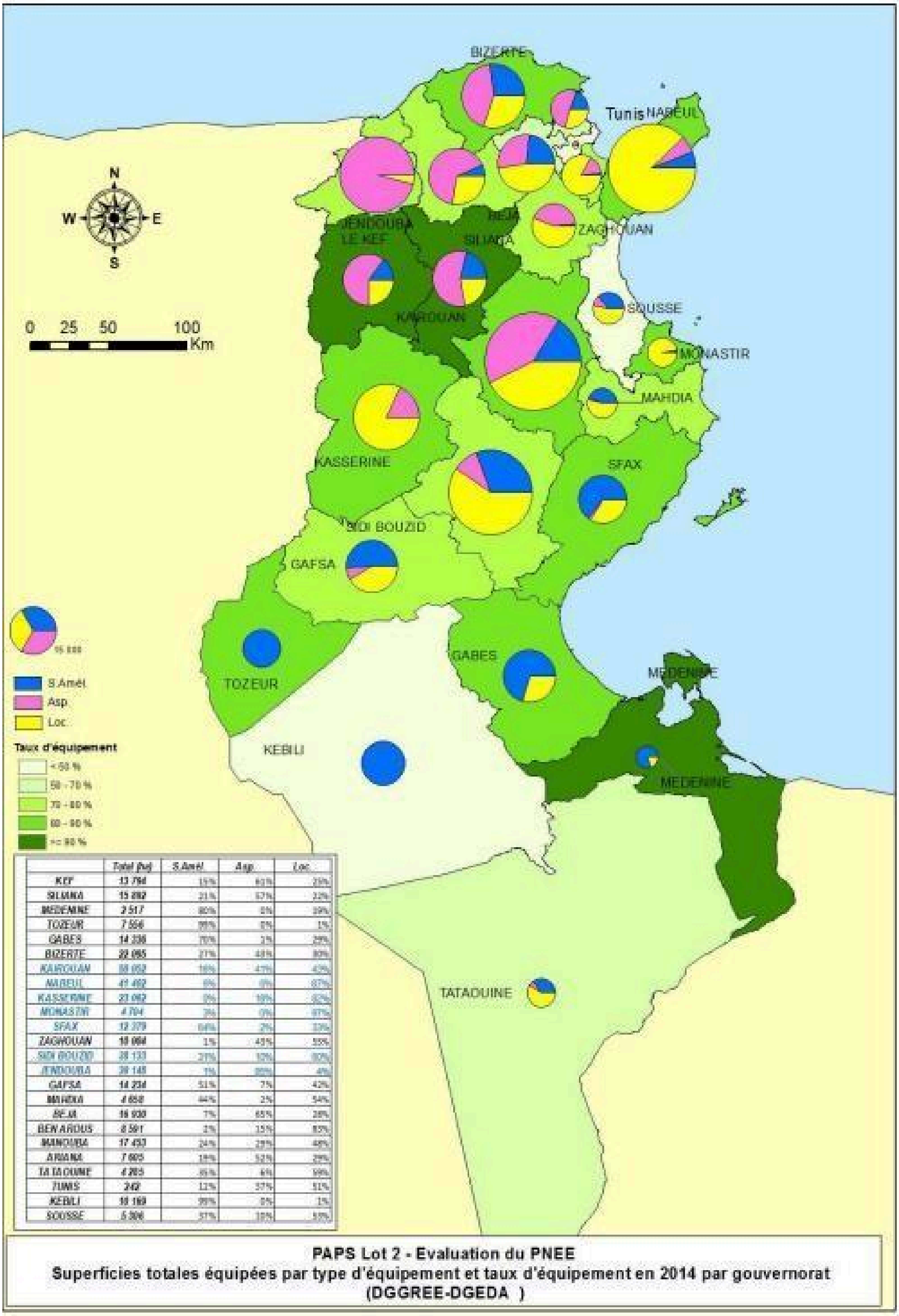

Figure 4: Map of total equipped areas by type of equipment as of 30/6/2014 and rate of equipment in 2014 by governorate

In 20 years (1995-2014), localized irrigation has gradually replaced other equipment to represent today the main surfaces equipped. The role of the PNEEI in the dissemination of water-saving equipment in general and drip equipment in particular is undeniable.

From this map, it can be seen that the North is characterized by the use of the sprinkler irrigation technique followed by the localized irrigation technique and the improved gravity technique. The same applies to the center of the country. In the south of the country, the most common irrigation technique is localized gravity irrigation. This distribution is explained by the types of crops grown in each area.

Regarding the rate of equipment by governorate, we notice that only (06) governorates have a rate higher or equal to 90% and which are Kairouan, Jendouba, Kef, Beja, Siliana and Medenine. The rest of the territory is characterized by the variation of the equipment rate in the governorates between 50% and 90%.

A survey was realized in 2015 by the agriculture ministry of Tunisia as part of the impact study (evaluation) of the national irrigation water saving program in 7 governorates; Jendouba, Kairouan, Monastir, Sfax, Sidi Bouzid, Kasserine and Nabeul. We are going to present the results of one and each irrigation system in the section below.

Sprinkler irrigation

According to the results of the survey, it can be noticed that:

- 39% of the 15,148 ha of public perimeters of the GDAs surveyed are basically managed by sprinkler irrigation.
- The GDAs of Kairouan and Jendouba practice sprinkling up to 42% and 73% of their surfaces respectively. The sprinkling practiced by the GDAs of these two governorates corresponds to 87% of the total surface equipped with sprinkling in the seven governorates combined.
- The rates of sprinkler equipment in the governorates of Kasserine, Monastir, Sfax and Sidi Bouzid did not exceed 2%. These low rates observed are generally due to the lack of pressure quality at the terminals necessary for the operation of sprinklers (low pressure collective networks initially intended for irrigation by subversion. In most cases, farmers are obliged to install expensive motor-driven pumps at the interface between the collective network and the plot irrigation system, thus increasing the financial costs, especially in the absence of electrification in the area.
- 4% of the surface occupied by market gardening for Jendouba and Nabeul is equipped with sprinklers. This practice makes it difficult to control fertigation and consequently is likely to give lower agricultural yields (commonly -40% of potentialities noted).

Drip irrigation and other

The results of the GDA surveys concerning the drip irrigation system used for forage crops, market gardening, arboriculture and olive trees show that:

- The average rate of drip equipment is 20% in relation to the total surface area of the GDAs in the seven governorates, which is much lower than the average rate of sprinkling.
- The drip equipment rates for the seven study governorates vary from 8 % for Jendouba to 88 % for Monastir
- The areas of market gardening and arboriculture are only equipped with drip irrigation at a rate of 10% and 8% respectively.
- The GDAs of three governorates (Jendouba, Kairouan and Kasserine) have an average rate of drip irrigation equipment that does not exceed 20%.
- Except for the GDAs of Monastir, the other GDAs of the six remaining study governorates are

characterized by an average rate of drip irrigation equipment that does not exceed 40%.

Overall equipment rate for pressure irrigation

The average rate of pressure irrigation equipment (sprinkler and localized) for the total surface area of the GDAs in the seven governorates studied is 60%. This value may seem average in Tunisia if all the perimeters are taken into account. However, in our case, the average overall equipment rate for the three governorates of Kasserine (18%), Sfax (30%) and Sidi Bouzid (41%) is only 30%. Jendouba thanks to the strong practice of sprinkling and Monastir for drip irrigation present the highest global equipment rates (sprinkling and drip) namely 82% and 88% respectively.

At the level of the GDAs surveyed, there is a great diversity of water saving equipment between the governorates with a strong dominance for sprinkler surfaces (40%) ahead of drip and gravity surfaces. The overall equipment rate is 60% but masks strong disparities. The choice of equipment without any constraint is dictated mainly by the crops, but most of the time these choices are saddened by the characteristics of the resource or service or the financial capacities of the irrigator, etc. This is how the drip is sometimes chosen to respond to the scarcity of the resource.

4.2. Water use in agriculture and irrigation development

Tunisia's primary agricultural products are wheat, barley, citrus fruits, tree fruits, dates, olive oil and market gardening.

The main irrigated crops are fruit trees, vegetables and cereals with respective shares of 58%, 28% and 12% contributing to more than 40% of the total irrigated production. Olives and date palms are the main irrigated fruit trees covering respectively 41% and 18% of the irrigated fruit trees.

In Tunisia, agriculture is essentially and traditionally conducted in the dry, which makes it susceptible to high annual variability. The area equipped with irrigated perimeters increased from 394,000 hectares (ha) in 2001 to 459,570 ha in 2011, an average annual increase of 1.4%. However, since the introduction of conservation measures in irrigated areas, consumption per hectare has started to decline. The projected volume allocated to irrigated agriculture will tend to decrease by 1.3% by 2030, freeing up 5% of this volume for other uses.

General performance of the irrigated sector in Tunisia

Despite the limited size of the irrigated areas, which represent only 8% of the country's cultivated land, the irrigated sector is strategic because of its impact on food security and the socio-economic and political role it plays.

Economic role: the irrigated sector has diversified its production and is one of the pillars of the agricultural economy, which is still largely dry. The sector represents about 40% of all agricultural production, 95% of market gardening, 70% of shrub crops and 30% of dairy production. From a socio-economic point of view, the sector represents 20% of agricultural exports (citrus fruits, dates, etc.). Beyond its role in the economy, irrigation helps farmers to stay on their farms by providing them with a relatively regular income, on average three times higher than that of rainfed agriculture.

Production could certainly be increased in irrigated areas, but low water productivity means that resources are not being exploited to their full potential. However, the technical progress made in irrigated agriculture over the past 20 years is undeniable. Nearly one in four farmers is now involved in irrigation, a proportion that is even higher for small farms.

The contribution of the irrigated sector in the national agricultural production in 2018 was around 35% and its contribution in the total export of agricultural products in terms of economic value was up to 25%.

Social role: The irrigated sector employs about 20% of the active population, a significant proportion.

Irrigation has an impact on employment in all upstream and downstream sectors (supplies, agri-food companies, services, etc.) with a positive influence on rural development in regions with irrigated agricultural activity.

Policy role: Although the contribution of agriculture to GDP is declining overall, irrigated agriculture still constitutes the core of small-scale agriculture, which has maintained its position despite the major technological and economic changes that have transformed the sector in recent decades. It is unfortunate that the emergence of irrigated agricultural growth "poles" - a development tool to initiate the transition from subsistence to commercial agriculture - is still not fully integrated with small-scale agriculture. However, agricultural development groups are emerging as farmer representation and management structures in a sector that generally suffers from a lack of professional representation (Hamdane A, 2019)

Numerous actions have been undertaken in recent decades to increase yields and reduce fluctuations in production. In the second half of the last century, large-scale irrigation works, including the creation of dams and conveyance works, led to an increase in irrigated land. The total area prepared for irrigation in 2018 was over 435,000 ha representing 8% of the cultivated land. Localized irrigation systems are used on 49% of the irrigated land and sprinkler systems on 28% of them (MINAGRI 2018a).

In order to ensure good management control of irrigated areas, major technical, economic, organizational and institutional reforms should be carried out with the aim of improving the efficiency of irrigation networks, setting up an adequate irrigation water pricing system, encouraging a redefinition of IP's agricultural development systems towards increasing water valorization, and to ensure a more active participation of users of water resources.

5. REGULATORY AND INSTITUTIONAL FRAMEWORK

5.1. Water legislation

The first decrees on water in Tunisia date from the French colonial period. Thus, the Decree of 24.09.1885 defined the commonality of surface waters, without however mentioning groundwater. In May 1920, a water committee was established. Between 1933 and 1938 various decrees institutionalized a regulation of use and fixed the rates for water exploitation. Between 1936 and 1949 further decrees regulated the role of the associations in water exploitation.

After independence, Tunisia saw the evolution of a water legislation relating to the mobilization of the resource and its exploitation by the various uses (urban, agricultural, industrial and tourist), while taking into account its quality. In order to satisfy the growing water demands, the State carried out a large number of hydraulic works and with the evolution of the hydraulic planning system, a water legislation system was set up with the major objective of defining the competences of the stakeholders in the water sector, in order to protect the resource and to ensure an equitable allocation between the user sectors. In 1975, all the legislative texts were updated with the promulgation of the Water Code (Law N° 75-16 of 31 March 1975).

Since then, the Water Code has been regularly amended and/or extended by laws and decrees in order to ensure good water management, to safeguard the environment and to define the competences of the actors involved in this sector. Similarly, the legislation on water user groups has evolved in an interesting way.

A critical analysis of the Water Code, which is limited to ad hoc amendments, gives the general impression that the Administration has extensive powers in the hydraulic field, while the users, who are stakeholders, have no alternative but to comply with its prescriptions. This state of affairs has undoubtedly had an impact on the operation of the water services and on the behavior of water users.

The revision initiated since 2009 of this text which is not yet promulgated, has integrated, according to the planning office essentially the management of demand and has taken into account the major changes that the water sector has undergone such as the preservation of resources, the expansion of the optimal development of their use to all water resources, the equity of their distribution, the management of climatic extremes and the storage strategy (Ministry of Agriculture, 2014).

Formerly known as Associations of Collective interest (AIC) with legal status since 1936, these basic groupings were especially known in the southern oases where their mission was the distribution of irrigation water and the maintenance of natural springs or the construction, with the help of credit, of hydraulic infrastructures. At the beginning of the 1970s, a hundred or so AICs were gradually pushed aside as the Administration and the Offices took over the implementation of projects and management. The new orientations of the agricultural policy in the middle of the 1980s rehabilitated them and a voluntarist policy provided them with more

flexible management regulations, while ensuring them more autonomy. They have been generalized to all small and medium-sized irrigated areas.

The former community form of irrigation management was progressively oriented towards an institutional aspect thanks to the two Beylical decrees of 5 August 1933 and 30 July 1936, which defined the institutional and financial arrangements for the water use associations as follows

- Establishment of a higher committee of agricultural hydraulics which elaborates the policy of the State in this matter;

- Establishment and definition of the mode of creation, operation and organization of associations of collective interest;
- Establishment of a supervisory body for these associations at regional level (the hydraulic interest groups - GIH).

The attributions of the Associations of Collective Interest (AIC) were modified following an amendment of law 75-16 by law N° 87-35 intervened on July 6, 1987 so as to attribute the following activities to the Groups of Collective Interest (GIC):

- The exploitation of the waters of the Public Hydraulic Domain in their perimeter of action;
- Irrigation or land reclamation;
- Operation of drinking water systems.

The organization and operation of the ICGs were governed by Decree No. 87-1261 of 27 October 1987, which stipulates the provisions for the establishment of ICGs and their mode of operation. Their creation is subject to the visa procedure issued by the Governor.

However, they are subject to the dual administrative supervision of the Governor (and on his behalf by the relevant territorial delegate) and the financial supervision of the Ministry of Finance. The ICGs were managed by a board of directors composed of 3 to 9 members elected for 3 years from among the users. The board is assisted by a director and an accountant.

The changes in the organization and operation of the ICGs are described in Decree No. 92-2160 of 4/12/1992. They are summarized as follows:

The ICG's accounts are managed by a treasurer appointed from among the members of the association on the proposal of the Board of Directors and after approval by the Governor; the

ICGs are required to act within the limits of the financial resources available; the ICG's management funds are held in a postal or bank current account opened after approval by the Governor concerned. Each ICG has its own budget, which it adopts annually and submits to the Governor for approval.

Concerning collectively operated irrigated areas, the management activities of the ICGs are subject to the provisions of a management contract established with the CRDA. Through the provisions of this management contract, this institutional reform constitutes a qualitative evolution that is not negligible in terms of State disengagement, especially since the GIC will have to take charge of all maintenance and operating expenses up to the limit of its financial capacity, which is the product of water sales and the contributions of the various members.

The latest guidelines on agricultural associations (Law 99-43 of 14 May 1999 and Law 2004- 24 of 15 March 2004) concern the transformation of ICGs into Agricultural Development Groups (GDAs). For the various existing GICs in the agricultural sector, they must adopt the name "GDA" and adapt their statutes to the standard statutes provided for by the law within a set period. Their objectives are: the protection of natural resources, the rationalization of their use and their safeguarding; the equipment and the realization of the basic infrastructures of their perimeter of intervention; the participation in the framing of the members to direct them towards the most reliable agricultural and fishing techniques in order to increase the productivity of the agricultural exploitations; the assistance of the organizations concerned by the clearance of the agrarian situations; the establishment of relations of cooperation and exchange of the experiences in the field.

The draft of the new Water Code (CDE) submitted by the government to the ARP in October 2019 (Bill No. 66-2019) was transmitted in December 2019 to the competent committee of the ARP: the Committee on Agriculture, Food Safety, Trade and Services. The process of examining this project within the parliamentary committee, began on 17 Dec. 2020 with a listening session of the Ministry of Agriculture, Water Resources and Fisheries – initiator of the project – to present its project. Subsequently, the commission, being aware of the importance of this law and its impact on all components of Tunisian society, set up a whole program of extended consultation with listening sessions to national professional organizations (UTAP, SYNAGRI and UTICA) and also to certain components of civil society, including representatives of GDA and experts.

5.2. Irrigation water pricing

Water pricing at relatively low levels has been a component of irrigation policy, mainly as an incentive for the adoption or intensification of irrigated agriculture. With the objective of promoting irrigation in order to improve the productivity of agriculture with a view to ensuring food self-sufficiency and reducing climatic impact, the Office of Development of Irrigated Public Perimeters, during the centralized management of the public irrigated perimeters, lowered the tariffs for irrigation water.

Until 1975, a single tariff system was applied. With the creation of other development boards, several specific tariff systems were developed according to the particular regional conditions.

However, the tariffs applied are usually far from the actual cost prices calculated by the various CRDAs, prices taking into account only the costs incurred by these regional irrigation water managers. The tariffs applied are usually far from the actual cost prices calculated by the various CRDAs, prices taking into account only the costs incurred by these regional irrigation water managers (CNEA, 2005).

The average price of water for irrigation is estimated at 0.110 D/m3; the actual rate varies between 0.028 D/m3 (Southern Oasis) and 0.175 D/m3 (large northern perimeters). Overall, the weight of water costs in relation to total crop costs averages around 14-15%, except in cereals where it reaches 20% despite the tariff advantages granted to these crops.

The implementation of the tariff proposals of the study is based on catching up the costs of the water service by the tariffs gradually, while modulating them according to the general state of the infrastructure and the quality of the water service. The entry into force of the new tariff began in 2019, with rate increases of 10 to 37% depending on the PPI fed by the Sidi Salem reservoir. The application of rate increases differs from one ARDC to another, or even from one PPI to another. For example, the CRDA of Manouba has made an increase for the PPI modernized in 2020 where is applied the two-part pricing:

- Price in 2019: 56 mil/m3 + 67 dT/ha
- Tariff in 2020: 62 mil/m3 + 74 dt/ha on the other hand, the mononomial tariff applied for the perimeters remained at the level of 110 mil/m3.

In light of this situation, some experiments have been conducted with regard to adopting new pricing structures. There should be mention of the experiments in generalized binomial pricing that were initiated in 1999 and of the preferential pricing that was also granted to so-called strategic crops (cereals).

6. MARKET STRUCTURE OF WATER EQUIPMENT

According to the report of PNEEI 2014, we distinguish two types of water equipment’s suppliers.

Local suppliers

Local suppliers provide support at different stages of the irrigation equipment project (upstream and downstream). They are small or very small structure of the "hardware" type selling water-saving equipment and other agricultural products. Concerning the staff, in this type of suppliers it is generally unskilled. In fact, they are learning from training done on the job or in-house exclusively on localized irrigation. In addition to that, the staff is often practicing agriculture in addition to trade.

The documentation used to explain and give information to the farmers is generally taken from the references provided by wholesalers. They have a diversity of sales, installation, study, consulting and maintenance activities. They are characterized by the domination of drip installation. The local suppliers carry out technical studies is widespread (for areas between 0.5 and 5 ha) and the consulting activity is almost general (1000 consulting / year paid). The installations WITHOUT subsidies represent between 10 and 80% of installations depending on the suppliers and governorates.

In addition, the private sector is playing a growing role in financing water-saving equipment more with large irrigators.

The cost/ha per crop by type of equipment varies greatly depending on the crop and the governorate. In fact, they have a limited relationship with the institutions: if they exist it is mainly with the administration CRDA, CTV, APIA very little with the professional agricultural organizations (UTICA, UTAP) even though 60% suppliers are informed of the regulatory context. The best-selling manufacturing standards for water-saving equipment are the Tunisian standard (NFT similar ISO), French AFNOR, and the European standard CEE.

The majority of suppliers are knowing the origin of the marketed product and the most used Tunisian brand are SICOAC and SCIPP in addition to the highly diversified foreign brands of Italian, French, Spanish, Chinese, Jordanian, Lebanese, and Saudi Arabia origin pursued for their quality and reliability. The inconvenient related to the Tunisian brand is that they are criticism related to the reliability of Tunisian manufactured accessories, the lack of standardization of diameters and plugs of GR pipes due to algae.

National suppliers

The national suppliers were created before the implementation of the PNEEI (1961 and 1994). They are charged by the Sale of irrigation equipment, agricultural equipment and sanitation throughout the Tunisian territory but with very variable development strategies. They are characterized by a Variable and qualified workforce in hydraulics and agronomy.

We can cite as an example of a national supplier the company Hydritech which 90% of its turnover comes from irrigation and all staff are trained in water saving and SOCCOPEC which is characterized by aggressive development strategy with the installation of branches with 100 already existing points of sale. They dominate the spare parts market. They also participate in annual meetings with the DG/GREE. For the company HTM, they are known for their possession of a test bench.

The national suppliers are characterized by high revenue in the governorates of Greater Tunis, Nabeul, Central and North-West. The Clients of the national suppliers are mainly wholesaler, retailer, private farmers and private companies, administration and OTD. To study the Market situation, the national suppliers participate in fairs and exhibitions and use digital (sales sites + social networks). Half of suppliers conduct satisfaction surveys. They have also confirmed suppliers' specialists in studies and installations, public procurement, consulting manufacture of special parts, trained in agronomy school (Chatt Mariem and Medjez El Bab).

The development of a local spare parts manufacturing market mainly concerns plastic parts, small accessories. 30 to 90% of the annual turnover from irrigation equipment. Marketed water-saving equipment benefit from subsidies and most of suppliers have relationships with government institutions (CRDA, APIA) and they are informed of the regulatory context. All of them use certified equipment and do not have the need to carry out the tests themselves. In fact, some materials like

GR pipelines are locally manufactured but engines and accessories come from abroad for reasons of reliability and quality.

National suppliers have mostly been criticized for non-conformances, the high cost of spare parts, leaks in drippers due to lack of maintenance, and unskilled labor.

PART II CREATE KPIS FOR THE EVALUATION OF THE IRRIGATION SYSTEM

7. KEY PERFORMANCE INDICATORS

7.1. Definition

Key Performance Indicators (KPIs) are the critical (key) quantifiable indicators of progress toward an intended result. KPIs provide a focus for strategic and operational improvement, create an analytical basis for decision making and help focus attention on what matters most.

7.2. Characteristics

Virtuous KPIs provide objective evidence of progress towards achieving a desired result, measure what is intended to be measured to help inform better decision making, offer a comparison that gauges the degree of performance change over time, can track efficiency, effectiveness, quality, timeliness, governance, compliance, behaviors, economics, project performance, personnel performance or resource utilization. They are balanced between leading and lagging indicators.

7.3. Literature Review

Irrigated agriculture must meet a triple ambition: to produce more food per unit of water consumed, to limit the environmental impact of irrigated agriculture and to improve the standard of living of farmers (Bos et al. 2005). The evaluation of irrigation performance is intended to be a tool at the service of these ambitions. Its ultimate objective is to contribute to an efficient and effective use of resources by providing appropriate feedback to system managers at all levels (Bos et al. 2005).

The process can be defined as "the systematic observation, documentation and interpretation of irrigated agriculture activities with the objective of continuous improvement" (Bos et al. 2005). To achieve this objective, several authors propose to follow a strict framework whose application makes it possible to improve the performance of the system studied (Murray-Rust and Snellen 1993; Gorantiwar and Smout 2005; Bos et al. 2005). For Bos et al. (2005), the first step, purpose and strategy, aims to establish the objective and approach to performance evaluation. During this stage, the target audience for the evaluation, the point of view adopted (user, manager, etc.), the type of evaluation (internal or external) and the spatial and temporal limits of the work are defined.

Then comes the design and planning phase. This part aims to define the criteria and performance indicators that will be used, to identify the necessary data, to plan the collection of this data and to define the expected results. Then comes the implementation, during which the actions planned in the previous phase are carried out. Finally, the application of outputs consists of taking a series of measures to integrate the conclusions drawn at the end of the evaluation process. A final evaluation step (further actions) is recommended to ensure that the process was successful and, if necessary, a new evaluation cycle should be undertaken.

This approach has a number of advantages. First of all, it makes it possible to be applied to any type of irrigated perimeter, regardless of its structure, level of institutionalization or size. The only requirement is that a single body coordinate its establishment. It also makes it possible to clearly identify the objective of the evaluation process and the target actors and thus makes it possible to focus the evaluation process on the defined objectives, thus avoiding its dispersion and improving its chances of success.

Finally, it does not constrain the notion of performance and therefore allows the integration of aspects as varied as technical, social, economic, environmental, institutional, strategic... Beyond its advantages, however, this approach has certain limitations. First of all, the implementation of the process as such and the implementation of the conclusions of the process require either the existence of a form of central authority with a power of constraint on the actors concerned by the implementation of the process and the implementation of its conclusions, or the adhesion of all the actors concerned to the evaluation process.

7.4. Identified KPIs from bibliography

In this section, we are going to summarize the most common indicators found in the literature review and we are going to classify them in three groups:

- Agronomic indicators,
- Economic indicators,
- And environmental indicators.

7.4.1. Agronomic performance

In the field of agronomy, the farmer is required to manage the practice of irrigation (Sabatier and Ruf, 1991). Agronomists have focused on the study of water productivity and water-plant-climate relationships (Sarma and Rao, 1997; Singh et al., 2006; Lorite te al., 2007) In particular, the agricultural sector faces a major challenge which is to produce more to feed the growing population while using less water.

In the Aim of maximizing the yield of stressed crops by optimizing their satisfaction of water needs, several studies have measured agronomic efficiency defined by the ratio between potential yield and water used for biomass production per unit area (Bos et al, 2005; Facon, 2006).

- Yield (t/ha): is an agronomic reference quantity that must be calculated over a period of 3 to 4 years to identify interannual variability. (Hanafi, 2011).
- Water productivity and water use efficiency:

Agronomic efficiency, or water use efficiency (WUE), is equal to the ratio between yield and the amount of water needed to obtain this yield (Viets, 1962; USDA, 2000), which is the ETr of the companion therefore:

$$WUE\ (kg/m^3\ /ha) = Rdt\ /\ ETr$$

This indicator mixes technical and agronomic aspects, which makes it difficult to interpret and use.

The term water use efficiency (WUE) should be used only to refer to the water use performance of the plant or by crops, irrigated or non-irrigated, to produce biomass and/or yield.

Water productivity is defined as crop production per unit of water used (Belder et al., 2004; Cantero-Martinez et al., 2003). It indicates the margin of yield improvement in relation to the amount of water allocated to transpiration. (Hanafi 2011).

AWP = Agricultural yield/water consumed by the crop

The term water productivity (WP) should be used to refer to the amount of product per an amount of water used, consumed or not consumed by crops (Pereira et al., 2011).

Agronomic performance, which can therefore be expressed by a yield or by water productivity or by the efficiency of water use, remains an appropriate concept for a given physical context (Hanafi, 2011).

According to Gamache, 2005, different indicators have been identified to express productivity and its evolution. Indeed, these indicators can be presented by unifactorial measures thus relating output to a single input, unlike the multifactor measure which simultaneously combines the effects of several inputs. Total factor productivity is therefore defined as the ratio of outputs to all actual inputs (Blancard and Bousselart, 2006).

The analysis of partial productivity of factors of production takes into account the contribution of a factor to production. However, this analysis neglects the interactions between factors of production. The analysis of economic efficiency makes it possible to overcome this limitation.

Conversion Efficiency of Water Consumption into Dry Matter Production and Yield (WUE).

WUE of Total Dry Matter (WUE-TDM) and WUE of yields (WUE-GY) will be calculated:

$$\textbf{WUE-TDM} = \textbf{TDM} / \textbf{WC}$$

$$\textbf{WUE-GY} = \textbf{GY} / \textbf{WC}$$

Where, WUE is the water use efficiency (kg m^{-3}), TDM is the total dry matter production (kg), GY is the yields (kg) and WC is the total water consumption over the whole growing season (mm).

Conversion Efficiency of Radiation Interception into Dry Matter Production and Yield (RUE).

RUE of Total Dry Matter (RUE-TDM) and RUE of yields (WUE-GY) will be calculated:

$$\textbf{RUE-TDM} = \textbf{TDM} / \textbf{PARabs}$$

$$\textbf{RUE-GY} = \textbf{GY} / \textbf{PARabs}$$

Where, RUE is the Radiation use efficiency (g MJ^{-1}), TDM is the total dry matter production (g m^{-2}), GY is the grain yields (g m^{-2}) and PARabs is the total radiation interception over the whole growing season (MJ m^{-2}).

7.4.2. Economic performance

The pioneers of economic efficiency analysis were Koopmans (1951) who proposed a measure of efficiency and Debreu (1951) who measured it empirically. The definition of economic efficiency was defined by Farrel and he was able to distinguish between technical efficiency and allocative efficiency.

Notion of efficiency:

Technical efficiency is defined by the way in which inputs entering the production process are used by a production entity (Farrell 1957). The purpose of calculating technical efficiency is to see whether, during production processes, the firm can increase its production without consuming more or less inputs while maintaining the same level of production (Amara and Romain., 2000).

Allocative efficiency is expressed by the way in which the proportions of different inputs are chosen in relation to the market price. In other words, it is the optimal combination of factors given their relative prices (Amara and Romain., 2000).

Economic efficiency is the result of the product of allocative efficiency and technical efficiency (Coelli et al., 1998). An agricultural operation is said to be economically efficient if it is both technically efficient and allocates its productive resources efficiently.

Productivity (PE)

We can also calculate the productivity in relation to the volume of water allocated for irrigation of the plot (Ve):

$$\textbf{PE} = \textbf{P/Ve}$$

Efficiency is defined as the ratio between the gross margin or net margin of the production of a unit area and the cost of irrigation water needed to achieve that production. This is called the valuation of irrigation water. The question they ask is: how many dirhams does a dirham of water (or the equivalent in cubic meters of water) invest in the irrigation of this or that crop? (1 US dollar is equivalent to about 10 Dirhams), in other words, what margin (in dirhams) can one have consumed a cubic meter of water?

Water use efficiency (WUE) = production (kg)/water applied or available (m^3)

With water applied or available (m^3) = irrigation water + rainwater

Water Use Efficiency (WUE) : The efficiency of irrigation water depends on plot irrigation methods and technologies, distribution, storage and conveyance solutions provided at the irrigation perimeter level. The method for calculating water use efficiency was adopted as part of the Strategy Mediterranean for Sustainable Development (MSSD) of Plan Bleu (Blinda, 2009):

EUE = E1*E2 ;

Where EUE indicates water use efficiency (%), E1 is the overall efficiency of transmission and distribution networks (%) and E2 is parcel efficiency (%). This index makes it possible to evaluate the efforts made in terms of water saving through demand management by reducing losses and waste during the transport and use of water (Benblidia, 2011).

The efficiency of irrigation per plot is calculated as follows:

$$E2 = \sum_{1}^{n} \frac{Sm*Et}{St}$$

With n is the number of irrigation techniques used within the plot, Sm is the area irrigated by the irrigation system, Em is the water efficiency in the different irrigation methods. Indeed, the theoretical average efficiency is estimated at 45% for gravity, 75% for sprinkler and 95% for localized irrigation, or the total irrigated area (ha) of all irrigation methods.

Cost-Benefit Analysis indicators:

Net present value (NPV) and rate of return (TR):

NPV is a concept similar to VPN that we defined in the analysis without refresh. It's the updating that makes the difference. A NPV of zero does not mean zero net profit, but refers to the fact that the project does not generate anything more than the interest paid by the bank that is considered to be acquired in advance.

Each time, it is a question of setting the profitability bar (which is often taken as the interest rate because it is the rate of arbitration between the present and the future), and to conclude the financial or economic supplement that the project will create in relation to this limit.

From the moment we have reached the discount rate that cancels the NPV outright, we will have determined the rate of return of the project (TR), which will allow us to compare the project to other investment alternatives (deposit in a bank, investment in another project, etc.).

$$VAN = \sum_{i=1}^{n} \frac{Bi-Ci}{(1+r)^{i}}$$

Bi : Profit for year i

Ci : Cost for year i

n : Project life

r : Discount rate

The TR is the discount rate r that verifies the equation:

$$\sum_{i=1}^{n} \frac{Bi-Ci}{(1+r)^{i}} = 0$$

Bi : Profit for year i

Ci : Cost for year i

n : Project life

r : Discount rate

Capital payback period (DRC):

The DRC is the minimum year n that verifies the equation:

$$\sum_{i=1}^{n} \frac{Bi-Ci}{(1+r)^{i}} \geq 0$$

Bi: Profit for year i

Ci: Cost for year i

n: Project life

A: Discount rate

Cost-benefit ratio (RCA):

This criterion compares the discounted incremental benefits to the discounted incremental costs of the project. When RCA is greater than 1, the discounted benefits exceed the levelized costs and the project is thus acceptable.

This ratio makes it possible to distinguish between different projects that have more or less the same benefit or the same cost.

$$RCA = \sum_{i=1}^{n} \frac{Bi}{(1+r)^{i}} \ / \ \sum_{i=1}^{n} \frac{Ci}{(1+r)^{i}}$$

Bi: Profit for year i

Ci: Cost for year i

n: Project life

A: Discount rate

Profitability Index:

The profitability index (or profitability index) is the result of the NPV report on the initial investment. Depending on whether the NPV is positive, negative or zero, the profitability index is higher, less than or equal to 1, respectively.

The interest of RI lies in the question: "Are the net benefits (excluding investment costs) large enough to invest all this money?"

RI measures what NPV represents in relation to invested capital.

RI also allows comparison between projects when the investment budget is limited and it is necessary to make a choice.

$$IR = \left(\frac{VAN+I}{I}\right) * 100$$

I: Investment cost

Economic valuation of water

Generally, agroeconomists define and calculate from the technical and economic management sheets of crops the following terms:

The gross product per hectare (GP), which is the yield per hectare (Rdt in kg/ha or Tonne/ha) multiplied by the unit price (PU per kg of product or tonne).

We can write:

GP (DT/ha) = Rdt (kg/ha) x PU

The value added per hectare (VA) of crop corresponds to the difference between the gross product per hectare (PB) and the costs per hectare (CHfm) of supplies (inputs: seeds, fertilizers, pesticides, etc.) and agricultural equipment (tractor rental and agricultural equipment during work, combine, etc.).

Thus, we can write:

VA (Dt/ha) = PB – CHfm

Real income (RR) per hectare is value added (VA) from which the costs of salaried labour (CHmos) are deducted. The calculation is done as follows:

RR (Dt/ha) = VA – Chmos

Net income (RN) per hectare is real income (RR) from which family labour costs (CHmof) are deducted. The calculation is done as follows:

RN (Dt/ha) = RR – CHmof

It is possible to estimate the economic value of water in dinars per cubic meter of water used throughout the crop cycle (Dinars/m3) or in dinars of product per dinar of water, if water tariffs are known and vary with irrigation mode.

7.4.3. Environmental performance

Ground water

The mobilization cost of one m^3 of water taken from the ground water can be estimated from the construction costs of a well, the purchase of the motor pump and operating costs.

Knowing that the amortization period of a well-equipped well is 20 years and that of a pump is about 5 years, the cost of one m^3 of water pumped per year will be as follows:

CMM = CT/ (VT x DV)

With:

CMM: the average cost per m^3 of water pumped into a surface well (DT/m^3).

CT: the total cost of pumping water.

VT is the total volume supplied by a well during one year.

DV well life which averages 20 years

Energy performance

Because of the costs involved, energy consumption is a decisive factor in the choice of technology when a farmer plans to upgrade his irrigation system and appears even more incentive than water savings proper.

$E = V \times \rho \times g \times h$

with E: amount of energy needed in Joules; V: volume of water in m^3; ρ: density of water in kg/m^3; g: Acceleration of gravity in m/s^2; h: Difference in altitude in m.

The overall energy performance in m3/kWh expresses the number of m3 of water applied thanks to 1 kWh consumed. This ratio is the inverse of the overall energy consumption ratio above.

Overall energy performance (m3/kWh) = volume of water applied / total E consumed

The overall energy consumption in kWh/m3 reflects the amount of energy required for the installation to apply 1 m3 of water to the plot /

Overall energy consumption (kWh/m3) = Total E consumed / volume of water applied

The total energy consumed can be considered at different levels of the hydraulic installation: final energy (at the pump inlet), useful energy produced (at the pump outlet), or plot energy (at plot inlet).

It is obvious that high irrigation water efficiency leads to a lower water requirement, and therefore lower energy consumption since energy consumption is proportional to the volume pumped (Claire Serra-Wittling, Bruno Molle, 2020).

Table 5: Summary of Performance Indicators

Indicator		Interest	Data	Method
Agronomic indicators	**Conversion Efficiency of Water Consumption into Dry Matter Production and Yield (WUE).**	Evaluate and improve agricultural systems in order to increase yields and the efficiency of resource use	TDM (g m-2) is the total dry matter production; and WC (mm) is the cumulative water consumption over the growing season.	**WUE= TDM/ Wc**
	Conversion Efficiency of Radiation Interception into Dry Matter Production and Yield (RUE).		TDM (g m-2) is total dry matter production; and PARabs (MJ m-2) is the cumulative photosynthetically active radiation intercepted over the growing season	**RUE-TDM = TDM / PARabs**

	Cost-Benefi t Analysis indicators	Cost–benefit analysis (CBA), as a common instrument in the decision-making process on how to allocate financial resources, has been widely used in various research areas and in almost all of countries over the world	Bi : Profit for year i Ci : Cost for year i n : Project life r : Discount rate	**VAN =** $= \sum_{i=1}^{n} \frac{Bi-Ci}{(1+r)^{i}}$ TR : VAN = 0 , DRC : $\sum_{i=1}^{n} \frac{Bi-Ci}{(1+r)^{i}} \geq 0$, $RCA = \sum_{i=1}^{n} \frac{Bi}{(1+r)^{i}} / \sum_{i=1}^{n} \frac{Ci}{(1+r)^{i}}$ $IR = \left(\frac{VAN+I}{I}\right) * 100$
	Economic valuation of water	It indicates the economic value of water per unit of production factor.	GP : Gross Product Rdt: Yield (kg/ha) PU: Unit price (Dt) VA: value added per hectare CHfm: costs of supplies/ha CHmos: labor costs CHmof: labor family costs RR: real income/ha RN: net income/ha	**GP (DT/ha) = Rdt (kg/ha) x PU** **VA (Dt/ha) = PB – CHfm** **RR (Dt/ha) = VA – Chmos** **RN (Dt/ha) = RR – Chmof**

	Productivity (PE)	It indicates the margin of yield improvement in relation to the amount of water allocated to transpiration.	P: Production Ve: water allocated for irrigation of the plot	**PE = P/Ve**
Environmental indicators	Ground water	the average cost per m^3 of water pumped into a surface well (DT/m^3).	CT: the total cost of pumping water. VT is the total volume supplied by a well during one year. DV well life which averages 20 years	**CMM = CT/ (VT x DV)**

	Energy performance	Helps the farmer planning to upgrade his irrigation system and appears even more incentive than water savings proper.	E: amount of energy needed in Joules; V: volume of water in m^3; ρ: density of water in kg/m^3; g: Acceleration of gravity in m/s^2; h: Difference in altitude in m. volume of water applied Total Energy consumed	**E = V x ρ x g x h** **Overall energy performance (m3/kWh) = volume of water applied / total E consumed** **Overall energy consumption (kWh/m3) = Total E consumed / volume of water applied**

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