*Desalination and Water Treatment*
www.deswater.com

doi: 10.5004/dwt.2020.26220

203 (2020) 254–266
November

# The assessment and optimization of agricultural reuse of wastewater treatment by-products

Hanane Bouanani[a,*], Ahmed Kettab[a,b], Nabila Bensacia[c], Rim Riahi[d], Laila Mandi[e], M. Nacer Chabaca[f], Salim Benziada[a], Maamer Nakib[a], Youcef Djillali[a], Amina Lisaneddine[e]

[a]*Laboratoire de Recherche des Sciences de l'Eau, Département Hydraulique, Ecole Nationale Polytechnique d'Alger (ENP), Bejaia, Algeria, Tel. +00213-790-458-252; emails: hanane.bouanani.911@gmail.com (H. Bouanani), kettab@yahoo.fr (A. Kettab), benziada@yahoo.fr (S. Benziada), mnakib@hotmail.fr (M. Nakib), djillali.you@gmail.com (Y. Djillali)*
[b]*Université Akli Mohand Oulhadj Bouira-Algérie, Bouira, Algeria*
[c]*Laboratoire de Chimie Physique Moléculaire et Macromoléculaire, Département de Chimie Industrielle, Faculté des Sciences de l'ingénieur, Université Saâd-Dahlab de Blida, BP 270, Route De Soumâa, 09000 Blida, Algeria, email: polyadsorption@yahoo.fr (N. Bensacia)*
[d]*Laboratoire Chimie et Catalyse, Faculté des Sciences de Tunis, Tunisie et Institut Supérieur des Etudes Technologiques de Zaghouan, Tunisia, email: rym_ryahi@yahoo.fr (R. Riahi)*
[e]*National Centre for Studies and Research on Water and Energy (CNEREE), University Cadi Ayyad, Avenue Moulay Abdellah, BP 511, 40000 Marrakech, Morocco, emails: mandi@uca.ma (L. Mandi), a.lissaneddine@gmail.com (A. Lisaneddine)*
[f]*Département du Génie Rural, Ecole Nationale Supérieure Agronomique (ENSA), Rue Hassen Badi Belfort, El Harrach, 1600 Alger, Algérie, email: chabacam@yahoo.fr (M.N. Chabaca)*

Received 18 October 2019; Accepted 5 June 2020

**ABSTRACT**

One of the main areas of scientific focus in dry countries is the optimization of wastewater treatment and the qualitative assessment of the resulting by-products in order to take advantage of their hydric and agronomic features without endangering the receptive environment and by extension the consuming species. The main aim of this research is the characterization of wastewater before and after treatment in three different plants located in Northern Algeria in order to assess the treatment performance and the possibility of agricultural reuse through a meticulous diagnosis of the fertilizing potential and the contamination risk. The origin of wastewater is mainly domestic.

The by-products that have been taken into account in this study are treated water and the mechanically dehydrated sludge resulting from the activated biological treatment. The diagnosis has been established on a database of laboratory records going from 2015 to 2018 by taking international guidelines as a reference for evaluation. The analyzed by-products turned out to represent a great resource of major fertilizing elements that can mostly satisfy the nutritive needs of many arboreal species. However, before irrigation or manuring, the amounts of nutritive as well as trace elements have to be regularly monitored in the soil and the presence of pathogen microorganisms, mainly *Escherichia coli*, has to be imperatively eradicated. Besides, the texture of sludge (Mohlman indicator) can be adjusted through the oxygen amounts in the aeration tank through a linear function. The energy consumption also depends strongly on the adjustment of this parameter to the accurate needs of the effluents. Consequently, a combination of these two optima is recommended to optimize the treatment cost-efficiency and the resulting sludge.

*Keywords:* Wastewater; Sludge; Treatment; Performance; Diagnosis; Valorization; Bejaia; Boumerdes

* Corresponding author.

1944-3994/1944-3986 

## 1. Introduction

Water management is currently becoming a serious challenge worldwide since the authorities of water-stressed countries are struggling to provide the minimal required amounts for the upcoming generations. The withdrawal to supply ratios are continuously increasing in those regions where the most optimistic management scenarios are predicting serious hydric challenges.

In Algeria, despite the tremendous improvements since the beginning of the 2000s to improve the accessibility and the quality of water, the current potentialities still need to be reassessed in order to ensure sustainable provision. Otherwise, critical hydric episodes are highly predictable [1–3].

Unconventional water resources become an unavoidable alternative, which must be explored and since treated wastewater represents the most common and significant category among unconventional water resources, it would be a waste to release those waters directly in nature without assessing their hydric and agronomic profitability [2,3].

Consequently, this research focuses on the accurate characterization of wastewater and its treatment by-products (water and sludge) as well as the exploration of other treatment process data in order to determine the optimal factors that lead to the lowest sanitary risks for consumers, the most cost-efficient treatment process, and the most advantageous use for irrigation.

## 2. Materials and methods

### 2.1. Work site

In order to lead our study, we have selected three different wastewater treatment plants in northern Algeria. The two first plants are located in the region of Bejaia (36°45′N 5°04′E) and the third plant is located in the region of Boumerdes (36°45′37.23″N 3°28′20.52″E). The three plants have been originally conceived to receive daily flows that equal 15,000; 3,000; and 5,710 $cm^3/d$, respectively, which also represent 75,000; 25,000; and 47,580 capita correspondingly.

They are all powered by Activated sludge process and extended aeration, which is known to remove mainly carbonaceous and partially nitrogenous pollution [4]. The first region has a unitary sewer system whereas the second region mainly has separate sewer systems; consequently, the pluvial flow is also collected and treated along with wastewater in the first plant.

In this article, the nominations of the plants will be respectively abridged to SAL (Sidi Ali Lebhar-Bejaia), SET (Souk El Tenine-Bejaia), and BM (Boumerdes).

### 2.2. Sampling and study approach

Wastewater and treated water are daily collected at the wastewater treatment plants, the samples are automatically collected using auto-samplers. Dehydrated sludge is weekly collected. The local laboratories are ruled by the standards "ONA" which is the national board for water sanitation. The covered spectrum of parameters as well as the analysis standards and frequencies are detailed in Table 1.

Some complementary parameters have been measured at the laboratory of the university Cadi Ayyad in Marrakech using three samples per matrix (wastewater, treated water, and dehydrated sludge). The samples have been collected in less than 24 h before their air transportation and preserved in isotherm iceboxes. All the procedures have been launched during the week afterwards and are described in Table 1.

#### 2.2.1. Microbiological analysis

For microbiological quantification, the preparation of nutritional Petri dishes has been arranged in advance using bile esculin agar for *Streptococcus*, eosin methylene blue for *Escherichia coli*, and Chapman for *Staphylococcus* [5]. The agar powders have been dissolved in distilled water bottles according to the corresponding industrial instructions. The obtained solutions have been heated and agitated until the color is homogeneous and then placed in a Bain–Marie and sterilized in an autoclave for 15 min at 121°C. The agar has been poured carefully in empty Petri dishes, which have been refrigerated until use.

The wastewater samples have been dissolved in saline water (9 g NaCl per liter) using a dilution coefficient of 1,000 whereas treated water samples have been directly used. A drop of 0.1 mL from each sample has been applied homogenously on each Petri dish. The cultures have then been incubated at 37°C. The microorganisms have been identified and counted under a microscope according to the corresponding color and shape (*streptococci* are darker, *staphylococci* are generally yellow, and *E. coli* resembles a purple tear drop). Sample filtration was rarely used for samples where the CFU number was inferior to 30 and not null.

#### 2.2.2. Calcium, sodium and potassium

The concentrations calcium, sodium, and potassium ions in treated water have been measured using a Flame spectrophotometer AFP 100 [5]. First the stock solutions (1 g/L for each element) have been prepared using the equivalent concentrations of $CaCO_3$ (8.33 g/L), NaCl (2.54 g/L), and KCl (1.91 g/L). In order to proceed with calibration, a spectrum of lower concentrations has been prepared which are: 5, 10, 15, 25, and 50 mg/L.

For each element, the previous concentrations have been digitally entered in the spectrophotometer and each corresponding solution has been detected by the nebulizer. Based on the calibration data, the spectrometer automatically generates the element concentration value for each sample through the nebulizer as well.

In order to measure the concentrations of anionic agents, a stock solution of dodecyl-benzene sulfonic acid methyl ester has been prepared in order to prepare a calibration range of the following concentrations: 0, 0.0025, 0.005, 0.01, 0.015, and 0.02 mg/L. Each concentration has been put in spectrophotometer at 650 nm in order to read the optical density and draw a calibration graph.

#### 2.2.3. Anionic agents

In order to prepare the sample, alkaline, and acid methylene blue solutions need to be prepared. The alkaline the

Table 1
Material and analytical method

| Parameter | | Standard | Short method description | Frequency |
|---|---|---|---|---|
| Wastewater and treated water | | | | |
| Temperature | | NF EN 25667 (ISO 5667) | The saved value is the average of the three values read on: an oximeter, a conductometer, and a pH meter | Daily |
| Dissolved oxygen | | AFNOR NE EN 25814 | The value is read on a multi parameter reader ino-LAB* pH/ION/Cond750 | Daily |
| pH | | AFNOR NF T 90-008 | | Daily |
| Conductivity | | AFNOR EN 27888 | | Daily |
| Suspended solids | | NF EN 872 | After filtration on a glass fiber disc, the residuals are put in an oven at 105°C and weighed | Daily |
| BOD | | NF-T-90-103 | Respirometry method: OxiTop flasks, WTW—enclosure 20°C | Daily |
| COD | | NFT 90-101 | COD reactor and a spectrophotometer nanocolor 500D WTW | Daily |
| Ammonium | | AFNOR T 90-015-2 | Colorimetric method using a spectrophotometer nano-color 500D WTW | Weekly |
| Nitrates | | NF EN ISO 13395 | | Weekly |
| Nitrites | | NF EN 26777 | | Weekly |
| Total nitrogen | | NF T 90-110 | | Weekly |
| Total phosphorous | | NF EN ISO 6878 | | Weekly |
| Microbiological analysis | *Streptococci* | ISO 7899 | Incubation at 37°C in petri dishes filled with a layer of the adequate agar | Yearly |
| | *Staphylococci* | NF T90-412 | | Yearly |
| | *Escherichia coli* | ISO 9308 | | Yearly |
| $Na^+$, $Ca^{++}$, and $K^+$ | | NF T90-019 | Flame spectrophotometer AFP 100 | Yearly |
| Anionic agents | | NF EN 903 | Methylene Blue index method | Yearly |
| Dehydrated sludge | | | | |
| Mohlman indicator | | NEN 6624 | 30 min settling in a transparent test tube | Weekly |
| Dryness | | NF T97-001 | 24 h drying at 105°C | Weekly |
| Organic fraction (VSS) | | Method 2540 E | 2 h calcination at 550°C | Weekly |
| N, P, K, and ETM | | ISO/FDIS 15586 and ISO 18227 | Atomic absorption spectrometry (AAS):: sample calcination, mineralization (using aqua regia), and spectrophotometry X ray-fluorescence (for result endorsement) | Yearly |

alkaline solution is prepared by pouring in a separation funnel: 100 mL of neutral methylene blue solution (0.35 g/L), 200 mL of a prepared basic solution (equal volumes of borax solution (19 g/L) and sodium hydroxide solution (4 g/L)) and 200 mL of chloroform. The bottom chloroformate phase is drained and the upper phase is rinsed with additional 60 mL of chloroform. The acid solution is very simply obtained by adding 6.5 mL of sulfuric acid to a liter of neutral solution.

Finally, 100 mL of the sample, 15 mL of the alkaline solution, and 15 mL of chloroform are put in a spacing funnel. After 2 min, the bottom phase is kept aside and put back in a clean funnel with 100 mL of distilled water and 5 mL of the acid solution. The chloroformate phase is once again kept aside and filtered through cotton into a 50 mL flask and completed with additional chloroform.

The obtained sample is then simply put in the spectrometer in order to read its optical density and deduce the corresponding concentration in the calibration graph.

### *2.2.4. Trace elements in the sludge*

X-ray fluorescence (XRF) helped to endorse and widen the analysis of some nutritive elements (phosphorous and potassium) as well as the metallic trace elements in the sludge, which had already been measured locally in the plants. The dry sludge samples have been put in cellophane wrap in order to have small square shapes of 3 cm × 3 cm. The squares have been put under the beam of a DELTA innova-X OLYMPUS XRF analyzer switching the state of the atoms to an excited state. Thus, the atoms release energy photons with specific wavelength. The analysis of these rays allows identifying the atom and its mass fraction in the sample in ppm. The range of the identified atoms that have been detected on the liquid-crystal display screen are:Le, Cl, Ca, Fe, Si, Al, K, P, Zn, Ti, S, Sr, Mn, Cu, Cd, Pb, Rb, Zr, As, Y, and Ag. For toxic elements in the same sample, the highest values of the two techniques have been taken into account to minimize the ulterior risk.

*2.3. Statistical synthesis*

The daily, weekly, and yearly collected records have all been abridged into statistical values (which are presented in the following form: average ± standard variation), some interpretive ratios (Table 3), and illustrative charts in order to accomplish:

- The assessment of the treatment performance according to the removal percentages and the electric consumption,
- The evaluation of the initial qualitative conditions and whether their impact is significant on the resulting by-products,
- The assessment of the fertilizing potential and the potential sanitary risk of the by-products,
- The determination of the optimal factors leading to the most sanitary and cost-effective outcome.

## 3. Results and discussion

*3.1. Characteristics of the studied effluents*

*3.1.1. Hydric parameters*

The daily flow records as well as the daily BOD records during the study periods have allowed us to make an estimation of the actual fraction of the flow that originates from human activities and not from rainfall or surface runoff.

First, the global daily BOD of the effluent can be calculated by a simple multiplication of the average BOD concentration in wastewater by the daily wastewater flow (Eq. (1)):

$$\text{Average daily BOD}\left(\frac{\text{g}}{\text{d}}\right) = \text{Average concentration}\left(\frac{\text{g}}{\text{m}^3}\right) \times \text{Daily flow}\left(\frac{\text{m}^3}{\text{d}}\right) \quad (1)$$

If we presume that, the average human waste contains 50 g of BOD/d [6], the actual sanitized population represents the division of the global quantity daily BOD (from Eq. (1)) by the average individual BOD waste (Eq. (2)):

$$\text{Population} = \frac{\text{Average Daily BOD}(\text{g/d})}{50\text{g}/\text{person.d}} \quad (2)$$

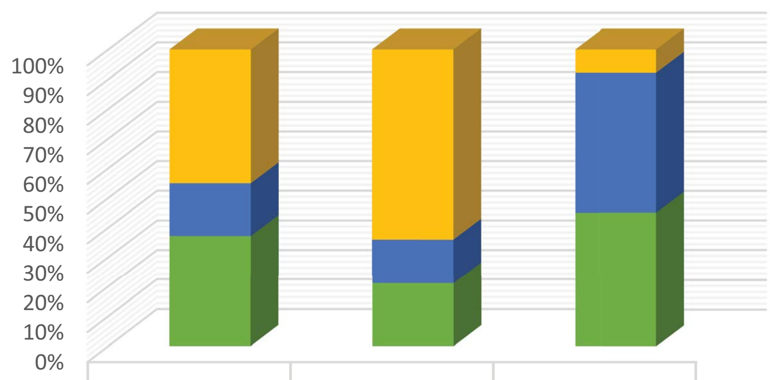
In order to deduce the actual flow originating exclusively from human activities (Eq. (3)), the result of the Eq. (2) is multiplied by the individual wastewater flow, which approximately equals to 1.20 $m^3$/capita d (80% of the individual fresh water provision per capita in northern Algeria):

$$\text{Flow originating from human waste}\left(\frac{\text{m}^3}{\text{d}}\right) = \text{Population} \times 0.12\frac{\text{m}^3}{\text{d}} \quad (3)$$

Fig. 1 illustrates the proportions of the human flow, the remaining fraction which is the pluvial flow and the unexplored fraction which is deduced from the design flow of each plant.

According to Fig. 1, the dilution coefficient of the human flow equals 1.47 in the wastewater treatment plant (WWTP) of SAL, 1.70 in the WWTP of SET, and 2.04 in the WWTP of BM. The dilution is higher in the third WWTP because of the combined type of the sewer system, which collects an important additional pluvial flow. In the other plants, it is lower but still indicates the presence of an important pluvial fraction despite the fact that the regions are known to possess separate sewer systems where rain water is collected separately and is conducted to the sea or the nearest channels.

The exploration rate percentage equals 54.90% in the first plant, 35.92% in the second plant, and 92.13% in the third




| | SAL | SET | BM |
|---|---|---|---|
| The unexplored fraction (m3/day) | 1353 | 3659 | 1181 |
| The pluvial fraction (m3/day) | 532 | 848 | 7068 |
| The human fraction(m3/day) | 1115 | 1203 | 6751 |

Fig. 1. Comparative hydric balance of the treatment plants ($m^3$).

plant. This is explained by the oldness of the third plant in comparison with the two others.

#### 3.1.2. Physico-chemical parameters

The daily records regarding physico-chemical parameters during the study periods have been abridged into average values with the standard variations during the 4 y of research (Table 2).

According to Table 2, the WWTP of SAL indicates higher amounts of conductivity and anionic agents in comparison with the other plants, this is partially due to the low dilution coefficient and the origin of wastewater that is mainly domestic; containing an important fraction of household detergents containing anionic agents. However, their concentration remains low in comparison with wastewater originating from grey sources (SPA, Hammam, etc.) where the value exceeds 16 mg/L [7,8].

#### 3.1.3. Indicative ratios

Some indicative ratios have been calculated based on some significant parameters such as chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS), nitrogenous, and phosphorous parameters.

Table 3 summarizes the average value of those ratios as well as the corresponding standard variation.

The first ratio (COD/BOD) represents the biodegradability of our effluent. In the three cases, the average value is inferior to 02, which indicates very high biodegradability. The standard variation induces some values that are slightly higher than 02 but still inferior to 03, which still indicates a good biodegradability [9]. These values are very common in urban and domestic wastewater where a significant fraction of the pollution originates from human waste.

The second ratio (BOD/N–$NH_4^+$/P–$PO_4^{3-}$) which represents the C/N/P ratio as well, indicates the nutritional balance for bacterial metabolism. In order to get an optimal nutritional environment for biological treatment, this ratio should ideally be the closest possible to: 100/5/1 [9]. In our case, there is a slight imbalance resulting from high concentrations of nitrogen and slight excess of phosphorous as well. The high portion of human metabolic waste originating from urine (nitrogen) and feces (phosphorous) endorses these results. The standard variations are quite significant especially in the case of nitrogen. Among the three plants, the third ratio is the closest to the ideal values because of the dilution factor. However, according to these results, during biological treatment, nitrogen, and phosphorous may not be efficiently eradicated in comparison with carbonaceous organic pollution.

The third ratio (TSS/BOD) represents the solubility of the pollutants. The suspended solids are either generated by the sediments that are transported by the pluvial flow or by the fixation of phosphorous on some topsoil deposits. In our case, the average values of that ratio are close to 01 [9], which indicate a balance between the presence of particulate and soluble pollutants (Gromaire et al.). The standard variation is due to the variation of the pluvial flow (especially in the third case) or the phosphorous amounts fluctuations that are likely to increase the SS concentration.

Table 2
Physicochemical parameters of the three effluents

| WWTP | Temperature (°C) | pH | Dissolved oxygen (mg/L) | Conductivity (µS/cm) | Anionic agents (mg/L) |
|---|---|---|---|---|---|
| SAL | 20.15 ± 3.75 | 7.62 ± 0.13 | 0.45 ± 0.33 | 2,088.10 ± 439.61 | 0.101 ± 0.001 |
| SET | 15.29 ± 4.22 | 7.80 ± 0.29 | 0.28 ± 0.39 | 1,622.61 ± 129.36 | 0.026 ± 0.001 |
| BM | 18.09 ± 4.92 | 7.40 ± 0.18 | 0.35 ± 0.25 | 1,360 ± 60.05 | 0.028 ± 0.001 |

Table 3
Indicative ratios of the quality of the effluent

| Ratio (dimensionless) | WWTP | | |
|---|---|---|---|
| | SAL | SET | BM |
| COD/BOD | 1.90 ± 0.23 | 1.75 ± 0.51 | 1.72 ± 0.30 |
| | 100 | 100 | 100 |
| BOD/N–$NH^{4+}$/P–$PO_4$ | 14.55 ± 4.77 | 22.39 ± 9.86 | 11.42 ± 4.03 |
| | 2.53 ± 0.76 | 2.76 ± 2.93 | 1.40 ± 0.53 |
| TSS/BOD | 1.13 ± 0.26 | 1.07 ± 0.46 | 0.88 ± 0.15 |
| COD/PT | 62.86 ± 17.09 | 60.39 ± 17.24 | 59.41± 12.42 |
| $NH^{4+}$/KTN | 0.82 ± 0.25 | 0.83 ± 0.25 | 0.52 ± 0.20 |
| BOD/nitrates | 18.89 ± 18.25 | 20.48 ± 19.78 | 12.14 ± 9.12 |
| BOD/KTN | 4.94 ± 1.08 | 3.17 ± 1.15 | 4.78 ± 2.25 |
| COD/KTN | 9.10 ± 1.06 | 5.50 ± 2.21 | 8.22 ± 4.03 |

The COD/PT ratio allows us to assess the possibility of eliminating phosphorous biologically. In our case, the values are mainly higher than 45, which means that the elimination of phosphorous during biological treatment is expected to be satisfactory [10].

The ammonia/KTN ratio values indicate great ammonification rates for the two first plants and an acceptable rate for the third plant. This is mainly due to the high exploration rate in the first plant especially during pluvial periods where residence time diminishes and is not sufficient to allow organic nitrogen to turn into ammonium [4].

The BOD/nitrates ratio values are higher than 02; which expectably indicate fast denitrification process that will be endorsed by the carbon pressure on the biomass. The COD/KTN ratio values are very close to the common urban interval [4,5] with relatively significant standard variations that are due to the nitrogen amounts fluctuations in the effluents [4]. The BOD/KTN ratios allows us to estimate the approximate speed of denitrification [5]. In the first WWTP, the average ratio is superior to 4 and inferior to 5; which corresponds to an average elimination going from 2.7 to 3 mg of $N–NO_3–$/g of VSS.h. In the second WWTP, the value is superior to 3.33 and inferior to 04; which corresponds to an average elimination going from 2.4 to 2.7 mg of $N–NO_3$/g of VSS.h. In the third plant, the results are similar to the first one [11].

The last three ratios: $BOD/NO_3–$, COD/KTN, and BOD/KTN, all indicate a great tendency for efficient biological denitrification if the right conditions are present such as optimal temperature, neutral pH, a balanced nutritional balance for bacteria, and more importantly, anoxic conditions that are imperative for this process [7].

### 3.2. Treatment performance assessment

#### 3.2.1. Water pollution removal rates

Fig. 2 illustrates the removal percentage of some physicochemical and microbiological parameters in order to assess the treatment performance whereas the tolerability of the remaining pollution will be illustrated and evaluated in Table 5 (3.3.1 – Toxicity assessment).

The elimination percentage of anionic agents in the WWTP of SAL turned out to be equal to 91%, which is the highest obtained value in comparison with the WWTP of SET and Boumerdes that had lower results, equaling 80% and 75%, respectively. Nevertheless, the dimension of their cumulative and differed impact in treated water has not been profoundly studied so far.

The removal efficiency of suspended solids, BOD, COD are all above 90% with very low standard variations that do not exceed 02%; which means that particulate and organic pollution are efficiently eliminated.

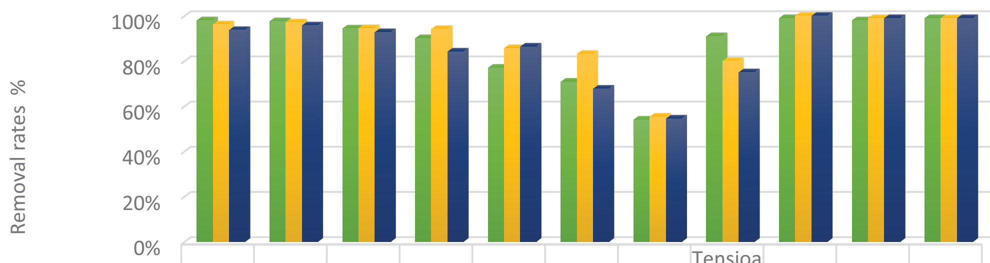
The elimination of ammonium is also excellent; which means that the process of nitrification has been completed successfully. The elimination of Kjeldahl nitrogen, total nitrogen, and phosphorous are mainly acceptable. The remaining concentrations are due to the incomplete process of denitrification resulting from the absence of anoxic conditions.

The eradication of many types of microorganisms turned out to be very high but the incompleteness of their eradication still represents a significant risk of contamination.

#### 3.2.2. Energetic efficiency

According to Fig. 3, the average required amount of electrical energy to produce a cubic meter of treated water equals 0.54 kWh in the first plant, 0.49 in the second plant, and 0.74 in the third plant. This may be explained by the bigger capacity of the third plant; which requires more power-consuming equipment and control devices.

However, the average required energy consumption to eliminate a kilogram of COD is higher in the second plant; which indicates that the aeration tank consumes a very important fraction of the total energy intake. The ideal interval for that ratio goes from 0.9 to 1.2 kWh/kg of COD




| | TSS | BOD | COD | N-NH4 | KTN | TN | TP | Tensioactive agents | Streptococci | E.C | Staphylococci |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SAL | 98% | 98% | 94% | 90% | 77% | 71% | 54% | 91% | 99% | 98% | 99% |
| | | | | | | | | | | | |
| SET | 96% | 97% | 95% | 94% | 86% | 83% | 55% | 80% | 100% | 99% | 99% |
| | | | | | | | | | | | |
| Boumerdes | 94% | 96% | 93% | 84% | 86% | 68% | 55% | 75% | 100% | 99% | 99% |
| | | | | | | | | | | | |

Fig. 2. Removal rates of physicochemical and microbiological pollutants.

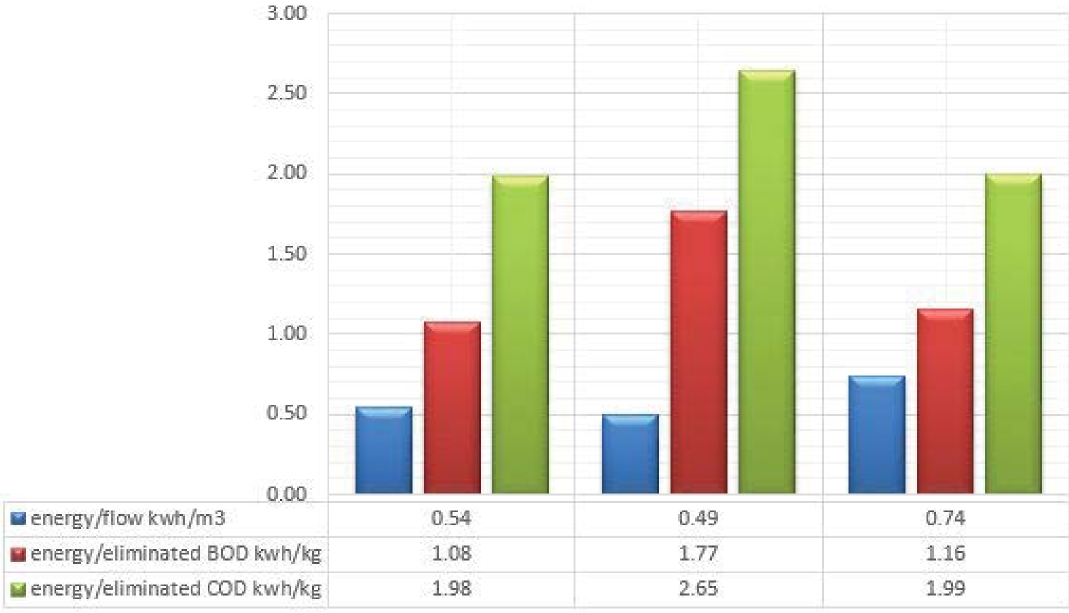



Fig. 3. Energetic ratios.

(whereas the average value of this ratio equals 1.77 kWh/kg of COD in the second WWTP [12]). The third ratio; which represents the average required energy consumption to eliminate a kilogram of BOD, endorses the last results since it should ideally not exceed 2.5 kWh/kg of BOD in the case of small wastewater treatment plants [12,13]; whereas, it has reached 2.65 kWh/kg of BOD in the second plant.

The reason for excessive energetic consumption in the aeration tank is either caused by excessive ventilation that exceeds the real oxygenation needs of the effluent or by the air distribution system (number of aerators, airflow, electrical specificities of the equipment, etc.). In our case, the aerators of the WWTP of SET are automatically programmed to turn on once the critical oxygen limit for bacteria is about to be reached. Consequently, the ventilation excess is very unlikely to occur but the complexity of the automation system may generate supplementary electrical intake.

In all cases, the accurate needs of every WWTP must be estimated in order not to waste unnecessary aeration time and energy [13]. The values in Table 4 represent the average aeration needs and their standard variations according to the average nature of the effluents based on Eq. (4) [14] (for low mass loading process):

$$\text{Oxygen needs} = 0.7\text{BOD}\left(\text{to be liminated during aeration}\right) + 0.05\text{VSS}\left(\text{in the aeration tank}\right) + 4.25\text{NTK}\left(\text{to be nitrified}\right) \quad (4)$$

Table 4
Theoretical daily oxygen needs

| WWTP | Daily oxygenation needs |
|---|---|
| SAL | 580 ± 90 kg $O_2$/d |
| SET | 700 ± 240 kg $O_2$/d |
| BM | 4,130 ± 2,070 kg $O_2$/d |

### 3.3. *By-products quality assessment*

#### 3.3.1. *Toxicity assessment*

According to Table 5, the physicochemical elements seem to be acceptable for release and irrigation [15] but a slight lack of oxygen is observed in the second plant, which may affect the biological balance of surface waters and suffocate aquatic flora and fauna. The impact could be moderated in the case of irrigation if the plant has a decent access to oxygen through photosynthesis.

The high value of conductivity in the first plant is due to the high salinity of the effluent (mainly caused by anionic agents) in addition to the final chlorination process where sodium hypochlorite is added to water increasing salinity and by extension the conductive potential of these waters. Even though the limit value for irrigation is not reached, some crops may experience sodium congestion after cumulative irrigation episodes. This issue could either be solved by enhancing the sedimentation efficiency with physico-chemical treatment or by selecting halophyte crops for irrigation: tamaris, atriplex, acacia, etc. Another exploitable option is to alternate the use of these waters with regular fresh water in order to reduce sodium amounts in the soil.

There is a slight excess of ammonium in the first plant, which may cause a real issue in the case of release, especially if the receiving area is slightly alkaline. When the pH value is high, the ammonium ions turn into ammonia atoms that are potentially toxic for aquatic fauna. Besides, the nitrates concentrations all exceed the limit values for release because of the absence of optimal conditions for efficient denitrification. However, the results are totally acceptable for agricultural use.

Table 5
Pollution parameters of treated wastewater in the three plants

| | SAL | SET | BM | Guidelines for surface waters (WHO and Algerian journal) [18] | Norm for irrigation (FAO, 1985) [19,20] |
|---|---|---|---|---|---|
| Temperature (°C) | 20.35 ± 4.34 | 19.39 ± 4.77 | 19.09 ± 4.50 | 30 | 35 |
| pH | 7.53 ± 0.16 | 8.00 ± 0.37 | 7.27 ± 0.46 | (6.5–8.5) | (6.5–8.5) |
| Conductivity (μS/cm) | 2,594.00 ± 257.55 | 1,423.04 ± 87.03 | 1,170 ± 70 | 2,700 | 3,000 |
| SAR (sodium adsorption ratio) | 3.10 | 1.58 | 2.18 | / | 0–3 for EC < 0.2 ds/m 3–6 for 0.2 < EC < 0.3 ds/m |
| Anionic agents (mg/L) | $9 \times 10^{-3}$ | $5 \times 10^{-3}$ | $7 \times 10^{-3}$ | / | / |
| Dissolved oxygen (mg/L) | 7.90 ± 0.58 | 1.21 ± 1.10 | / | >5 | >5 |
| TSS (mg/L) | 6.03 ± 4.74 | 7.55 ± 3.07 | 10.31 ± 2.00 | 30 | 30 |
| BOD (mg/L) | 6.68 ± 2.86 | 6.53 ± 4.00 | 9.22 ± 3.07 | 30 | 30/10 |
| COD (mg/L) | 28.66 ± 8.43 | 19.34 ± 6.74 | 22.45 ± 7.00 | 90 | 90 |
| Ammonium (mg/L) | 4.26 ± 8.80 | 1.75 ± 1.41 | 3.04 ± 1.84 | 5 | / |
| Nitrites (mg/L) | 0.10 ± 0.10 | 0.04 ± 0.02 | / | 10 | / |
| Nitrates (mg/L) | 13.11 ± 10.64 | 31.21 ± 26.59 | 32.66 ± 12.03 | 10 | 130 |
| TP (mg/L) | 4,02 ± 1.65 | 3.39 ± 2.84 | 1,53 ± 0,85 | 3 | / |
| E.C | <2,000 UFC/mL | <600 UFC/mL | <1,000 UFC/mL | / | Norm for total coliforms: 10 UFC/mL |
| *Streptococcus* | Presence < 10 UFC/mL | Absence | Absence | / | / |
| *Staphylococcus* | Presence < 15 UFC/mL | Presence < 5 UFC/mL | Absence | / | / |

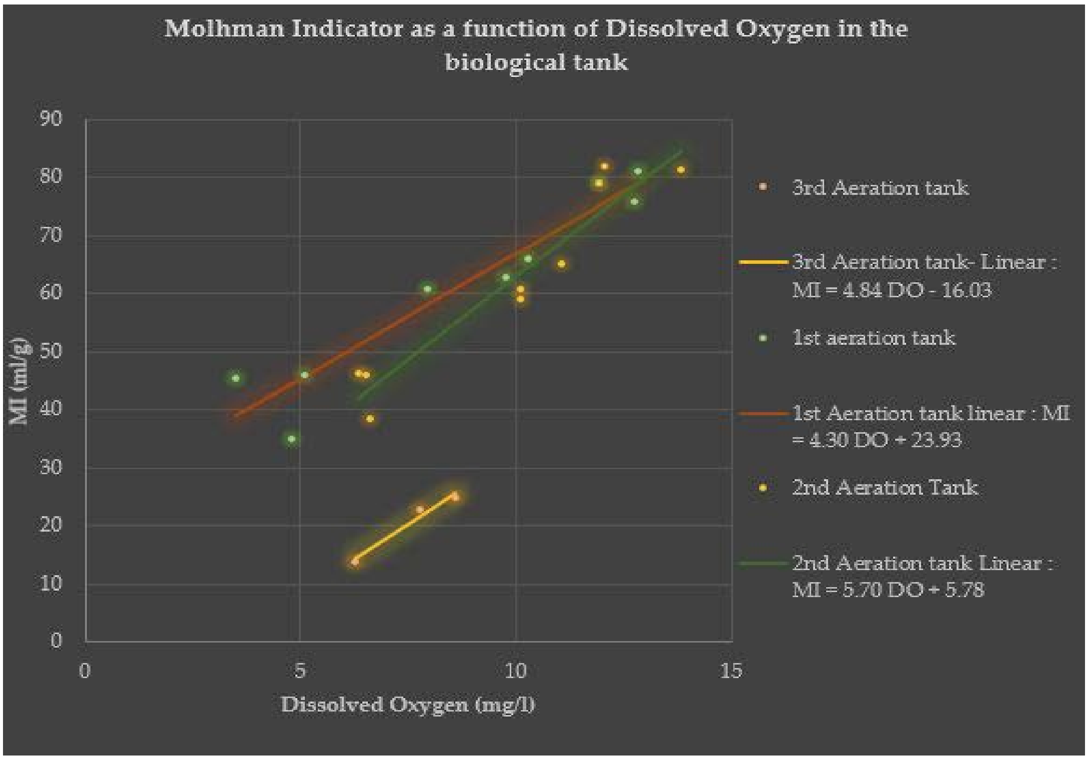



Fig. 4. MI = *f* ($O_2$ concentration in the aeration tank).

Phosphorous amounts also seem to exceed the limit values for release in the two first plants. This issue is very common in plants that do not possess anoxic compartments to complete nitrates and phosphorous elimination [16].

Microbiological analysis indicated very significant amounts of *E. coli* in the three plants despite the fact that the first and the third plants possess chlorination compartments. We have also noticed a slight manifestation of *streptococcus* in the first plant and *staphylococcus* in the first and the second plant. If we aim for agricultural reuse, these waters will not be tolerable since they may present a contamination risk, especially in Algeria where flood irrigation is the most common method. The only solution is to complete or replace chlorination with UV treatment.

A last worrying point is the cumulative effect of anionic agents since they are usually associated with 05% to 10% of industrial humectant agents such as dimethicone, etc. and 01% of preservative agents like parabens for instance. Some of these molecules are known to be endocrinal disruptors; they may not have an instant environmental impact but their ulterior accumulation is very likely to affect the endocrinal system of aquatic species and the healthy development of the plants that are irrigated with these waters [17].

The greatest fraction of trace elements are concentrated in the sludge [16]. The results in Table 6 show no excess of these elements in comparison with the WHO limit values for fertilization.

### *3.3.2. Agricultural features of treated water and dehydrated sludge*

Since human metabolic waste is an untapped resource of nitrogen, phosphorous, and potassium, treatment by-products contain an important fraction of these elements. While potassium is predominantly soluble in treated water, nitrogen, and phosphorous are mainly found in the resulting sludge [22].

Table 7 illustrates the agricultural amendment that can be supplied by a water sheet of 5,000 $m^3$/ha/y which is the usual dose that suits arboreal crops in northern Algeria such as citrus, orange, and vine trees [15].

As illustrated in Table 7, treated wastewater that originates from the three plants can entirely satisfy vineyard potassium needs (103%, 78%, and 145%, respectively for the three plants). Moreover, it can still supply important fractions of vineyard Nitrogen needs (71%, 51%, and 48%, respectively for the three plants) and phosphorous needs (22%, 19%, and 8%, respectively for the three plants). The lack of nitrogen and phosphorous could easily be adjusted using commercial fertilizers.

While the nitrogen, phosphorous and potassium (NPK) balance in the first WWTP is the most adapted to vineyard needs, treated wastewater from the third plant would be more adapted to cultures that have higher potassium needs in their NPK ratio like citrus trees.

Calcium, magnesium, and sodium are also beneficial elements that are supplied by treated wastewater [16]. Nevertheless, in the first case where sodium amounts are the highest, vineyards, and other similar cultures could suffer from sodium intolerability and develop leaf tips necrosis. Thus, the destination soil has to contain very low amounts of sodium and other cultures like lavender cotton are preferable since they tolerate salty environments. Besides, the diminution of sodium hypochlorite intakes in the chlorination basin and the use of UV technologies instead will efficiently solve this issue.

In order to estimate the fertilizing potential of the dehydrated sludge of our WWTPs, the yearly produced volumes of sludge have been weighed (first line in Table 8). Accordingly, the spreadable area has been calculated by estimating an ideal manuring dose of 10 t/ha (second line in Table 8) [23].

The fraction of the nutritive elements (NPK) in dry matter has been measured locally using atomic absorption spectrometry (Table 1). The concentrations of these elements

Table 6
Trace elements concentrations (in ppm) in the dehydrated sludge of the three plants

| Element | WWTP of SAL | WWTP of SET | WWTP of Boumerdes | Limit values (WHO-NFU 44-095) [21,22] |
|---|---|---|---|---|
| Cu | 104 ± 5 | 113 ± 6 | 106 | 1,000 |
| Cd | 0 | 0 | 1 | 20 |
| Pb | 44 ± 3 | 50 ± 3 | 16 | 800 |
| Cr | 0 | 0 | 15 | 1,000 |
| Hg | 0 | 0 | 6 | 10 |
| Ni | 0 | 0 | 23 | 200 |
| Zn | 648 ± 9 | 673 ± 10 | 547 | 3,000 |
| Ti | 534 ± 72 | 390 ± 44 | / | / |
| Sr | 373 ± 3 | 402 ± 4 | / | / |
| Rb | 22 ± 1 | 23 ± 1 | / | / |
| Zr | 20 ± 2 | 30 ± 2 | / | / |
| Ag | 0 | 15 ± 4 | / | / |
| As | 6 ± 2 | 3 ± 2 | / | / |
| Y | 3 ± 1 | 7 ± 1 | / | / |

Table 7
Major fertilizing elements in treated wastewater of the three plants

| WWTP | Potential irrigation surface (arboreal crops, mainly citrus and vineyards) | Nutritive elements (kg/ha) | | | | | |
|---|---|---|---|---|---|---|---|
| | | N | P | $K_2O$ | Ca | Mg | Na |
| SAL | 95 ± 18 ha | 92.25 ± 16.85 | 20.10 ± 7.25 | 67.35 ± 0.75 | 185.50 ± 7.35 | 144,6 | 519.15 ± 19.55 |
| SET | 115 ± 25 ha | 66.65 ± 28 | 16.95 ± 1.80 | 50.65 ± 0.25 | 102.15 ± 9.65 | 192 | 262 ± 26.35 |
| BM | 890 ± 450 ha | 62.8 ± 16.30 | 7.55 ± 4.20 | 94.50 ± 0.85 | 97.15 ± 4.25 | 192 | 370.15 ± 19 |
| Vineyard needs (FAO) | Kg/ha | 130 | 90 | 65 | / | | |

Table 8
Major fertilizing elements in the dehydrated sludge of the three plants

| | | WWTP of SAL | | WWTP of SET | | WWTP of Boumerdes | |
|---|---|---|---|---|---|---|---|
| Yearly produced sludge weight (t) | | 395 | | 490 | | 1,800 | |
| Estimated spreadable area – (condition: 10 t/ha) | | 39.50 ha | | 49 ha | | 180 ha | |
| Dry fraction % | | 19.44 ± 1.20 (approximately 77 *t*) | | 20.10 ± 1.65 (approximately 99 *t*) | | 22.73 ± 4 (approximately 409 *t*) | |
| Mohlman indicator (standard interval: 50–150 mL/g) | | 80 ± 28 | | 75 ± 25 | | 115 ± 30 | |
| Organic fraction (VSS)-% | | 58.00 ± 3.63 | | 58.06 ± 5.05 | | 57.00 ± 9.00 | |
| pH | | 6.8 ± 0.45 | | 6.65 ± 0.45 | | 7.1 ± 0.50 | |
| | | Supplied amount (t/y) | Supplied amount (kg/ha) | Supplied amount (t/y) | Supplied amount (kg/ha) | Supplied amount (t/y) | Supplied amount (kg/ha) |
| Major | N | 2.13 | 54 | 2.05 | 41 | 11.66 | 65 |
| Nutritive | P205 | 1.13 | 29 | 1.23 | 25 | 12.39 | 69 |
| elements | K20 | 0.96 | 24 | 0.92 | 19 | 6.76 | 38 |

have been multiplied by the total quantity of dry matter; which is the total produced sludge volume multiplied by its dryness percentage) in order to obtain the yearly produced quantities of these nutrients which are mentioned in the last line of Table 8. This calculus id summarized in Eq. (5).

$$\text{Supplied amount of NPK}\left(\frac{\text{t}}{\text{y}}\right)= \frac{\text{Mass fraction of the element N / P / K}\left(\text{ppm}\right)\times \text{yearly sludge weight}\left(\text{t}\right)\text{x dryness}\left(\%\right)}{1{,}000} \quad (5)$$

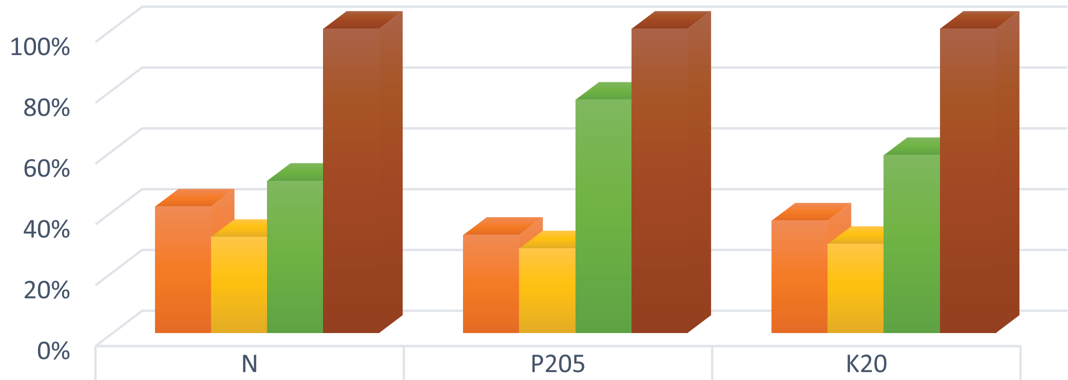
Subsequently, the yearly amounts of major nutritive elements have been divided by the corresponding spreadable area in order to get the supplied amount per hectare (kg/ha).

Besides, the table indicates great fertilizing amendments brought by dehydrated sludge originating from water treatment with highest portions of nitrogen and phosphorous, which confirms the soluble aspect of potassium [15–23]. The third plant has higher amounts of nutritive elements due to its higher dryness in comparison with the other plants.

Other important features, which are also brought out by Table 8, are the main physical aspects of the sludge. In our case, the results are mainly satisfying. The obtained dry matter percentage values are very expectable and common after mechanical dehydration process. The pH values are mainly neutral (6.5–8.5). The fractions of VSS are mainly inferior to 65%, which globally implies decent mineralization [24].

Mohlman indicator values are also in the conventional interval [50–150]; which means the sludge is neither too liquefied (<50 mL/g), nor too filamentous (>150 mL/g). However, a linear correlation between Mohlman indicator and oxygen amounts in the aeration tank has been established using previous records from two aeration tanks in the WWTP of Kolea [15] (Tipaza, Algeria) and the aeration tank of the WWTP of Tizi-Ouzou-West (Algeria). The resulting coefficients exceed 0.95, which implies a strong dependency between these two parameters. Unfortunately, in our case, oxygen amounts are only measured in wastewater and after final treatment; so, the correlation could not be applied to our study case.

The Mohlman indicator in Fig. 4 Fig. 4 seems to progress as a linear function of the dissolved oxygen concentration in the aeration tanks. The values "*a*" and "*b*" have been deduced by linear regression and are typical to each tank where:




| | N | P205 | K20 |
|---|---|---|---|
| SAL | 42% | 32% | 37% |
| SET | 32% | 28% | 29% |
| BM | 50% | 77% | 58% |
| Vineyard needs | 100% | 100% | 100% |

Fig. 5. Rates of major nutritive elements brought by dehydrated sludge in comparison with vine tree need.

- "*b*" indicates Mohlman indicator values at anoxic conditions, that is, when oxygen concentrations are null
- "*a*" expresses the speed of the biological process and the plopping development.

These two values are specific to each aeration tank according to the nature and age of the activated sludge.

Consequently, the oxygen alimentation during biological process could be adjusted to approach ideal value of 100 mL/g (Eq. (6)) by taking into account the minimal oxygen amounts needs of each effluent as estimated in Table 4 and Eq. (6).

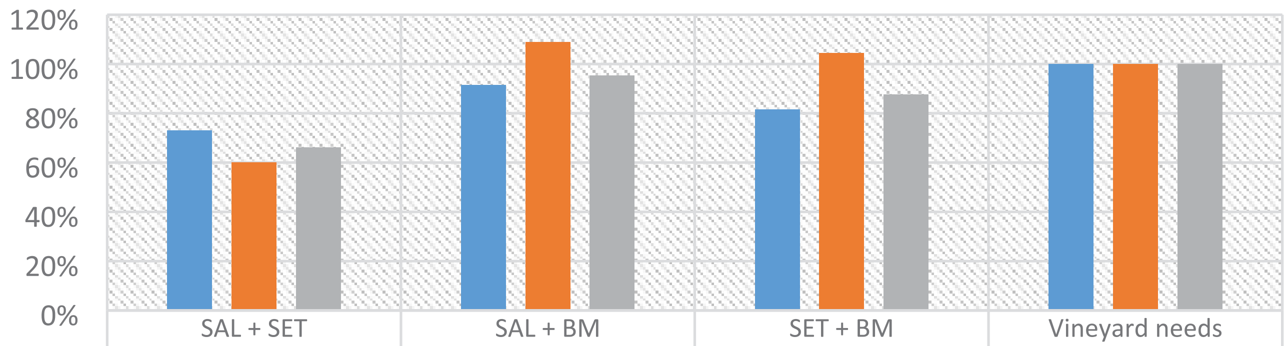
$$\text{Optimal oxygen concentration}\left(\frac{\text{mg}}{\text{L}}\right) = \frac{100 - a}{b} \quad (6)$$

*3.3.3. Vineyard manuring scenario*

The percentage of nutrition brought by our sludge according to vineyard needs is illustrated in Fig. 5. The sludge coming from the first and second plant covers around 30% to 40% of the nutritional demand of vine trees whereas the sludge originating from the third WWTP covers more than 50%. Accordingly, the third plant has richer sludge, which can satisfy vineyard fertilization faster but the first, and second plants have better balance in their sludge composition.

The optimal adjustment is to correct the imbalance in the third WWTP by additional nitrogen and potassium fertilizers and double the spread dose in the case of the first and second plants without any artificial alteration.

Another scenario to consider is the combination of sludge from different plants as illustrated in Fig. 6; the chart shows




| | SAL + SET | SAL + BM | SET + BM | Vineyard needs |
|---|---|---|---|---|
| N | 73% | 92% | 82% | 100% |
| P205 | 60% | 109% | 104% | 100% |
| K20 | 66% | 95% | 88% | 100% |

Fig. 6. Different combinations of sludge in comparison with vineyard needs.

that the second combination is the closest to the ideal balance (100%, –100%, and –100%) with a slight excess of phosphorous, while the two other combinations can be artificially adjusted to reach the ideal balance.

Another considerable solution is to enhance the dryness of sludge in order to raise the nutritional amounts by using sludge drying beds or greenhouse beds. However, this solution requires large areas and the concentration of trace elements and other pollutants per hectare can considerably increase.

## 4. Conclusion

This study has allowed assessing the profitability of wastewater treatment by-products using activated sludge process. First, the laboratory analysis of the by-products, that are mainly treated water and partially dehydrated sludge, has been a mandatory step in order to build a preventive basis against any eventual contamination risk whether it is instantaneous or deferred; and from that, the agricultural features can be pointed out in order to come up with cost-effective perspectives.

In our study cases, the resulting diagnosis has led to the following deductions:

The total hydric potential of treated wastewater from the three plants; which could satisfy around 1,000 ha of arboreal surfaces, represents 1% of the actual irrigated surface in Algeria. This rate is unneglectable since there are almost 200 operational wastewater treatment plants in Algeria using activated sludge process.

Furthermore, treated wastewater from the three plants contains satisfying amounts of major nutritive elements (NPK) that can totally satisfy arboreal needs for potassium and partially for nitrogen and phosphorous. Consequently, there can be tremendous savings of commercial fertilizers.

Nitrogen and phosphorous removal rates are mainly acceptable but the final concentrations do not meet the conventional requirements for release and can suffocate aquatic fauna especially if the receptive area has a basic pH where ammonium ions ($NH^{4+}$) turn into ammonia ($NH_3$). However, agricultural reuse can be a very appealing alternative since these elements have a high fertilizing potential.

As observed in the first WWTP, wastewater originating from domestic activities with low dilution rates (separate sewer systems in small collectivities) is more likely to have higher amounts of tensioactive agents and by extension, higher sodium rates and conductivity values. Even though the latter are still acceptable for release but the resulting sodium adsorption ratio is slightly higher than the conventional limit for irrigation. Consequently, for agricultural purposes, the soil composition, and the crop tolerability have to be monitored and the use of chloral biocides containing sodium during disinfection is not recommended.

The dehydrated sludge also represents a great source of major nutritive elements and some beneficial microelements that are not found in commercial fertilizers. If 10 tons of this resource are used for landfilling a hectare of soil, an important fraction of nutritional needs for many arboreal crops. A combination of the sludge from the first and the third WWTP can help reach the ideal nutritional balance of vineyard for instance. Since treated wastewater from the WWTP of Boumerdes is already reused to irrigate this type of crop, the agricultural perimeter could be extended in order to valorize the sludge on new parcels. However, treated wastewater and sludge cannot be used on the same parcel in order to avoid excessive use of major nutritive elements.

The presence of trace elements in sludge is not alarming since it does not exceed the limit values for agricultural valorization. However, primitive and continuous soil monitoring is imperative to assess the cumulative aspect.

The optimization of the treatment performance and cost-efficiency relies mainly on energetic consumption, which is highly concentrated in the aeration tank. Consequently, the oxygen intake has to be regularly adjusted to the accurate needs of the effluent and to nature of sludge in order to reach the ideal sludge consistency (Mohlman indicator). Besides, the sludge concentration also has to be monitored and accustomed to the effluent as well. Another recommendation is the reduction of chloral products use for decontamination using UV treatment since it destroys the DNA of most microorganisms without chemical persistence in water.

Finally, this study has allowed bringing out the positive and negative insights of the agricultural reuse of wastewater treatment by-products and proposing the right adjustment to make the valorization safe, profitable, and rewarding both environmentally and economically.

## References


[1] A. Kettab, Water resources in Algeria: strategies, investments, and vision, Desalination, 136 (2001) 25–33.

[2] A. Kettab, Water for all with quality and quantity: it is the concern of all!, Desal. Water Treat., 52 (2014) 1965–1966.

[3] Ahmed Kettab, N.M. Chabaca, S. Karef, M. Nakib, W. Boumalek, H. Bouanani, Y. Djillali, S. Benziada, S. Benmamar, Urban Wastewater Treatment and Agricultural Reuse, EUE Editions (European University Editions), ISBN: 978–3-330–87310–0, 2017.

[4] M.Y. Saidam, A Regional Overview of Wastewater Management and Reuse in the Eastern Mediterranean Region, WHO-EM/CEH/139/E, World Health Organization, Regional Office for the Eastern Mediterranean, Regional Centre for Environmental Health Activities, CEHA, 2005, p. 67.

[5] J. Rodier, B. Legube, N. Merlet, R. Brunet, L'analyse de L'Eau Eaux Naturelles, Eaux Résiduaires, Eau de Mer, (Analysis of natural, saline and wastewater), 8 éme éd., Dunod, Paris, 1996, p. 1383.

[6] S.J. Arceivala, S.R. Asolekar, Wastewater treatment for Pollution Control and Reuse, Tata McGraw Hill Education Edition, 2007.

[7] E. Eriksson, K. Auffarth, M. Henze, A. Ledin, Characteristics of grey wastewater, Urban Water, 4 (2002) 85–104.

[8] C. Noutsopoulos, A. Andreadakis, N. Kouris, D. Charchousi, P. Mendrinou, A. Galani, I. Mantziaras, E. Koumaki, Greywater characterization and loadings – physicochemical treatment to promote onsite reuse, J. Environ. Manage., 216 (2018) 337–346.

[9] S. Karef, M. Nakib, A. Kettab, S. Benmaamar, S. Benziada, K. Bouguerra, Study of Performance Indicators of a Sewage Treatment Plant (Algeria), 3rd International Water Conference, Algiers, November 2013.

[10] A.E. Stricker, A. Héduit, Phosphorous in Wastewater: New Data and Effects on Treatment, Final Report: Action 28bis-5, ONEMA, France, 2010.

[11] G. Deronzier, S. Schétrite, Y. Racault, J.P. Canler, A. Liénard, A. Héduit, P. Duchène, Nitrogen Treatment in Wastwater Treatment Plants of Small Communities, Technical Memo: Fndae N° 25, Cemagref Éditions – ISBN 2-85362-555-9, 2001.

[12] S. Karef, A. Kettab, D. Loudyi, M.C. Bruzzoniti, M. Del Bubba, F. Ait Nouh, N. Boujelben, L. Mandi, Pollution parameters

and identification of performance indicators for wastewater treatment plant of Medea (Algeria), Desal. Water Treat., 65 (2017) 192–198.
[13] A. Heduit, J.P. Tabuchi, Note de contexte vers une plus grande économie énergétique des stations d'épuration?, Sciences Eaux & Territoires-(Informative Note on Greater Energy Management in Wastewater Treatment Plants), N°09, 2012.
[14] E. Adler, Eléments sur l'épuration des eaux usées et la gestion des sous-produits de l'assainissement, ACONSULT (Official Manual on Wastewater Treatment and the Management of Byproducts), ENTPE (National School of State Public Works), France, 2005.
[15] M. Nakib, A. Kettab, A. Berreksi, S. Tebbal, H. Bouanani, Study of the fertilizing potential of the treated wastewater of the Kolea wastewater treatment plant (Algeria), Desal. Water Treat., 57 (2016) 5946–5950.
[16] S. Karef, A. Kettab, M. Nakib, Characterization of byproducts from wastewater treatment of Medea (Algeria) with a view to agricultural reuse, Desal. Water Treat., 52 (2014) 2201–2207.
[17] M. Gavrilescu, K. Demnerová, J. Aamand, S. Agathos, F. Fava, Emerging pollutants in the environment: present and future challenges in biomonitoring, ecological risks and bioremediation, New Biotechnol., 32 (2015) 147–156.
[18] JORA, Official Journaling of the Algerian Republic: Emissions Standards in the Receiving Environment, Algiers, Algeria, 1996.
[19] J.R. Tiercelin, A. Vidal, Treaty of Irrigation, 2nd ed., TEC and DOC, Lavoisier, 2006.
[20] Y. Djillali, M.N. Chabaca, S. Benziada, H. Bouanani, L. Mandi, M.C. Bruzzoniti, N. Boujelben, A. Kettab, Effect of treated wastewater on strawberry, Desal. Water Treat., 181 (2020) 338–345.
[21] French Standards Association (AFNOR), NF U44-095 Standard: Organic Amendments-Composts Containing Substances of Agronomic Interest from Water Treatment, Paris, 2002.
[22] W. Boumalek, A. Kettab, N. Bensacia, M.C. Bruzzoniti, D.B. Othman, L. Mandi, M.N. Chabaca, S. Benziada, Specification of sewage sludge arising from a domestic wastewater treatment plant for agricultural uses, Desal. Water Treat., 143 (2019) 178–183.
[23] M. Nakib, A. Kettab, A. Berreksi, L. Mandi, Study of the prospects for agricultural utilization of sludge produced from WWTPs in North Central Algeria, Desal. Water Treat., 55 (2015) 1152–1166.
[24] J.P. Canler, Technical Issues in Wastewater Treatment Plants: Causes and Solutions?, Technical Document: Fndae N°33, Cemagref Editions, 2005a.