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Analysis of treated wastewater and feasibility for reuse in irrigation: a case study from Chlef, Algeria

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ABSTRACT

A quantitative and qualitative analysis was performed on treated wastewater to see if it can be used for irrigation, using as a case study the effluent from a wastewater treatment plant in Chlef, Algeria. The results showed that the average removal efficiencies of suspended solids (TSS), chemical oxygen demand (COD), and biochemical oxygen demand (BOD5) were 88, 94, and 98%, respectively. The average effluent concentrations ranged from 3 to 29 mg/L for TSS, 30 to 57 mg/L for COD, and 3 to 8.9 mg/L for BOD5. All were within the World Health Organization standards. Furthermore, the total coliform concentration of the treated wastewater was also within the national and international standards. There was an absence of toxic micro-pollutants such as heavy metals, which suggests that treated water can be used as an alternative water resource for irrigation. The reuse of treated wastewater is both a political and socioeconomic challenge. However, this route may help to alleviate water shortages by better conserving natural resources and also contributing to the development of integrated water management systems.

Keywords: Chlef Algeria; Treated wastewater analysis; Wastewater reuse; Irrigation

1. Introduction

The utilization of non-conventional water resources, in particular desalination of sea water and reuse of treated wastewater, constitutes one of the possible responses to deal with the economic and social crises resulting from chronic water shortages [1–4]. Desalination, by itself however, is not an option for sustainable development since it involves such large energy consumption [5,6]. Furthermore, climate change has aggravated the water shortage problem [7]. Wastewater reuse on the other hand is a strategy

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that is motivated by the necessity to preserve groundwater and the need to try and keep water desalination for drinking water. In addition, the reuse of wastewater helps to conserve the natural environment by exploiting the fertilizing power of such treated waters [1–4].

The impact of climate change on water resources has been extensively studied over the past few decades [8–14]. Semi-arid regions, such as the Mediterranean basin, are considered to be particularly vulnerable to acute water scarcity in the coming years [1,15–18]. Water deficiency is also expected to intensify because of population growth and an increasing water demand by different sectors of the economy (e.g. agriculture, industry) [13,15,16,19–22].

The aim of this study was to perform a quantitative and qualitative analysis of treated wastewater to see if it can be reused for irrigation using as a case study of the effluent from a wastewater treatment plant in Chlef, Algeria.

2. Case study region

During the three last decades, Algeria, one of the Mediterranean countries located in North Africa, has suffered from a succession of persistent periods of drought [15,22]. This was particularly intense in the western region of the country where a decrease in annual rainfall of between 10 and 20% was observed [23–25]. It was noted that the water shortage problem was accentuated by mismanagement of available water resources, as well as a significant surge in the population which increased from 25 million in 1990, to more than 34 million in 2008. Intense agricultural irrigation and economic development exerted further pressure on the limited water resources [16,22,26]. Presently, an overall potable water deficit of 0.9 billion m^3 has been reported which is predicted to increase to more than 1 billion m^3 by 2025 [26]. Furthermore, 55% of the water demand comes from agricultural irrigation, which helps to explain the search for alternative water sources. Currently, the total freshwater produced from desalination of the sea water in Algeria is estimated as 536 Hm^3/year (i.e. 536×10^9 L/year) [27,28]. The total treated wastewater which could be used for irrigation is estimated at approximately 10 Hm^3/year. This volume of water could irrigate 1,285 ha of farmland [29].

The Wilaya (i.e. province) of Chlef already suffers from water scarcity due to a combined effect of increased demand and reduced supply. The intensive use of the water resources, in particular the overexploitation of groundwater for agricultural use [1,16,25], has led to an increased need for the reuse of treated wastewater. There is also a political and socioeconomic stake to provide an alternative water resource at a low cost and which could contribute to reduce considerably the water stress on the society. The use of non-conventional water resources to satisfy the increased demand such as the use of treated wastewater appears to be a possible solution. There is a need to evaluate the reuse of treated wastewater for irrigation. The question is can these non-conventional water resources constitute a guaranteed alternative to groundwater and rainwater for Chlef?

The study region corresponds to an area serviced by a wastewater treatment plant located at Chlef which is one of the administrative regions in Algeria, situated in the northwest of the country, between latitude 36°33′–35°50′ N and longitude 0°44′–1°45′ E (Fig. 1). It covers 4,074 km^2 of surface area and has over 1 million inhabitants. The climate is semi-arid, which is influenced by the Mediterranean Sea in terms of the seasonality of rainfall. Average precipitation for the coastal area is 420 mm/year, which decreases to 370 mm/year in the southern part of the case study region. The mean annual temperature is 19°C. Both precipitation and temperature are the highest in summer and the lowest in winter.

The average altitude varies between 75 and 500 m. Geologically, the region is Miocene, Pliocene, and Quaternary and mainly composed of limestone, sandstone, conglomerates, and clay. The depth of the groundwater table varies from 5 to 50 m. The economic activities are chiefly based on agriculture. The Chlef sewage wastewater plant, which is located near the river Cheliff, west of the capital of the province, was put into service in 2006. The maximum processing capacity of the plant is 36,405 m^3/d [30]. Currently, it handles 6,640 m^3/d. The wastewater treatment plant (WWTP) at Chlef functions with an activated sludge process with low load and prolonged aeration.

After a series of pre-treatment (screening, grit, déshuillage), wastewater is admitted directly into the aeration tanks for biological treatment. The operation of an aeration basin is anaerobic/aerobic. After degradation of the carbonaceous and nitrogenous pollution, wastewater is directed to a clarifier for solid–liquid separation. The clarified water from the clarifier is directly released into the Oued Chellif.

The total water resources of Algeria is estimated as 17 billion m^3, of which 80% is renewable (i.e. 70% surface water and 10% groundwater) [31]. Water usage is distributed as 55.3% for irrigation, 34.2% for drinking water, and 10.5% for the industry [32].

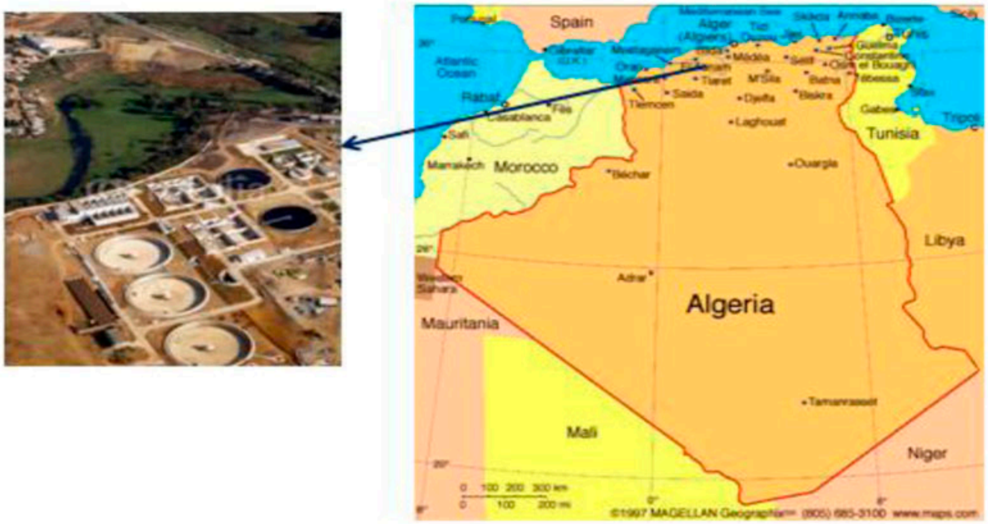

Fig. 1. Location of the treatment plant [30].

Furthermore, in the north of the country, groundwater resources are estimated as 1.9 billion m^3. These resources have been depleted. Surface water resources are estimated as 12.4 billion m^3 [31]. These resources which depend on rainfall are unevenly distributed and are characterized by high variability in annual rainfall ranging from 1,100 mm to less than 100 mm with an overall decline of 10% in recent years due to climate change [7,25,33].

Faced with this challenge, the country implemented a new policy of more effective management of water resources through, for example, construction of new dams, which rose from 52 dams in 2002 with a total water capacity of 5.2 billion m^3 to 72 dams currently with a capacity of 7.4 billion m^3 [27]. In addition, non-conventional water resources were also addressed by the completion of thirty new seawater desalination plants consisting of 21 small plants built in 2001 and 9 large plants implemented since 2005, with a total production volume 536 Hm^3/year. Four other big stations in large cities are also underway with a total capacity of 900,000 m^3/d and a production volume estimated as 328.50 Hm^3/year.

Studies were also initiated on the reuse of treated wastewater for agricultural purposes [27]. Currently, 9.81 Hm^3/year of treated wastewater is employed to irrigate 1,285 ha of land. The potential exists to utilize another 79 Hm^3/year treated wastewater for irrigation of more than 7,570 ha of land. Related studies showed that there is a possibility of using 54 Hm^3/year to irrigate more than 9,799 ha. Other projects are in progress which will highlight an additional volume of 51 Hm^3/year and which will be intended for the irrigation of 838 ha [27].

3. Methodology

Analysis of wastewater and treated water was performed at the laboratory of WWTP (wastewater treatment plant) of Chlef. A total of ten physicochemical and microbiological parameters were assessed (Table 1). Collected samples of untreated and treated wastewater were analyzed for temperature (*T*), pH, total dissolved salts (TDS), electrical conductivity (EC), total suspended solids (TSS), biochemical oxygen demand (BOD5), chemical oxygen demand (COD), total nitrogen (TN), nitrate (NO_3-N), and ammonia (NH_3-N).

The concentration of TSS was measured using the drying method at 103–105˚C by standard methods; temperature was measured using a thermometer probe. The pH was determined by a pH meter brand HACH. The conductivity and the TDS were measured with a conductivity meter HACH 54500-18. The BOD5 was analyzed using a BOD meter. The COD, nitrate, ammonia nitrogen, and TN were determined by spectroscopy using a spectrophotometer DR 2500. The microbiological analysis of total coliforms (TC), fecal coliforms (FC), fecal streptococci, and Salmonella were measured in laboratory according to standard methods.

Measurements were daily made on entering and exiting water from the WWTP in order to evaluate efficiency and performance and also reveal any malfunction in the treatment process.

The results were compared with guidelines of the international standards of the World Health Organization (WHO) [34], the food and agriculture organization of the United Nations (FAO) [35], and the Algerian

Table 1
Effluent quality from the Chlef WWTP in Algeria: temperature (*T*), pH, TDS, EC, TSS, BOD5, COD, TN, NO_3-N, and NH_3-N

Parameters	Raw water Max	Raw water Min	Treated water Max	Treated water Min	Standards	Removal efficiencies (%)
TSS (mg/L)	679	138	29	3	30	88
BOD5 (mg/L)	421	184	8.9	3	20	98
COD (mg/L)	880	429.7	57	30	120	94
NH_3-N (mg/L)	28.3	10.4	6.3	0.10	3–5	98
TN (mg/L)	61.2	28	11	2	15	87
NO_3-N (mg/L)	–	–	10	1.6	8–10	
T (°C)	29.9		27.5			
pH	7.84	7.02	7.8	7.00	6.5–8.5	
EC (mS/cm)	3.40	2.64	2.78	2.00	3	
TDS (mg/L)	1,645	1,340	1,248	1,011	2,000	

Government inter-ministerial decree of 2nd January 2012, published in the Official Gazette No. 41, fixing the specifications of treated wastewater used for irrigation [36].

The technical, legal, social, economic, and climatic challenges in wastewater reuse in irrigation were also discussed.

4. Results and discussion

4.1 Qualitative and quantitative analysis of treated wastewater

TDS and EC of treated wastewater ranged from 1,011 to 1,248 mg/L and 2.00 to 2.78 mS/cm, respectively (Table 1). This was a decrease compared to raw wastewater at 1,340–1,645 mg/L and 2.64–3.40 mS/cm, respectively. The reference values for TDS and EC proposed for the irrigation have been reported to be 3 mS/cm and 2,000 mg/L, respectively [34–36]. It can be argued that the effluents of Chlef treatment plants meet or fulfill the national standards. These criteria indicate that the highest EC value of irrigation water should not exceed the 3 mS/cm. The observed EC of treated wastewater was less. Furthermore, the value of TDS was always less than the national standard. These results suggest that treated wastewater can be used for irrigation [35]. However, precautions need to be taken in cases where soil drainage is poor since this could results in solids buildup. High salinity concentration, for example, could result in severe soil degradation and have impact on plant growth. Although soil salinity may be reduced by winter rainfall in the case study region, it should be checked regularly to ensure the sustainable long-term use of wastewater [37].

The maximum temperature of the treated water was 27.5°C, and the pH ranged from 7.0 to 7.8 which falls within the 6.5–8.5 pH range appropriate for irrigation reuse. These values are in the normal range based on FAO standards [35]. The reported effects of treated wastewater irrigation on soil pH have been variable with many researchers who found that wastewater irrigation lowered soil pH [38], while others reported that a long-term wastewater irrigation increased soil pH [39]. Effluent quality from the Chlef WWTP is summarized in Table 1.

The TN, NO_3-N, and NH_3-N concentrations in the treated wastewater were 2–11 mg/L, 1.6–10 mg/L, and 0.1–6.3 mg/L, respectively. The TN in raw water, in particular, was reduced from 2–11 mg/L to 28–61.2 mg/L by treatment. It can be argued that nutrients in recycled water could replace fertilizers normally added to fields, and therefore, the cost of crop production could be reduced significantly [40]. It has also been reported that the absorption of nutrients by plants irrigated with treated wastewater has significantly increased crop yields [41,42]. Although these nutrients improve plant growth, they should be scrutinized regularly to avoid accumulation. Rusan et al. [42] warned that the long-term effect of wastewater irrigation of forage crops on soil and plant quality parameters need to be better monitored.

The WWTP, which operated with an activated sludge process with low load and prolonged aeration, was very effective in reducing the BOD5, the COD, and TSS values. While raw water had values for BOD5, COD, and TSS ranging from 184 to 421 mg/L, 430 to 880 mg/L, and 138 to 679 mg/L, respectively, for treated wastewater, these were reduced to 3–8.9 mg/L, 30–57 mg/L, and 3–29 mg/L, respectively.

These were equivalent to removal efficiencies of 98% for BOD5 (i.e. reduction of the organic load), 94% for COD, and 88% for TSS. Furthermore, for treated wastewater, the BOD5, COD, and TSS values were all lower than the international standards of the WHO, of the food and agriculture organization of the United Nations (FAO), and for wastewater disposal by the Algerian standard (Table 1) where values for BOD5, COD, and TSS of 20 mg/L, 120 mg/L, and 30 mg/L, respectively, are reported [34,36]. A comparison of the physicochemical values (Table 1) to corresponding reference values proposing wastewater reuse criteria for irrigation [34–36] indicates that the outlet BOD5, COD as well as the TSS values are lower than the proposed limit values for irrigation and suggests that treated wastewater can be employed in irrigation [43].

The variation in monthly BOD5 and COD values between the inflow (WWR inlet) and outflow (WWR outlet) wastewater are also reported in Figs. 2 and 3. Concentrations were in most samples, within the limits fixed for wastewater disposal by the Algerian Government standards [36]. The monthly BOD5 presents average values which varied from 421 to 184 mg/L for raw water (WWR inlet); the monthly DOB5 at the exit of the plant, ranged from 8.9 to 3 mg/L with an overall average 5.7 mg/L, so a reduction of 98% of the organic load (Fig. 2). These results suggest that it is important to regularly monitor the outlet concentrations to ensure that they meet the acceptable standards.

The presence of organic matter affects soil properties, including physical (i.e. structural stability, aeration, retention, and water conservation), chemical (i.e. exchange capacity), and biological [44].The organic matter concentration in treated wastewater was within the acceptable limits for irrigation water as represented by TSS, BOD5, and COD (Table 1). The monthly COD for raw water (WWR inlet) ranged from 429.7 to 880 mg/L with an annual average of 647 mg/L (Fig. 3). The monthly COD for treated wastewater (WWR outlet) ranged from 30 to 57 mg/L with an overall annual average of 42 mg /L. The monthly average removal efficiency ranged from 91 to 96% with an annual average of 94%. The outlet values fall within the acceptable standards fixed by the WHO for wastewater reuse [34]. Additionally, no toxic micropollutants (i.e. heavy metals) were found in the treated water suggesting the absence of industrial wastewater discharges.

The microbiological analysis of TC, FC, fecal streptococci, and Salmonella are shown in Table 2. The average number of TC and streptococcus found in the Chlef effluent were less than 200 CFU/100 ml and 2.3 CFU/100 ml, respectively. The values are much lower than the proposed limit values for unrestricted irrigation (that is, for uses that include crops likely to be eaten uncooked), the Algerian guidelines are <1,000 UFC/100 ml [36]. Neither FC nor salmonella were detected in any samples of treated wastewater. Treated waters may be used as irrigation water on well-drained soil and for irrigation of parks and lawns with which the public may come into direct contact, according to the WHO standard [34] and the Algerian standard [36] enacted for treated wastewater use for irrigation. Treated wastewater can also be used for irrigation of fruit trees and other crops by crop groups listed in the Algerian Government decree of 2012 (recommended threshold <1,000 CFU/100 ml) [34,36].

The volume of treated water was variable ranging from 5,081 to 7,750 m^3, with an average monthly volume of 6,350 m^3. The total volume in 2010 was 2,208,017 m^3, which reached 2,378,532 m^3 in 2012 (Figs. 4 and 5). Furthermore, it is estimated that the treatment plant at Chlef will be processing around 36,000 m^3/d of raw water by 2025. But, at present, this plant works at less than half the capacity and the

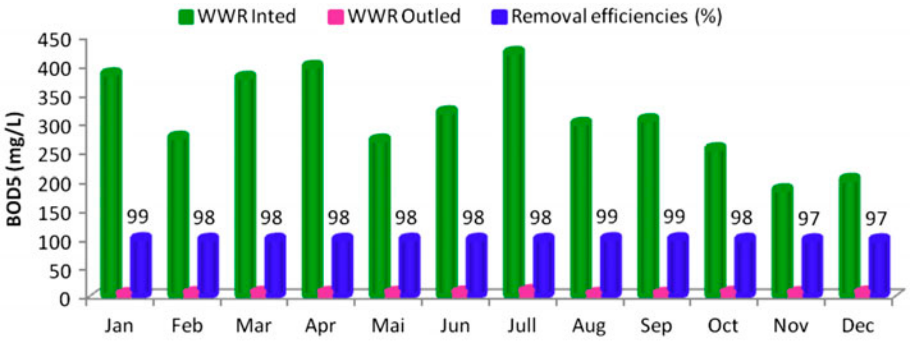

Fig. 2. Monthly variation of the concentration of BOD5 in treated water and removal efficiencies in 2012.

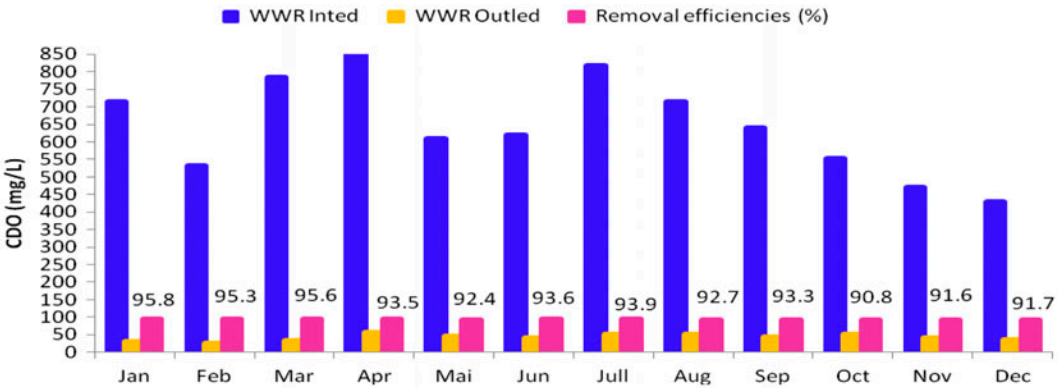

Fig. 3. Monthly variation of the COD in treated water and removal efficiencies in 2012.

Table 2
Microbiological analysis of treated water from Chlef WWTP (11-07-2012)

Parameters	Water of WWTP	Standards WHO
Total coliforms at 37°C/100 ml	<200 CFU	<1,000/100 ml
Fecal coliforms at 37°C/100 ml	abs	
Streptococcus	2.3	
Salmonella	abs	

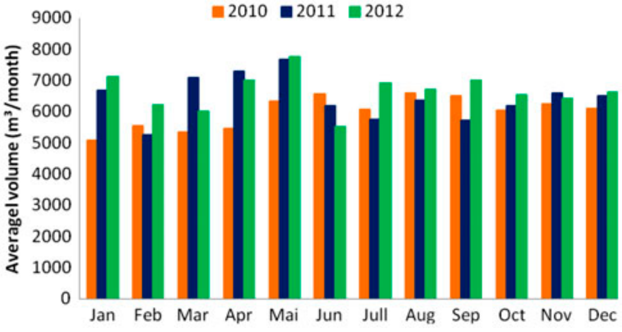

Fig. 4. Average volumes of treated wastewater per month.

volume of treated wastewater is 2.2 million m^3/year. This situation is due in large part to problems associated with the collection of all wastewater and transfer to the treatment plant.

To help alleviate the stress on conventional water resources such as ground water, it is necessary to try and reuse as much treated wastewater for irrigation as is possible. This will partially solve the problem of lack of irrigation water in the case study region and help to reduce the overall water deficit. This reuse is facilitated by an absence of toxic micro pollutants (i.e. heavy metals) in the treated water due to a lack of industrial wastewater discharges.

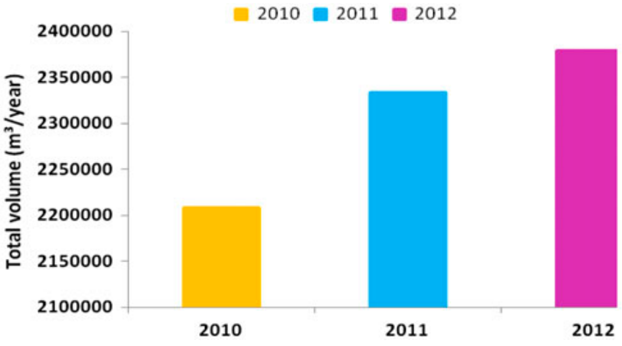

Fig. 5. The total annual volume of water treated.

4.2 Wastewater reuse in irrigation and technical, legal, social, economic & climatic challenges

The beneficial effects of irrigating with wastewater have been shown previously. Alkhamisi et al. [45] for instance reported enhanced growth in wastewater irrigated crops, compared to freshwater irrigated crops. The enhanced growth was attributed primarily to higher nutrient content (e.g. nitrogen) and lower salinity of the reclaimed water. The study concluded that treated wastewater irrigation increased yields of forage crops and their water use efficiency. The same enhanced crop growth benefits can be expected from the Chlef treated wastewater reported in this study which showed the presence of nitrogen (i.e. TN, NO_3-

N, and NH_3-N) in the treated wastewater, but within internationally accepted standards (Table 1).

The agricultural sector is the largest consumer of groundwater in Chlef (i.e. over 57% used for irrigation) (Fig. 6) with the useful agricultural land (UAS) being 205,687 ha. The irrigable land is only 16,534 ha [32,46,47]. The irrigated land supplied by water primarily from groundwater (i.e. 76%) and from small dams. The water requirements of Middle Cheliff, which has an irrigable surface of 21,000 ha, were estimated at 88 Hm^3 in 2010. A water deficit of 19 Hm^3 has been reported (Table 3) [32,46,47]. The total surface which can be irrigated by treated wastewater is estimated as 2,482 ha, this surface will increase in the future as soon as three plants of Boukadir, Chettia, and Oued Fodda enter service, and the rest of treated water will then allow improving the low flow of wadis.

Mizyed [48] in a recent paper evaluated the technical legal, social, and economic challenges facing treated wastewater reuse in arid and semi-arid areas. The author argued that although treated wastewater reuse is recognized as a strategic option in augmenting agricultural water supplies in arid and semi-arid areas, there are many challenges that face the utilization. Legal challenges included adopting relevant and appropriate standards for reuse, which could be implemented at the farm level. Social and economic considerations need to be considered in developing reuse options and strategies. Field surveys and interviews with farmers showed that farmers are willing to irrigate many crops utilizing treated wastewater. However, the study by Mizyed [48] showed that there are discrepancies between what farmers are willing to implement and what planners and policymakers would recommend. Farmers indicated a good understanding of the technical solutions on how to make treated reuse safe and technically sound. However, emphases on social and economic implications are highly essential for the success of reuse. Surveys of farmers showed that they need to understand and know the economic costs, returns, and benefits of the different qualities of treated wastewater to select appropriate reuse alternatives. Therefore, public awareness campaigns are needed to address the legal, social, economic, and institutional consideration for treated wastewater reuse. The author went on to recommend that participation of farmers in developing guidelines, standards, policies, and plans for agricultural reuse is very important for the sustainability of treated wastewater reuse.

Table 3
Balance: resource, requirements in 2010 [27]

Water availability (Hm^3/year)	
Surface resources mobilized (Hm^3)	137
Groundwater resources mobilized (Hm^3)	11
Desalination of sea water (Hm^3)	1.6
Total resources mobilized (Hm^3)	149.6
Water requirement (Hm^3/year)	
Drinking water supply (DWS) (Hm^3)	68
Water for industry (WI) (Hm^3) "estimation"	1.1
Irrigation (Hm^3)	99.5
Total (Hm^3)	168.8
Balance sheet (Hm^3/year)	−19.2

Mok and Hamilton [49] reported that there is health risks associated with wastewater irrigation for human food crops, particularly with surface irrigation techniques common in the developing world. Many farmers in water-scarce regions of developing countries, for instance, use wastewater to irrigate vegetables and other agricultural crops, a practice that will expand with climate change, as noted earlier. The WHO recommends using quantitative microbial risk assessment to determine if the irrigation scheme meets health standards. Results from Mok and Hamilton [49] indicated that estimated risks from reuse exceeded WHO guideline thresholds for acceptable disease

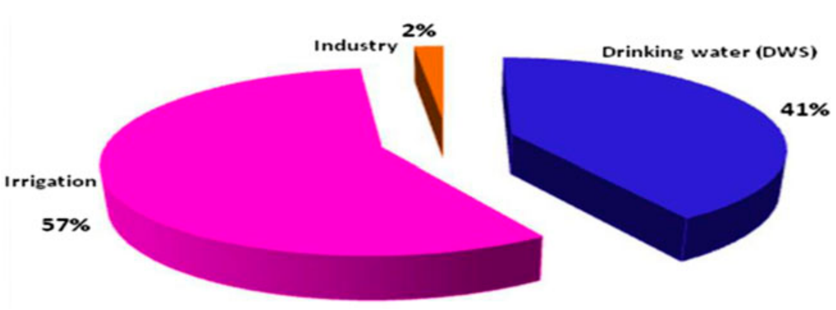

Fig. 6. Distribution of the underground resource mobilized for different uses in Chlef.

burden for wastewater use, signifying that reduction of pathogen concentration or stricter risk management is necessary for safe reuse. It can be argued that the analysis of treated wastewater, as reported in the current study, indicates that treated water reuse in irrigation should reduce health risks for consumers worldwide.

Climate change has also increased the pressure to find alternative water resources for irrigation. The climate projections for Algeria, by the use of a climatic model total UKHI (scenario average "IS92" of the GIEC) [31,50] were carried out on a seasonal basis and compared to the base period 1961–1990. This model predicts a rise in average temperature of approximately of 0.8 to 1.1˚C by 2020 and 1 to 2.2˚C by 2050. In addition, a fall in average precipitation is predicted of about a 10% by 2020 and 20% by 2050. It can be argued that this means less conventional water and increased need for reuse of treated water.

The rainy period for the North Africa region projected by the HadCM2 model for 2050 is expected to be concentrated in a shorter period causing flood risks [16,33,50]. Also an increase is predicted in the frequency of drought and a deficit in contribution to surface water of 15%, resulting in a groundwater decline of 4.4% by 2020 and 6.6% by 2050 [33]. So the region is headed toward a significantly more severe water shortage over the coming decades. All of this has placed an increased urgency on finding sustainable new water resources, such as treated wastewater, which can be used in agricultural irrigation.

5. Concluding remarks

The reuse of treated wastewater is increasing especially in arid regions with chronic water shortages. This study has shown that the average removal efficiencies of suspended solids (TSS), COD, and BOD5 were 88%, 94%, and 98%, respectively. Additionally, the total coliform concentration was below the national and international standards. Likewise, the absence of toxic micro-pollutants such as heavy metals suggests that treated water can be used as an alternative water resource for irrigation. The presence of nitrogen (i.e. TN, NO_3-N, and NH_3-N) in treated wastewater, which was within internationally accepted standards, could replace fertilizers normally added to fields, and therefore, the cost of crop production could be reduced significantly. It can be argued that this may also increase yields of forage crops and their water use efficiency.

A significant annual deficit (i.e. 19.2 Hm^3) was observed, which is exacerbated by climate change. This constitutes a permanent pressure on public services in charge of the management of water resources. Treated wastewater reuse is recognized as a strategic option in augmenting agricultural water supplies in arid and semi-arid areas. However, there are many challenges that face its full utilization; there need to be an increased emphasis on the social and economic implications which are highly essential for the success of reuse. Therefore, public awareness campaigns are needed to address the legal, social, economic, and institutional consideration for treated wastewater reuse.

Finally, the reuse of treated wastewater is both a political and a socioeconomic challenge. Though, this route may help to alleviate water shortages by better conserving natural resources and also contributing to the development of integrated water management systems.

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