



Development and Conservation of Water Resources for Agriculture in an Arid Environment: A Case Study of the Souf Oasis (Algerian Sahara)

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Abstract: In the majority of arid regions, the groundwater is the only source of water available for different uses. It is, however, depleting at very fast rate due to heavy dependence on groundwater for practically all purposes. Present study, highlights the problems of water resource depletion in Souf Oasis as a typical example. This Oasis has been known for sharp decline in the groundwater level, caused by the constant attrition of phreatic aquifer, particularly by the agricultural sector. The decline in groundwater level has led to many problems particularly, deterioration of traditional irrigation system (Ghout). The first part of the paper has concentrated on the rational use of available water resources and, second part focuses on research on alternative water resources such as, reuse or treatment of wastewater. This resource can be exploited directly for irrigation or indirectly through artificial recharge technique to support the available stock of phreatic aquifer.

Key words: Phreatic aquifer, artificial recharge, water scarcity, treated wastewater, agriculture, Souf Oasis.

Water is one of the most vital natural resources. It is crucial for the survival of all living organisms and is essential for agriculture, domestic, industrial input, tourism besides sustenance of the earth's ecosystems. According to the United Nations estimates, the world population is expected to rise to 9 billion by 2050. This phenomenal rise in population will cause major demand on freshwater supplies for consumer use and irrigated agriculture (Taft, 2015). In Africa, the Food and Agriculture Organization estimates that by 2025, approximately 480 million people would be living in areas of high water scarcity (Omotobora *et al.*, 2014).

The environment, economy and development of any country are significantly influenced by the regional and seasonal variation in the available quantity and quality of surface and groundwater (Odhiambo, 2016). At the beginning of the 21st century, the world faces a water crisis, with respect to both quantity and quality, caused by continuous population

growth, industrialization, food production practices besides increased living standards and poor water use strategies (Pereira *et al.*, 2002; Iglesias *et al.*, 2007; Corcoran *et al.*, 2010). Global water consumption is doubling every 20 years. By the year 2025, two out of three people in the world will be living in water scarce-regions, especially in developing countries and even in some developed countries (Matheyarasu *et al.*, 2015). This crisis will be more severe in the arid and semi-arid regions (Kahil *et al.*, 2016), because it covers one-third of the lands on earth and hold one-fifth of the global population (Jackson *et al.*, 2001).

In many arid and semi-arid areas in the world, the groundwater is the only source available for all types of uses (Ebrahimi *et al.*, 2016). The over-exploitation of this resource has led to a significant decrease of the groundwater level and the degradation of its quality (Lachaal *et al.*, 2011). Currently, searching for alternative water resources is a difficult challenge for these countries. According to Kadirkhodjaeva (2015), under arid and semi-arid conditions, only Cyprus, Tunisia and Jordan, practice wastewater

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treatment and reuse, as an integral component of their water management strategies.

In the Souf Oasis (Algerian Sahara) is a typical example of arid environment. According to many studies, all parts of Souf Oasis (except for El Oued municipality), are currently declining in the level of phreatic water table, caused by the over-exploitation for a long time, especially by the agriculture sector. So, it is envisaged that the remaining water shall also exhaust soon.

The main objective of this paper is to identify possible methods for development and conservation of water resources for agricultural purposes in Souf Oasis and in other similar regions.

Study Area Description

Souf Oasis, located in the Eastern South of Algeria, extends over an area of 11738.4 km², divided into 18 municipalities and represents nearly 26% of the total territory of the El-Qued province (Khezzani and Bouchemal, 2016) (Fig. 1). The quaternary formations (sand dunes) cover most of the region, especially in the southern part and salt flats (Shatt) exists in the northern extreme part. The altitude above the mean sea level varies from 50 meters in the north to 100 meters in the south.

The climate of the Oasis is hyper-arid, characterized by a very hot and dry summer, and mild winter (Khechana and Derradji, 2012). The rainfall is sporadic, low and erratic, with an annual average not exceeding 70 mm. The annual evaporation exceeds 2200 mm (Khezzani *et al.*, 2016). Temperature drops to near-freezing point in winter and reaches 45 degrees Celsius during summer. The relative humidity is usually about 30% during summer (July and August) and may reach up to 65% during winter (December and January). Winds are usually mild, but in the spring and autumn their speed is very high.

In the year 2016, the total population in Souf Oasis was 586465 inhabitants (71.52% of the total population of El-Oued province), with density of 48.23 people per km². Life in this Oasis is based on irrigated farming from the phreatic aquifer, whose original depth did not exceed a few meters from the surface (Khezzani and Bouchemal, 2017).

Hydrogeology of Souf Oasis

Climatic conditions prevailing in Souf Oasis do not permit development of any kind of surface water resources. However, the situation is completely different at below ground because all recent and old geological

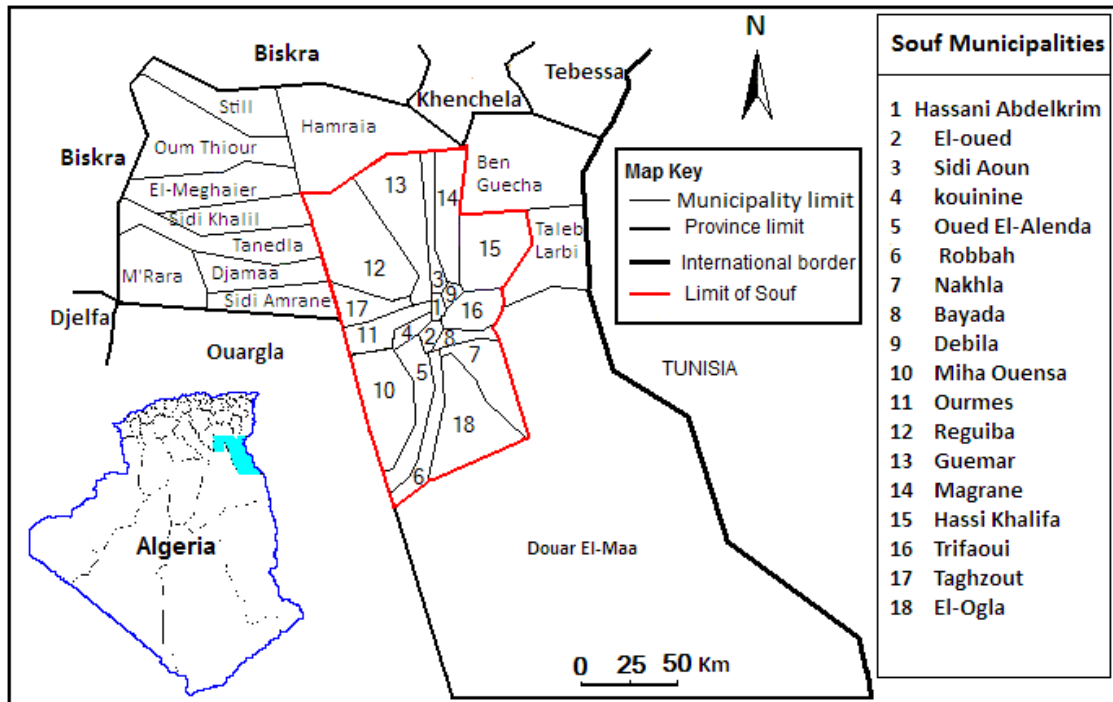


Fig. 1. Study area location.

studies confirm that the region is located above considerable reservoirs of fossil water. According to Drouiche *et al.* (2013), Chebbah and Allia (2014), this groundwater is the only water resource available for all kinds of uses. From a hydrogeological point of view, it is found within three main strata, which vary in the depth and physicochemical characteristics (Messekher and Menani, 2010; Khechana *et al.*, 2011; Meziani *et al.*, 2011).

From the bottom, the first strata is called Intercalary Continental (CI), between 1800 and 2200 meters depth, with a thickness between 200 and 400 meters (Guendouz *et al.*, 2006). Here water is characterized by very high temperature that often exceeds 60 degrees Celsius. Since 1986, only four deep wells were drilled from the (CI) for drinking purposes. The second strata is called Terminal Complex (CT), the depth of which varies between 400 and 600 meters and its thickness is about 400 meters (Saibi *et al.*, 2009). Until now, about 177 deep wells (149 for irrigation and 28 for urban and drinking purposes) were drilled from this level. The third level is a free aquifer contained in fine sands, locally intercalated with sandy clay and gypsum lenses (Guendouz *et al.*, 2006; Bouselsal and Kherici, 2014). This aquifer is located on an impermeable clay substratum, with a thickness not exceeding 100 meters and a depth between 1 and 40 meters (Saibi *et al.*, 2016). This level is exploited by thousands of traditional wells and according to the Directorate of Water Resources (DWR), it had an estimated number of more than 35000 units in 2015.

The Importance of Groundwater and its Management History in Souf Oasis

According to Khezzani *et al.* (2016), for a long time, the presence of groundwater close to the surface was the main reason for the human settlement in Souf Oasis. Agriculture is practised here by Ghout technique (Fig. 2) where in a big hole is dug by farmers and is then planted by date palm trees whose roots benefit directly from groundwater. For its historical, economic and environmental role, the Food and Agriculture Organization (FAO), identified the Ghout system among agriculture as World Heritage in the year 2005.

In 1930, the majority of Souf Oasis was aware of a significant decline in the groundwater level, mainly due to the increase in demand for human and agricultural purposes. The decline was steep during the period of 1940 to 1942 (Bataillon, 1955), primarily due to increase in population which reached around 87,400 inhabitants in 1954 (Voisin, 2003).

In 1956, as the phreatic aquifer were unable to meet the increasing water needs, both for agriculture and population. Therefore, the local authorities resorted to the exploitation of the deep aquifers. A deep well was drilled for drinking purposes, in El-Oued municipality, from the Terminal Complex (CT), with a flow of 30 l s^{-1} and a depth of 250 meters (Côte, 1998; Meziani *et al.*, 2012). Thereafter each year, many wells are being drilled from this deep aquifer for other municipalities.



Fig. 2. The Ghout system.

Table 1. Evolution of groundwater exploitation quantity (litre per second) according to different categories of aquifers and sectors from 1991 to 2015

Years	According to aquifer category (litre per second)			According to sector category (litre per second)			Total
	PA	CT	CI	Irrigation	Drinking	Industry	
1991	20659	980	317	21211	735	10	21956
1998	30541	1283	455	31073	1186	20	32279
2001	33187	915	290	33448	917	27	34392
2003	36335	1391	306	36597	1383	52	38032
2005	41112	1684	321	41352	1645	120	43117
2007	47056	3131	352	46798	2917	824	50539
2010	51989	4877	402	51626	4625	1017	57268
2013	58205	6040	496	57341	5737	1663	64741
2015	65429	6346	347	63453	6122	2547	72122

In 1986, to meet the growing needs of the population, which now reached at more than 224,000 inhabitants, a deep and hot well was drilled for drinking purposes, but this time from the Intercalary Continental (CI), at a depth of 1850 meters and artesian flow up to 200 l s⁻¹ (Côte, 1998). Subsequently every year, 2 or 3 wells are being drilled from two deep aquifers (CT and CI) for drinking purposes and for irrigation. However, with respect to sewerage system, no significant change has been observed. The waste water from three aquifers is discharged in the phreatic aquifer, which led to the rising in the groundwater level, especially in the southern part and in the center of municipalities where the population density is relatively high.

After 2000, rapid development of the agricultural sector, which depends entirely on the phreatic aquifer, has led to the depletion of water resources, especially in the northern part of the Oasis. After placing the sewerage system in service in the year 2009, treated wastewater has not entered into the phreatic aquifer, but has been drained away from the Oasis. This situation has also exacerbated the problem of the phreatic aquifer. In recent years, all parts of Souf Oasis registered decline in the groundwater level (except for El Oued municipality) besides the deterioration their quality.

The deterioration of the traditional irrigation system (Ghout) is one of the problems that have emerged as an inevitable result of the decline in the groundwater level. Tens of thousands of palms also stopped producing due to the

drought that has been caused by decline in groundwater level.

When we compare among the sectors that consume water (Table 1), we find that the agriculture sector consumes the majority of water (88.57%), followed by drinking sector (8.86%) and finally least by the industry sector (2.57%). Additionally, a big percentage (89.90%) of the exploited resource is from a phreatic aquifer (PA), followed by Terminal Complex (CT) with 9.33% and finally, the Intercalary Continental (CI) with 0.77%. Thus, close relationship between the agricultural sector and phreatic aquifer exist. Hence, proper management of these two aspects shall have a clear impact on solving the crisis of agriculture and water scarcity in this Oasis.

Alternatives for Conservation and Development of Water Resources

Water demand reduction strategies

Rational use of water in agricultural, drinking and industrial sector achieved by several methods reduces water demand. Among them, the use of modern irrigation systems that saves water; besides development of strains and new varieties of crops tolerant to the drought and saline water irrigation are being attempted.

Selection of plant strains that tolerate drought and salinity: Drought and salinity are the major abiotic stresses that reduce plant growth and crop productivity worldwide (Mahajan and Tuteja, 2005; Fayez and Bazaid, 2014). In Souf Oasis, the change from the subsistence

farming to commercial farming, has effectively contributed to the depletion of available groundwater resources. So, in order to sustain this advancement in agriculture and maintain the gains achieved, the development of new plant genotypes capable of tolerating salinity, drought and irrigation by salt water, should be carefully considered, through research programs. According to Fita *et al.* (2015) and Kiriga *et al.* (2016), this can be achieved both by conventional breeding methods and by genetic engineering. Certainly, the success of this important step, will effectively contribute in reducing the pressure on water resources.

Irrigation methods and their development:

Before 2005, the flood irrigation method was used widely. Later, due to quantitative and qualitative development in the agricultural sector, this method no longer met the needs of the farmers who later adopted the sprinkler irrigation method along with irrigation with the surface drip. These two methods were well

adopted by the farmers. Though surface drip irrigation and sprinkler irrigation methods are considered one of the most effective methods for water economy, but the prevailing harsh conditions in arid environment leads to the loss of a significant part of water by evaporation. This led to the recommendation of the use of the subsurface drip irrigation method (Fig. 3). The proposed method is based on the principle of no contact between the water and the free soil surface so as to minimize loss by evaporation. To achieve this goal, the perforated water pipe (similar to the one used in drip irrigation system) are embedded in the sub-surface (Fig. 3). This technique called as sub-surface drip irrigation, is similar to the traditional irrigation method followed since long in date palm trees that existed in Souf Oasis.

Many studies around the world confirmed that subsurface irrigation method improves yield and water use efficiency. The study on date palm trees in Saudi Arabia, shows that

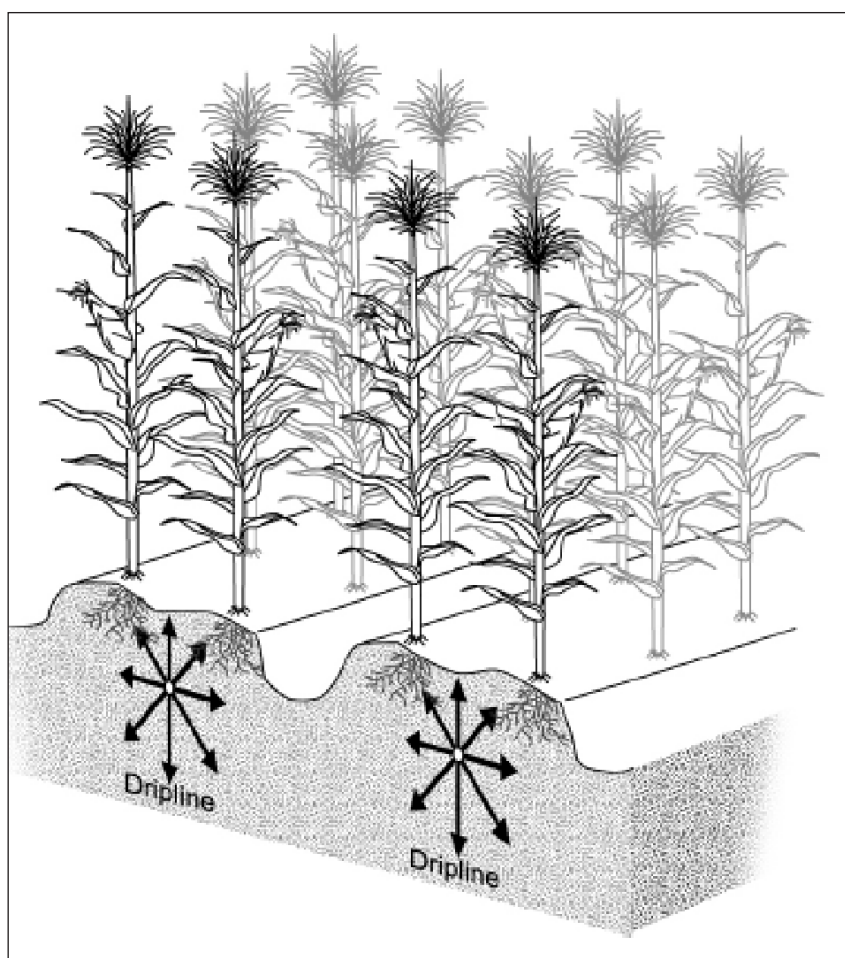


Fig. 3. Schematic representation of subsurface drip irrigation.

water saving could reach up to 60% with 25% increase in yield (Al-Amoud, 2010). Subsurface drip irrigation on cotton crop in Larissa (Greece), improves water use efficiency by more than 20% in comparison to surface drip irrigation Kalfountzos *et al.* (2007). In Spain, a study reported that the subsurface irrigation increased water use efficiency by reducing irrigation water application by about 19% without any negative impact on yield (Robles *et al.*, 2016).

Additionally there are many other advantages of the subsurface drip irrigation system such as reduced weed growth (Solomon, 1993) and low incidence of root rot and other soil diseases. Furthermore, this irrigation method prevents crust formation that inhibits soil aeration. Sub-surface location also protects the system from exposure to the sun and extreme weather conditions that is likely to reduce the life span of this system.

Researching of Alternative Water Resource

Search for alternative water sources e.g. seawater desalination and reuse of treated wastewater could also preserve existing natural resources. According to Pedrero *et al.* (2010), Wood and Alsharhan (2003), in recent years, use of wastewater has gained great importance in water-scarce regions. This has been practiced for over 5000 years; however, during the last 100 years, efforts have been made in many regions of the world, for the production of high quality reused water, following strict quality guidelines (Angelakis and Gikas, 2014).

The reuse of treated wastewater, in particular for irrigation, is an increasingly common practice encouraged by governments and official entities worldwide (Becerra-Castro *et al.*, 2015). However, the dependence rate on the use of treated wastewater varies from a country to another. The Gulf countries use this technology more compared to other countries. According to an estimate, per cent utilization is 92 in Qatar, 86 in Oman, 62 in Kuwait and 61 in United Arab Emirates (Alsharhan *et al.*, 2001).

Currently, treated wastewater is the only available alternative resource in the study area, moreso since the operation of four stations in 2009 for treating this type of water. The treated wastewater production has increased from 3 million cubic meters in 2010 to 5.3 million cubic meters in 2012 and further to 9 million cubic meters in 2015 (Fig. 4). However, in the absence of any program for its reuse all treated wastewater are being discharged towards the salt flats (Shatt).

As the El Oued municipality has been suffering for a long time from the rise of the groundwater level, drainage water is another important alternative water resource, which has excellent biological and physicochemical characteristics, similar to those found in irrigation water. Moreover, it does not require any treatment process. Consequently in 2011, 58 wells were equipped with submersible pumps in order to reduce the groundwater level to suit the need of the region. These wells annually produce about 4.5 million cubic meters of water similar in the characteristics to those used in irrigation (Fig. 4). This water is mixed with

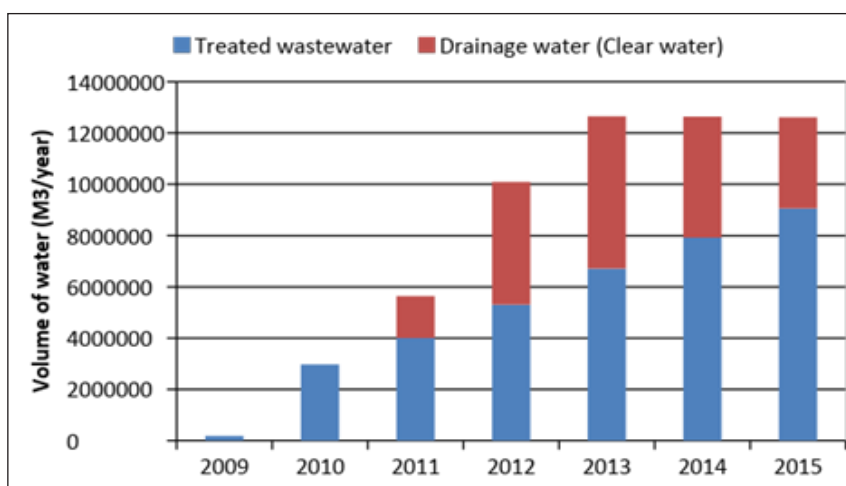


Fig. 4. Progressive production of wastewater and drainage water production.

treated wastewater in the main channel and is evacuated at the salt flats region.

Direct use of treated wastewater: Wastewater, whether industrial, agricultural or domestic, can be treated with modern techniques and reused in many sectors such as industry, public works, fighting fire and in the agricultural sector (Bouwer, 2002; Vo *et al.*, 2014). Treated wastewater can also be utilized directly to irrigate various crops. In the study are the agricultural fields located on either side of the main channel and sub-channels of about 53 km that come out of the treatment stations, can be irrigated from this type of water, through the direct link from this source (Fig. 5). What encourages to use this water is that about 40% is clean similar to the one used in irrigation. Surely, this solution has potential to ease the pressure on the water from phreatic aquifer.

The importance of treated wastewater for agriculture has been increasingly recognized, not only as a valuable water resource, but also for its nutrient value (Elgallal *et al.*, 2016). The crops that are irrigated by treated wastewater, can also be benefited by nutrients that are found in this type of water (Hidri *et al.*, 2013). Phosphorus, nitrogen and potassium contribute effectively to the improvement of

soil fertility, more so because the soil of Souf Oasis is characterized by low content of organic matter. Study of Zdenek and Demnerova (2007) confirmed that the wastewater irrigation on a sandy soil resulted in positive effects on soil activities and had no risk of contamination.

Indirect use of treated wastewater: The artificial recharge technique: The use of wastewater can encounter strong public resistance due to a lack of awareness and trust with respect to aspects related to the human health risks (Salgot *et al.*, 2003). The social customs and cultural and religious traditions also stand in many cases as an impediment to the exploitation of this kind of water (Faruqui *et al.*, 2003). So, according to Bouwer (1993), the ideal solution of these obstacles is to inject and store this water in an empty aquifers.

In the case of Souf Oasis, firstly, we have a large overexploited phreatic aquifer (almost empty in the northern part); moreover, millions of cubic meters of treated wastewater is being discharged into the salt flats. Hence, artificial recharge could be a viable alternative. According to ONA (2015), the volume of evacuated water exceeded 17 million cubic meters for the year 2015. In this context, two techniques are discussed below.

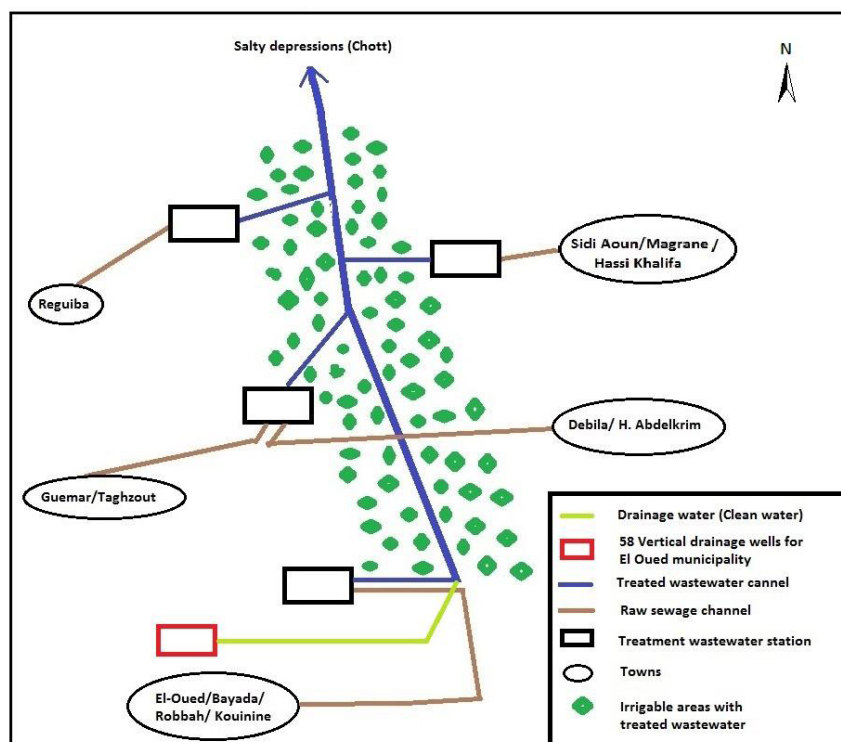


Fig. 5. Scheme of direct use of treated wastewater and drainage water.

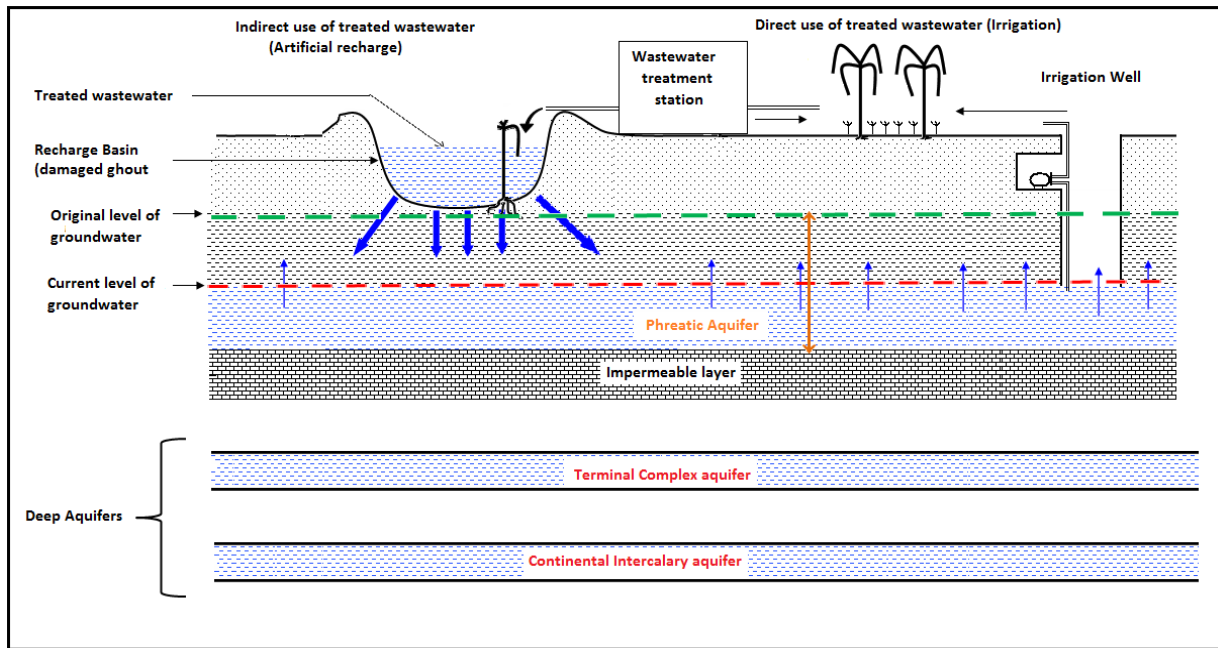


Fig. 6. Scheme of artificial recharge by the basins.

Artificial recharge by the basins: Artificial recharge from the basins is a simple and easy technique to use when recharging the water table because its principle is based on filling natural or artificial basins with water to supply the empty aquifer through infiltration (Fig. 6) (Guttman *et al.*, 2010). Phreatic aquifers in Souf Oasis due to absence of impermeable or semi-permeable layer does not prevent recharging process. Consequently empty Ghouts could be used as recharge basins as the floor of Ghout is in direct contact with water table. Additionally,

this technique is characterized by low costs of construction and ease in the implementation of maintenance works (Fig. 6).

Artificial recharge by the wells: Artificial recharge by wells, on the contrary, is a more complicated technique than the basins, where water is injected into the aquifer through wells similar to the ones used in pumping or draining (Fig. 7). This method is widely used in the area of artificial groundwater recharge. The advantages of this technique is its potential to reach the centre

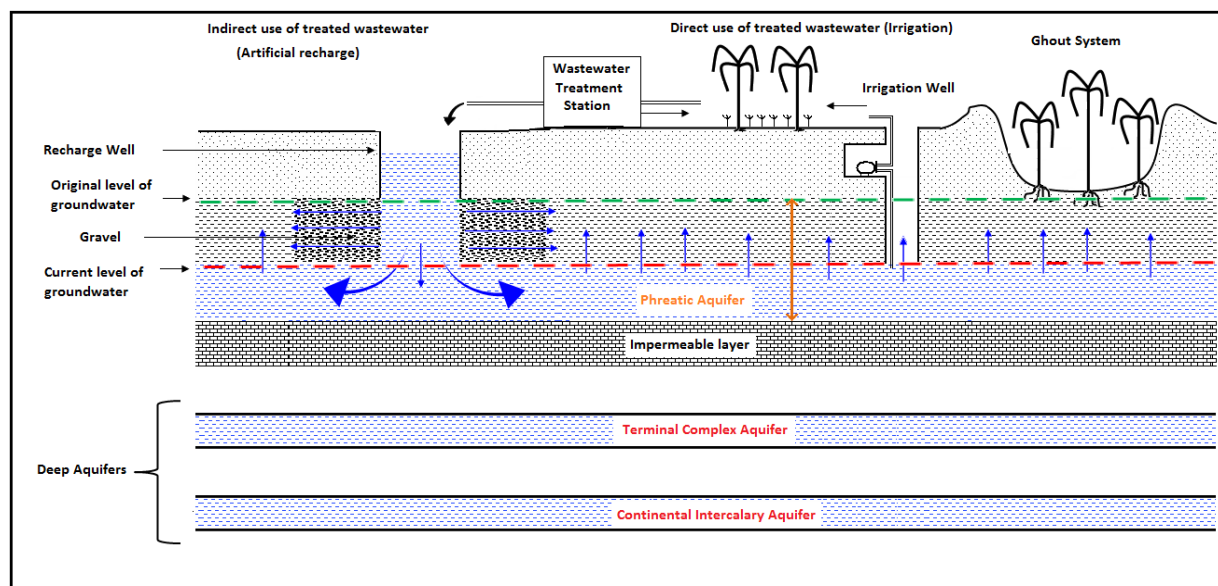


Fig. 7. Scheme of artificial recharge by the wells.

of recharged aquifers, especially when there is an impermeable substratum that prevents the recharging process from the top, or when the aquifer is very deep. Also, the possibility of recharging different levels of a single well also exists. In this method, the problem of water loss by evaporation does not occur.

Among the factors that helps in improving the efficiency of this technique in the study area, is the thickness of the phreatic aquifer which does not exceed 100 meters besides its proximity to the surface with a high soil porosity. Therefore, the water used in the recharge is in direct contact with the roof of the aquifer. This technique can be used in the recharging, especially, in the northern part of Souf Oasis. According to Margat and van der Gun (2013), many artificial recharge projects around the world use this technique such as that realized in California (US), Spain, Saudi Arabia, Kuwait and Oman.

Conclusion

In the majority of arid regions, groundwater is the only source of available water for all kinds of uses, particularly in the agriculture sector. In Souf Oasis, the unsustainable management of this limited resource led to sharp decline in its level besides degradation of its quality. This negatively influenced all domains of life. Alleviation of their adverse effects is possible through rationale use available water resources by switching over to sub-surface drip irrigation, advocating salinity and drought tolerant genotypes and exploring alternatives such as use of treated wastewater either directly in irrigation or indirectly through artificial recharge technique to support the available stock in phreatic aquifer.

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References

- Al-Amoud, A.I. 2010. Subsurface drip irrigation for date palm trees to conserve water. In *IV International Date Palm Conference 882*, pp. 103-114.
- Alsharhan, A.S., Rizk, Z., Nairn, A.E.M., Bakhit, D.W. and Alhajari, S.A. 2001. *Hydrogeology of An Arid Region: The Arabian Gulf and Adjoining Areas*. Elsevier, 366 p.
- Angelakis, A. and Gikas, P. 2014. Water reuse: Overview of current practices and trends in the world with emphasis on EU states. *Water Utility Journal* 8: 67-78.
- Bataillon, C. 1955. *Le Souf, étude de géographie humaine*. Travaux de l'Institut de Recherches Sahariennes, Alger, Algérie, 140 p.
- Becerra-Castro, C., Lopes, A.R., Vaz-Moreira, I., Silva, E.F., Manaia, C.M. and Nunes, O.C. 2015. Wastewater reuse in irrigation: A microbiological perspective on implications in soil fertility and human and environmental health. *Environment International* 75: 117-135. doi:10.1016/j.envint.2014.11.001.
- Bouselsal, B. and Kherici, N. 2014. Effets de la remontée des eaux de la nappe phréatique sur l'homme et l'environnement: Cas de la région d'El-Oued (SE Algérie). *Afrique Science: Revue Internationale des Sciences et Technologie* 10: 161-170.
- Bouwer, H. 2002. Artificial recharge of groundwater: Hydrogeology and engineering. *Hydrogeology Journal* 10: 121-142.
- Bouwer, H. 1993. From sewage farm to zero discharge. *European Water Management* 3: 9-16.
- Chebbah, M. and Allia, Z. 2014. Geochemistry and hydrogeochemical process of groundwater in arid region: A case study of the water table in the Souf valley (Low Septentrional Sahara, Algeria). *African Journal of Geo-Science Research* 2: 23-30.
- Corcoran, E., Nelleman, C., Baker, E., Bos, R., Osborn, D. and Savelli, H. 2010. *Sick Water?: The Central Role of Wastewater Management in Sustainable Development: A Rapid Response Assessment*. UNEP/Earthprint, Arendal, Norway, 88 p.
- Côte, M. 1998. Des oasis malades de trop d'eau? *Sécheresse* 9: 123-130.
- Drouiche, A., Chaab, S. and Khechana, S. 2013. Impact du déversement direct des eaux usées et de drainage dans la nappe libre de l'Oued Souf et son influence sur la qualité des eaux souterraines. *Revue des Sciences et de la Technologie* 27: 50-62.
- Ebrahimi, H., Ghazavi, R. and Karimi, H. 2016. Estimation of groundwater recharge from the rainfall and irrigation in an arid environment using inverse modeling approach and RS. *Water Resources Management* 30: 1939-1951. doi:10.1007/s11269-016-1261-6.
- Elgallal, M., Fletcher, L. and Evans, B. 2016. Assessment of potential risks associated with chemicals in wastewater used for irrigation in arid and semi-arid zones: A review. *Agricultural Water Management* 177: 419-431. doi:10.1016/j.agwat.2016.08.027.
- Faruqui, N.I., Biswas, A.K. and Bino, M.J. 2003. *La gestion de l'eau selon l'Islam*. Karthala, Paris, France, 144 p.

- Fayez, K.A. and Bazaid, S.A. 2014. Improving drought and salinity tolerance in barley by application of salicylic acid and potassium nitrate. *Journal of the Saudi Society of Agricultural Sciences* 13: 45-55. doi:10.1016/j.jssas.2013.01.001.
- Fita, A., Rodríguez-Burruezo, A., Boscaiu, M., Prohens, J. and Vicente, O. 2015. Breeding and domesticating crops adapted to drought and salinity: A new paradigm for increasing food production. *Frontiers in Plant Science* 6: 1-14. doi:10.3389/fpls.2015.00978.
- Guendouz, A., Moulla, A.S., Remini, B. and Michelot, J.L. 2006. Hydrochemical and isotopic behaviour of a Saharan phreatic aquifer suffering severe natural and anthropic constraints (Case of Oued-Souf region, Algeria). *Hydrogeology Journal* 14: 955-968. doi:10.1007/s10040-005-0020-1.
- Guttman, J., Hötzl, H., Marei, A., Subha, A. and Wolf, L. 2010. Hydrogeologic preconditions for a reasonable application of artificial aquifer recharge measures. In *Integrated Water Resources Management* (Ed. H. Steusloff), pp. 235-241. KIT Scientific Publishing, Karlsruhe, Germany.
- Hidri, Y., Fourti, O., Jedidi, N. and Hassen, A. 2013. Effects of ten years treated wastewater drip irrigation on soil microbiological properties under Mediterranean conditions. *African Journal of Biotechnology* 12: 5761-5770. doi:10.5897/AJB2013.12412.
- Iglesias, A., Garrote, L., Flores, F. and Moneo, M. 2007. Challenges to manage the risk of water scarcity and climate change in the mediterranean. *Water Resources Management* 21: 775-788. doi:10.1007/s11269-006-9111-6.
- Jackson, R.B., Carpenter, S.R., Dahm, C.N., McKnight, D.M., Naiman, R.J., Postel, S.L. and Running, S.W. 2001. Water in a changing world. *Ecological Applications* 11: 1027-1045.
- Kadirkhodjaeva, F. 2015. Economic assessment on ponds construction for utilization of waste water in arid zone of Uzbekistan. *Journal of Arid Land Studies* 25: 229-231. doi:10.14976/jals.25.3_229.
- Kahil, M.T., Dinar, A. and Albiac, J. 2016. Cooperative water management and ecosystem protection under scarcity and drought in arid and semi-arid regions. *Water Resources and Economics* 13: 60-74. doi:10.1016/j.wre.2015.10.001.
- Kalfountzos, D., Alexiou, I., Kotsopoulos, S., Zavakos, G. and Vyrlas, P. 2007. Effect of subsurface drip irrigation on cotton plantations. *Water Resources Management* 21: 1341-1351. doi:10.1007/s11269-006-9085-4.
- Khechana, S. and Derradji, F. 2012. Management of water resources in a hyper-arid area: Strategy and issues (Case of Oued-Souf Valley-South Eastern of Algeria). *Journal of Water Resource and Protection* 4: 922-928. doi:10.4236/jwarp.2012.411108.
- Khechana, S., Derradji, F., Derouiche, A. and Mega, N. 2011. Caractéristique hydro chimiques des eaux de la nappephréatique du valléed'OuedSouf (SE Algérien). *European Journal of Scientific Research* 62: 207-215.
- Khezzani, B. and Bouchemal, S. 2017. Demographic and spatio-temporal distribution of cutaneous leishmaniasis in the Souf oasis (Eastern South of Algeria): Results of 13 years. *Acta Tropica* 166: 74-80. doi:10.1016/j.actatropica.2016.11.012.
- Khezzani, B. and Bouchemal, S. 2016. A study of epidemic of typhoid fever in the Souf Oasis (Eastern South of Algeria). *Research Journal of Pharmaceutical, Biological and Chemical Sciences* 7: 1299-1307.
- Khezzani, B., Bouchemal, S. and Halis, Y. 2016. Some agricultural techniques to cope with the fluctuation of the groundwater level in arid environments: Case of the Souf Oasis (Algerian Sahara). *Journal of Arid Land Agriculture* 2: 26-30. doi:10.19071/jaa.2016.v2.3060.
- Kiriga, W.J., Yu, Q. and Bill, R. 2016. Breeding and genetic engineering of drought-resistant crops. *International Journal of Agriculture and Crop Sciences* 9: 7-12.
- Lachaal, F., Bédir, M., Tarhouni, J., Gacha, A.B. and Leduc, C. 2011. Characterizing a complex aquifer system using geophysics, hydrodynamics and geochemistry: A new distribution of Miocene aquifers in the Zéramdine and Mahdia-Jébéniana blocks (east-central Tunisia). *Journal of African Earth Sciences* 60: 222-236. doi:10.1016/j.jafrearsci.2011.03.003.
- Mahajan, S. and Tuteja, N. 2005. Cold, salinity and drought stresses: An overview. *Archives of Biochemistry and Biophysics* 444: 139-158. doi:10.1016/j.abb.2005.10.018.
- Margat, J. and van der Gun, J. 2013. *Groundwater Around the World: A Geographic Synopsis*. CRC Press 376 p.
- Matheyarasu, R., Seshadri, B., Bolan, N.S. and Naidu, R. 2015. Impacts of Abattoir waste-water irrigation on soil fertility and productivity. In *Irrigation and Drainage - Sustainable Strategies and Systems* (Ed. M.S. Javaid), pp. 55-75. InTech, Rijeka, Croatia.
- Messekher, I. and Menani, M.R. 2010. Evolution de la piezometrie de la villed'OuedSouf (Entre 1993, 2002 et 2007): Perspectives de la maitrise du phenomene de remont e de la nappephréatique. *Journal International Network Environmental Management Conflicts* 1: 259-266.
- Meziani, A., Dridi, H. and Kalla, M. 2011. The aquifer system of the Souf Valley: Algerian Northern Sahara. *European Journal of Scientific Research* 65: 416-423.
- Meziani, A., Dridi, H. and Kalla, M. 2012. la reutilisation des eauxuseesdans la region du

- Souf (Sahara Algerien). *Canadian Journal of Technology and Scientific Management* 1: 1-6.
- Odhambo, G.O. 2016. Water scarcity in the Arabian Peninsula and socio-economic implications. *Applied Water Science* 2016: 1-14. doi:10.1007/s13201-016-0440-1.
- Omotobora, B.O., Adebola, P.O., Modise, D.M., Laurie, S.M. and Gerrano, A.S. 2014. Greenhouse and field evaluation of selected sweet potato (*Ipomoea batatas* (L.) LAM) accessions for drought tolerance in South Africa. *American Journal of Plant Sciences* 5: 3328. doi:10.4236/ajps.2014.521348.
- ONA 2015. Volume des Eaux Rejetées Vers Rejets Chott Halloufa (eaux épurées + eaux de drainages) de l'année 2009 à 2015. Rapport. Office National d'Assainissement (ONA). El Oued, Algérie. 5 p.
- Pedrero, F., Kalavrouziotis, I., Alarcón, J.J., Koukoulakis, P. and Asano, T. 2010. Use of treated municipal wastewater in irrigated agriculture: Review of some practices in Spain and Greece. *Agricultural Water Management* 97: 1233-1241. doi:10.1016/j.agwat.2010.03.003.
- Pereira, L.S., Oweis, T. and Zairi, A. 2002. Irrigation management under water scarcity. *Agricultural Water Management* 57: 175-206. doi:10.1016/S0378-3774(02)00075-6.
- Robles, J., Botía, P. and Pérez-Pérez, J. 2016. Subsurface drip irrigation affects trunk diameter fluctuations in lemon trees, in comparison with surface drip irrigation. *Agricultural Water Management* 165: 11-21. doi:10.1016/j.agwat.2015.11.008.
- Saibi, H., Mesbah, M., Moulla, A., Guendouz, A. and Ehara, S. 2016. Principal component, chemical, bacteriological and isotopic analyses of Oued-Souf groundwaters (revised). *Environmental Earth Sciences* 75: 1-17. doi:10.1007/s12665-015-4878-5.
- Saibi, H., Semmar, A., Mesbah, M. and Ehara, S. 2009. Variographic analysis of water table data from the Oued-Souf phreatic aquifer, northeastern part of the Algerian Sahara. *Arabian Journal of Geosciences* 2: 83-93. doi:10.1007/s12517-008-0021-1.
- Salgot, M., Vergés, C. and Angelakis, A. 2003. Risk assessment in wastewater recycling and reuse. *Water Science and Technology: Water Supply* 3: 301-309.
- Solomon, K. 1993. Subsurface drip irrigation: Product selection and performance. In *Subsurface Drip Irrigation: Theory, Practices and Application* (Eds. G.S. Jorgensen and K.N. Norum), pp. 3-25. CATI Publication.
- Taft, H.L. 2015. Water scarcity: Global challenges for agriculture. In *Food, Energy and Water. The Chemistry Connection* (Ed. S. Ahuja), pp. 395-429. Elsevier.
- Vo, P.T., Ngo, H.H., Guo, W., Zhou, J.L., Nguyen, P.D., Listowski, A. and Wang, X.C. 2014. A mini-review on the impacts of climate change on wastewater reclamation and reuse. *Science of the Total Environment* 494: 9-17. doi:10.1016/j.scitotenv.2014.06.090.
- Voisin, A.R. 2003. *Le Souf, Monographie*. El-Walid, El-Oued, Algérie, 319 p.
- Wood, W.W. and Alsharhan, A.S. 2003. *Water Resources Perspectives: Evaluation, Management and Policy*. Elsevier Science, 398 p.
- Zdenek, F. and Demnerova, K. 2007. Effects of wastewater irrigation on chemical, microbiological and virological status of soil. In *Wastewater Reuse-Risk Assessment, Decision-Making and Environmental Security* (Ed. M.K. Zaidi), pp. 331-336. Springer, Dordrecht, Netherlands.

