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Management of agricultural irrigation in the Algerian Sahara and its impact

Samia Benguergoura Laradj

Department of Engineering Process, Faculty of Engineering, University Saad Dahleb Blida, 9000, Algeria, email: samialaradj@yahoo.fr

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ABSTRACT

The mismanagement of irrigation led to an excess water from urban discharges. The absence of an appropriate and effective drainage system and the overexploitation of the water table induce the upwelling of water and an imbalance in some Saharan areas. The sterilization of many agricultural areas was observed further to the intense evapotranspiration of about 2207.5 mm/y. A quotient of precipitation Q = 6.68 indicates that the climate of the region belongs to the Saharan type. The waters of the collecting channel and the groundwater are of very poor quality, very loaded with mineral salts, very hard, and have a very high salinity, an electrical conductivity up to 26.30 ms/cm, a TDS value (Total Dissolved Salts) up to 21 g/l and 14 g/l in groundwater. The type of facies is sodium chloride. Various irrigation techniques have been developed to try to control salinity while avoiding the rise of the water table.

Keywords: Water management; Irrigation; Damage; Date palm; Soil

1. Introduction

The northern Algerian Sahara is characterised by a water-bearing system composed of two important deep water tables known as the Intercalary Continental (I.C) and the Terminal Complex (T.C). They are expanded on an area of 700,000 km^{2}and 350,000 km^2 successively. The theoretical reserves of the two water tables are estimated at about 60,000billionm^3 [1]. In addition, in the superior part of the continental, the non-captive deep water tables of 02 to 10 meters increase the hydraulic reserve of the low Sahara.

The agricultural system of production in this area revolves essentially around the phoéniculture, which forms the main frame of this system. However, the water endowment intended to irrigation increased considerably on the whole of oases of the northern Sahara. It is witnessed that the flooding induced by the backwaters in the oases of Souf and Ouargla and recession of the water table in the areas of Touat and Guourara is explained by the upwelling of the groundwater (Fig. 1) [2].

The second salinization further to the irrigation with highly mineralized waters led to a permanent hardness that caused the extension of the salinity in all palm groves.

Therefore, a study estimated that 800,000 tons of salt accumulated every year in the cultivated lands of OuedRigh induced the suffocation of date palm [3]. As a result, several hectares of the cultivated land have been destroyed and the decline in yield in date cropping has led to a serious economic problem.

OuedRigh valley, situated in the east of northern Sahara (Touggourt), also called low Sahara, is a long meridian depression included between the big oriental erg and the chotts zone in the north. It is a vast synclinal dissymmetric hole characterised by the existence of a sandy soil, in general siliceous and formed of pure quartz therefore intractable [4]. It extends about 150 km along a South-North axis with a width ranging from 20 to 30 km; latitude 32°54′ to 39°9′N, longitude of 05°50′, 05°75′Est; straddles two provinces between El Goug (P. Ouargla) and Oum El Thiour (P. El Oued) where the highest hill is + 100 m in El Goug up stream and –30 m in the chott Merouane downstream [5]. The general declivity is very weak of which it has the order of 1% and it permits the flow of the excessive waters to the north. A well-precise economic entity gathers near 50 oases and covers around 25,000 ha of palm groves (Fig. 2) [6].

*Corresponding author.

Fig. 1. The upwelling of waters of the water table [2].

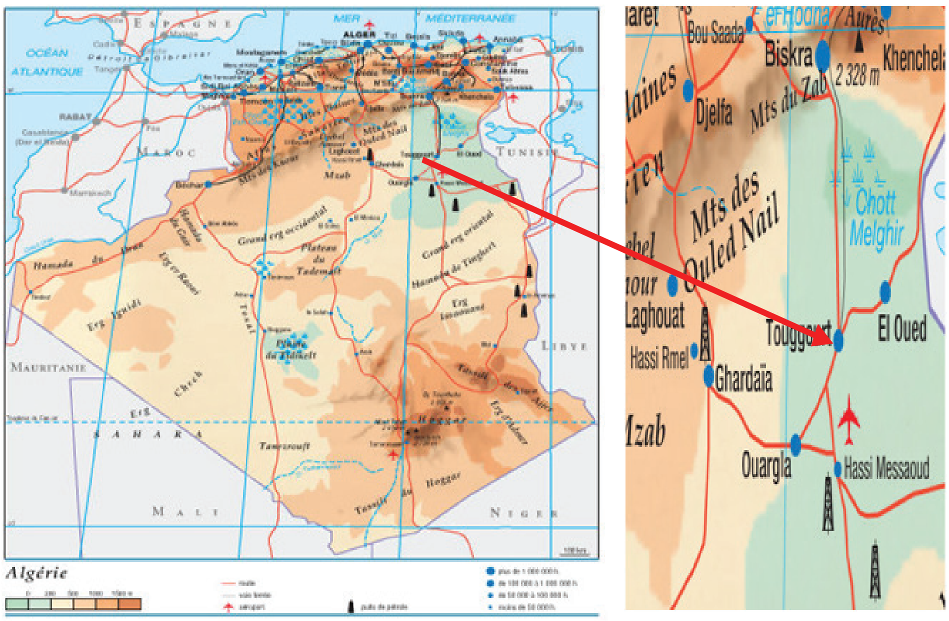

Fig. 2. Location of the Touggourt region in the Algerian Sahara[6].

2. Materials and methods

In the first study on irrigation water, the choice was made according to the geomorphological point of view, namely, the High OuedRigh (Zone I) which is the area of Touggourt, historically capital of OuedRigh that is located 160 km from Ouargla, and 220 km from Biskra, and Middle OuedRigh (Zone II)which is the Gama'a zone. This later depends to the province of ElOued. Lastly, Lower OuedRigh (Zone III) which is the Meghaier area. The agricultural activity in these areas based primarily on phoéniculture where we find traditional and modern palms. Analyses of the concerned irrigation water for this study are the following:

- Electrical conductivity (E.C) at 25°C using a conductivity meter (DELTA OHM) HD 3406.2, which gives directly the conductivity of the sample mmhos/cm, or ds/m at the temperature adopted [7].
- The pH (Hydrogenpotential), pH-meter glass electrode inolab (W.T.W) 720 [7].
- The total solids (TS) by drying a water volume of 50 ml in an oven at 105°C for 24 h [7].
- The quantification of the elemental mineral particles grouped in different classes was carried out by a dry process of classifying by sieving the different fractions in the sample using a series of sieves (2.0 mm, 1.0 mm, 0.40 mm, 0.20 mm, 0.10 mm, 0.08 mm) [7].

A sampling collection system is chosen to allow acquiring representative data about the spatial and chronological variability of canal waters quality of OuedRigh (Touggourt) and their influence on the ground water near the palm trees of the region. Note that this channel is the one and only outlet that receives all the sewage and drainage in the region of Touggourt. Moreover, this collection system is composed of 9 stations flowing in the canal, covering a portion of about 50 km, going over the upstream canal (West) to the downstream (East). A physicochemical analysis of waters of the groundwater was done in every sector of a cultivated land taking into consideration 5 piezometric stations of measurement covering a portion of about 46 km. The piezometers are kept equipped by tubes of PVC (polyvinyl chloride) and their depth was fixed at 2m.

The physicochemical water samples and pollution analyses were performed in water treatment laboratory of National Agency of Hydraulic Resource (NAHR) where measurement procedures are deducted from the standard analytical methods. A variety of analytical methods had to be used for the various experimental tests, going through titrimetric, electrochemical and spectroscopic methods. With a direct reading HACH.DR/2000spectrophotometer, and a SKALAR branded device coupled to a SCHERWOOD brand flame spectrometer Model420 [7].

3. Results and discussion

3.1. Hydro-climatology of Touggourt region

The temperature influences the degree of evapotranspiration and it acts on the water salinity where the yearly averages of climatic factors are 28.7°C as maximum temperature average, 14.1°C as minimum temperature average and 21.4°C as medium temperature average. The quantity of yearly precipitations is 77 mm [8].

The curve of average monthly variations of precipitations (Fig. 3) shows that the month of December is the rainiest with 18 mm followed by the month of February with 15 mm, so that the month of august is the driest with 0 mm followed by the month of June and July with 1 mm. The determination of this dry period is very essential to estimate the water needs. Concerning the region of Touggourt where ouedRigh is situated, the aridity sign of De Martonne is equal to: *Ia* = 2.45 which allows to say that the climate is of type hyper-arid. The evaporation is very intense, mostly when it is reinforced by hot winds. It is of the order 2207.5 mm/y with a monthly maximum of 310.20 mm on July and a minimum of 69.90 mm on January [9]. This climatological study is made to highlight the following climatic characteristics: precipitation, temperature, humidity, the maximum wind speed, insolation and evapotranspiration [8] (Table 1), in order to have a clear idea about the climate of our study area.

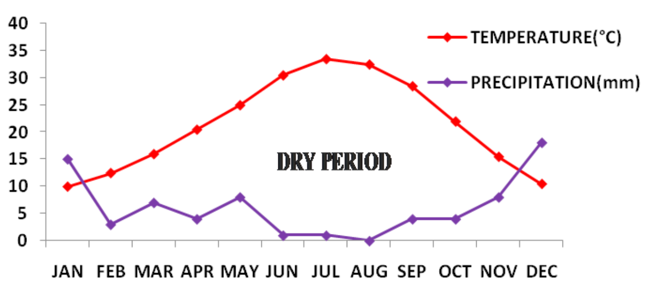

Fig. 3. Ombro thermic diagram of Gaussen of Touggourt region.

3.2. Water and soil characteristics of the Touggourt area

The water used for irrigation comes from groundwater Pliocene. According to the characterization results of irrigation water, it is noted that these waters are alkaline (pH = 8) (Fig. 4), heavily salted and the facies type is chlorinated sodic. They are used for irrigation but are dangerous for alkalizing and soil salinization. It is also noticed that the humidity increases with the depth from ground level of the three zones. For bareland, soil moisture is low in comparison to land grown; this is due to the effect of irrigation (Fig. 5).The results of particle size analysis in the resorts of studies show that the sand fraction is dominating visibly. For the cultivated land in zone I, the soil is sandy so that the clay fraction and silt are low. Mainly the sand, which has a high percentage, forms textural composition of the soil in zone II. The values of silt with clay vary but remain significant. In zone III, the soil is characterized by the dominance of sand and low presence of Limon with clay (Fig. 6). So our study on the soils of the regions shows that they are dominated by the fine sand fraction, which promotes capillary upwelling. Various factors, such as those of the groundwa-

Table 1
Climatic variations in the Touggourt region [8]

Climatic variations	Minimum values/month	Maximum values /month
Precipitation (mm)	17.31 (January)	0.84 (July)
Temperature (°C)	10.46 (December)	33.57 (August)
Humidity (%)	32.34 (July)	65.75 (December)
Wind speed (m/s)	2.60 (December)	4.20 (May)
Insolation duration (h)	234.40 (Junuary)	334.70 (August)
Evapotranspiration (mm)	107.40 (December)	399.80 (July)

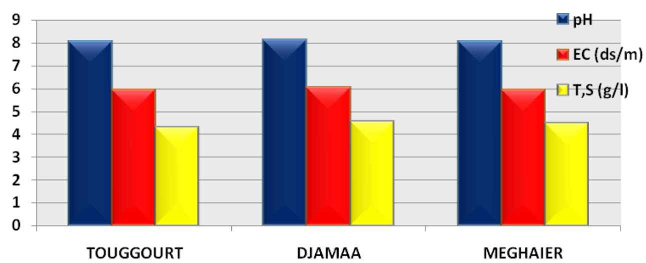

Fig. 4. Evolution of the parameters (pH, E.C, T.S) in all three zones.

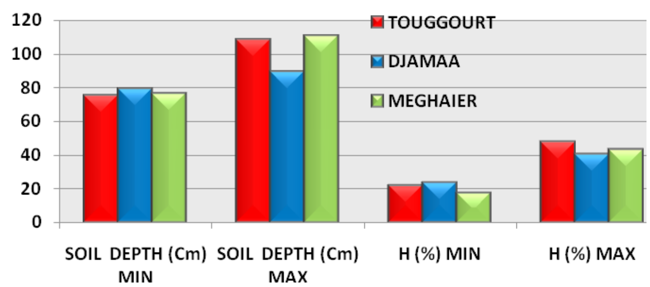

Fig. 5. Evolution of humidity soil according to its depth.

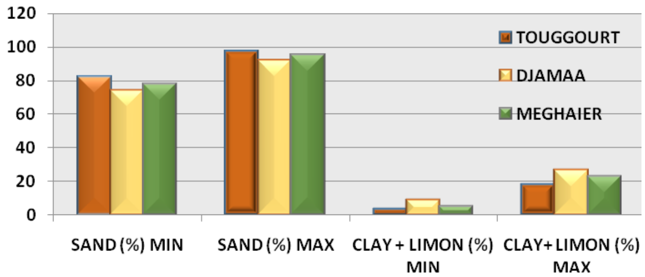

Fig. 6. Study of the Composition granulo metric of the ground for the three zones.

ter, including the ones of the terminal complex (relatively charged) and more or less salty parental rocks carry out the accumulation of salts in the soil.

3.3. Study of the evolution of the physicochemical parameters of canal water and ground water according to time

The pH varies between 7.3 and 7.9 during the period of high waters, whereas in the period of low waters it varies between 7.4 and 8.3 [10]. The waters of canal present an alkaline bicarbonate character especially in summer. In addition, the Sahara soils are generally poor in nutrients, and their alkaline pH is more than 7.5 (pH >7.5). Noting also that the pH of irrigation water must take place between 5.5 and 6.5 [11], by these values, the solubility of the most microelements is optimal. The electrical conductivity which varies from 15.00 to 26.30 ms/cm evaluates the salinity degree of water and increases with the concentration of ions in solution and of temperature where all the measured values indicate a very high mineralization. It is noted that in a higher conductivity at 20 ds/m only palms can vegetate normally. Beyond 22.5 ds/m, water is strictly unusable. It allows classifying the water in class C5 as an exceptional water [12].

3.3.1. Determination of the main hydro-chemical facies

The mineral salts contained in the irrigation waters have an impact on the soil and plants, as well as make a change in the structure of soil (modifying also its permeability and its airing) and disturbance of development of vegetation [13]. Other factors also exist such as the biogeochemical environment, the climate, the aridity, the soil texture, the water table depth in addition to three other big geochemical ways (acid, neutral or alkaline). In order to evaluate the quality of the waters of canal and of ground waters in the (I.C) and (T.C), and to understand the danger of salinization and sodication of soils; the diagram of PIPER was used [14] (Figs. 7, 8).

It is noted that the sodium chloride facies appear in the majority of waters of canal with a high conductivity, which coincides here with the presence of very conducting grounds (Triassic gypsiferous clays).

In the absence of bicarbonate facies, all waters in (I.C) and (T.C) appear to be highly mineralized and rich of chloride ions; sulfide; in particular calcium and sodium. The most concentrated water therefore corresponds to the sodium chloride facies and the dissolution of the halite (rock salt NaCl) or gypsum. All these accumulations of gypsum represent a physical and chemical constraint for a better management of the soils and for sustainable and productive agriculture [15].

The combined action of a climate characterized by intense evapotranspiration and a presence of a shallow water table means that most soils are subject to secondary salinization where the type of salinity is sodium sulphate on average, and sodium chloride in general.

3.3.2. Water quality of OuedRigh valley and its impact on the date palm cultivation

As a low rainfall, high evaporation, and a groundwater too loaded with chlorides and sulphates characterize the region of Touggourt, the risk of soil salinization is well felt. The main factors that can degrade the quality of irrigation water are the TDS (total dissolved salts) which are connected to the electrical conductivity (EC). The accumulation of water-soluble salts in the soil negatively affects the growth of palm trees with dates in reduced yields hardly exceed 50 kg/palm in the region of OuedRigh.

The values of TDS of the canal water reach up to 21 g/l (Fig. 9) reflecting a strong accumulation of salts that can harm the growth of palm trees. Indeed all the irrigated crops with water to 5,000 ppm of salt eventually die and only a few survived from 2,500 ppm [16]. In this study, these values sometimes exceed the standards. If the TDS values >10,000 ppm the cultivated lands should undergo an excellent drainage followed by an irrigation program.

However concerning the waters of groundwater, the TDS values reach up to 14.32 g/l in the station of SidiSlimane, which is an area cultivated near the canal. As a result, this study deduces that at this level, the waters of the canal contaminate the waters of the aquifer and the Halophytic plants are among the ones that are the most tolerant to salt, but to certain limits.

4. The study of water management in the Sahara

4.1. Date palm irrigation

The purpose of rational irrigation of palm trees is to ensure, throughout the year, the quantities of water necessary for the development of a good crop. The most frequent number of 25,000 m^3/ha/y gives a water consumption of nearly 4 m^3 per kg of date. For all the palms of OuedRigh, this quantity necessary for the production of 1 kg of dates amounts to 6 or 7 m^3 where an important part of the water is intended to the fight against salt. The amount of irrigation water seems to have a direct effect on fruit growth and weight. In (El Arfiane) where water contains 9–16 g/L of salt, there is a physiological success, but the fruits are very small (4 g on average) and their growth is very long. Finally, the proportion of 8–9 g/L of salt seems to be a limit must not to be exceeded in order to obtain a valid economic result [17].

4.2. The salinization caused by the irrigation

Over the past fifty years, large-scale irrigation practices have changed the functioning of soils and increased the risk

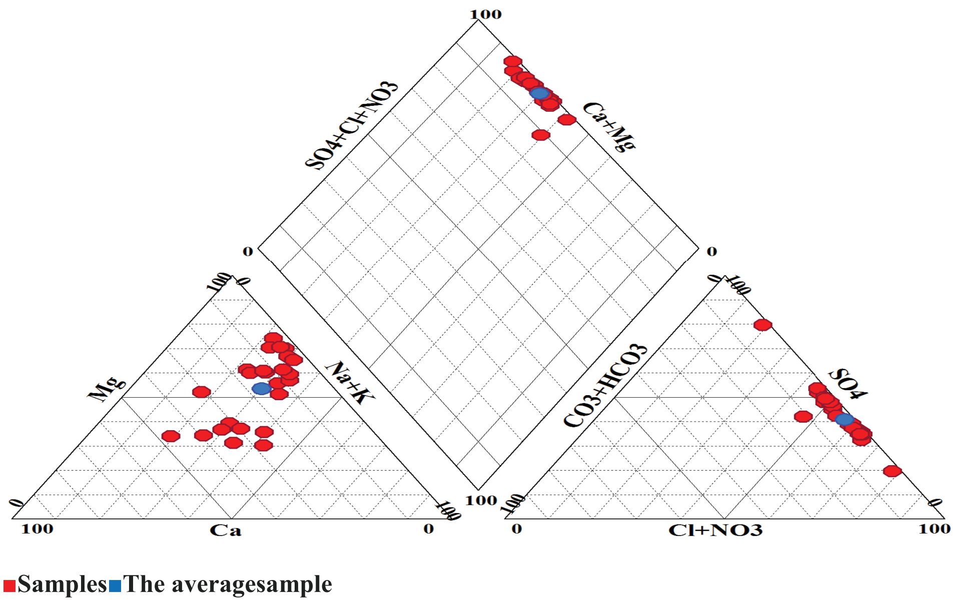

Fig. 7. Piper diagram Water Terminal Complex of TOUGGOURT.

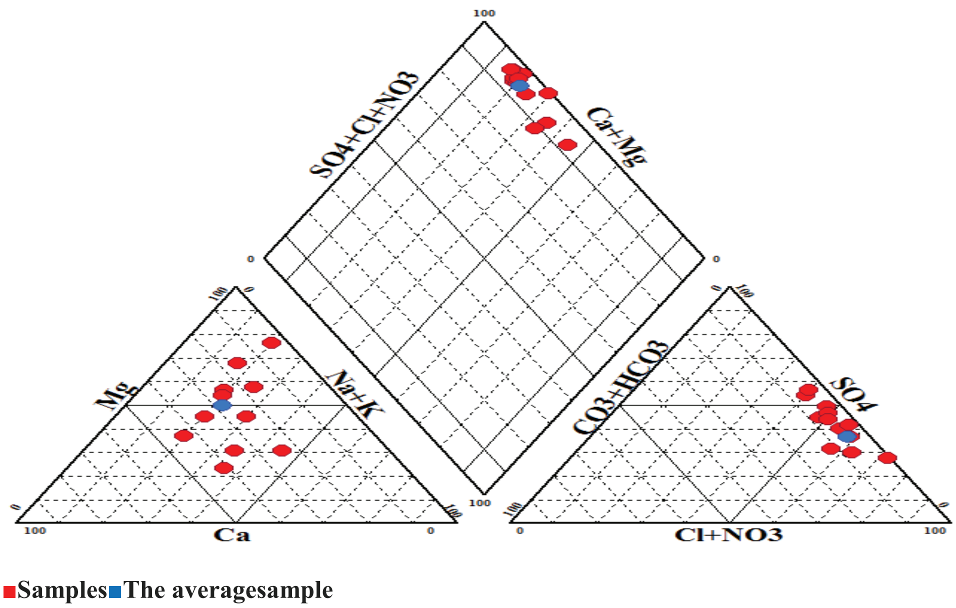

Fig. 8. Piper diagram Intercalary Continental waters of TOUGGOURT.

of salinization. More than 20% of irrigated soils are affected by the salinity problem [18] and nearly 50% of irrigated soils are located in the dry zone (Fig. 10). In the Saharan regions, groundwater, largely non-renewable, is the main source of water for irrigation. In the other hand, deep water used in the Sahara either artesian or pumped is generally highly mineralized where the groundwater salinity level varies from 6 to 7 g per liter in OuedRigh and 2.5 g per liter in Saouara and from 1.2 to 2.5 g per liter in the albian to the Sahara [19]. In general, the water table (IC) shows a significant decrease in areas where a high level of exploitation

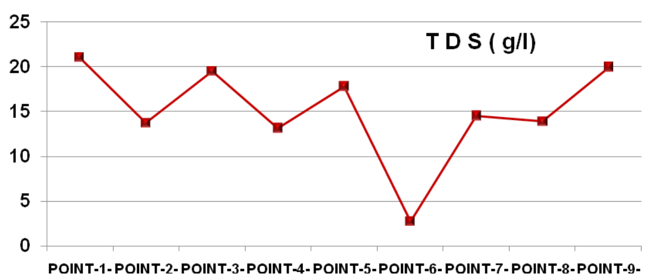

Fig. 9. TDS Evaluation of Touggourt oued Righ waters canal.

Fig. 10. Representation of a cover by a salt crust [10].

exists. As in OuedRigh, Ouargla, El Oued where the water table often exceeds 2 m/y during the last two Decades, causing upwelling of the waters and crop degradation.

4.3. Irrigation techniques of oases in the south Algeria

4.3.1. Oasis of Ouargla

The irrigation water is extracted from the groundwater by traditional wells,which is a local specialty. However, their number (250–300 wells) decreases because of the water table drying which led the community members to share water by a unit time according to the subtle technique of water turns being in many oases [20].

4.3.2. Oasis of M'Zab

The hydraulic system based on a water table fed artificially by small structures composed of a diversion dam and a set of pipes, which store and canalise the water of the valley (oued) towards underground canals expended on hundreds of meters. The flows are estimated according to the number of palm tree (Fig. 11) [20].

4.3.3. Oasis of foggaras

They are known as (Quanat) or (Kariz) in Iran, called (Foggara) in Algeria and (Kettara) in Morocco. They are of Persian origin [21]. Foggras develop in the southwestern regions of Algeria, particularly in Adrar, Touat and Gourara where hydro-geological and topographic conditions are favorable. They are represented by a set of underground galleries executed in the same aquifer. The gallery is represented by vertical wells, spaced 10–15 m apart; the depth of the wells is 5–10 m and a width of 1 m. The number of Foggaras active in Algeria rises to 572 for a total of 1,377 km and an overall flow of 2,942 l/s able to irrigate 3,000 ha [22]. At the liberation of the foggaras, the water is channeled through a channel to a comb-shaped diver made by the clay. The water escapes, divided and then directed by a mass of canals towards the plots that must irrigate the oases (Fig. 12). The flow of foggaras is divided into 24 parts where "Guesma" is itself divided into 24 subparts. However, the foggaras offer the advantage of continuously supplying water by gravity, with a continuous flow of up to 400 l/s. The excess water flows to a collection basin called "Madjen" to irrigate other plots downstream (Fig. 13).

Fig. 11. Small structures composed of dams in the oasis of M'zab [20].

Fig. 12. Canalization of water by canals at the release of a Foggaras [21].

Fig. 13. Foggara water catchment area (Madjen) [21].

4.3.4. Irrigation by drilling

This corresponds to eight cities, namely Touggourt, SidiSlimane, Megarine, ZaouiaLabidia, Tebesbest, Nezla, Temacine and Blidet Amor. In this zone, 342 boreholes operate the layer of the Mio-Pliocene and Eocene terminal complex at a depth between 30 and 240 m. The flow provided by the borehole is between 10 and 40 l/s. The volume taken is 17.3 million m^3/month and 208 million m^3/y, or 55% of the total volume extracted. Six boreholes collect the Continental Intercalary, which is a water tank with a temperature exceeding 50°C, and a mineralization of water between 1–2 g/L of dry residue. Each one providing a flow of about 130 l/s on average, providing also the agglomerations with the supply of drinking water [22].

4.3.5. Irrigation by flooding

The flood irrigation system, underground low-pressure pipes such as Sidi Mahdi or open-air as SidiSlimane, is an irrigation technique that will ensure a regular supply of water according to needs. Flooding is also an excellent desalination technique, and it is even the only one that should be adopted in order to lead a good leaching.

5. Problem of irrigation water in Touggourt region

OuedRigh valley is characterized by a very complex hydro-agricultural state of land. Currently in this region, the practice of irrigation in a very permeable soil and with the existence of a non-deep argillaceous groundwater causes an abuse of irrigation water of poor quality, non-saline soils originally evolved in saline to extreme salinity. A poorly planned, deep, poorly maintained and inefficient drainage system (Fig. 14), which causes stagnation of wastewater and sanitation, resulting in many nuisances, also an obstruction of the soil by high salinity of the irrigation water, from the upper layer which reduces the drainage efficiency, and an abnormal ascent of groundwater.

5.1. Sodicity and salinity risks

Salinization can cause bad effects on irrigation water quality because the presence of sodium and chloride exerts a harmful effect on vegetation and soil such as increase in osmotic pressure (O.P) that makes the water hardly mobilized by plants,a toxicity of certain ions to plants (Cl^-, Na^+ ... etc.) and Soil degradation (changes in structural state, reduction of permeability… etc.). The agricultural production suffered a permanent decline over the years because the irrigation development perspectives, which are part of the rehabilitation project and expansion of the palm groves of OuedRigh require extensive knowledge about the hydro saline regime of soils to provide the basis for optimum control of the following parameters: Watering techniques, drainages type, doses and leaching technology. Noting besides that the ground water irrigated perimeters are often high in salts.

Water evapotranspirates progressively, which concentrates the soil solution and makes the process of evapo-concentration. This phenomenon not only cancels the leaching, but also re-drives the salts in the upper part of the soil, the more sensitive to the growth of plants (Fig. 15).

5.2. Means to fight against salinity

In arid countries where water is often mineralized and contains dissolved salts, agriculture is often threatened. To fight against this scourge it is necessary to:

- Use water abundantly to remove excess salts, especially before planting. And use rainwater or freshwater as much as possible to desalinate groundwater.
- Maintain or restore the water table sufficiently deep to prevent the rising of saline water, especially if the water table itself is brackish.
- Keep the Na^+ ion in a small proportion by adding the appropriate amendments and maintain the soil by providing an adequate fertilization.

Fig. 14. Drainage ditches degraded due to lack of maintenance [10].

Fig. 15. Infertility soil and degradation of palm [10].

- Reduce evaporation by hoeing, soil mulching with reeds or a film of bitumen to avoid depositing salts in the root zone. It is also possible to supply sulfur oxide that lowers soil pH in areas that are too arid, but its action is slow.
- Ensure rapid drainage to avoid asphyxiation of crops. Surface irrigation is not recommended because it is generally practiced with too little water that does not permit leaching of the salts.

6. Conclusion

The waters of the two water tables of Touggourt (T.C) and (I.C) show that they are not safe for human consumption because they are too hard and mineralized and have very poor chemical quality for irrigation. Some of these waters must be treated (treatment station) before being used for soil and plants. To conclude, drinking water of good chemical quality remains a dream for the Touggourt region.

The evolution of the chemical elements (Na^+, Cl^-, Ca^{2+}, SO_4^{2-}, HCO_3^-), which characterize the main geological formations of the region OuedRigh (Touggourt), showed the dominance of salt-bearing ions (Na^+, Cl^-), gypsiferous (Ca^{2+}, SO_4^{2-}) and versus carbonate (Ca^{2+}, HCO_3^-) in the acquisition of salinity. Thus, it can be said that the parental material of the soil of the Touggourt region is of mixed origin aluvial-colluvial dating from the ancient quaternary or Mio-Pliocene. The monitoring of water quality over time showed the effect of evaporation on the mineralization of the canal waters and ground water, which are characterized by high

(EC) salinity and unfavourable (TDS) velocities for a rich and sustainable production of agriculture. The texture of the soil becomes compact which prevents water from seeping into the soil. Therefore, the saltier the soil is, the higher the osmotic pressure (O.P) and the more difficult it is for shrub roots to extract water from soil reserves. This has the effect of slowing growth under the effect of water stress. The salt concentration depends on the moisture content of the soil and increases with drying. As a result, excessive salts affecting crops are affected much more rapidly in sandy soils than in clay soils that contain more water. To solve this problem, environmental factors must be taken into account when rationalizing the quantities and qualities of used water by avoiding the use of (TC) and (IC) waters in irrigation to avoid the rise in groundwater levels and crop degradation.

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