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Prospective scenarios for the management of wastewater resources in Mostaganem region, Algeria

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ABSTRACT

Treatment performances of five lagoon (natural and aerated) wastewater treatment stations in the Mostaganem Region (Western Algerian) were evaluated to meet the expectations of stakeholders. This assessment was based on collected data to verify the functioning of the lagoons and the regulatory compliance of their discharge in order to evaluate the conditions of operation of the treatment facilities. Available historic data were supplemented by a sampling and analysis campaigns performed by the National Sanitation Office (Mostaganem Unit). The methodology used is based on the coupling of both functional and structural diagnoses of the treatment system and the use of conventional formulae to check the capacity of the different components of the system and justify scientifically and technically the adopted operational choices. The evaluation of Benyahi Station's performance showed relatively good performances, exceeding 80% for chemical oxygen demand and biochemical oxygen demand up to the horizon 2045. The kinetic model of Ekcenfelder was used to simulate the reduction of solids and organic matter, and to estimate the specific power of the aeration system. The analysis of the situation of the five lagoons were carried out with satisfaction, where prospective scenarios of control of the process and management of the transfers of sewage between localities were carried out to better characterize the situation of wastewater treatment in the region by 2045. Finally, recommendations, based on rigorous computations and in-depth diagnoses, were proposed to reinforce the obtained management scenarios.

Keywords: Wastewater; Lagoon; Diagnosis; Mostaganem; Algeria

1. Introduction

In Algeria, water is a commodity increasingly rare and less renewable [1]. Water resources are irregularly distributed in time and space and are mainly concentrated in the Northern Flank of the Atlas. According to Mozas and Alexis [2], Algeria's water potential is estimated on average at 18 billion m^3/y, of which 12.5 billion m^3 are concentrated in the north (10 billion m^3 of surface runoff and 2.5 billion m^3 of renewable groundwater resources) and 5.5 billion m^3 in the Saharan regions (0.5 billion m^3 of surface runoff and 5.0 billion m^3 of fossil groundwater resources). In terms of allocation, about 60% of water resources are allocated to irrigation, 30% to drinking water, and about 5%–10% to industry. Water is being competitively exploited between the needs of the population and those of agriculture and industry, which are competing for limited availability [3]. Indeed, with the expansion of cities and changing consumption patterns, drinking demand is increasing, resulting thereby in an increase in wastewater production. The annual volume of wastewater generated by the Algerian population is 927 million m^3/y, of which 700 million m^3/y are treated and reused by industrial activities (3.1 million m^3/y) and agricultural irrigation (3.4 million m^3/y) [4].

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Wastewater is a polluted effluent, which is usually discharged directly without any treatment in the natural environment. Pollution of surface and groundwater resources is attributed to discharges of both domestic and industrial wastewater as well as the use of fertilizers and pesticides in agriculture [5]. Pollution may constitute, in the short term, a risk of increased water shortage imposing the need to protect this resource against any alteration and irrational use.

The Algerian state resorted to the treatment of wastewaters before their disposal into natural receiving water bodies. The public sanitation service ensures collection, treatment, and disposal of domestic wastewater as well as the treatment of sewage sludge. Algeria has recently given more importance to the coverage of wastewater treatment plants (WWTP). Indeed, according to a report published by the National Office of Sanitation (ONA) in 2017, there were 142 exploitable WWTPs, including: (i) 68 activated sludge stations; (ii) 71 lagoon stations; (iii) 03 planted filters. The total installed capacity of these 142 stations is 9,621,714 population equivalents, which corresponds to an average nominal flow of 1,478,928 m^3/d. On the other hand, the reuse of treated wastewater is estimated at 42% of the effluent volume of the 17 WWTPs and at 08% of the total treated wastewater volume produced by all the 142 WWTPs in operation by the ONA. Regarding electrical energy consumption, it was shown to be 6,223,882 KWh in October 2017, corresponding to a specific energy consumption rate of 316 Wh/m^3 of treated wastewater.

The traditional activated sludge treatment plant is often in mind when it comes to wastewater treatment. However, other aerobic biological treatments exist. They rely on self-purification phenomena occurring spontaneously in bodies of water, in which microorganisms degrade organic matter and transform it into mineral elements. This is the case of the lagoon process [6]. The latter is a rustic and extensive process that, like any biological system, strongly depends on several parameters: the pollutant load, the hydraulic load, the residence time, and the climatic conditions [7]. The process design consists of different lagoons, including a first basin which is optional and allows primary treatment (settling digester, settling lagoon, and filter planted with reeds). It is followed by the actual treatment which includes at least three lagoons in series. Lagooning may also be followed by sand seepage treatment to retain suspended solids (mostly algae) and in some cases also ensure a controlled release of effluents in the groundwater system [8].

Lagoon wastewater treatment is a widespread and expanding process both technically and scientifically throughout the world, extending to the tropics [9]. In Germany, the oldest natural lagoon was built in Bavaria in 1920. Today, in the United States, there are more than 8,000 lagoon stations in place, representing more than 50% of existing wastewater treatment facilities. One of the handicaps encountered with this system was to put in place good control or a prediction of proper management, especially in cold environments [10].

The study of Boutayeb and Bouzidi [11] showed that the system of treatment of domestic wastewater in natural lagoons remains among the most used processes in countries with arid to semi-arid hot climates, especially in rural areas. This is the oldest system in the industry. However, given the poor quality of the treated water, this system was improved by the installation of aerated lagoon systems. According to Chaouki et al. [12], treatment efficiency has been greatly improved with the new technique of aerated lagoons. In fact, this yields values of 82%, 83%, and 88% for biological oxygen demand (BOD_5), chemical oxygen demand (COD), and suspended solids (SS), respectively.

The literature presents numerous studies dealing with the behavior of lagoon basins in terms of physico-chemical and environmental parameters [13,14], the performance of basins in reducing control bacteria [15], pathogenic bacteria [16,17], and intestinal parasites [18,19]. In Morocco, Idrissi et al. [20] developed a study of treatment performances of the natural lagooning technique of the Azilal-MAROC-domestic wastewater treatment plant in order to apply Moroccan standards, to increase the degree of treatment, and to valorize the treated effluent, after having carried out works of rehabilitation of the old network. This has allowed the increase of the connection rate to the existing network and consequently the increase of the flow of wastewater.

Lagoon control strategies were presented by Peitz and Xavier [21] to evaluate the behavior of aerated lagoons in the variation of the organic load coming from a paper mill to take the necessary measures of good functioning. With regard to lagoon optimization techniques, Young et al. [22] conducted an in-depth study of high-throughput algal ponds in Kingston-on-Murray (Kom), South Australia. The objective of this research was to evaluate the capacity and treatment performance of lagooning after inactivating indicators of pathogenic bacteria, viruses, and protozoa in domestic wastewater over a longitudinal time series. In another context, Wrede et al. [23] presented a management scenario related to the use of microalgae to treat secondary effluents and developed a simple model for the production of biomass in an open pond environment with high pH. The study examined several variables for predicting algal growth; temperature, solar radiation, and ammonia concentration.

Today with the tightening of regulations, sanitation in Mostaganem, in general, faces innumerable difficulties, including: (i) the need to collect all wastewater and eliminate the cant in nature without any treatment; (ii) the inspection of sanitation facilities in the Mostaganem Region and their management has shown a situation, at least, worrying; and (iii) the presence, sometimes, of effluents combined with oils and industrial waste from washing stations and chemical plants.

The lagoon system in the Mostaganem Region suffers from several problems. First, the actual characteristics of the lagoons are not well known to managers. In fact, apart from the characteristics of its design, no data is available to predict its real capacity and foresee the need for its expansion to meet future needs. Moreover, lagoon managers shall maintain control of the effluent under all operating conditions of the system, even if the substances to be controlled are numerous and their threshold values are low. Last, but not least, biological processes are delicate and sometimes difficult to control; they can cause unforeseen situations, which impose costly interventions for the reorganization of the system (for example, phenomena of sludge swelling in secondary sedimentation, or intoxication of the biomass).

Currently, in response to the problems mentioned above, the Directorate of Water Resources (DRE) has launched a study on the master plan for the sanitation of the region by 2045. In this perspective, the evaluation of treatment performances is considered in this study in the framework of diagnosis of lagooning in the region of Mostaganem in order to provide essential elements to allow decision makers to better base scientifically and technically their management strategies of the lagoon systems.

In this context, this study expects to develop a strategy to manage wastewater effluents produced in Mostaganem Region. The purpose is first to characterize the functioning and operation of the lagoon systems in the study area based on information and data from previous studies and technical reports (design, performance, and operation). Next, we will tend to propose a management tool in order to assess the treatment potential of these lagoons and identify the interactions between different policies implemented at the local level (transfer, cost, planning, etc.). The study presented here highlights the alarming observation of the current situation in the lagoons, provides the priority aspects to be included as a matter of urgency in the new sustainable development policy adopted by the public water and sanitation service and leads to a first perspective on the actions needed and expected results for effective management of wastewater treatment systems in Algeria.

This work is expected to yield a calculation tool for both types of aerated and natural lagoons, resulting in optimizing the operation of the lagoons (exploitation, control strategies, etc.) by proposing adequate solutions to (i) improve wastewater treatment performance and sanitation status in the region, (ii) design structures (new lagoons and proposed extensions), and (iii) predict future operations (transfer, evolution of charges, etc.).

2. Material and methods

The methodology adopted in this work is based on a field survey, targeting organizations active in the field of water resources in the region of Mostaganem. These are the DRE, the ONA, and lagoon stations (SL). Field campaigns were conducted to gather information from relevant agencies. In addition, field investigations, interviews with officials and stakeholders in the field of water resources, bibliographic research, and web graphics on the internet and on the official websites of national and international organizations were carried out. Data were also collected and selected from written documents, data sheets, official, and statistical reports produced by relevant bodies at the ministry level (texts and directives).

The different steps followed in this study are summarized in the flowchart of Fig. 1. First, all the available information related to the sanitation situation in the region and precisely lagoon stations are collected and analyzed. In this context and with respect to the state of the art of lagoons, Boutin et al. [24] provided basic elements for the choice of this treatment technique and its adequacy to local constraints, the updated design rules, the performances that can be expected, the type of exploitation to be carried out and assistance in the interpretation of basin behavior. Next, structural and functional diagnoses of the five lagoons are undertaken in order to better understand their operating conditions depending on their sizes and their states. Indeed, the design and hydraulic operation of the different installations, when they contain defects, can cause major malfunctions (local overload, short hydraulic circuits, etc.) [25]. Shilton [26] also showed a great importance of hydraulics on lagoon performance [26]. Finally, a station calculation tool is developed to check treatment performance and its adequacy to the problem. This latter part presents management scenarios for both types of aerated and natural lagoons, helping to manage and properly exploit future operating conditions (transfer, load evolution) according to the method described by Bouchaala et al. [4].

2.1. Models used

2.1.1. Model for aerated lagoons

Many sophisticated models have been used to predict algal growth in lagoon ponds. These models tend to be specific and less reliable for ambient open basins that contain many species. These models were shown to be useful in a controlled laboratory environment [27,28]. However, they are less applicable to large open basins because of weather fluctuations, nutrient concentrations, and microalgae. Most models require large amounts of predetermined values such as optimal and minimal growth rates under certain conditions, and at specific nutrient concentrations. They are usually too specific to a particular set of conditions to be used outside the controlled laboratory environment.

Most models assume that nutrients are not limiting or that temperature and light are kept constant. Some previous models are species-specific and would not be able to predict biomass production in a natural crop [28–30]. Several studies have examined systems with many species, but tend to be very complicated and need data which are not commonly available [31].

The volume of aerated ponds is based on a calculation of removal of BOD_5 as a function of hydraulic retention time. Various mathematical models were developed for this purpose. To better describe the process, the Eckenfelder model was used [32]. This model is expressed as follows:

$$\frac{S_e}{S_0} = \frac{1}{1 + K_e \times t} \times \mathrm{FC} \tag{1}$$

where S_e is the BOD_5 at the effluent, mg/L; S_0 is the BOD_5 influent, mg/L; FC is the correction factor to account for BOD from products of anaerobic decomposition at the bottom of the pond. The FC values used are 1.2 and 1.05 for summer and winter conditions, respectively.

The t is the retention time, calculated by the following formula:

$$t = \frac{1 \times S_0 \times \mathrm{FC}}{K_e + \left(S_e \times 1\right)} \tag{2}$$

where K_e is the removal rate of BOD_5, d^{-1}; the value of K_e at temperature T can be established by means of the following equation:

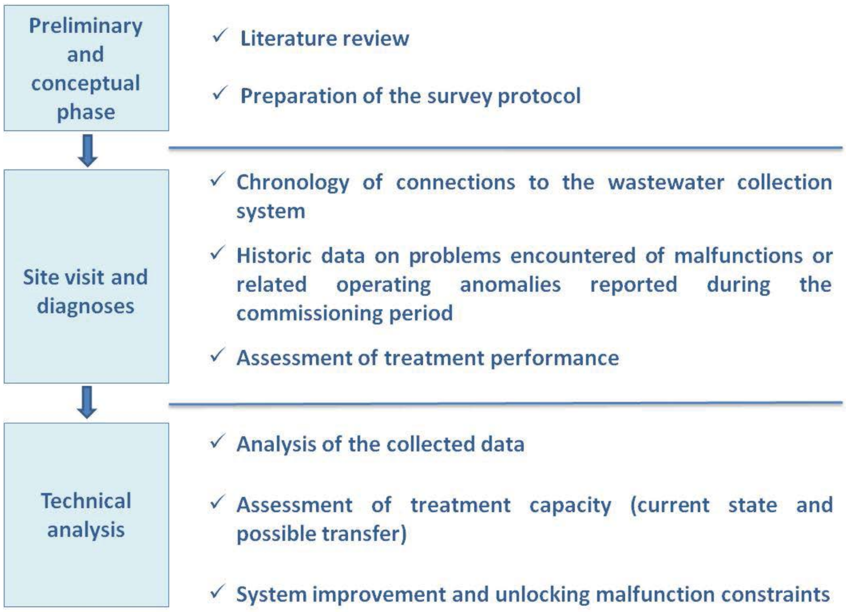

Fig. 1. Flowchart for the proposed methodology.

$$K_e(T) = K_e(20°\text{C}) \times \theta^{(T-20)} \quad (3)$$

where T is the water temperature in the pond, °C; K_e (T) is the overall rate of disappearance of the substrate at temperature T, d^{-1}; θ is the temperature coefficient; the recommended θ value for assessing the effect of temperature for domestic wastewater is 1.07; K_e (20°C) is the K_e value at 20°C, d^{-1}; the value of K_e depends on temperature and the nature of the wastewater. The recommended K_e value in Quebec for domestic wastewater is 0.37 d^{-1} at 20°C.

2.1.2. Model for natural lagoons

The evaluation of design parameters is based on empirical or theoretical mathematical models. Empirical methods are most often based on correlations between applied and eliminated charges while theoretical methods generally use the kinetics of degradation. Combining both approaches makes it possible to define the maximum admissible loads on a treatment basin and to predict the treatment yields as a function of optimal residence time.

The model commonly used to express the evolution of carbon pollution in planted systems is based on an approximation of the piston flow model (Eq. (4)). The model, recommended the International Water Association (IWA) [33–35] among others, assumes that plants contribute to residual pollution, consisting mainly of bacteria (dead or alive), dead roots, runners, and dead leaves. The treatment limit of these systems cannot therefore reach values lower than this residual pollution. Taking into account this intrinsic contribution of pollutants, the kinetics of degradation is expressed as follows (Eq. (4)):

$$\frac{dC}{dt} = K_T(C - C_r) \quad (4)$$

where C is the concentration of a pollutant at time t (mg/L); C_r is the residual concentration of the pollutant (mg/L); K_T and k 20°C are the kinetic reaction constant at temperature T and at reference temperature 20°C; θ is the temperature coefficient = 1.053.

Solving Eq. (4) results in the following:

$$C - C_r = (C_i - C_r)e^{-k_t \cdot t} \quad (5)$$

with C_i is the initial concentration (mg/L).

Taking into account C_r in the kinetics of elimination of carbon pollution makes it possible to approach the real value of the kinetic constant with minimum error. C_r values vary from 1 to 15 mg BOD_5/L for basins with rooted macrophytes [35].

2.2. Study area

The region of Mostaganem is located on the west coast of Algeria; it has a maritime facade of 124 km. This region is located 365 km west of the capital, Algiers (Fig. 2). The mountainous reliefs of Dahra, extending over a total area of more than 78,000 ha (or 34.4% of the region), is notched by a very hairy hydrographic network with slopes varying between 12% and 25%. The rest of the region is characterized by topography favorable for agricultural intensification (mechanization and irrigation). In terms of potential, the coastal cordon, the Dahra Mountains, and the sublittal hills represent the privileged domain of cereal crops and viticulture, while the Bordjias Plain, the Mostaganem Plateau, and the Cheliff Valley are areas of market crops and grain production.

The sewage network system stretches over a linear 1,565 km, with an insufficient coverage rate of 70% due to the low connection rate in the surrounding rural areas. The total production capacity of the treated water of the

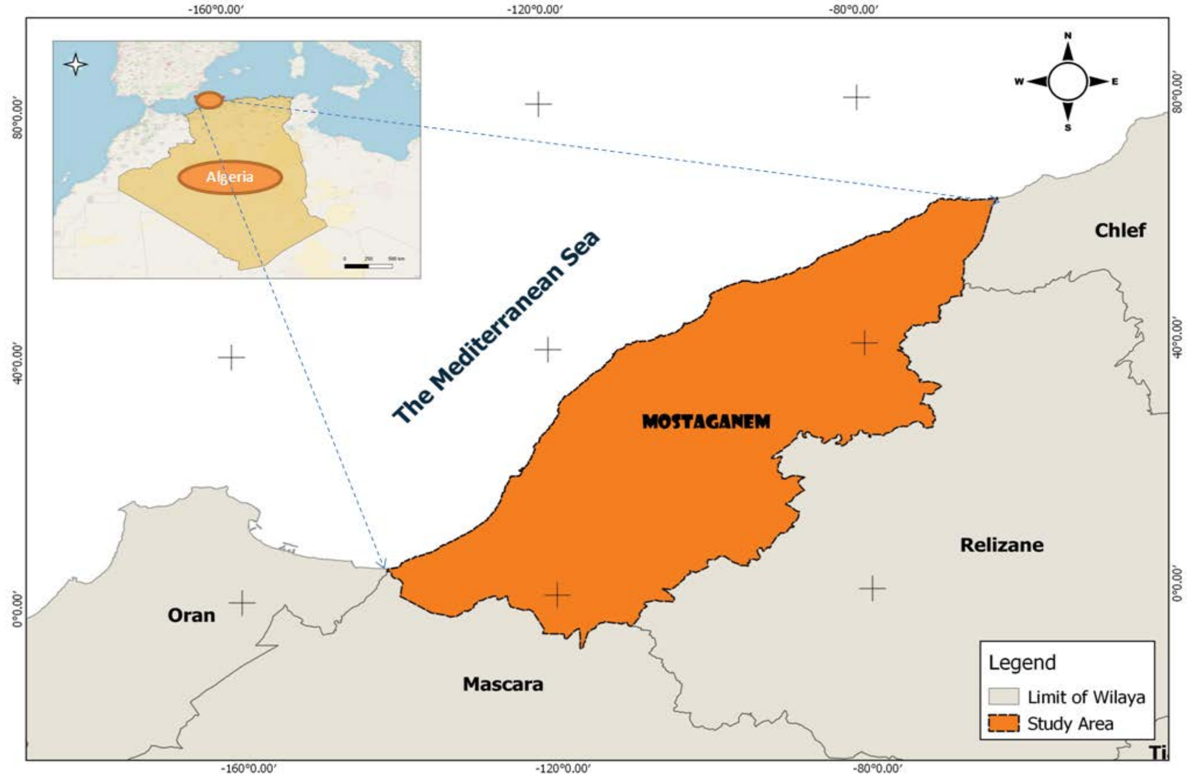

Fig. 2. Location map for the study area (Mostagnem Region).

region is 82,007 m^3 by the year 2016, ready to be used for irrigation of an area of 2,180 ha.

2.3. General presentation of Mostaganem lagoons

Mostaganem Region is characterized by a total wastewater treatment capacity of 114,000 m^3/d ensured by five lagoon stations spread throughout the region (Fig. 3). The analysis of the data provided by the National Sewerage Board (ONA) shows that the overall installed capacity of 11,500 m^3/d far exceeds the treated flow rate of 7,345 m^3/d, and that the wastewater produced is not fully connected (Table 1). This clearly shows that a significant amount of wastewater is discharged into the environment without treatment, while the lagoons have sufficient capacity to treat the whole.

3. Results

A calculation tool is developed to better understand the operating conditions of lagoon stations in Mostaganem Region depending on their size and condition. This tool aims to study the performance indicators and judge their adequacy to the problem. This section presents management scenarios for aerated and natural lagoons, helping proper management and good exploitation whose objectives are: (1) optimization of the operation of the lagoons, (2) proposal of adequate solutions to improve the treatment performance and sanitation status of the region, (3) design of structures (new lagoons and extensions), and (4) prediction of future operating conditions (transfer, changes in expenses, etc.).

3.1. Ben Yahi lagoon

The Ben Yahi lagoon receives wastewater from the localities of Aïn Nouïssy and BeniYahi. These agglomerations have a total population (2017) of around 16,824 Hab. In view of the population projection, we recorded an increase with a rate of 1.5%. The population of the two localities will be approximately 26,537 inhabitants by 2045.

The increase in population and the corresponding growth rate have a direct influence on the consumption of drinking water as well as the volume of discharge of wastewater, assumed to be equal to 80% of water consumption. We will have a wastewater flow of 4,292 m^3/d by 2045. Fig. 4 shows the evolution of population and the variation of flow over the period (2017–2045) based on their nominal capacity and a nominal daily flow of 2,800 m^3/d. The figure clearly shows that the lagoon is expected to reach its maximum capacity for dry weather conditions in 2030 and therefore its capacity needs to be increased.

3.1.1. Findings on energy consumption

Fig. 5 illustrates power consumption for the year 2016. Energy consumption reached 50,439 KWh in the second quarter of the year 2016. Indeed, the energy ratio to eliminate 1 kg of BOD_5 was reduced to 0.45, which reflects the vision of the lagoon managers to face the problem of high energy cost.

Fig. 6 represents the rate of energy consumption to treat 1 m^3 of wastewater in 2016, which is approximately

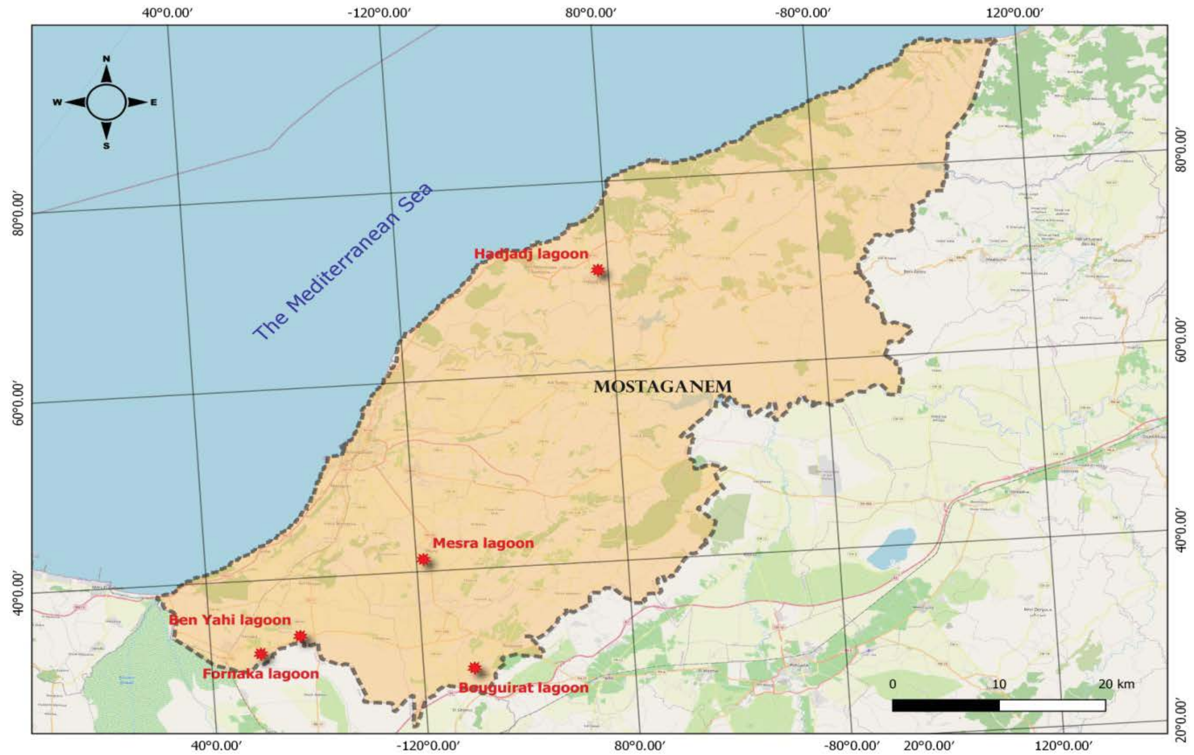

Fig. 3. Location map for Mostagnem lagoons.

Table 1
General characteristics of the five lagoons

Lagoon	Nominal capacity (EQH)	Population (inhabitants)	Wastewater production (m³/d)	Nominal daily flow (m³/d)
Ben Yahi aerated	25,000	16,824	1,730	2,800
Fornaka natural	27,000	11,767	1,085	2,100
Mesra aerated	18,000	18,360	1,890	1,400
Hadjaj aerated	26,000	12,133	1,267	2,600
Boughirat natural	18,000	13,142	1,373	2,600

0.27. The latter is relatively low in comparison to the results obtained from various studies cited in the Chenoweth et al. [36] study. For example, according to water UK's "towards sustainability" report, England and Wales wastewater system have a ratio of 0.634 kWh/m³. The second example is another study of 85 WWTP providing services for 3.5 million equivalent inhabitants (EH) in a German Land which obtained the value of 75 kWh/EH/y (~1.7 kWh/m³).

3.1.2. Impact of connecting other agglomerations

The three agglomerations concerned by this connection are Mansourah, Bled Touahrya, and Sirat, with a total population of 12,589 inhabitants. Population is expected to reach 20,726 inhabitants in 2045, which corresponds to a production of wastewater reaching 3,303 m³/d by the same horizon. Fig. 7 shows that the nominal capacity of the lagoon will be insufficient for the connection of these agglomerations. So, this operational choice of connection does not meet the technical operating conditions.

3.1.3. Proposed scenario

Ben Yahi lagoon has two symmetrical channels in its treatment chain. For this reason, a provisional operating mode was carried out in this lagoon to identify some response elements with respect to its treatment performance. The proposed protocol consists of directing all of the wastewater to a single channel for a given period. After launching this operating mode, the performance analysis results are satisfactory from a quality point of view. Figs. 8 and 9, display the eight (08) measurement samples in terms

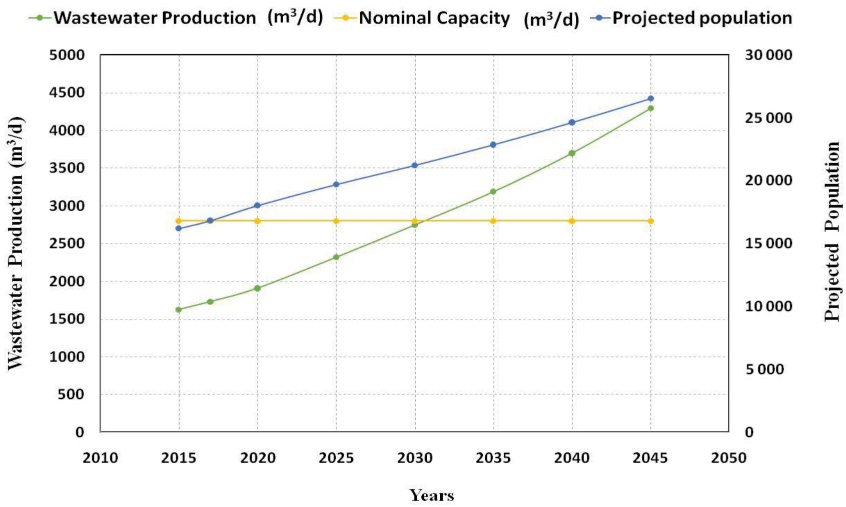

Fig. 4. Population and wastewater production over the period (2015–2045) for Ben Yahi.

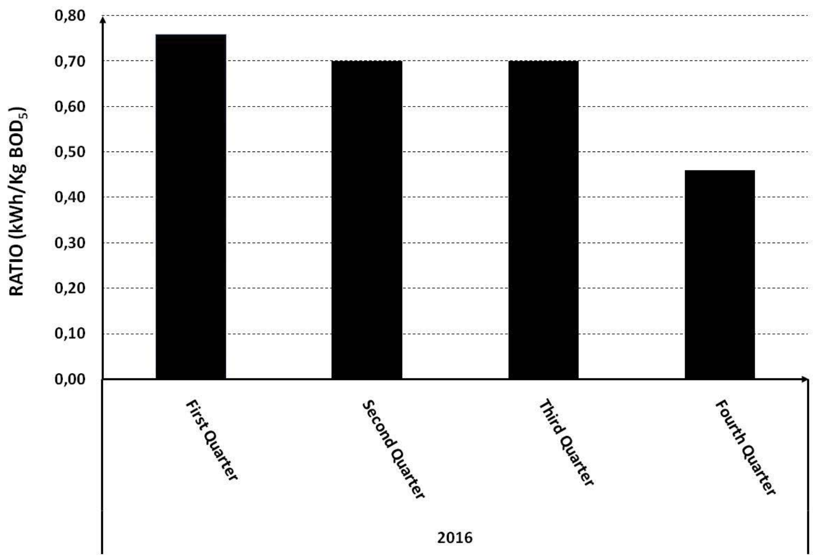

Fig. 5. Estimated KWh/ration (Kg BOD_5 eliminated).

of BOD and COD, respectively. These were developed following a campaign on-site at the outlet of the lagoon for an average operating flow of 1,850 m^3/d. This analysis shows a satisfactory treatment quality of the sector, in spite of specific values exceeding the recommended standard for discharge into the receiving environment for a few samples. In terms of treatment efficiency, there is a reasonably good efficiency with an average value that exceeds 80%, which indicates an interesting rate of pollution. It is important to note at this stage that COD and BOD_5 concentrations obtained in the proposed scenario for Benyahi Station respect the Algerian National standards as well as those of the World Health Organization [37,38].

The COD samples illustrated in Fig. 9 also indicate a satisfactory reduction at a rate of 77%, with an average concentration of 135 mg/L, which generally exceeds the standard threshold. Compared to the current operating mode, this scenario shows similar performance results.

Based on an analysis of the obtained results, we can confirm that this scenario indicates the possibility of transporting all the wastewater to a single sector, provided that we provide some elements of response with regard to management and operation of the lagoon structures. According to the proposed scenario, the design of an aerated pond, summarized in Table 2, was calculated using the following methodology: first, the number of surface aerators is determined. Indeed, it is necessary to calculate the actual oxygen requirement and the standard oxygen rate (clear water at 20°C). The oxygen transfer rate field can also be determined in relation to its capacity under standard oxygen transfer rate. The relationship between the actual conditions and the standard conditions is established using the Shell method [39]. Next, the number of devices required to meet oxygenation needs is obtained by dividing the standard oxygen rate value of a pond by the standard oxygen transfer rate value of the device or by dividing the actual oxygen

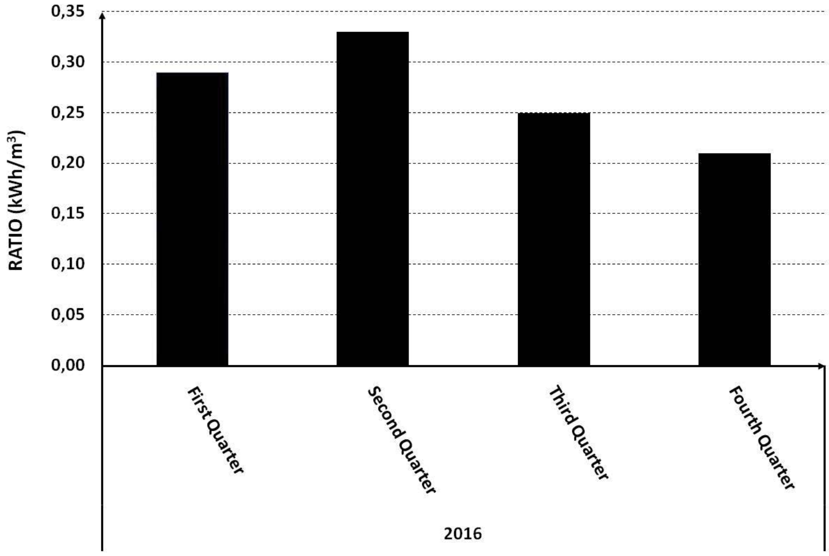

Fig. 6. Rate of KWh/m^3 consumption.

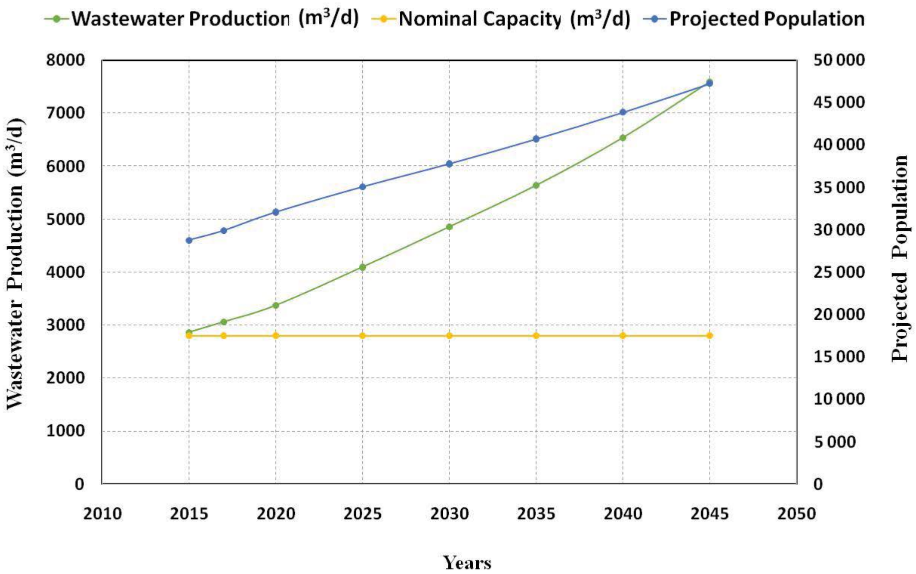

Fig. 7. Production of wastewater according to the projection of the population in the different horizons (with the rejection of Mansourah-Bled Touahriya-Sirat).

requirement value of the pond by that of oxygen transfer rate field of the device. The oxygen transfer rate at standard conditions for aeration devices must result from tests of clear water yield following the procedure corresponding to conditions of complete mixing defined by the ASCE [40]. In optional aerated ponds, where the mixing intensity is greatly reduced, a factor of 90% should be applied to the values of the oxygen transfer rates of the aeration devices used.

3.2. *Fornaka lagoon*

Wastewater from Fornaka lagoon is produced by both localities of Fornaka and Keddadra, with a total population of 11,767 Hab. Through the population projection, we noticed an increase at a rate of 1.5%. Population of both localities can reach 18,512 inhabitants by 2045. According to the population projection and the drinking water demand, estimated on the basis of the national water plan drawn up in 2010, the used water flow reaches 1,085 m^3/d which increases over time. Its value reaches 2,656 m^3/d by 2045 (Fig. 10).

From the increase in the production of wastewater and compared to the nominal capacity, it can be concluded that the year 2037, which represents a production of wastewater of the order of 2,661 m^3/d becomes the threshold of the capacity of operation. This would imply that the capacity of the Fornaka lagoon needs to be improved.

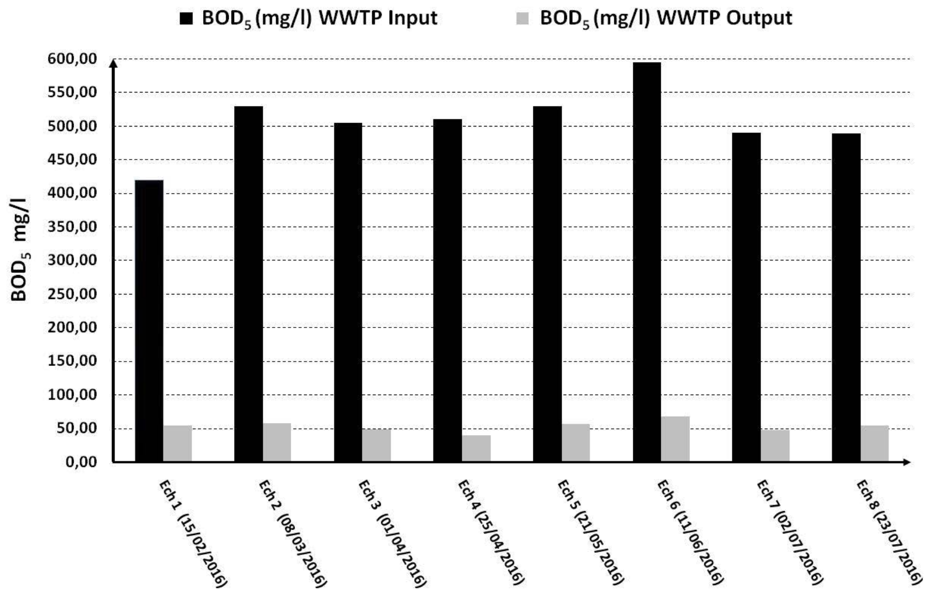

Fig. 8. Characteristics of wastewater samples in terms of BOD_5.

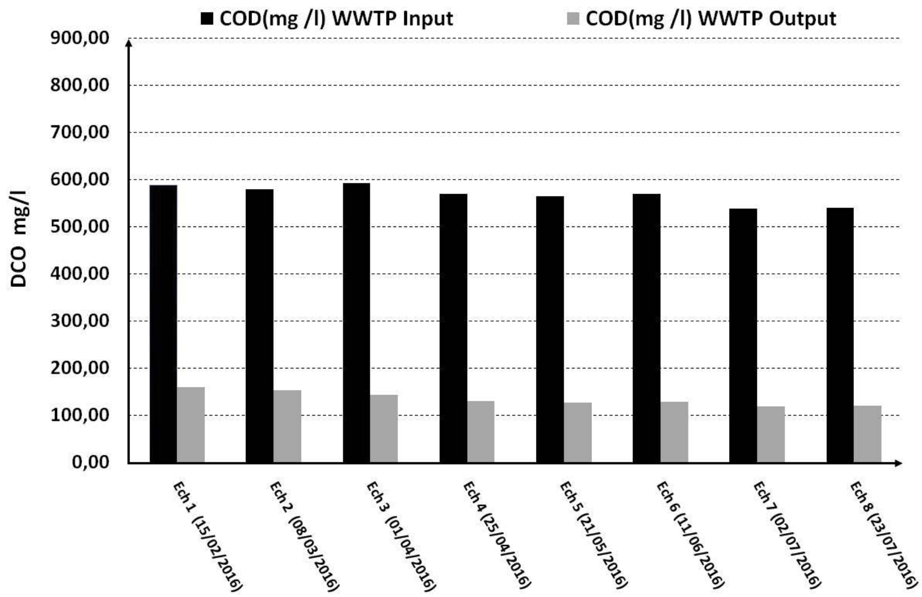

Fig. 9. Characteristics of wastewater samples in terms of COD.

3.2.1. Revised design of the natural lagoon (Fornaka lagoon)

Compared to the real design established by the operating guide of the lagoon, volumes of both aerobic basins were found to be closer to our calculations. However, the calculated dimensions of the two optional and maturing basins exceed the current configuration (Table 3).

As a first proposal to achieve the proper functioning of the lagoon, taking into account a possible transfer of illicit effluents, we recommend an extension of the optional basin and create another maturation basin in order to increase the treatment capacity (especially for suspended solids) and to obtain a satisfactory quality of treated water respecting the reuse standards.

3.2.2. Assessment of sludge production

The volume of sludge accumulated in the ponds directly influences the performance of the treatment plant because it reduces the hydraulic retention time in the cells and, in some cases, the rate of oxygen available in the ponds. In addition, an excessive accumulation of sludge near the raft at the outlet of the last pond can give rise to suspended solids

Table 2
Design parameters for surface aerator

Settings	Symbol	Units	Value
Average daily flow	Q_{AD}	m^3/d	5,973.03
Daily wastewater flow	Q_{DWW}	m^3/d	4,778.43
Peak wastewater flow	Q_{PWW}	m^3/d	7,167.64
Pollutant load in BOD5	BOD_5	kg/d	2,150.29
Volume load	V_L	kg $DBO_5/m^3/d$	0.11
Mass load	M_L	kg DBO_5/kg MS/d	0.02
Breathing coefficients	a'_i		0.32
	b'_i		0.07
Quantity of sludge present in the aeration tank	Sa	Tons	100
Real need for oxygen	AOR_i	kg O_2/h	341.49
Dissolved oxygen concentration at saturation in process water	CSW	mg/L	49.01
Dissolved oxygen concentration at saturation in clear water for standard conditions	CSS	mg/L	51.65
Oxygen transfer rate at process conditions	OTR	Kg O_2/h	42.55
Number of aerators	N_A		8
Water volume	V	m^3	12,672
Retention time	R_t	d	7.45
Overall rate of disappearance of the substrate at temperature	D^{-1}	Ke (T)	0.42
Reduction of solids	X_1	mg-MVE/L	182.60
Specific power	P	W/m^3	6.27

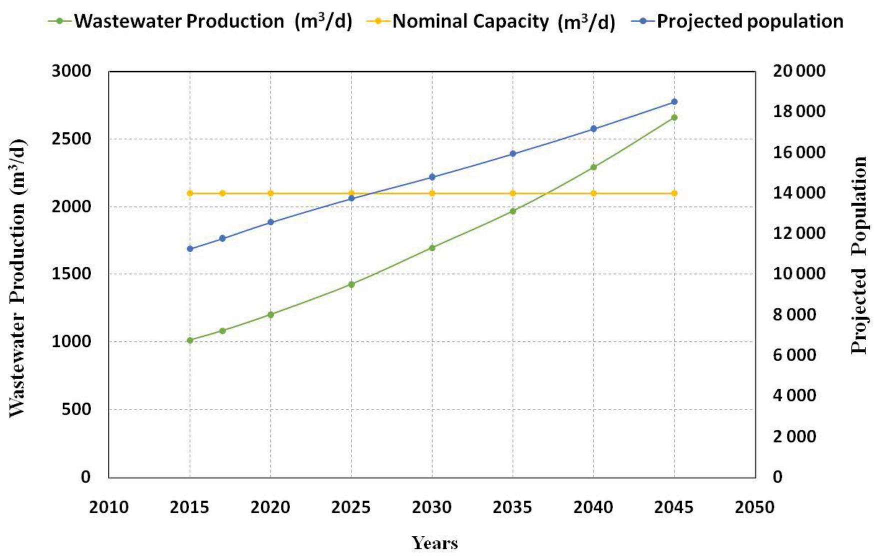

Fig. 10. Wastewater production as a function of population projection in different horizons.

Table 3
Characteristics of natural lagoon basins

Basin	Residence time (days)	Volume (m^3)	Area (m^2)	Depth (m)	Length (m)	Width (m)
Optional	8	17,679.8	15,993	1.5	219.04	37
Aerobic	12	23,990	4,420	4	94.02	47
Maturation	4	7,723.01	6,435.8	1.2	113.45	55

concentrations higher than those normally expected in the effluent of aerated ponds on the basis of an annual average, that is, 13 mg/L. The volume of sludge usually retained when designing the ponds represents 10% of the total water volume of all the cells of the treatment plant [41].

In natural lagoons, the average annual production of sludge is 40 L year per equivalent inhabitant [42]. We can estimate the production of sludge for a daily flow of 2,100 m^3/d. Table 4 represents the production of sludge for Fornaka lagoon. Basin cleaning is done periodically each 2 or 3 y for capacity in equivalent inhabitants exceeding 2,500 equivalent inhabitants.

3.3. Boughirat lagoon

The lagoon receives wastewater from two localities (Boughirat and Souafliya). These agglomerations have a population (2017) of 13,142 inhabitants. Taking into account an increased rate of 1.5%, the total population of both localities is estimated to be around 20,630 inhabitants by 2045. The production of wastewater is expected to reach a flow rate of 3,375 m^3/d at the horizon 2045. Comparing the projection of wastewater production to the nominal capacity of the lagoon, we can say that the lagoon reaches its maximum capacity in the year 2036 (Fig. 11). This clearly shows that improving the lagoon capacity and considering certain maintenance actions become a necessity.

3.3.1. Proposed scenario

In order to protect the environment and eliminate the unauthorized discharge of wastewater, we propose the connection of certain agglomerations while respecting the nominal capacity of the lagoon (Fig. 12). This connection aims to convey wastewater from the Safsaf agglomeration to the main collector of Souafliya. The population connected increases from 1,395 to 2,028 inhabitants with an increased rate of 1.5%. The production of wastewater reaches a flow rate of 335 m^3/d by 2045. The flow rate of the proposed connection coincides with the nominal capacity of the lagoon from the year 2034. Although the capacity of the lagoon was reduced with this type of connection, we gave a medium-term solution to eliminate the maximum of unauthorized effluents. Moreover, this solution shall result in the preservation of the environment and public health.

Table 4
Sludge production in Fornaka lagoon

Maturation	Basin 1 settings	Optional basin 2	Aerobic basin 3
BOD_5 (mg/L) Input S_0	128	76.8	38.4
BOD_5(mg/L) Output Sf	76.8	38.4	30.72
BOD_5eliminate (mg/L)	51.2	38.4	7.68
Daily flow(m^3/d)	2,100	2,100	2,100
Charge eliminate (kg BOD_5/d)	107.52	80.64	16.5
EH	1,784	1,344	257
Total annual sludge production (m^3)	71.36	53.76	8.36

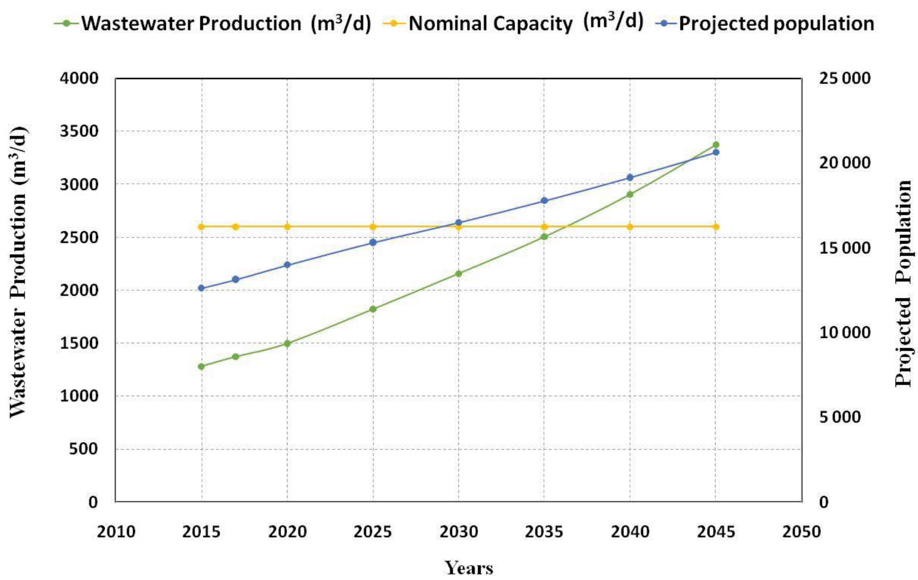

Fig. 11. Population and wastewater production over the period (2015–2045) for Boughirat.

3.4. Hadjadj lagoon

The population of Hadjadj connected to this lagoon in 2017 is around 12,133 Hab. The population is expected to reach 18,961 inhabitants by 2045, which leads to an increase in wastewater discharge from 1,267 to 2,600 m³/d. Fig. 13 shows that by 2038, the lagoon with its current configuration will undergo a biological dysfunction, and therefore increasing its capacity becomes shall be required.

3.4.1. Proposed scenario

The urban area Abdelmalek has a current population of 5,855 inhabitants and is expected to reach 9,149 inhabitants by 2045. From this projection, the flow of wastewater increases from 609 to 1,510 m³/d by 2045. So, with this connection to the Hadjadj lagoon, we will have a dysfunction of the system in 2023 (Fig. 14).

3.5. Mesra lagoon

The population (2017) of the localities Mesra and Aïn Sidi Chérif and the corresponding wastewater discharge volume are estimated to be 18,360 inhabitants 1,890 m³/d, respectively. The population is estimated to increase at a rate of 1.5%. Population of the agglomeration will be around 28,925 inhabitants by 2045. Fig. 15 shows that

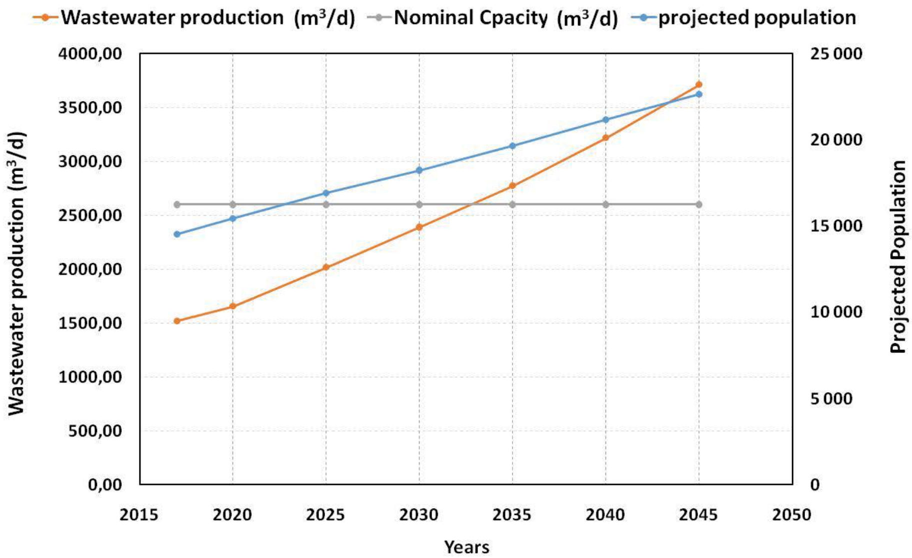

Fig. 12. Wastewater production evolution according to the population growth (taking into account the connection of Safsaf Locality).

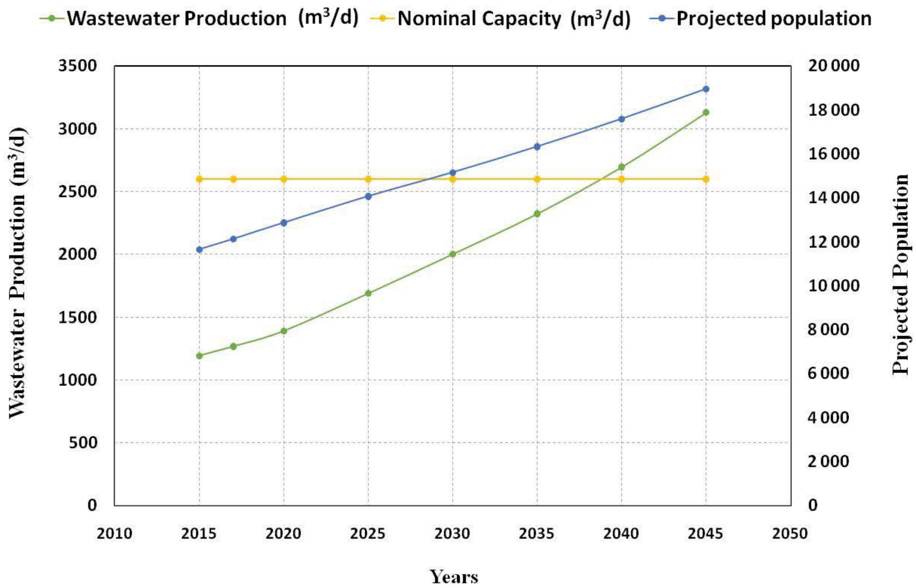

Fig. 13. Wastewater production as a function of population growth in different horizons.

the nominal capacity of the lagoon is insufficient and therefore its capacity needs to be improved.

The lagoon operates in a wastewater treatment system by an aeration tank with a volume of 10,000 m^3 and a settling tank with a volume of 4,300 m^3 and two retention basins with a total volume of 15,000 m^3. Currently, to ensure the suggested capacity for wastewater discharged by both localities, we must proceed with the creation of a second sector which is characterized by other technical specifications to cope with the large volume of oils from the copper industrial unit implanted in the region. This last observation confirms the degradation of the quality of treated wastewater which completely eliminates the possibility for reuse. Therefore, pretreatment of metallic industrial effluents is required prior to its discharge to the public sewerage network.

4. Conclusions and recommendations

Structural and functional diagnostic tasks of the lagoon structures were considered to better characterize all the anomalies and causes of malfunction. This work of evaluation of the treatment performance and the analysis of the current and future situations of sanitation in the study region resulted in the following:

- The possibility to test scenarios and their interactions, to calculate and help interpret the global phenomena observed in the lagoons;
- The energy aspect was addressed with satisfaction for the aerated lagoon of Ben Yahi and led to the establishment of eight surface aerators instead of six;
- Based on the current configuration of the lagoon of Ben Yahi, its biological treatment capacity was found

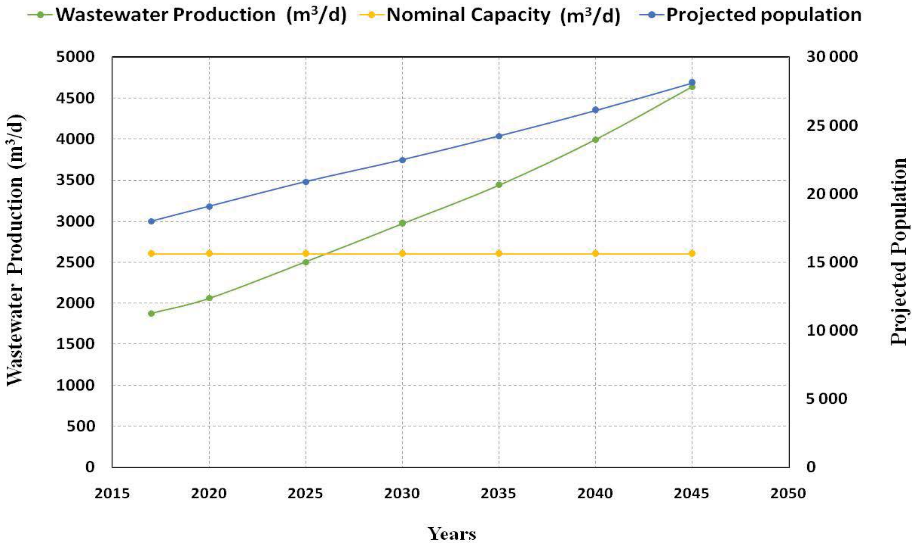

Fig. 14. Wastewater production according to population growth in different horizons (with the discharge of AbdAlmalek Locality).

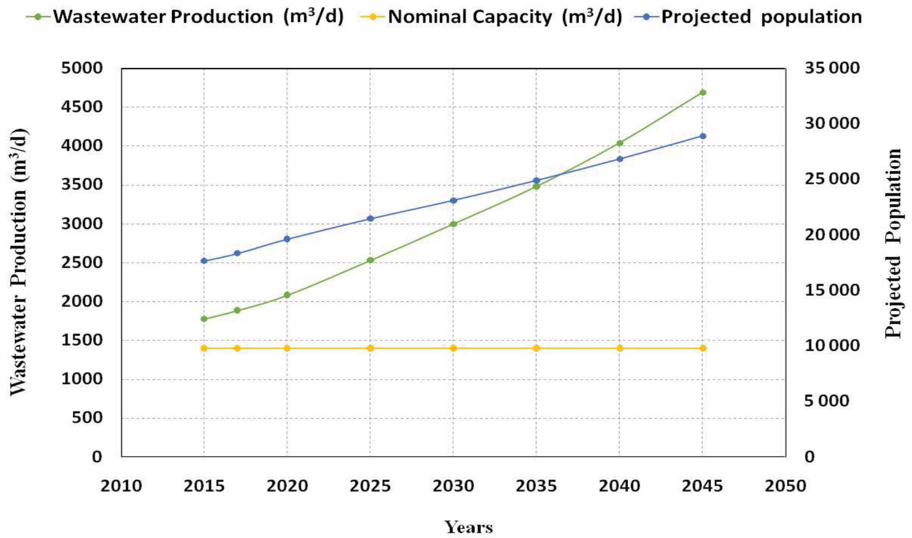

Fig. 15. Wastewater production according to population growth in the different horizons.

to be 2,800 m^3/d. The proposed scenario of operation of two units is expected to yield biological satisfactory treatment.

- Treatment capacities of Hadjaj and Boughirat lagoons were found to be sufficient to receive wastewaters from the localities of Abdelmalek and Safsaf, respectively.
- Based on the current configuration of the Mesra lagoon, the system had become saturated since 2015, which requires the establishment of another aeration basin similar to the first one and another retention basin downstream of the process.
- The results obtained in this study may be valorized in the wastewater management plan fixed by the Algerian State, where proposed scenarios and operational choices may have sound scientific and technical justifications.

References

[1] N.M. Chabaca, A. Kettab, M. Nakib, S. Karef, S. Benziada, S. Benmamar, W. Boumalek, H. Bouanani, Y. Djillali, The lagunage for the purification of waste water in the Sahara: an approach integrated into the environmental conditions, Algerian J. Environ. Sci. Technol., 3 (2017) 419–425.

[2] M. Mozas, A. Ghosn, State of the Water Sector in Algeria, Institute of Economic Perspective of the World Mediterranean (IPMED), 2013, pp. 1–27.

[3] D. Singh, R. Gupta, A. Tiwari, Phytoremediation of lead from wastewater using aquatic plants, Int. J. Biomed. Res., 2 (2011) 411–421.

[4] L. Bouchaala, N. Charchar, A. Gherib, Ressources hydriques: traitement et réutilisation des eaux usées en Algérie, Algerian J. Arid. Environ., 7 (2017) 84–95.

[5] R. Craggs, J. Park, D. Sutherland, S. Heubeck, Economic construction and operation of hectare-scale wastewater treatment enhanced pond systems, J. Appl. Phycol., 27 (2015) 1913–1922.

[6] K. Mohammadreza, Z. Khodaparast, Review on recent developments on pulp and paper mill wastewater treatment, Ecotoxicol. Environ. Saf., 114 (2015) 326–342.

[7] P. Boutin, Y. Racault, Natural lagooning, current situation of a purification technique in France, Tech. Sci. Methods, 81 (1986) 273–284.

[8] Hydroplus, Wastewater Recovery for Agriculture, A National Project, Vol. 61, 1996, pp. 32–35.

[9] B. Adan, E.W. Lee, High Rate Algal Growth Pond Study under Tropical Conditions, Wastewater Treatment and Resource Recovery: Report of a Workshop on High Rate Algae Ponds, Singapore, 1980.

[10] K.R. Chaffee, Heat Transfer Wastewater Treatment System U.S., Patent Application Reports, WO2016/100990, 2017.

[11] M. Boutayeb, A. Bouzidi, Optimization of the design of treatment basins by natural lagooning in the Chaouia Ouardigha-Morocco region, Nat. Technol., 10 (2014) 1–15.

[12] H. Chaouki, L. Elwatik, Y. Ramchoun, R. Fath-Allah, A. Ayyach, Z. Fathallah, A. El Midaoui, E.M. Hbaiz, Study of the treatment performance of the technique of aerated lagoons applied of the wastewater treatment plant of the city of Errachidia-Morocco, Afr. Sci. J. Int. Sci. Technol., 10 (2014) 173–183.

[13] H.W. Pearson, S.T. Avery, S.W. Mills, P. Njaggaht, P. Odiambotet, Performance of the phase II Dandora waste stabilisation ponds the largest in Africa: the case for anaerobic ponds, Water Sci. Technol., 33 (1996) 91–98.

[14] M.M. Saqqar, M.B. PESCOD, Performance evaluation of anoxic and facultative wastewater stabilization ponds, Water Sci. Technol., 33 (1996) 141–145.

[15] T.P. Curtis, D.D. Mara, S.A. Silva, Influence of pH, oxygen, and humic substances on ability of sunlight to damage fecal coliforms in waste stabilization pond water, Appl. Environ. Microbiol., 58 (1992) 1335–1343.

[16] L.M. Evison, Comparative studies on the survival of indicator organisms and pathogens in fresh and sea water, Water Sci. Technol., 20 (1988) 309–315.

[17] D. Koné, Purification of Wastewater by Microphyte and Macrophytes Lagooning in West and Central Africa: Inventory, Purification Performance and Sizing Criteria, PhD Thesis from École Polytechnique Fédérale De Lausanne, 2002.

[18] H.I. Shuval, P. Yekutiel, B. Fattal, An epidemiological model of the potential health risk associated with various pathogens in wastewater irrigation, Water Sci. Technol., 18 (1986) 191–198.

[19] A. Klutsé, Epuration des Eaux Usées Domestiques par Lagunage en Zone Soudano-sahélienne: Ouagadougou, Burkina Faso, PhD Thesis From Montpellier 2, France, 1995.

[20] Y.A. Idrissi, N. Darwesh, I. Belhaili, A.L. Achheb, A. Alemad, K. Elkharrim, D. Belghyti, Study of the treatment performance of the technique of Natural lagoons of the treatment plant for domestic wastewater of the city Azilal-Maroc, J. Int. Innovation Appl. Stud., 13 (2015) 507–517.

[21] C. Peitz, C.R. Xavier, Evaluation of aerated lagoon modified with spongy support medium treating Kraft pulp mill effluent, Rev. Facing Univ. Antioquia, 92 (2019) 60–69.

[22] P. Young, N. Buchanan, H.J. Fallowfield, Inactivation of indicator organisms in wastewater treated by a high rate algal pond system, J. Appl. Microbiol., 121 (2016) 577–586.

[23] D. Wrede, S.U. Hussainy, W. Rajendram, S. Gray, Investigation and modeling of high rate algal ponds utilizing secondary effluent at Western water, Bacchus marsh recycled water plant, Water Sci. Technol., 78 (2018) 20–30.

[24] C. Boutin, O. Caquel, N. Dimastromatteo, M.A. Durot, P. Molle, G. Fernandes, S. Parotin, S. Prost Boucle, C. Tscherter, Ouvrages de Traitement par Lagunage Naturel, Filière Classique et Filières Combinées, Guide d'Exploitation, 2018.

[25] M.A. Durot, P. Molle, L. Vasseur, Improvement of the Discharge from Treatment Lagoons, Bibliographic Synthesis, EPNAC Report. Available at: https://epnac.irstea.fr/wp-content/uploads/2016

[26] A. Shilton, Pond Treatment Technology, IWA Publishing, London, 2006.

[27] S.K. Jayaraman, R.R. Rhinehart, Modeling and optimization of algae growth, Ind. Eng. Chem. Res., 54 (2015) 8063–8071.

[28] D. Undurraga, P. Poirrier, R. Chamy, Microalgae growth kinetic model based on the PSII quantum yield and its utilization in the operational curves construction, Algal Res., 17 (2016) 330–340.

[29] Y.H. Wu, X. Li, Y. Yu, H.Y. Hu, T.Y. Zhang, F.M. Li, An integrated microalgal growth model and its application to optimize the biomass production of *Scenedesmus* sp. LX1 in open pond under the nutrient level of domestic secondary effluent, Bioresour. Technol., 144 (2013) 445–451.

[30] Q. Béchet, P. Chambonnière, A. Shilton, G. Guizard, B. Guieysse, Algal productivity modeling: a step toward accurate assessments of full-scale algal cultivation, Biotechnol. Bioeng., 112 (2015) 987–996.

[31] M. Huesemann, B. Crowe, P. Waller, A. Chavis, S. Hobbs, S. Edmundson, M. Wigmosta, A validated model to predict microalgae growth in outdoor pond cultures subjected to fluctuating light intensities and water temperatures, Algal Res., 13 (2016) 195–206.

[32] W.W. Eckenfelder Jr., Water Quality Engineering for Practicing Engineers, Barnes and Noble, New York, NY, 1970.

[33] P. Kumar, R.J. Garde, Potentials of water hyacinth for sewage treatment, Res. J. Water Pollut. Control Fed., 61 (1989) 1702–1706.

[34] R.H. Kadlec, R.L. Knight, Treatment Wetlands, CRC Press Inc., Boca Raton, FL, 1996.

[35] R. Knight, J. Vymazal, H. Brix, P. Cooper, R. Haberl, Constructed Wetlands for Pollution Control, IWA Publishing, London, 2000.

[36] J. Chenoweth, B. Durham, L. Job, Economic value of treated wastewater, Techn. Sci. Methods, 12 (2007) 95–109.

[37] Executive Decree No. 06–141 of 19 April 2006 Laying Down the Limits of Industrial Liquid Effluent Discharges, Official Journal of Republic of Algeria, 2006 (in French).

[38] WHO, Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture: Report of a WHO Scientific Group, WHO Technical Reports Series 778, World Health Organization, Geneva, Switzerland, 1989.
[39] Environment Canada, Guide for the Study of Conventional Technologies for Treating Domestic Wastewater, 2002. Available at: http://www.environnement.gouv.qc.ca/eau/eaux-usees/domestique
[40] ASCE, Standard - Measurement of Oxygen Transfer in Clean Water, ANSI/ASCE 2–91, 2nd ed., 1992.
[41] F.L. Burton, G. Tchobanoglous, R. Tsuchihashi, H.D. Stensel, Metcalf & Eddy, Inc., Wastewater Engineering: Treatment and Resource Recovery, McGraw-Hill, London, 2013.
[42] M. Vuillot, C. Boutin, The Exploitation of Natural Lagoons, Technical Guide for the Use of Small Communities, Technical Documentation FNDAE, Cemagref Editions, 1985.