



Received 01.02.2019
 Reviewed 30.05.2019
 Accepted 04.07.2019

A – study design
 B – data collection
 C – statistical analysis
 D – data interpretation
 E – manuscript preparation
 F – literature search

Irrigation with treated wastewaters and the protection of Hennaya groundwater – Tlemcen, Algeria

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For citation: Bemmousat A., Adjim M., Bensaoula F. 2019. Irrigation with treated wastewaters and the protection of Hennaya groundwater – Tlemcen, Algeria. *Journal of Water and Land Development*. No. 43 (X–XII) p. 19–27. DOI: 10.2478/jwld-2019-0059.

Abstract

The Henaya Irrigated Perimeter (HIP) is an agricultural area irrigated by treated wastewater (TWW) of Ain El Hout treatment plant. Various analyses have shown that i) this water has low concentration of heavy metals and toxic elements, ii) the average values of the physicochemical parameters for 136 samples are satisfactory (29.2 mg O₂·dm⁻³ for chemical oxygen demands – COD, 13.14 mg O₂·dm⁻³ for biological oxygen demands – BOD, 14.2 mg·dm⁻³ of suspended matter – SM, 1.82 mg·dm⁻³ of N-NO₃, 7.7 for pH and 927.74 μS·cm⁻¹ for electric conductivity – EC). Thirdly, it contains a high number of bacteria and nematodes (7200 CFU·(100 dm³)⁻¹ for faecal coliforms and 30 eggs·dm⁻³ for intestinal Nematodes) which makes it dangerous for groundwater contamination.

The objective in this work is to characterize the TWW and evaluate the impact of its use for irrigation on the quality of Hennaya groundwater. Before this, one has to prove that there is an amount of TWW that feeds the water table to show that there is a risk of pollution. We then estimated the aquifer minimum recharge value by TWW using the Thorntwaite method. The estimation has given 92 mm which is an important quantity. The results of the groundwater microbiological analyses reveal no sign of contamination. The cause is the efficiency of the degradation of pollutants of the Vadose zone. The soil purifying power *M_d* of the HIP was evaluated by the Rehse method and gave values ranging from 2.1 to 12.7 which indicated a complete purification.

Key words: groundwater, irrigation, pollution, treated wastewater

INTRODUCTION

The recovery of treated wastewater (TWW) for different uses is an interesting practice that can contribute to a better management of water resources all over the world. This fact is especially important in arid and semi-arid zones, where water resources are becoming both quantitatively and qualitatively scarce [GÓMEZ-LÓPEZ *et al.* 2009]. It has to be pointed that, in those regions where the water demands in agriculture is increasing, the TWW represents

a source of additional water and fertilizers which are renewable and reliable [FAO 2003]. Also, the residual sludge from wastewater treatment has an important value in soil improvement and plant nutrition [ANTOLIN *et al.* 2005].

Reusing TWW for irrigation has many advantages but also several inconvenients and especially in the case of absence of the tertiary treatment. The large fluctuations in daily pollution need some actions to modernize the technological process of treating [BUGAJSKI *et al.* 2017]. Other-

wise, fluctuations of the TWW quality may cause the problem of compliance with using standards, which induces big management difficulties. Recently, the search for a renewable water source, such as the effluent from secondary treatment systems, used for irrigation is considered to be practically applicable. However, a relatively high level of heavy metals, persistent organic pollutants, salt ions, and other elements, as well as a certain amount of pathogenic bacteria have provided limits to its direct agricultural reuse [RIZZO *et al.* 2014; WEI *et al.* 2016]. Insufficiently treated of urban and industrial effluent leads to pollution not only of surface water but also groundwater [FYLYPCHUK *et al.* 2017; SHIRAZI *et al.* 2015; SMOROŃ 2016].

In this context, several studies at various locations on the world showed that irrigation with TWW have changed the chemical makeup of aquifers. For example, in the state of California, this agricultural practice has resulted in nitrate contamination [EKDAHL *et al.* 2009]. In Girona, Spain, chlorine concentration reached up to $1200 \text{ mg}\cdot\text{dm}^{-3}$ ten months after starting the irrigation [CANDELA *et al.* 2007]. In Tunisia the content of some heavy metals exceeds in some sites the values of reuse standards [DAH-MOUNI *et al.* 2019]. In Iran the groundwater has a high salinity level. As a result, application of the TWW for agriculture need monitored [RAHIMI *et al.* 2018].

In Algeria, wastewater treatment plants (WWTP) are equipped with a primary and secondary treatment system which aims to eliminate only organic matter by some biological treatment. The decree fixing the Algerian standards for irrigation with TWW was developed solely to avoid the health risks and to prevent the contamination of crops. However, regarding the vulnerable zones, the limit concentrations imposed by this decree cannot prevent the risks incurred of a possible contamination by infiltration of TWW into the groundwater. For effective risk management, the ministry recommends rigorous monitoring of the quality of groundwater, especially in vulnerable aquifers.

This study aims to compare the analysed parameters with the standards for the TWW use in irrigation purposes in Algeria [Arrêté interministériel 2012] and find out if it concentration values may have a negative impact on the quality of the groundwater.

MATERIAL AND METHODS

STUDY AREA

The Hennaya aquifer is an area of about 29 km^2 , located 10 km North of Tlemcen city (Fig. 1). The region is characterized by a semi-arid climate with annual rainfall mean of 395.5 mm (Tab. 4). The irrigated perimeter is located in the Plain of Hennaya, north of Tlemcen (Fig. 1). It was put into operation in 2009, and is served by the effluent from secondary treatment systems produced from the WWTP with activated sludge of Ain El Hout. This perimeter extends over 912 ha, it is part of the Large Irrigated Perimeters, newly created by the Ministry of Water Resources (Fr. Ministère des Ressources en Eau) and managed by the National Office of Irrigation and Drainage (Fr. Office Nationale d'Irrigation et de Drainage – ONID). The WWTP of Ain El Hout, is located 11 km upstream of the

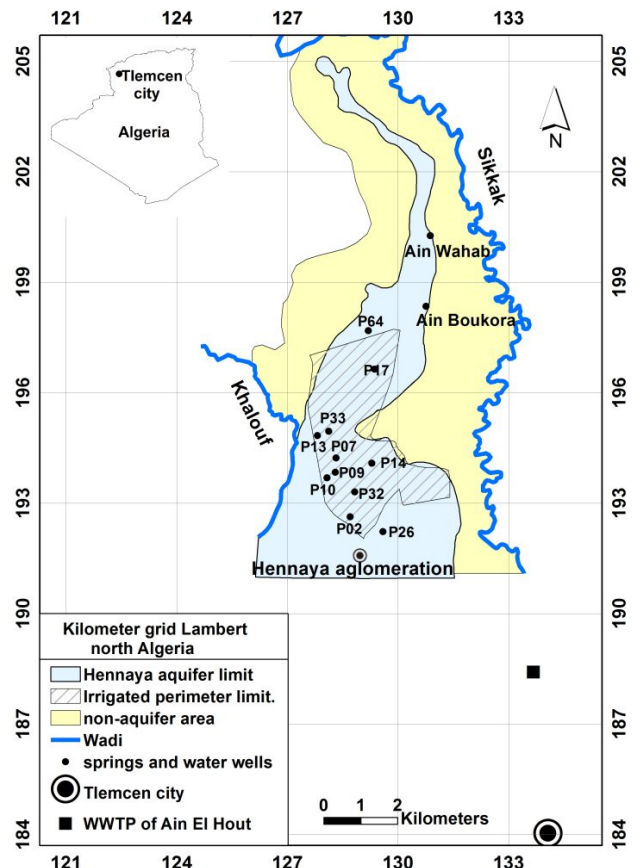


Fig. 1. The study area map; source: own elaboration

targeted perimeter. This WWTP currently processes $15.000 \text{ m}^3\cdot\text{d}^{-1}$. This quantity supplies the irrigation hydrants with TWW by gravity. Citrus is the main cropping activity on the irrigated plots.

The study area is constituted as a whole of Quaternary and Miocene formations (Fig. 2). The aquifer horizons of the region are the tortonian sandstones, the conglomerates, the travertines, gravel and clayey gravels. As for the impermeable formations constituting the substratum, they are represented by the Helvetian marls with thin layers of sandstone.

EVALUATE THE TREATED WASTEWATER INFILTRATION RATE INTO THE AQUIFER

Monthly allocated volumes for irrigation at plot levels from 2013 to 2016 was obtained, (data source ONID). The mean monthly temperatures was obtained from the Zenata meteorological station (Tab. 1). As for the monthly rainfall values, they could be obtained from five different rain gauges (Tab. 1). One uses the isohyets method to calculate the mean monthly rainfall values and estimate the hydrological water balance.

The infiltration estimation is done in the same way as for the calculation of effective rainfall using the Thornthwaite water balance technique [THORNTHWAITE, MATHER 1955]. The Blaney–Criddle [BLANEY, CRIDDLE 1950] procedure for estimating potential evapotranspiration (*ETP*) was used. This method is usually used in semi-arid climate type [ZHAO *et al.* 2013].

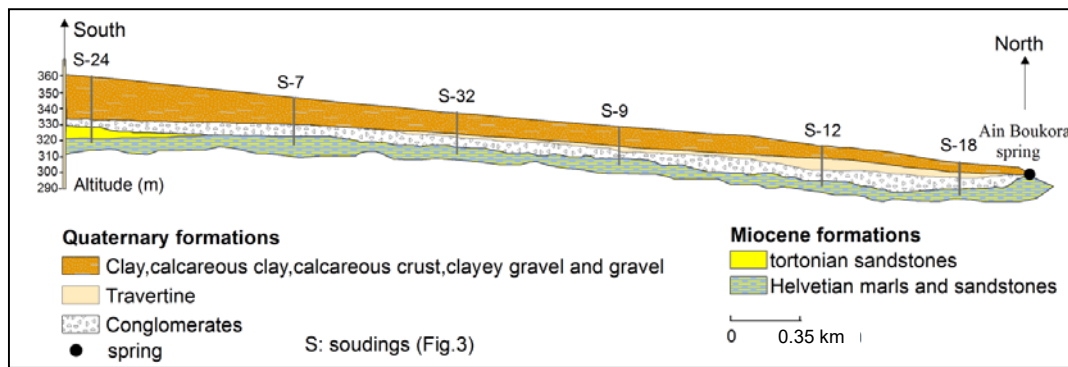


Fig. 2. South-North geologic cross-section of the studied area; source: Technoexporstroy [1971], modified

Table 1. Characteristics of rain gauges and meteorological station

ID	Station name	X Lambert (m)	Y Lambert (m)	Elevation (m)	Period observational	Data source
160403	Beni Bahdel	115	164.6	666	1971–2015	ANRH
160516	Hennaya	126.8	188.2	515		
160701	Me-frouche	135.6	180.2	1100		
160705	Lala Setti	133.9	181.8	1007		
160802	Pierre du chat	122.4	213.2	50		
160601	Chouly	151.8	181.2	725		
605300	Zenata	120.1	198.6	587	1981–2016	ONM

Explanations: ANRH = Hydrological Resources National Agency (Fr. Agence Nationale des Ressources Hydrauliques), ONM = Meteorological National Agency (Fr. Agence Nationale de la Météorologie). Source: own elaboration.

$$ETP = k \cdot p (0.46T + 8.13) \quad (1)$$

Where: T = mean temperature, °C; p = monthly percentage of day light hours in the year; k = crop coefficient = 0.65 for citrus [FAO 2000].

Available water capacity of the soil (ACW) is calculated by the Perarnaud formula [PERARNAUD, RAYNAL 1991]. We generally take the available water content of the soil (AW) is half of the ACW .

$$ACW = D (HPC - HPf) / (100 Z) \quad (2)$$

Where: D = soil bulk density; HPC = weight moisture to field capacity HC ; HPf = weight moisture at wilting point Hf ; Z = soil thickness explored by roots, in mm.

Recharge is estimated in the water balance model based in the available water content of the soil. The soil has a maximum carrying capacity, if the water in there exceeds this value, it percolates into the aquifer. It is difficult to estimate the actual recharge by irrigation. On the other hand, the calculation of the minimum value of infiltration due to irrigation with TWW confirms that there is percolation up to the water table. For this calculation, we assumed that the entire precipitated fraction infiltrated and we adopted the following method:

$$I = IP + ITWW \quad (3)$$

Where: IP = infiltration due to precipitation; $ITWW$ = infiltration due to irrigation treated wastewater

$$\text{If } I > p \quad ITWW (\text{min}) = I - P \quad (4)$$

$$\text{If } I < P \quad ITWW = 0 \quad (5)$$

$$Excess = R + I \quad (6)$$

Where: R = runoff; I = infiltration.

The surface runoff in the plain of Hennaya is unimportant because the relief is practically flat. Slopes generally range from 0 to 2%. Consequently, the runoff term R , which depends very strongly on local topographic conditions, can be neglected.

Finally,

$$Excess = I \quad (7)$$

TREATED WASTEWATER AND GROUNDWATER QUALITY

In this work, the results analyses of TWW and groundwater were obtained from the monitoring institutions of irrigation with treated wastewater (Tab. 2). There are samples taken to which we have participated.

CHARACTERIZATION OF THE UNSATURATED ZONE

For the characterization of the unsaturated zone we used the data of 46 mechanical soundings (Fig. 3) carried by the bureau of studies [Technoexporstroy 1971]. The lands covering the aquifer zones constitute a reactor which contribute to purify the water that infiltrates. It is important to know the functions and limits of this natural filter. For this, the purifying power soil, especially in the unsaturated zone, is important to determine and to prevent the spread of pollution directly into the groundwater [CHAOUÏ *et al.* 2013]. In this context, REHSE [1977] presented an empirical method for the evaluation of purifying power Md of pollutant transfer into the groundwater cover (soil and unsaturated zone). The method estimates the degradation and elimination of organic waste substances, pathogenic bacteria, and viruses in porous sediments.

The purifying power (Md) is calculated by the following formula:

$$Md = h_1 i_1 + h_2 i_2 + h_3 i_3 + \dots \quad (8)$$

Table 2. Data type and sources

Type of analysis	Conducting research	Laboratory	Number of analyses	Date
Treated wastewater				
Physico-chemical	wastewater treatment plant management, DRE, DSA	internal WWTP laboratory	136 ¹⁾	01.01.2016–30.05.2017
Heavy metals and toxic elements	wastewater treatment plant management	– private laboratory El-Feth, in the city of Oran – National Sanitation Office (Fr. Office Nationale d’assainissement)	1 3	2014, 2015, 2016, 2017
Microbiology	wastewater treatment plant management	– private laboratory El-Feth, in the city of Oran – Pasteur Institute of Algiers (Fr. Institut Pasteur d’Algérie)	2 1	2011, 2017
Wells and springs (see: Fig. 1)				
Microbiology	authors	– Regional veterinary laboratory in the city of Tlemcen (Fr. Laboratoire Regional Vétérinaire de Tlemcen) – Pasteur Institute of Algiers (Fr. Institut Pasteur d’Algérie)	14	2011

¹⁾ Quality control was done at a frequency of four times per month.

Explanations: DRE = Water Resources Department of Tlemcen (Fr. Direction des Ressources en Eau de Tlemcen). DSA = Agricultural Services Department of Tlemcen (Fr. Direction des Services Agricoles de Tlemcen).

Source: own elaboration.

Table 3. Index of purification of different materials

Material	Purification index
Humus, humus 5–10%, clay humus 5–10%	0.8
Clay, clay loam, clayey sand, silty clay.	0.5
Clayey silt to silt, fine silt	0.4
Silt, silty sand, little silty clayey sand, silty sand	0.22–0.33
Fine to medium sand	0.17
Medium to coarse sand	0.10
Coarse sand	0.07
Silty gravel, rich in sand and clay	0.13
Little silty gravel, lots of sand	0.08
Fine to medium gravel rich in sand	0.04
Medium to coarse gravel, little sand	0.03
People	0.02

Source: ES SAOUINI *et al.* [2017], modified.

Where: $h_1, h_2, h_3 \dots$ = the thicknesses of different layers in the unsaturated zone; $i_1, i_2, i_3 \dots$ = purification index (Tab. 3) corresponding to each type of soil encountered.

Two cases can be stated: $Md \geq 1$ and $Md < 1$. In the first case, the purification is total. In the second, the self-purification is not complete. In this case, the contamination continues in the aquifer. In our approach, firstly, we have not taken into consideration the pedological cover as a precaution. Secondly, we attribute 0.5 (Tab. 3) for the parame-

terization of the index because the vadose zone is constituted mainly of clay, calcareous clay and clayey gravel.

RESULTS AND DISCUSSION

ESTIMATION AQUIFER RECHARGE BY TREATED WASTEWATER

The computations summarized in Table 4 present the essential water balance. It should be noted that the low rainfall for the study area is recorded in summer, it reaches its maximum in November. Note also that the hydrological year consists of a single period in which evapotranspiration is always greater than precipitation. In this case, the reconstitution of the water in soil, which is essential for plant growth, is irrigation-dependent. The zone in question receives on average less than 395.5 mm of rain per year, however the water requirements of the dominant crops in the region, citrus, is 900 to 1200 mm·year⁻¹ [FAO 1987]. So, the rainfall insufficiency is relatively filled by TWW irrigation with quantity exceeds 200% of annual average rainfall.

The monthly analysis of the irrigation shows that the water contributions of the months of January and February are very important compared to the deficit rainfall ($ETP - P$) which are respectively of 7.1 mm and 16.7 mm for these

Table 4. Hydrological water balance for the irrigated perimeter (mm)

Month	Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
<i>P</i>	57.7	46.3	41.3	40.2	35.7	5.8	1.7	2.8	18.7	35.7	61.0	48.5	395.5
<i>Ir</i>	116.4	103.4	49.0	0	6.7	69.6	86.6	97.0	113.4	84.2	67.2	44.8	838.3
$TI = P + Ir$	174.1	149.7	90.3	40.2	42.4	75.4	88.3	99.8	132.1	119.9	128.2	93.3	1233.7
<i>ETP</i>	64.8	63.0	74.9	87.8	106.0	119.8	129.7	123.3	104.2	90.7	68.7	61.6	1094.5
$TI - ETP$	109.3	86.7	15.4	-47.6	-63.6	-44.4	-41.4	-23.5	27.9	29.2	59.5	31.7	139.3
<i>AWB</i>	80.0	80.0	80.0	80.0	32.4	0	0	0	0	27.9	57.1	80.0	517.4
<i>AWE</i>	80.0	80.0	80.0	32.4	0	0	0	0	27.9	57.1	80.0	80.0	517.4
<i>ETr</i>	64.8	63.0	74.9	87.8	74.8	75.4	88.3	99.8	104.2	90.7	68.7	61.6	954.0
<i>Excess</i>	109.3	86.7	15.4	0	0	0	0	0	0	0	36.6	31.7	279.7
<i>I</i>	109.3	86.7	15.4	0	0	0	0	0	0	0	36.6	31.7	279.7
<i>ITWW</i>	51.6	40.4	0	0	0	0	0	0	0	0	0	0	92.0

Explanations: *P* = monthly precipitation; *Ir* = monthly irrigation inputs; *TI* = total inputs; *AWB* = water content of the soil beginning of the month; *AWE* = water content of the soil end of the month; *ETr* = actual evapotranspiration; *I* = total infiltration; *ITWW* = infiltration minimum due to irrigation treated wastewater.

Source: own study.

months. This situation has led to significant surplus water, which can be explained as follows: the management of irrigation in the area is done in a traditional and unscientific way. Practices over-irrigation has been identified especially during the period of ripening of the fruit which starts at the end of December until the end of February. As a result, this irrigation practice has induced an excedent of water, thereby promoting infiltration into the lower layers of the subsoil.

The minimum value of recharge due to the use of TWW is 92 mm, which is equivalent to 11% of the irrigation inputs. This result confirms that a significant part of this water infiltrates and percolates towards the aquifer, hence the need to monitor the quality of TWW to objectively evaluate its impact on groundwater.

QUALITY OF TREATED WASTEWATER

Physico-chemical parameters

The quality of wastewater treatments is controlled by monitoring a variety of carefully selected physicochemical indicators that reflect the type and level of contamination present in the water [HOWARD *et al.* 2004]. We present in Table 5 a mean value of the analyses results for all parameters monitoring the quality of TWW. We notice that both COD and BOD are significantly below the thresholds for water reuse in irrigation. It confirms the effectiveness of the treatment for removing of organic materials. Nitrogen can act as a fertilizer to plants, but when highly concentrated, it can be at the origin of a contamination of the aquifer with nitrate. This is not our case, TWW show low and permissible amounts of NH_4^+ , N-NO_2^- and N-NO_3^- . The average pH value was 7.4, which indicates that the effluent is slightly alkaline. The average of electrical conductivity (EC) is $928 \mu\text{S}\cdot\text{cm}^{-1}$ indicating a low level of salinity according to the FAO classification [FAO 2013]. It is known that TWW with high salt content can pollute the aquifer and create salinity and alkalinity problems in soils and hence must be avoided as an irrigation water resource [GUNDUZ, TURKMAN 2006]. The N-NO_2^- , N-NO_3^- , PO_4^{3-} ,

Table 5. Average values and descriptive statistics of physico-chemical parameters of the treated wastewater

Parameter	Average value	Max	Min	SD	Standards ¹⁾
SM ($\text{mg}\cdot\text{dm}^{-3}$)	14.20	42.0	7.0	5.68	30
BOD ₅ ($\text{mg O}_2\cdot\text{dm}^{-3}$)	13.14	59.7	5.4	7.60	30
COD ($\text{mg O}_2\cdot\text{dm}^{-3}$)	29.20	57.0	13.0	9.56	90
NH_4^+ ($\text{mg}\cdot\text{dm}^{-3}$)	2.64	6.77	0.32	1.63	–
N-NO_2^- ($\text{mg}\cdot\text{dm}^{-3}$)	0.19	0.83	0.02	0.17	–
N-NO_3^- ($\text{mg}\cdot\text{dm}^{-3}$)	1.82	8.4	0.3	1.49	30
PO_4^{3-} ($\text{mg}\cdot\text{dm}^{-3}$)	4.19	11	0.032	2.20	–
O_2 ($\text{mg}\cdot\text{dm}^{-3}$)	4.34	5.02	4.03	0.16	–
pH	7.47	8.16	7.31	0.13	6.5–8.5
T ($^{\circ}\text{C}$)	17.30	24.5	8.0	3.80	–
EC ($\mu\text{S}\cdot\text{cm}^{-1}$)	927.74	1081.0	585.0	84.67	3000

¹⁾ Standards acc. to Arrêté interministériel [2012].

Explanations: SD = standard deviations, SM = suspended matter, BOD₅ = five-day biochemical oxygen demand, COD = chemical oxygen demand, T = temperature, EC = electrical conductivity.

Source: own study.

pH, T, EC values respect standards of human consumption [Décret exécutif 2011]. The low standard deviations show a low variation in the physico-chemical parameters removal.

It should be noted from Table 5, that the results of the measurements carried out on TWW comply with the standards previously set out in the decree mentioned above. This confirms the good treatment process performance.

Heavy metals and toxic elements

High levels of heavy metals in raw sewage is one of the major concerns of WWTP management, it affects microbial activity in the system and impede biological wastewater process [AZIZI *et al.* 2016]. In order to protect the purification process, Algerian standards were established in June 2009 setting limit values for the content of harmful substances other than domestic at the time of their discharge into a WWTP. It can be seen in Table 6 that the results of the samples analysed are on the whole very satisfactory. This can have two explanations, the first one is that Tlemcen is a city with agricultural vocation where there is very little industry, so the discharges are domestic, and it is known that the industrial waste is the major source of heavy metals contamination [LIXANDRU 2017]. The second one is the way of treatment, since activated sludge (ASP) process provides good removal of metals such as Cd, Cr, Cu, Zn, Ni, and Pb. Metal removal by ASP is due to sorption of the flocs [ÜSTÜN 2009].

Heavy metals concentrations and toxic elements (Tab. 6) were found to be very low, therefore using TWW presents no risk of groundwater contamination.

Table 6. Concentrations of heavy metals and toxic elements detected (in $\text{mg}\cdot\text{dm}^{-3}$) in treated wastewater

Element	Test results				Standards ¹⁾
	12.08. 2014	26.07. 2015	13.07. 2016	15.03. 2017	
Aluminium	–	0.1010	0.0960	0.0724	20.0
Arsenic	–	0.0063	0.0001	0.0043	2.0
Beryllium	–	0.0009	0.0300	0.0710	0.5
Boron	–	0.1010	0.0584	0.0920	2.0
Cadmium	0.002	0.0100	<0.001	0.0029	0.05
Chromium	<0.50	<0.010	–	0.0700	1.0
Cobalt	<0.10	0.0030	<0.010	0.0490	5.0
Copper	<0.05	<0.010	0.01	0.0320	5.0
Cyanide metal	–	0.0791	0.0805	0.0400	0.5
Fluorine	–	–	0.0213	0.0634	15.0
Iron	0.150	0.0300	0.1690	0.0630	20.0
Lead	–	0.0050	0.0100	0.0058	10.0
Lithium	–	0.0691	0.0051	0.0100	2.5
Manganese	–	–	0.0182	0.0500	10.0
Mercury	–	0.0025	<0.004	0.0037	0.01
Molybdenum	–	0.0030	0	0	0.05
Nickel	0.420	0.0070	<0.01	0.0840	2.0
Selenium	–	0.0071	0	0.0018	0.02
Vanadium	–	0.0044	0.0620	0.0490	1.0
Zinc	<0.20	<0.040	0.1300	0.0954	10.0

¹⁾ Standards acc. to Arrêté interministériel [2012].

Explanations: “–” = element not analysed.

Source: own study.

Microbiological parameters

The results of the microbiological analyses (Tab. 7) confirm that, in reality, the conventional processes of wastewater treatment (primary and secondary treatments) allows a satisfactory removal of the organic load, but appears to be less efficient in removing pathogenic microorganisms [HASSEN *et al.* 2000]. We also notice the instability of the microbiological parameters at the exit of the WWTP. When such a situation happened, the manager is facing problems, he would authorize a farmer to irrigate then prohibit it if the results of subsequent analyses are found exceeding standards. This is a real aberrance; irrigation was never prohibited in this case. The perimeter manager directed the irrigation towards the arboriculture only.

Table 7. Microbiology data in water samples collected from the WWTP effluent

Parameter	Test results			Standards ¹⁾
	28.08.2011	15.03.2017	12.04.2017	
Faecal coliforms (CFU·(100 cm ³) ⁻¹), geometric average	7 200	240	75	<1 000
Intestinal Nematodes (eggs·dm ⁻³), arithmetic average	–	30	abs	<1

¹⁾ Standards acc. to Arrêté interministériel [2012].

Explanations: “–” element not analysed, abs = absence.

Source: own study.

The high concentration of pathogens in the effluent from the secondary treatment can contaminate the Henaya water table, hence the need to characterize the microbiological quality of the latter as an aid to the assessment of pollution hazard.

MICROBIOLOGICAL QUALITY OF GROUNDWATER

The use of TWW in irrigation is associated with some health risks due to the possibility of the presence of a wide spectrum of pathogens [LONIGRO *et al.* 2016]. Contaminated water in some cases may also have a negative impact on the quality of groundwater. For example in North-East of Cairo (Egypt), irrigation with TWW is favoured for some field crops, but groundwater samples were positively examined for the presence of pathogenic bacteria (salmonella) and faecal coliform bacteria. As a result, the groundwater is of poor quality, and would be unsuitable for the human consumption or irrigation purposes [ABD EL LATEEF *et al.* 2006]. On the contrary, with regard to our study, analyze of the water samples collected from springs and wells indicated no faecal coliforms, *Escherichia coli* or *Enterococci* (Tab. 8). It is to be mentioned that despite the fact that almost all farmers in the region drink water directly from their own irrigation wells, no water-transmitted diseases were declared in the region at rural health centers, since 2011 until now. This allows us to conclude that these groundwaters are of good microbiological quality conform of drinking water standards [Décret exécutif 2011].

It is observed that despite high concentrations in TWW (Tab. 7), they have no negative impact on aquifer. In our approach, it can be directly concluded that contaminant

Table 8. Microbiology data in water samples collected from springs and wells

Date	Springs and water wells	<i>E. coli</i>	Intestinal enterococci	Faecal coliforms
		CFU·(100 cm ³) ⁻¹		
27.04.2011	P102	abs	abs	–
	P7	abs	abs	–
03.07.2011	P02	abs	abs	–
	P7	abs	abs	–
	P32	abs	abs	–
	P64	abs	abs	–
26.06.2011	P33	abs	abs	–
	P13	abs	abs	–
	P14	abs	abs	–
14.08.2011	Ain Boukora	abs	abs	–
	P17	abs	abs	–
	P26	abs	abs	–
28.08.2011	P10	–	–	abs
	P09	–	–	abs

Explanations: abs = absence, “–” element not analysed.

Source: own study.

degradation is attributed to the purifying ability of the protective layer above the aquifer. Otherwise, if there is detection of pollution in the groundwater, we cannot directly blame the purificatory efficiency of the unsaturated zone, other factors can be at the origin of this contamination, more investigations and field surveys are needed to draw conclusions.

EVALUATION OF THE PURIFYING POWER OF THE VADOSE ZONE OF THE AQUIFER

Hydrologically, the unsaturated zone is often the main factor controlling water movement from the land surface to the aquifer. Thus it strongly affects the rate of aquifer recharge, critical for the use and management of groundwater. It is often regarded as a filter that removes undesirable substances. The isolating and absorbing characteristics of the unsaturated zone are often used to prevent or mitigate contamination [USGS 2017]. In this context, soil aquifer treatment (SAT) is a managed aquifer recharge system that has been practiced in different parts of the world using primary, secondary and tertiary effluents from wastewater treatment [SHARMA, KENNEDY 2016]. For decades, SAT systems have been investigated both in the laboratory and field experiments to show that their efficiency of removal of pathogens is very high [ELKAYAM *et al.* 2015].

In our case study, unintentional aquifer recharge with irrigation indicated that purifying power of the vadose zone has a very good potential for removal of bacteria and Nematodes in the irrigated area by TWW. The perimeter manager will provide the extension of irrigated areas by TWW, that is why it is important for management to delimitate the vulnerable areas whose purifying power is less than 1. Efficiencies of the unsaturated zones treatment for natural degradation of pollutants, dependent mainly on its thickness and the different geological formations that compose it. The purifying power (*Md*) map (Fig. 3), was established on the basis of a detailed data from mechanical

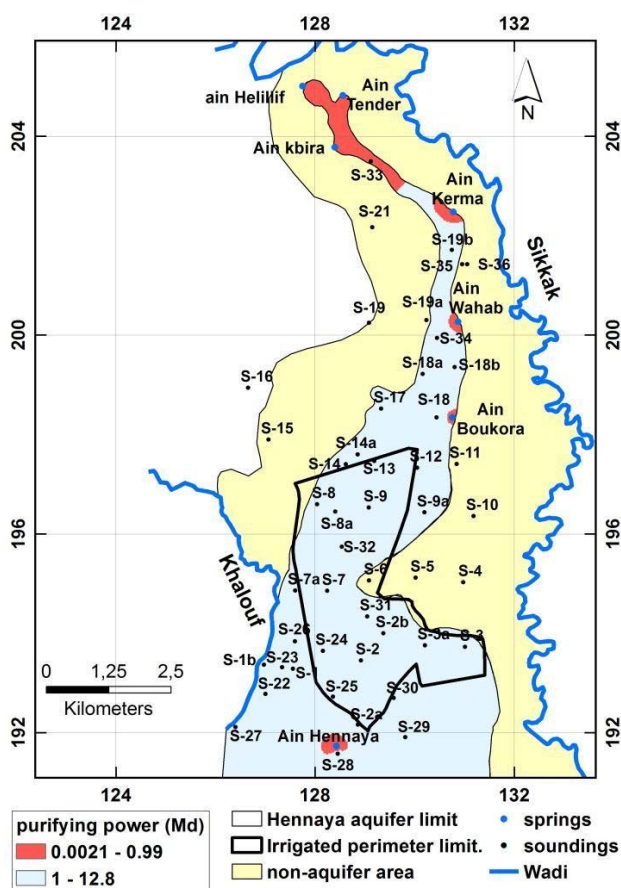


Fig. 3. The purifying power Md ; source: own study

soundings carried by the bureau of studies [Technoexport 1971].

In the Hennaya Irrigated Perimeter (HIP), the Md value varies from 2.1 to 12.7. In this case, the purification is total, which proves that the vadose zone plays the crucial role of protector against all microbial pollution. It is also noted that the vulnerable zones whose Md is less than 1 are situated at resurgences of the aquifer and occupies 2% of its total surface.

CONCLUSIONS

The estimation of a minimum value of the recharge shows that a certain amount of treated wastewater has infiltrated to the groundwater and underground water. The purification of wastewater by the activated sludge process at the Ain El Hout plant proved to be efficient, as was confirmed by the results of the analyses of the physicochemical parameters. Characterization of TWW has shown that there are high concentrations of pathogenic microorganisms. At the contrary, the results of microbiological analyse in wells and sources are of good quality and comply with drinking water standards. This proves that there is no contamination of groundwater by TWW irrigation. This is due to the natural filter of the unsaturated zone of the Hennaya perimeter, since pathogenic microorganisms have been completely removed during travel from the surface to the water table.

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Nawadnianie oczyszczonymi ściekami a ochrona wód gruntowych na obszarze Hennaya – Tlemcen, Algieria

STRESZCZENIE

Obszar nawodnień Hennaya to grunty rolnicze nawadniane oczyszczonymi ściekami z oczyszczalni Ain El Hout. W wyniku analizy stwierdzono, że w oczyszczonych ściekach stężenia metali ciężkich i substancji toksycznych jest małe, a średnie wartości parametrów fizycznych i chemicznych mierzonych w 136 próbkach są zadowalające (ChZT – 29,2 mg O₂·dm⁻³, BZT – 13,14 mg O₂·dm⁻³, zawiesina – 14,2 mg·dm⁻³, N-NO₃ – 1,82 mg·dm⁻³, pH – 7.7 i przewodnictwo – 927,74 μS·cm⁻¹). Ścieki zawierają dużą liczbę bakterii coli pochodzenia kałowego (7200 jtk·(100 dm³)⁻¹) i jaj nicieni przewodu pokarmowego (30 jaj·dm⁻³), co stanowi zagrożenie dla jakości wód gruntowych.

Celem badań była analiza oczyszczonych ścieków i ocena ich wpływu na wody gruntowe nawadnianych nimi obszarów. Wstępnie należało dowiedzieć, że ścieki zasilają wody gruntowe i istnieje ryzyko zanieczyszczenia. Za pomocą metody Thormthwaite'a oszacowano minimalne zasilanie wód podziemnych – 92 mm, czyli jest to znacząca ilość ścieków. Nie stwierdzono mikrobiologicznych zanieczyszczeń wód gruntowych. Przyczyną tego jest zdolność strefy aeracji do redukcji zanieczyszczeń. Redukcję zanieczyszczeń przez gleby nawadnianej strefy oceniano metodą Rehse, a uzyskane wartości wynoszące od 2,1 do 12,7 wskazują na całkowite oczyszczenie.

Słowa kluczowe: nawadnianie, oczyszczone ścieki, wody gruntowe, zanieczyszczenia