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Impact of Treated Wastewater Reuse for Irrigation Purposes in Tunisia on Crops Growth, Human Health and Soil

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Abstract

This work analyzed several Tunisian researches about reused water quality and their effects on crops growth and soil properties as well as harmful substances content and human health risks. Five irrigation areas were selected (Nabeul-oued Souhil, Sfax-Elhajeb, Sousse-Zaouit, Borj Touil and Gabés-El Hamma). Results Showed a very higher TWW conductivities (3.5-5.6ms/cm). An important level of toxic compounds were observed; sodium from 4.87meq/L to 32meq/L, Chloride from 15.45 to 49.77meq/L and nitrate from 13.4 to 22.74mg/L compared to FAO guideline which recommended 3meq/L, 4meq/L and 5mg/L respectively. A medium sodium hazard was observed (SAR ranged from 1.33 to 10.74). Due to higher salinities TWW were classified according to Riverside as doubtful (C_4S_1) and unsuitable (C_5S_1 and C_5S_2) for irrigation purposes. Nutrients, trace of metals (cadmium, lead, iron and manganese), SS, biochemical and chemical oxygen demand exceeded sometimes the Tunisian restrictions 106.03 for water reuse. Pathogens and drug degradations were also detected in some Tunisian regions (Sapovirus, antibiotic resistance genes, polycyclic aromatic hydrocarbons and polychlorinated biphenyls).

Reused wastewater in irrigation with current quality can reduce crops yield growth 50% for olive, citrus and pomegranate and 25% for sorghum, corn and bersim. To prevent human health risks, soil properties modification and damage, defoliation and desiccation of plants, desalination of treated wastewater with an adequate pretreatment steps and hybrid membrane systems combined reverse osmosis and nanofiltration was necessary.

Abbreviations

BOD5: Biologic Oxygen Demand
COD: Chemical Oxygen Demand
EC: Electro-conductivity
ECe: Soil conductivity
ECm: Soil salinity at threshold point
ECw: Water conductivity
ESP: Exchangeable Sodium Percentage
FAO : Food and Agriculture Organisation
Ks: Yield reduction coefficient by salinity
OPI: Organic Pollution Index
PAHs: Polycyclic Aromatic Hydrocarbons
PCBs: Poly Chlorinated Biphenyls
RSC: Residual Sodium Carbonate
S: Rate of yield decline
SAR: Sodium Absorption Rate
SS: Suspended Solid
SSP: Soluble Sodium Percentage
T: Threshold soil salinity
TSS: Total Suspended Solid
TWW : Treated Waste Water
WHO: Water Human Organization
Wt: Weight
WWTP: Waste Water Treatment Plant
Ym: Maximum yield
Yr: Relative yield

Introduction

The successive years of drought, induced by climate change and population growth, increasingly reduced the amount of water reserved for agriculture. It is estimated that 50% of the world population will live in water stressed regions in 2025 [1], which highlights the importance of adequate water management and treatment. In Mediterranean countries, natural water resources are limited, whereas their demand is constantly increasing [2].

Treated wastewater can be considered as a reliable source of water and nutrients that is available all year around. Its availability and nutrients properties are important factors that make it a valuable resource particularly in arid and semi-arid zones [3]. In Tunisia, the reuse of treated wastewater (TWW) has been adopted since the 1960s with the planning of many irrigated perimeters [4]. Actually Tunisia has 119 wastewater treatment plants (WWTP) using in general activated sludge process and producing 260 million m^3 per year. Only 10% of Tunisian WWTP has a tertiary treatment. The total volume of directly reused wastewater is 29 million m^3 per year and 33 million per m^3 after treatment. 62 WWTP are concerned by the reuse of treated water. 12.7% of total treated wastewater is reused to irrigate 2734 exploited hectares from 8415 managed ones in the agricultural sector. 45% of treated wastewater is used to irrigate arboriculture, 36% for forage crops, 15% for cereals and 4% for industrial crops [5]. Previous studies have focused on the effect of treated wastewater irrigation in Tunisian olive oil quality [6-8]. Other studies are interested to the accumulation of toxic components in soil and plants in terms of heavy metals [9-10], of pathogens or other contaminants such as antibiotic resistance genes [11] and of polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyles (PCBs) and organochlorinated pesticides [12].

A risk to human health, environment and soil destruction can result of various types and concentrations of contaminants in wastewater depending on its source and the degree of treatment. This study attempts to provide an overview of negative impacts of long term treated wastewater irrigation in Tunisia on soil salinization and sodicity, crop yields and human health in relation to the chemical and microbiologic water compounds. Several variables are considered to evaluate the quality of reused wastewater in different Tunisian regions and its usability for irrigation purpose related to water salinity, infiltration rate, specific ions toxicity, excessive nutrients and substances harmful to human health, such as pathogens or other contaminants from, e.g., drug degradations.

Materials and Methods

Case Studies

The present investigation was conducted in many sites located in the north, south, and central of Tunisia. Five irrigated area in Tunisia by treated wastewater are selected to evaluate the impact of reused water in irrigation as well as the contaminant compounds. Selected zones are based on literature research, available data and important irrigation area.

ELHajeb Sfax

The first one site is El Hajeb area irrigated by treated wastewater obtained from Sfax plant localized in the south of Tunisia. This WWTP is an aerated lagoon process receiving municipal and industrial wastewaters. Its treatment capacity is 24,000m^3/day. The effluent is used to irrigate olive trees and intercrops such as cotton, oats and sorghum [7]. The irrigated area of El Hajeb covers an area of 700 ha spread over three properties:
- Henchir-Ghalia: that covers 450 acres;
- Henchir-Bessis that covers 76 ha;
- Henchir Avocato that covers 166 ha

The irrigation was delivered using a drip irrigation system, with four drip nozzles, the daily water supply per olive tree was 4.5 m^3, for a total water supply of 5000 m^3 ha^{-1} $year^{-1}$ [13].

Souhil Oued-Nabeul

The second site is Souhil oued area irrigated by TWW for about 20 years derived from a medium-sized treatment plants SE4 (activated sludge) and SE3(oxidation ditch) of about 100,000 habitants [14] located in Nabeul Government in the North of Tunisia. Together SE4 and SE3 receive and treat approximately 6000 000 m^3/year. 25-30% of this is reused for irrigation approximately 250 000 - 300 000 m^3/year [15]. The treated wastewater that is distributed to the Souhil irrigated district from storage basins of 4500 m^3 is used to irrigate 263 ha of Citrus [12].

Borj Touil

The Borj-Touil field located 20 km north of Tunisian covers an area of 3200 ha. It's the main recycled water irrigated site surrounding the capital city, Tunis [16]. It was planned for treated wastewater irrigation for fodder and cereal crop and is supplied by the treated effluents of four wastewater treatment plants (Charguia, Chotrana1, Choutrana 2 and North Tunis).

Zaouit Sousse Perimeter

The perimeter of Zaouit Sousse is a part of the Tunisian central Sahel. It is situated in the South of Sousse city [4]. It covers 450ha, 205ha of which are currently exploited. Since 1989, the perimeter is irrigated by wastewater from the Sousse treatment plant which uses trickling filters coupled to an activated sludge system with a capacity of 18700 m^3/day [17]. Irrigated crops are olive trees, bersim and the sorghum.

El Hamma Agricultural Area

El Hamma Agricultural area is located in Gabes government in the south of Tunisia like Sfax city. It's irrigated by treated wastewater from el Hamma plant which receives 2000 m^3/day of municipal wastewater and which is composed by a secondary treatment through the use of activated sludge. A portion of the effluent from this treatment facility is made available for farmers in an adjacent agricultural area [18].

Farmers at El Hamma are motivated by the opportunity to use the relatively inexpensive treated wastewater to produce fodder and certain types of crops, particularly pomegranates and olive trees.

Reused Water Quality Evaluation

Tunisia was among the first countries around the Mediterranean Rim to have established and implemented a water reuse policy in the 1980s with water reuse operations integrated into the planning and design of sanitation projects [19], The main crops irrigated with treated wastewater are fruit trees (citrus, grapes, olives, peaches, pears, apples, grenades 28.5%), fodder (alfalfa, sorghum, berseem, 45.3%), industrial crops (sugarbeet,3.8%), and cereals (22.4%).

57% of the equipped area are sprinkler irrigated and 48% surface irrigated. Some farmers use localised irrigation systems [20]. Tunisian researchers are interested to reused water effects on qualitative effects on olive trees [7,8,13,21] and some other crops such as corn [22] and Cenchrus ciliaris [23].

This work analyzes the available data of treated water reused in Tunisia for agriculture. Physic-chemical water characteristics used in Tunisian irrigation area (conductivities, salinity, pH, major elements (anions and cations)) are compared to Tunisian standards 106.03 [24] and FAO guidelines [25]. The sodium absorption rate SAR expresses the toxicity effect of irrigation water on crops and degradation effects on soil fertility due to sodium ions are calculated using equation 1 [26].

$$SAP = \frac{[Na^{2+}]}{\sqrt{\frac{[Ca^{2+}]+[Mg^{2+}]}{2}}}$$

The sodium hazard are also assessed by calculation of residual sodium carbonate RSC (Equation 2), soluble sodium percentage SSP (Equation 3) and ESP (exchangeable sodium percentage (Equation 4) [26].

$$RSC = ([CO_3{}^{2-}]+[HCO_3{}^{-}]) - ([Mg^{2+}]+[Ca^{2+}])$$

$$SSP = 100\left(\frac{[Na^{+}]}{([Ca^{2+}]+[Mg^{2+}]+[K^{+}]+[Na^{+}])}\right)$$

$$ESP = \frac{100(-0{,}0126+0{,}01475SAR)}{1+(-0{,}0126+0{,}01475SAR)}$$

Other toxicity effects were evaluated based on ion TWW contents such as sodium, chloride, nitrate and bicarbonate. The levels of toxicity are qualified based in FAO guideline, types of the crops and publisher analyses.

The combination of EC and SAR had also been used to determine the suitability of water for Irrigation. The riverside diagram was used to classify the treated wastewater from different Tunisian irrigation area.

For the main crops irrigated by TWW in Tunisia the decrement of yield growth is calculated based in water conductivity (ECw) and soil conductivity (ECe).

The accumulation of toxic components in soil and plants is also controlled in terms of heavy metals based in several studies carried out in Tunisia and the results were compared to FAO guideline and Tunisian standards 106.03 as well as bacterial analyses (*E.Coli,* fecal streptococci, coliforms, intestinal nematodes and salmonella), nutrients (nitrogen, phosphate and potassium), pathogens and harmful substances (PAH, drug degradation) and organic matter (COD, BOD_5 and SS).

Results

In order to study the effect of salinity on crops irrigated by treated waster in Tunisia, physic-chemical characterizes of treated wastewater from four irrigation area: Sfax, Nabeul, Sousse and Borj Touil were regrouped. Results were illustrated in Table 1. The pH of four waters was in the range of Tunisian standards (106.03) [24] and FAO guidelines [26]. Conductivitiy of treated wastewater varied between 3.5ms/cm (Sousse) and 5.6 ms/cm (Sfax) not exceeded Tunisian standards (7ms/cm), But it was very higher to FAO recommendations (<0.7 ms/cm). It can affect soil chemical properties and limit the range of crops to irrigate especially sensitive crops like Citrus. Tunisian restrictions should be revised. Toxic compounds (sodium, chloride and nitrate) were also higher than FAO guideline. In Fact, sodium can cause a soil sodicity, the sodium bicarbonate can be formed and water infiltration rate will be reduced. Sodium concentrations were between 4.87meq/L (Sousse TWW) and 32meq/L (Borj Touil TWW). Chloride concentrations were between 15.45meq/L (Nabeul TWW) and 49.77meq/L (Sfax TWW). Tunisian standards tolerated a chloride concentrations of 56 meq/L for water reused in irrigation. However FAO recommended 4meq/L of chloride for surface irrigation and 3meq/L for sprinkler irrigation. As a consequence crops potential yield reduce, leaves injure and plant desiccate. Concerning nitrate the higher value was an indicator of fertilizer contamination. Evaluation criteria of water quality (SAR, RSC, SSP and ESP) were calculated by Equation 1,2,3 and 4 and the results were summarized in Table 2. The SAR which was in indicator of sodicity hazard varied between 1, 33 (Sousse TWW) and 10.76 (Borj Touil TWW). The FAO recommended a sodium absorption rate of 3 for water irrigation. A lower value of SAR like the case of Sousse TWW and Sfax was related to high values of magnesium and calcium concentration. The SAR of Borj Touil was higher than regulators limits (FAO) as well as SSP and ESP values. As a result long term irrigation with wastewater can damage the soil. As shown in Figure 1 waters salinities were very high and carried a very high risk of salinisation. According to the classification of Riverside the classes of waters were C_4S_1 for Sousse and Nabeul TWW, C_5S_1 for Sfax TWW and C_5S_2 for Borj Touil TWW. Irrigation water quality was doubtful (C_4) and unsuitable (C_5). Salinity was a constraint of treated wastewater reused in Tunisia. Based in literature (Table 3) and the values of water and soil conductivities, the yield decrement of the main crops irrigated by TWW in different Tunisian sites was calculated. As shown in Table 4, using saline water in irrigation reduces the yield growth of olive by 25-50% in Sfax, 10-25% in Sousse and 10-50% in Gabés El-amma. The same result is obtained for Pomegranate in Gabés. The yield growth of sensitive crops "Citrus" in Nabeul decrease by 50%. In Borj Touil, the yield decrement varies between 25 and 50% for Alfalfa and Corn and 25% for Bersim and Sorghum. Concentrations of all metals (Table5) were below the Tunisian standards limits except cadmium, lead and iron in Sousse WWTP, manganese and iron in Sfax WWTP.

Cadmium and lead may harmful to humans and inhibit plant growth, manganese and iron cause soil acidification and clogging of irrigation system. Higher concentrations of these elements can be related to the increase of industrial wastewater origin in Sousse especially textile industry and chemical industry in Sfax. Continuous irrigation with TWW over the long term could potentially result in high levels of some heavy metals in the soil. Other constraint of reused wastewater in Tunisia was a higher concentration of nitrogen and phosphorus [Table 6] due to process management but nutrient was benefic for crops at low level. In addition Levels of microorganisms (Table 7) were higher than FAO recommendations also the level of SS, biochemical oxygen demand (BOD) and chemical oxygen demand (COD) exceeded the Tunisian standards for wastewater reuse in irrigation (NT 106.03) except Sousse TWW and the BOD of Sfax effluent. Secondary effluent quality limited the reuse of TWW. The salinity of the treated water was relatively high making it inappropriate for sensitive crops. Indeed, the accumulation of toxic components in soil and plants has to be controlled in terms of heavy metals, chloride and sodium level. The risks to public and environmental health, particularly microbial and organic contamination cannot be ignored. Best management of wastewater treatment plant was recommended. Wastewater plants coupled with desalination plants, may have improve irrigation water quality. The recourse to membrane technologies gives the possibility of producing irrigation water with adequate concentration for high crop production in a sustainable way, through either the use of treated saline waters or the reuse of wastewater, thus reducing salinity, substances harmful to human health (such as pathogens or other contaminants from, e.g., drug degradations and toxic component. Adequate pretreatment steps to prevent membrane fouling should be taken account. Nutrient recovery from wastewater can be also a best alternative.

Table 1: *Physic-chemical characterization of treated wastewater in Tunisia*

	Sfax [23]	**Nabeul [14]**	**Sousse [4]**	**Borj Touil [14]**	**Tunisian restrictions NT106.03 [24]**	**FAO guideline [25,26]**
pH	7.6	7.15	7.8	7.95	6.5-8.5	Normal range 6.5-8.4
ECw (ms/cm)	5.6	3.96	3.5	4.81	7	0.7
$[Ca^{2+}]$ (meq/L)	4.92	6.33	12.9	7.99		
$[Mg^{2+}]$ (meq/L)	7.14	7.5	13.83	10.04		
$[Na^+]$(meq/L)	9.00	17.79	4.87	32.31		3
$[K^+]$(meq/L)	0.86	0.80	8.51	3.50		
$[HCO_3^-]$ (meq/L)	5.83	5.65		5.62		Sprinkling only <1.5
$[Cl^-]$	49.77	15.45	19.38	31.42	56	Surface irrigation <4 Sprinkler irrigation <3
$[SO_4^{2-}]$	7.18	8.88		15.92		
$[NO_3^-]$	0.22	0.36				<0.08

Table 2: *Evaluation criteria of water quality for irrigation in Tunisia*

	SAR	RSC	SSP	ESP
Sfax	3.66	-6.23	41.05	3.98
Nabeul	6.76	-8.185	54.84	8.02
Sousse	1.33		12.14	0.70
Borj Touil	10.76	-12.41	60.02	12.75
FAO guideline [26]	<3	<0	<60	2-10

Table 3: *Crops yield decrement according to soil and water conductivity [27]*

Crops/ Yield decrement	0%		10%		25%		50%		Maximum
Conductivity (ms/cm)	**ECe**	**ECw**	**ECe**	**ECw**	**ECe**	**ECw**	**ECe**	**ECw**	**ECe**
Olive	2.7	1.8	3.8	2.6	5.5	3.7	8.4	5.6	14
Citrus	1.7	1.1	2.3	1.6	3.2	2.2	4.8	3.2	8
Alfalfa	2	1.3	3.4	2.2	5.4	3.6	8.8	5.9	15.5
Corn(Forage)	1.8	1.2	3.2	2.1	5.2	3.5	8.6	5.7	15.5
pomegranates	2.7	1.8	3.8	2.6	5.5	3.7	8.4	5.6	14
Bersim	1.5	1	3.2	2.1	5.9	3.9	10.3	6.8	19
Sorghum	4	2.7	5.1	3.4	7.2	4.8	11	7.2	18

Table 4: *Crops yield decrement in different Tunisian sites*

Region/ Crops decrement yield	Conductivity (ms/s)		Olive	Cit-rus	Alfalfa	Corn	pome-granate	Bersim	Sor-ghum
Sfax	ECw [23]	5.6	25-50%						25%
	ECe [21]	4 to 8							
Nabeul	ECw [14]	3.96		50%					
	ECe [15]	1.5 to 2.4							
Sousse	ECw [4]	3.5	10-25%					10-25%	0-10%
	ECe [4]	1.12 to 3							
Borj Touil	ECw [14]	4.81			25-50%	25-50%		25%	25%
	ECe [9]	3.25 to 7.9							
Gabes, El-Ham-ma	ECw [18]	5.13	10-50%				10-50%		
	ECe [28]	3.5							

Table 5: *Heavy metals contents of treated wastewater in different Tunisian sites*

Heavy metals (mg/L)	Sfax [10]	Nabeul [14]	Sousse [4]	Borj Touil [14]	Gabes-El-Hamma [18]	Tunisian restrictions NT106.03 [24]	FAO guideline [25]
Cd	<0.004 [23]	0.009	0.03		<0.001	0.01	0.1
Pb	<0.004 [23]	0.03	2.51	0.11	0.001	1	5
Co	-	0.005	-	0.03	<0.001	0.1	0.05
Cu	0.06-0.16	0.006	0.09	0.03	0.007-0.022	0.5	0.2
Fe	0.13-1.7	0.228	1.3	0.03	0.047-0.049	O.5	5
Mn	0.64-0.66 [23]	0.006		0.04	0.047-0.049	0.5	0.2
Al			2.25		0.046-0.055		5
Ni	0.018-0.13	0.03	0.08	0.04	0.01-0.012	0.2	0.2
Zn	0.16-0.27	0.009	0.18	0.08	0.031-0.038	5	2
Cr	0.05-0.11	0.003	0.01		<0.001	0.1	0.1
As					0.007	0.1	0.1

Table 6: *Nutrients contents of treated wastewater in different Tunisian sites*

Nutrients (mg/L)	Sfax [7]	Nabeul [29]	Sousse [4]	Borj Touil [22]	Gabes [18]	Long term irrigation water [1]	FAO common quantity in irrigation water [1]
K^+	38	38-54	333	40.6		50	0-2
NO_3^-	15.90	22.3-17.3			23.5 to 39.0	50	0-10
PO_4^{3-}					3.6 to 4.5		
NH_4^+	37.90	25.2-45.3					0-5
P_{total}	10.30	31.03		7.8		0.05	0-2
N				30.9			

Table 7: *Bacteriological analyses of treated wastewater in different Tunisian sites*

MPN/100 mL	Borj Touil [14]	Nabeul (oued Souhil) [14]	Gabes [18]	WHO Standards
Total Coliforms	3.4*10^5	6.6*10^5	1.19*10^6 to 2.10 *10^6	
F.Streptococi	7.1*10^4	4.5*10^5		
***E.Coli* (Fecal Coliforms)**	2.7*10^5	6.6*10^5		<1000

Table 8: *Organic component of treated wastewater reused in different Tunisian irrigation areas*

	Sfax [7]	Nabeul [30]	Sousse [4]	Borj Touil [31]	Gabes [18]	Tunisian restrictions NT106.03 [24]
COD	273	127-341	87.9	133.4	223.9	90
BOD_5	22	16-75	18.5	75	20.0 to 20.8	30
SS	56	30-250	32.7	90		30

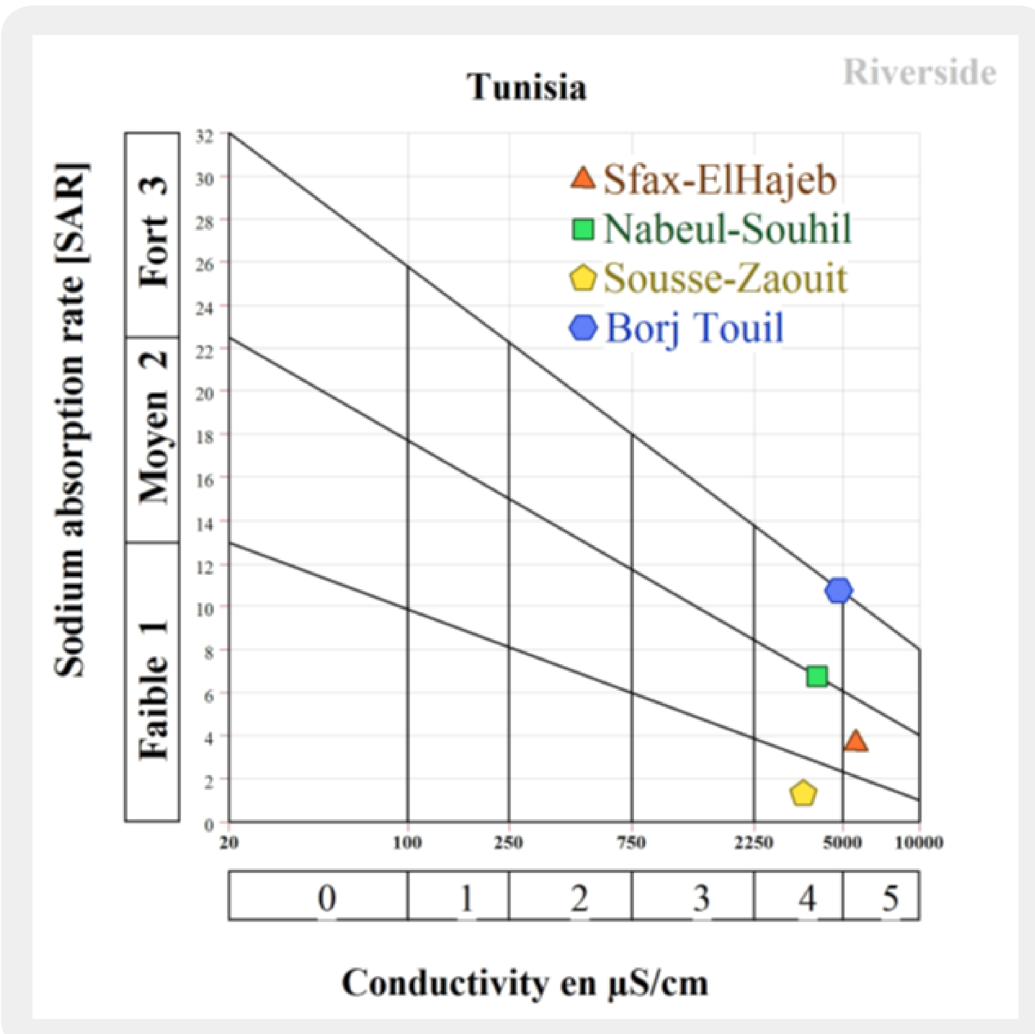

Figure 1: *Riverside Diagram for different treated wastewater in Tunisian sites*

Discussions

Salinity Effect on Crops

Tunisian regulations allow secondary treated effluents on all crop types except vegetables, whether eaten raw or cooked [16]. Salinity effects on crops were summarized in this work. Due to industrial activities salt load limits the range of crops to irrigate and the benefits related to water reuse. In fact 80% of treated wastewater salinity was in the range 3-6 g/L and 8% was in the range 6-14 g/L [20]. Compared to FAO recommendations 88% of treated wastewater were unsuitable for irrigation purposes. Bedbabis S. *et al.* [13] reported that long term irrigation with treated wastewater modified some chemical and physical properties of the soil. In particular decreased the pH and increased organic matter and electro-conductivity. It induced also a significant accumulation of Na and Cl in all the soil layers, lead to a significant increase of SAR and reduction of the water infiltration rate. Regarding to sodium and chloride accumulation Simpsom C.R. *et al.* [32] concluded that mortality of the citrus trees increased and standing leaf area decreased with increasing tissue Na^+ and Cl^- concentrations. Grattan S.R *et al.* [33] described the yield potential of orange based on osmotic effects only as:

$$Y_r = 100 - 13.1(ECe - 1.3)$$

Where ECe is the soil salinity in ms/cm

They concluded that specific ion toxicities due to sodium, chloride or boron would reduce the yield potential even more. Visual injury to leaves (Chlorisis and necrosis) can became apparent when Na^+ concentrations in the leaves reach 0.1-0.25% dry wt and yellowing or bleaching in between veins can appear on citrus leaves when concentrations in the leaf reach exceed 1% Cl^- on dry weight base.

Concerning olive trees, osmotic stress caused by NaCl supply reduced stem diameter, number of shoots, shoot length and nutrients [34]. Furthermore, salinity reduces the number of perfect flowers per inflorescence, the viability and germinability of the pollen and fruit set in olives. At a whole-plant level the impacts of salinity are reflected through declines in growth, reduction in yield, and leaf injuries, which can lead to complete defoliation of plants and their subsequent desiccation [35]. Chartzoulakis K.S. [35] reported that problem cannot observed for olives irrigated by a water with a conductivity of 2.5 ms/cm, sodium concentration of 0.25 g/L, chloride concentration of 0.35 g/L. However the problem increased when EC was in the range 3-5 ms/cm, sodium concentration in the range 0.3-1 g/L and chloride concentration in the range 0.4-1.5 g/L. Finally the degree of problem was severe when these values exceeded 5.5 ms/cm, 1.2 g/L and 1.8 g/L respectively.

Mass, E.V. and Hoffman G. J. [36] described the relative olive trees yield by Equation 6.

$$Y_r = 100 - (EC_e - t)s$$

Where
• Yr is the relative crop yield (%),
• 100 is the maximum yield,
• ECe is the average salinity of soil saturation extract (ms/cm),
• t is the threshold soil salinity value where yield begins to decline (ms/cm),
• s is the rate of yield decline per unit increase in ECe.

Beder B. *et al.* [37] concluded that the growth of olive cultivars is reduced and the onset of leaf damage could be expected at Na+ leaf concentration higher than 0.4% of dry matter and that response to salinity differed greatly among the cultivars. 'Picholine' was considered a salt tolerant, showing a lower reduction of growth and the ability to limit leaf Na^+ concentration. 'Ascolana' and 'Meski' demonstrated to be salt sensitive because growth was highly suppressed by high salinity. Gharsallaoui M. *et al.* [7] reported that long term olive irrigation by treated wastewater has a significant effect in oil fatty acid composition; the percentage of palmitoleic acid, linoleic (C18:2) and linolenic (C18:3) increased and the percentages of stearic and oleic acid decreased and that oils were more sensitive to the oxidization especially after olive storage due to decreasing of antioxidant compounds (total phenols and pigments) [6].

Few works were also interested to salinity effect on corn which is one of the most important cereals for human and animal consumption. Kamal H.A. [38] demonstrated that the grain yield of corn was significantly affected in a linear relationship (r2 ≥0.95) by salinity conditions. He described the relationship between relative reduction yield and relative excessive soil solution salinity by equation 7 and ks was found as 0.214 with r2 = 0.964 [37].

$$1 - \frac{Ys}{Ym} = k_s\left(\frac{EC_e}{EC_m} - 1\right)$$

Where
• Ks is yield reduction coefficient by salinity,
• $(1 - Y_S/Y_m)$ is relative yield reduction by soil solution in adequate water condition,
• ECe and ECm are, respectively, average soil solution salinity at any point and threshold (reference) point corresponding to expecting yield YS and maximum yield Ym.

For Sorghum Saadat S. and Homaee M. [39] reported that salinity threshold value is 1ms/cm at seedling stage, and the seedling rate reduces to 50 percent at 11ms/cm of soil salinity. An approximate 86% reduction in leaf area was recorded in two varieties of sorghum at 250 mM of Chloride [40]. Finally for promeganate crops Bhantana P. and Lazarovitch N. [41] fitted the Maas and Hoffman [36] relative yield to salinity and showed a 10% decrease in yield crops per unit increase in EC_e with a threshold of 1 ms/cm. Compared physic-chemical characteristics of treated wastewater and literature review showed that the higher chloride, sodium contents and salinity will damage the soil, decrease a crop yield and it can accumulate a salts on crops. A precaution and a modification of Tunisian Standard 106.03 essentially for chloride concentration and water conductivity should be taken. Complementary treatment can reduce a consequence of wastewater reuse in Tunisia for irrigation purposes.

Heavy Metals

The increase of heavy metals availability and their potential uptake for crops can have possible phytotoxicity effects and dangerous consequences in the food chain [42]. According to FAO guidelines for trace metals in irrigation watrer [25] the aluminum can cause non productivity in acid soil (pH< 5.5), cadmium is toxic to beans, conservative limits recommended due to its potential for accumulation in plants and soils to concentrations that may be harmful to humans. Iron can contribute to soil acidification and loss of availability of essential phosphorus. Manganese (Mn), and Iron (Fe) caused negative effect in irrigation systems especially clogging resulting in low distribution uniformity [42]. The lead can inhibit plant cell growth at very high concentrations and the zinc is toxic to many plants at widely varying concentrations and this toxicity can be reduced at pH >6 and in fine textured or organic soils.

Khaskhoussy *et al.* [9] studied the effect of treated wastewater irrigation on heavy metals distribution in a Tunisian soil and they concluded after one cycle of irrigation that cadmium and nickel content in soil were increased. However no changes was shown in Zn, Co and Pb contents in irrigated soil with TWW. In another work, Khaskhoussy *et al.* [22] observed that Cu, Zn and Co contents in corn irrigated with TWW increased significantly on all organs as compared to corn irrigated with freshwater. In conclusion Tunisian Treated wastewater not contained higher concentrations of heavy metals but after long term irrigation a trace of heavy metals can be accumulated in the soil and caused a health problem for humans.

Nutrients

Plant nutrients generally occur in water at very low levels. Presence in irrigation water at levels higher than a few parts per million may indicate the presence of pollution from fertilizers or other contaminants [1]. The additional supply of potassium reduced to some extent the adverse effects of salinity by reducing the transport and accumulation of toxic ions in both leaves and fruits [35]. Tekaye *et al.* [6] proved that reused treated wastewater improved the plant physiological performance by improving photosynthetic parameters and chlorophyll content in olive leaves, due to its considerable content of essential nutrients. However Bahri A. [20] suggested that over-application of nitrogen exceeding requirements for crop growth may present some risks for crops and/or groundwaters. Nitrate is a health risk to humans at 10 mgN/L and animals at 30 mgN/L [43].

In Tunisia carbon, nitrogen and phosphorus removal were carried out by activated sludge process and in the same reactor, anoxic and anaerobic conditions were not satisfied as a consequence denitrification and dephosphatation were not realized in best conditions as a consequence nitrate and phosphate concentrations in effluent were important. Nutrients contents were higher than recommended by FAO and can cause a problem. A best solution is the nutrients recovery from wastewater.

Pathogens and Drug Degradations

The different treatment processes in Tunisia did not result in a complete removal of pathogenic bacteria such as salmonella except effluents from stabilization ponds which were free of these pathogens [20]. Among fecal coliforms, *Escherichia coli* are the predominant species, and for this reason, the count of it is the most satisfactory indicator for assessing the quality of wastewater for irrigation use. The WHO recommends the use of water for crops irrigation only if the concentration of fecal coliforms in 100 mL is <1000 [42]. Concerning helminth eggs, sedimentation is the most effective method, which requires a minimum retention time of 5-20 days depending on the initial content [42]. Ben Salem I. *et al.,* [44] collected sixty wastewater samples from fifteen different regions of Tunisia and 20% percentage were found concerning salmonella in WWTP output and 53.3% were found concerning the ETEC pathotype which is considered strongly pathogen associated with diarrhea that should be taken as a public health problem. Varela M. F. *et al.* [45] analysed the treated wastewater sampled from four Tunisian WWTPs (Sidi bouzid, Sbeitla, Msaken and Dkhila) and they concluded that 23.9% of effluent contained Sapovirus, Dkhila was the most contaminated with a Sav prevalence of 63%. The viral rate detected in the central Tunisian WWTPs was 38.9% in Sidi bouzid and 35.2% in Sbeitla. Mahjoub O. *et al.* [46] showed that treated wastewater reused in oued souhil area for irrigation contains ER (Estrogen receptor), AhR(aryl hydrocarbon receptor) and PXR (pregnane X receptor) active compounds not removed during treatment which can be accumulated in the soil or infiltrate with water. Thirteen out of the fifty six antimicrobial compounds analyzed were detected in effluent WWTP into southern sfax from 7.5 (for cefalexin) to 370.04 ng/L for spiramycin [47]. Denden Rafraf, I. *et al.* [11] investigated the abundance of antibiotic resistance genes (ARGs) after treatment in five wastewater treatment plants (WWTPs) located in different areas of the Monastir Governorate (Tunisia). They detected All ARGs and the intI1 gene in the effluent, except the *blaCTX-M* gene, which was not detected in both influent and effluent samples from Sahline and Beni Hassen WWTPs, and the qnrS gene, which was not detected neither in the WWTP influent in Moknine nor in the WTP effluent in Beni Hassen. Hadddaoui I. *et al.* [12] studied the distribution of organic pollutants (Ops) in a cropped soil irrigated with TWW in Nabeul (Tunisia) for more than 30 years. They concluded that effluents contribute to the transfer and distribution of OPs at the soil surface (0-10cm) and subsurface (10-20cm). Pyrene was the most abundant PAHs (polycyclic aromatic hydrocarbons) indicating the presence of light petroleum products and biomass burning. For PCBs polychlorinated biphenyles, the six indicator congeners (28, 52, 101, 138, 153, and 180) were predominant compounds with a prevalence of tri-, tetra-, and hexa-PCB congeners. For OCPs (organochlorinated pesticides), results revealed that some compounds, like DDT, are relevant in agricultural soil. As shown secondary treatment were insufficient to remove pathogens and dangerous compounds such as drugs degradation, ER and PXR also some virus. Industrial contributions should be controlled and affluent discharged from hospitals also. UV treatment will be not sufficient, membranes technologies and desalination should be used to resolve human health risks.

Organic Matter

The total suspended solids (TSS) value influences the production quality and irrigation systems operation. The irrigation water with high TSS values over a long period of time can result in clogging issues in irrigation systems and the reduction of production quality due to its deposition on leaf and/or fruits and because particles can be related to microbial pollution [42]. Shakir, E., *et al.* [48] used organic pollution index to classify the organic pollution due to organic compounds in the treated wastewater described by Equation8:

$$OPI = \frac{BOD}{BOD_S} + \frac{COD}{COD_S} + \frac{Nitrate}{Nitrate_S} + \frac{Phosphate}{Phosphate_S}$$

They classified the water as being to be contaminated (OPI values: 1-2), lightly polluted (OPI values 2-3), moderately polluted (OPI values 3-4) and heavily polluted (OPI 4-5).

High organic loading reduce soil's infiltration, the limit organic load suggested by effluent irrigation policy guidelines for environment protection in Austria was below or equal to 40kg/ha/day and it should be annually monitor organic matter and soil structure to detect the deterioration [43].

Conclusions

The results of this study showed that secondary treated effluents for many regions in Tunisia were saline with conductivities in the range from 3.5ms/cm to 5.6ms/cm, contained a higher level of toxic compounds (chloride, sodium and nitrate). Sodicity hazard (SAR) was important for borj Touil TWW as well as SSP and ESP due to high level of sodium compared to FAO guideline. As a result yield decrement was important for the main crops (olive, citrus, pomegranate, alfalfa, bersim, sorghum and corn). According to riverside classification reused water in Tunisia was doubtful (C_4S_1) and unsuitable (C_5S_2, C_5S_1) for irrigation purposes. Treated wastewater contained also some trace of metals (cadmium, lead, iron and manganese) higher than Tunisian standards 106.03 due to industrial contribution. Also pathogens and organic contaminants compounds were detected in effluent in the middle and Sahel of Tunisian, in Nabeul and in Sfax WWTP (Sapovirus, Estrogen receptors, antibiotic resistance genes, polycyclic aromatic hydrocarbons and polychlorinated biphenyls). Secondary effluent nutrients, microorganisms and organic matter contents (BOD5 and COD) exceeded regulators limits for wastewater reuse in Tunisia. This means, consequently, soil salinization and human health risks. A higher variability of organic parameters which, for N and P, may be also a constraint and low trace elements content, far below the expected toxicity thresholds which led to the rejection of reuse by farmers. The main recommendations were revised a Tunisian restrictions for water reuse conductivities and chloride content and in second time coupled treatment wastewater plant with a complementary treatment " desalination" was a necessity after choice an adequate pretreatments steps to prevent membrane fouling.

Conflicts of Interests

No conflict of interest

Bibliography

1. Quist-Jensen, C. A., Macedonio, F. & Drioli, E. (2015). Membrane technology for water production in agriculture: Desalination and wastewater reuse. *Desalination, 364,* 17-32.

2. Farahat, E. & Linderholm, H. W. (2015). The effect of long term wastewater irrigation on accumulation and transfer of heavy metals in Cupressus semppervirens leaves and adjacent soils. *Science of the Total Environment,* 512-513, 1-7.

3. Elgallal, M., Fletcher, L. & Evans, B. (2016). Assessment of potential risks with chemicals in wastewater use for irrigation in arid and semiarid zones: A review. *Agricultural water management, 177,* 419-431.

4. Klay, S., Charef, A., Ayed, L., Houman, B. & Rezgui F. (2010). Effect of irrigation with treated wastewater on geochemical properties (saltiness, C, N and heavy metals) of isohumic soils (Zaouit Sousse perimeter, Oriental Tunisia). *Desalination, 253*(1-3), 180-187.

5. ONAS. (2017). *Sanitation National office Activity report.* Tunisia.

6. Tekaya, M., Mechri, B., Dabbaghi, O., Mahjoub Z., Laamari, S., Chihaoui, B., *et al.* (2016). Changes in key photosynthetic parameters of olive trees following soil tillage and wastewater irrigation. *Agricultural Water Management, 178,* 180-188.

7. Garsallaoui, M., Benincasa, C., Ayadi, M., Perri, E., Khlif, M. & Gabsi, S. (2011). Study on the impact of wastewater irrigation on the quality of oils obtained from olives harvested by hand and from the ground and extracted at different times after the harvesting. *Scientia Horticulturae, 128,* 23-29.

8. Khabou, W., Ben Amar, F., Rekik, H., Beghir, M. & Touir,A. (2009). Performance evaluation in olive trees irrigated by treated wastewater. *Desalination, 246*(1-3), 329-336.

9. Khaskhoussy, K., Kahlaoui, B., Messoudi Nefzi, B., Jozdan, O., Dakheel, A. & Hachicha, M. (2015). Effect of Treated Wastewater Irrigation on Heavy Metals Distribution in a Tunisian Soil. *Engineering, Technology & Applied Science Research, 5*(3), 805-810.

10. Belaid, N., Neel, C., Lenain, J. F., Buzier, R., Kallel, M., Ayoube, T., *et al.* (2012). Assessment of metal accumulation in calcareous soil and forage crops subjected to long-term irrigation using treated wastewater: Case of El Hajeb-Sfax, Tunisia. *Agriculture, Ecosystems and Environment, 158,* 83-93.

11. Denden Rafraf, I., Lekunberri, I., Sanchez-Melsio, A., Aouni, M., Borrego, C. M. & Balcazar, J. L. (2016). Abundance of antibiotic resistance genes in five municipal wastewater treatment plants in the Monastir Governorate, Tunisia. *Environmental Pollution, 219,* 353-358.

12. Haddaoui, I., Mahjoub, O., Mahjoub, B., Boujelben, A. & Di Bella, G. (2016). Occurrence and distribution of PAHs, PCBs, and chlorinated pesticides in Tunisian soil irrigated with treated wastewater. *Chemosphere, 146,* 195-205.

13. Bedbabis, S., Ben Rouina, B., Boukhris, M. & Ferrara G. (2014). Effect of irrigation with treated wastewater on soil chemical properties and infiltration rate. *Journal of Environmental Management, 133,* 45-50.

14. ICBA. (June 2015). The safe use of TWW in Tunisian agriculture. Technical report of regional project: Adaptation to climate change in WANA marginal environments through sustainable crop and livestock diversification.

15. Lundqvist, H. & Nilsson, E. (2013). *Salt transfer under irrigation with treated wastewater in semi arid-Tunisia.* Master thesis, Lund University, Faculty of Engineering, LTH Departments of Earth and Water Engineering, 116 pages.

16. Ben Brahim Neji, H., Villaverde, A. R. & Gomez, F. G. (2014). Decision aid supports for evaluating agricultural water reuse practices in Tunisia: the Cebala perimeter. *Agricultural water management, 143,* 113-121.

17. Ben Fredj, F., Han, J., Irie, M., Funamizu, N., Ghrabi, A. & Isoda, H. (2012). Assessment of wastewater irrigated soil containing heavy metals and establishment of specific biomarkers. *Ecotoxicology and environmental safety, 84,* 54-62.

18. Dare, A. E., Mohtar, R. H., Jafvert, C. T., Shomar, B., Engel, B., Boukchina, R., *et al.* (2017). Opportunities and challenges for treated wastewater reuse in the West Bank, Tunisia, and Qatar. *American Society of Agricultural and Biological Engineers, 60*(5), 1563-1574.

19. Ait-Mouheb, N., Bahri, A., Ben Thayer, B., Benyahia, B., Bourrié, G., Cherki, B., *et al.* (2018). The reuse of reclaimed water for irrigation around the Mediterranean Rim: a step towards a more virtuous cycle. *Regional Environmental Change, Springer Nature, 18*(3), 693-705.

20. Bahri, A. (2002). *Water reuse in Tunisia: stakes and prospects.* Actes de l'atelier du PCSI, Montpellier, France, 28-29 mai.

21. Kallel, M., Belaid, N., Ayoub, T., Ayadi, A. & ksibi, M. (2012). Effects of Treated Wastewater Irrigation on Soil Salinity and Sodicity at El Hajeb Region (Sfax-Tunisia). *Journal of Arid Land Studies, 22*(1), 65-68.

22. Khaskhoussy, K., Hachicha, M., Kahlaoui, B., Messoudi-Nefzi, B., Rejeb, A., Jouzdan, O., *et al.* (2013). Effect of treated wastewater on Soil and Corn Crop in the Tunisian Area. *Journal of Applied Sciences Research, 9*(1), 132-140.

23. Ben Said, I., Adele, M., Mezghani, I. & Chaieb M. (2016). Effects of Irrigations with Treated Municipal Wastewater on Phenological Parameters of Tetraploid Cenchrus ciliaris L. *J Food Process Technol, 7*(2), 553.

24. Institut National de la Normalisation et de la Propriete Industrielle. (1989). Environment Protection - Use of reclaimed water for agricultural purposes - Physical, chemical and biological specifications (in French), Tunisian standards, INNORPI, NT 106.03.

25. World health organization. (2006). A compendium of standards for wastewater reuse in the eastern Mediterranean region.

26. Bunani, S., Yörükoğlu, E., Yüksel, Ü., Kabay N., Yüksel, M. & Ser, G. (2015). Application of reverse osmosis for reuse of secondary treated urban wastewater in agricultural irrigation. *Desalination, 364,* 68-74.

27. Ayers, R. S. & Westcot, D. W. (1976). *Water quality for agriculture.* Food and Agriculture Organization of the United Nations.

28. Hachicha, M., Khaldi, R. & Mougou, A. (2012). Irrigation with geothermal saline water in Tunisian south. *Etude et gestion du sol, 19*(2), 91-103.

29. Jemai, I., Ben Aissa, N., Gallali, T. & Chenini, F. (2013). Effects of Municipal Reclaimed Wastewater Irrigation on Organic and Inorganic Composition of Soil and Groundwater in Souhil Wadi Area (Nabeul, Tunisia). *Hydrol Current Res., 4*(4), 160.

30. Fries, E., Mahjoub, O., Mahjoub, B., Berrehouc, A., Lions, J. & Bahadir, M. (2016). Occurrence of contaminants of emerging concern (cec) in conventional and non-conventional water resources in Tunisia. *Fresenius Environmental Bulletin, 25*(9), 3317-3339.

31. Dridi, I., Louati, A., Arfaoui, A., Hamrouni, H. & Gueddari, M. (2016). Evaluation des impacts de l'irrigation par les eaux usées traitées sur les propriétés du sol du périmètre irrigué Cebela-Borj Touil (Nord de la Tunisie), Revue des Régions Arides n°41 (1/2017) - Special number - *Scientific Days of the Medjerda,* ESIER Medjez El Bab (Tunisie).

32. Simpsom, C. R., Nelson, S. D., Melgar, J. C., Jifon, J., King, S. R. & Schuster, G. (2014). Growth response of grafted and ungrafted citrus trees to saline irrigation. *Scientia Horticulturae, 169,* 199-205.

33. Grattan, S. R., Diaz, F. J., Pedero, F. & Vivaldi, G. A. (2015). Assessing the suitability of saline wastewaters for irrigation of citrus spp: Emphasis and specific ion interactions. *Agricultural Water Management, 157,* 48-58.

34. Soriano, A. P., Soriano Martın, M. L., Piedra, A. P. & Azcon, R. (2009). Arbuscular mycorrhizal Fungi increased growth, nutrient uptake and tolerance to salinity in olive trees under nursery conditions. *Journal of Plant Physiology, 166*(13), 1350-1359.

35. Chartzoulakis, K. S. (2005). Salinity and olive: Growth, salt tolerance, photosynthesis and yield. *Agricultural Water Management, 78*(1-2), 108-121.

36. Mass, E. V. & Hoffman, G. J. (1977). Crop salt tolerance-current assessment. J. Irrig. Drainage, Div. ASCE., 103, 115-134.

37. Bader, B., Aissaoui, F., Kmicha, I., Ben Salem, A., Chehab, H., Gargouri, K., *et al.* (2015). Effects of salinity stress on water desalination, olive tree (Olea europaeaL. cvs 'Picholine', 'Meski' and 'Ascolana') growth and ion accumulation. *Desalination, 364,* 46-52.

38. Kamal, H. A. (2010). Corn crop response under managing different irrigation and salinity levels. *Agricultural Water Management, 97*(10), 1553-1563.

39. Saadat, S. & Homaee, M. (2015). Modeling sorghum response to irrigation water salinity at early growth stage. *Agricultural Water Management, 152,* 119-124.

40. Netondo, G. F., Onyango, J. C. & Beck, E. (2004). Sorghum and salinity: II. Gas exchange and chlorophyll fluorescence of sorghum under salt stress. *Crop Sci., 44,* 806-811.

41. Bhantana, P. & Lazarovitch, N. (2010). Evapotranspiration, crop coefficient and growth of two young pomegranate *(Punica granatum L.)* varieties under salt stress. *Agricultural Water Management, 97*(5), 715-722.

42. Bortolini, L., Maucieri, C. & Borin, M. (2018). A Tool for the Evaluation of Irrigation Water Quality in the Arid and Semi-Arid Regions. *Agronomy, 8*(2), 23.

43. Hanjra, M. A., Blackwell, J., Carr, G., Zhang, F. & Jakson, T. M. (2012). Wastewater irrigation and environmental health: implications for water governance and public policy. *International journal of Hygiene and Environmental Health, 215*(3), 255-269.

44. Ben Salem, I., ouardani, I., Hassine, M. & Aouni, M. (2011). Bacteriological and physic-chemical assessment of wastewater in different region of Tunisia: impact of human health. *BMC research notes, 4,* 144.

45. Varela, M. F., Ouardani, I., Kato, T., Kadoya, S., Aouni, M., Sano, D., *et al.* (2018). Sapovirus in wastewater treatment plants in Tunisia: Prevalence, removal and genetic characterization. *Ppl.Environ.Microbiol., 84*(6), 1-11.

46. Mahjoub, O., Lecqulercq, M., Bachelot, M., Casellas, C., Escande, A., Balaguer, P., *et al.* (2009). Estrogen, aryl hysdrocarbon and pregnane X receptors activities in reclaimed water and irrigated soils in oued souhil area (Nabeul, Tunisia). *Desalination, 246*(1-3), 425-434.

47. Harrabi, M., Varela, S., Giustana, D., Aloulou, F., Mozaz, S. R., Barcelo, D., *et al.* (2018). Analysis of multiclass antibiotic residues in urban wastewater in Tunisia. *Environmental Nanotechnology, Monitoring & Management, 10,* 163-170.

48. Shakir, E., Zahraw, Z. & Al Obaidy, A. H. M. J. (2017). Environmental and health risks associated with reuse of wastewater for irrigation. *Egyptian journal of petroleum, 26*(1), 95-102.