Desalination and Water Treatment
www.deswater.com
doi: 10.1080/19443994.2015.1070752

57 (2016) 15250–15262
July

Taylor & Francis
Taylor & Francis Group

Relieving the water shortage crisis of Algeria by reusing treated wastewater lagoons

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Received 23 February 2014; Accepted 25 June 2015

ABSTRACT

The natural lagoon is the most suitable system for rural areas, where there is a large agricultural activity that requires a large consumption of water. Consequently, if the natural lagoon allows wastewater to have a quality consistent with the standards of agricultural reuse, then the problem of water shortages faced by the agriculture sector in Algeria could be relieved. The aim of this work was to study the purification performance of natural lagoons in Algeria. The following four stations were studied: Sidi Senoussi, Sidi Safi, El Maleh, and Amir Ebdel Kader. Incoming and outgoing waters of these lagoons were analyzed by the following parameters: alkalinity, total suspended solids, biological oxygen demand, chemical oxygen demand, ammonium (N-NH_4^+), nitrate N-NO_3^-, dissolved oxygen, electrical conductivity, and microbiological parameters. These analyses were carried out twice a month, during the years 2010, 2011, and 2012. The results indicated that the natural lagoon alone is not sufficient to produce clean water with an adequate quality to meet the standards for agricultural reuse.

Keywords: Natural lagoon; Algeria; Agricultural reuse of treated wastewater

1. Introduction

Algeria is one of the poorest countries in terms of water potential, due to the weakness of the resource, worsened by drought and urban, industrial, and agricultural pollution [1]. The agricultural sector is the most affected sector by the water crisis because the majority of growing areas are located where water is scarce and difficult to exploit. Therefore, alternatives need to be explored to mobilize and improve resource management [2]. Unfortunately, these procedures are slow and too costly for the state and communities. A more economical solution would be the reuse of treated wastewater for agricultural purposes. Irrigation by treated wastewater, which is more readily available, will encourage farmers to practice all types of cultures without fear of drought. These wastewater contain fertilizers that enable farmers to save the cost of the use of the agricultural amendments. According to the studies by Choukr-Allah and Aghai in Drarga (Morocco), the use of treated wastewater in irrigation improved the quality and quantity of the harvest (the quantity was doubled), and it also allowed farmers to improve their standard of living [3]. In Algeria, there are 102 working wastewater treatment stations

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(52 STEP and 50 lagoons) for a capacity of 570 h/m^3 per year [4]. Therefore, the lagoons ability covers almost half of the purification systems used in Algeria. The natural lagoon system appears to be the most appropriate in rural areas due its simplicity. This study examines the quality of treated wastewater by this lagoon system and identifies the problems and imperfections.

Water resources in Algeria are characterized by an irregularity in space and time and a persistent drought. With regard to surface water, the volume of water resource will be mobilized to 4.5 billion m^3 resources (including dam construction or those programmed). This volume can be considered as a ceiling because it encompasses all geologically favorable sites [5]. Whereas water needs in 2020 will be over 8.3 billion m^3 per year, almost twice the volume presently mobilized.

Regarding groundwater, Algeria has 1.9 billion m^3 in the north, where the resource is being exploited at more than 90%; soon facing critical state of overexploitation [6]. In the south of Algeria there are 4.9 billion m^3 of usable resource. Some of the big, deep sheets of water are not renewable in the Sahara [6].

The useful agricultural area is 8,560,509 ha, and the irrigable land is 2.3 million ha (1.3 million ha can be irrigated without irrigation development). The irrigated area is 950,000 ha on average (11% of the agricultural area and 40% of irrigation potential) [2].

Because of the water shortage, Algeria can use only 40% of the irrigable area, while 60% of agricultural land remains unexploited. Finding additional supply of water resources has become an urgent need, and ambitious programs of reuse of treated wastewater for agricultural purposes have been launched [2]. Algeria has set the limit values for irrigation with purified water to physicochemical and microbiological parameters, as presented in Tables 1 and 2.

2. Materials and methods

To assess the treatment performance of natural lagoons and provide the technical solutions needed to improve effectiveness in Algeria, we chose to study four operating stations located in the following western Algerian wilaya: Sidi Senoussi (wilaya of Tlemcen), Amir Ebdel Kader, Sidi Safi, and El Maleh (wilaya of Ain Temouchent).

2.1. Climate

The climatic conditions of the lagoon stations are identical because the stations are next to each other. To study the climate context, we have used the climate stations next to the study area (stations of Ain Temouchent and Sidi Abdeli). Climate measures noted in the regions bordering the lagoon stations showed the following type of climate: a wet winter and a dry summer. The climate of the coastal zone is of the Mediterranean type, characterized by a long period of drought (from May to October) as well as by mild temperatures and relatively high rate of humidity. For the study of temperature we used for the lagoon of Sidi Senoussi the climatology station of Sidi Abdeli, and for lagoons of Amir, Sidi Safi, and El Maleh we used the climatology station of Ain Temouchent station. The measurements are summarized in Tables 3 and 4.

Table 1
Algerian standards for wastewater reuse in irrigation: microbiological parameters

	Microiological parameter	
Crop groups	Fecal coliforms (CFU/100 ml) (Geometric mean)	Intestinal nematodes (eggs/l) (Arithmetic mean)
Unrestricted irrigation culture products that can be eaten raw	<100	without
Vegetables that are eaten only cooked	<250	<0.1
Vegetables for canning or non-food processing		
Fruit trees	Recommended threshold	<1
Crops and fodder shrubs	<1,000	
Cereal crops		
Industrial crops		
Forest trees		
Floral and ornamental plants		

Note: Source: Directorate of hydraulic “water police”.

Table 2
Algerian standards for wastewater reuse in irrigation: physicochemical parameters

Parameters		Unit	Maximum allowable concentration
Physical	pH		6.5 < pH < 8.5
	Total suspended solid	mg/l	30
	Electrical conductivity	ds/m	3
Chemical	BOD5	mg/l	30
	COD	mg/l	90
	Nitrogen (NO_3^--N)	mg/l	30
	Aluminum	mg/l	20
Toxic elements for type of fine-textured soils, neutral or alkaline	Arsenic	mg/l	2.0
	Beryllium	mg/l	0.5
	Boron	mg/l	2.0
	Cadmium	mg/l	0.05
	Chrome	mg/l	1.0
	Cobalt	mg/l	5.0
	Copper	mg/l	5.0
	Cyanides	mg/l	0.5
	Fluorine	mg/l	15
	Iron	mg/l	20
	Phenols	mg/l	0.002
	Lead	mg/l	10.0
	Lithium	mg/l	2.5
	Manganese	mg/l	10.0
	Mercury	mg/l	0.01
	Molybdenum	mg/l	0.05
	Nickel	mg/l	2.0
	Selenium	mg/l	0.02
	Vanadium	mg/l	1.0
	Zinc	mg/l	10.0

Note: Source: Directorate of hydraulic "water police".

Table 3
Average monthly temperatures (Sidi Abdelli station) 2004–2005

	September	October	November	December	January	February	March	April	May	June	July	August
˚C	24.3	21.1	13.1	10.3	8.5	8.2	13.2	16	21.7	24.4	27.6	27.5

Table 4
Average monthly temperatures (Ain Temouchent station) 1994–2001

	September	October	November	December	January	February	March	April	May	June	July	August
˚C	22.98	20.29	16.64	14.49	11.90	13.93	14.90	16.8	19.24	22.29	24.64	25.60

2.2. Description of the lagoon stations

The basic data of the studied lagoons are summarized in Table 5.

The lagoon of Sidi Senoussi is a natural one, and the waters treated are of domestic nature. The lagoon is composed of:

(1) Pretreatment (screening and grit removal),
(2) Biological treatment: this course is composed of six basins, which are divided in three stages: two anaerobic ponds (the surface is 30 m × 30 m with a depth 4 m), two facultative ponds (38 m wide, 150 m long, and 1.5 m

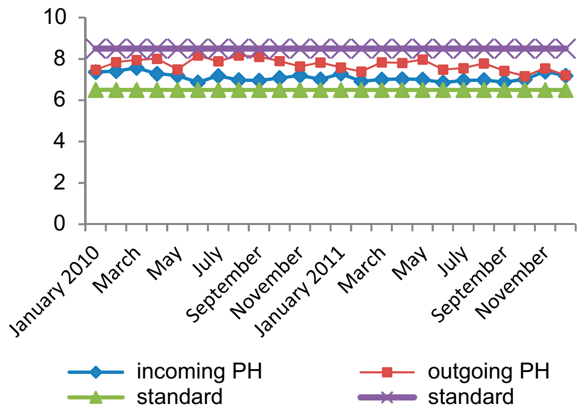

Fig. 1. Changes in pH for Sidi Senoussi.

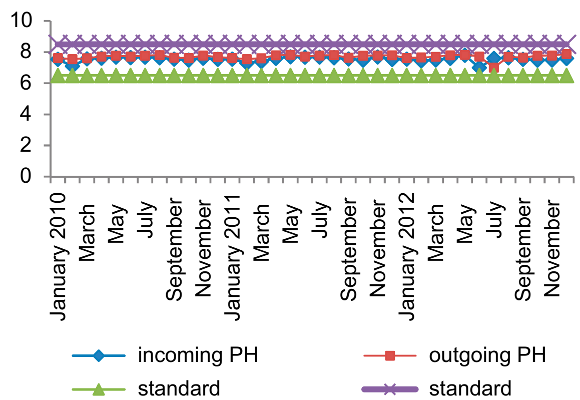

Fig. 2. Changes in pH for Amir Ebdel Kader.

deep), and two maturation ponds of a surface 54 m × 54 m and a depth 1.2 m.

The natural lagoon of Amir Ebdel Kader (wilaya of Ain Temouchent) treats water of domestic nature and consists of:

(1) Pretreatment (screening and grit removal).
(2) Biological treatment (a 2.5 m deep facultative basin and a 1.50 m deep maturation pond).

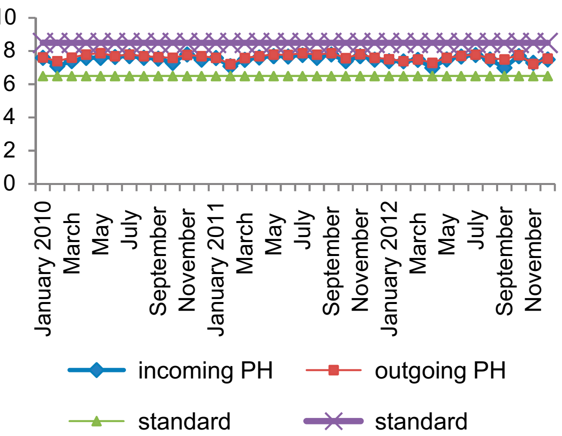

Fig. 3. Changes in pH for Sidi Safi.

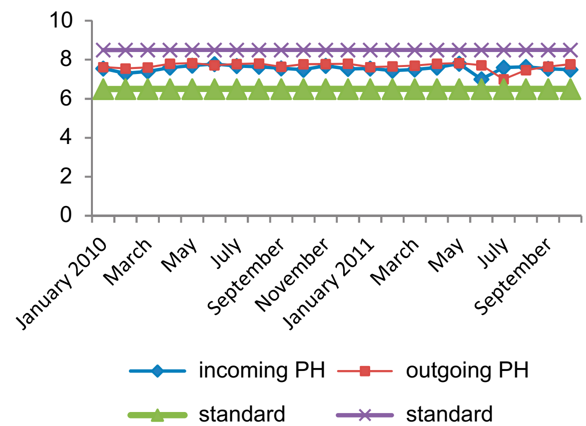

Fig. 4. Changes in pH for Amir Ebdel Kader.

(3) There is tertiary treatment consisting of a decanter and a disinfector. Unfortunately, this system has never worked because of its flawed design.

The lagoon of Sidi Safi, situated in the Daira of Beni Saf (wilaya of Ain Temouchent), is composed of:

Table 5
Data on the lagoon stations

	El Maleh	Amir	Sidi Safi	Sidi Senoussi
Lagoon capacity by inhabitant equivalent	For 2030 27,000	For 2015 4,000	For 2030 14,500	For 2030 12,000
Wastewater quality	Domestic water	Domestic water	Domestic water	Domestic water
Site area occupied by the lagoon (ha)	11.5	4.45	9.4	6.3
Date of commissioning	October 2008	May 2005	October 2008	December 2007
Annual discharge treated (m^3/d)	968	314	397	838

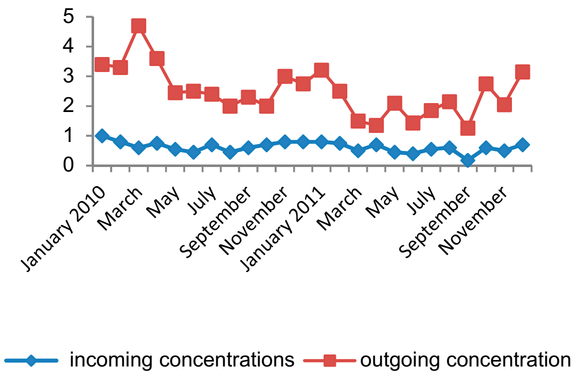

Fig. 5. Changes in dissolved oxygen for Sidi Senoussi.

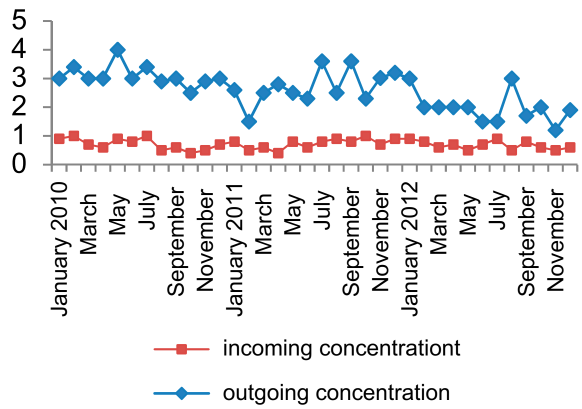

Fig. 7. Changes in dissolved oxygen for Sidi Safi.

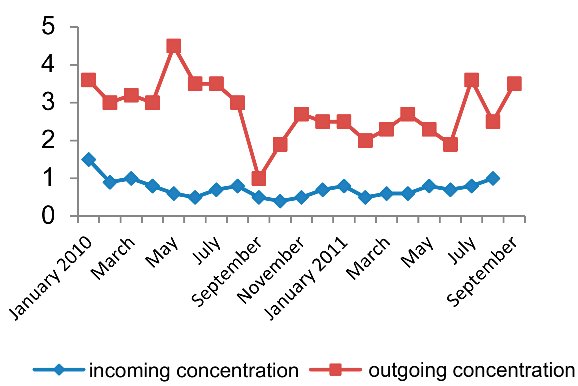

Fig. 6. Changes in dissolved oxygen for Amir Ebdel Kader.

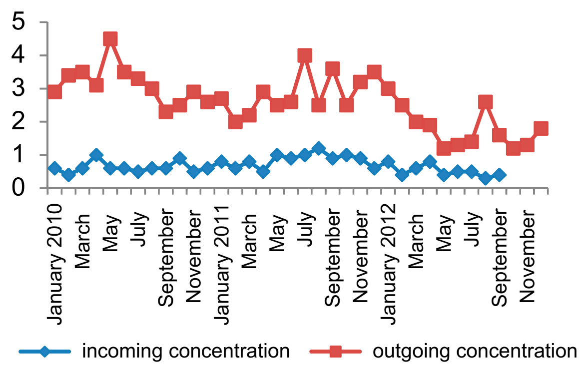

Fig. 8. Changes in dissolved oxygen for El Maleh.

(1) Pretreatment (screening and grit removal).
(2) Biological treatment: An circular anaerobic pond (3 m deep with a surface area of 1,134.11 m^2).
(3) A facultative pond which has the shape of bean grain with, a depth of 1.5 m, and a surface area of about 5,511 m^2.
(4) A maturation pond that is shaped like a bean grain with a depth of 1 m and a surface of 6,630 m^2.

The lagoon of El Maleh consists of:

(1) Pretreatment (screening, grit removal).
(2) Biological treatment, which consists of three lagoons.
(3) An anaerobic square pond with a surface area of 4.30 × 44.30 m and a height of 4 m.
(4) Two facultative ponds (two units of 280 × 87 m and a height of 2 m each).
(5) A maturation pond with a surface dimension of 80 × 80 m and a height of 1.50 m.

Table 6
Critical values of pH

	Sidi Senoussi	Amir Ebdel Kader	Sidi Safi	El Maleh
Average concentration incoming/outgoing	7.10/7.71	7.3/7.69	7.53/7.68	7.54/7.67
Max incoming/outgoing	7.57/8.17	7.79/7.88	7.8/7.88	7.8/ 7.83
Min incoming/outgoing	6.85/7.16	6.9/7.1	7/7.22	7/7.1
Standard	9.5–8.5			

Table 7
Critical values of dissolved oxygen

	Sidi Senoussi	Amir Ebdel Kader	Sidi Safi	El Maleh
Average concentration incoming/outgoing (mg/l)	0.62/2.48	0.74/2.79	0.66/2.54	0.70/2.59
Max incoming/outgoing (mg/l)	1/4.7	1.5/4.5	1/4	1.2/4.5
Min incoming/outgoing (mg/l)	0.18/1.26	0.4/1	0.3/1.2	0.3/1.2

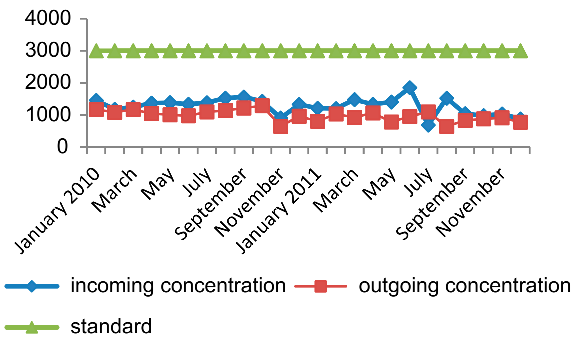

Fig. 9. Changes in electrical conductivity for Sidi Senoussi.

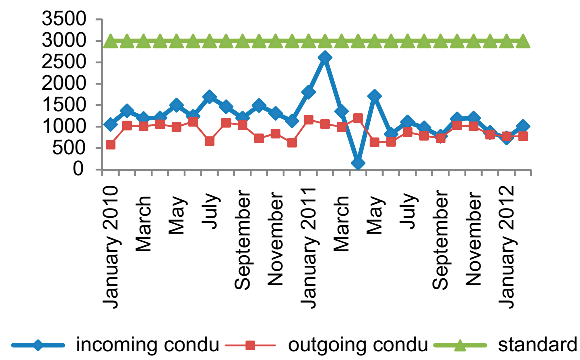

Fig. 11. Changes in electrical conductivity for Sidi Safi.

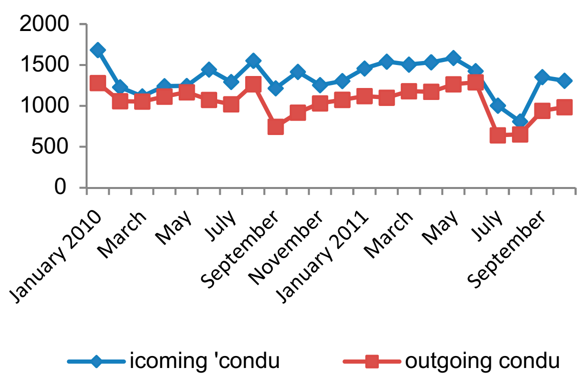

Fig. 10. Changes in electrical conductivity for Amir Ebdel Kader.

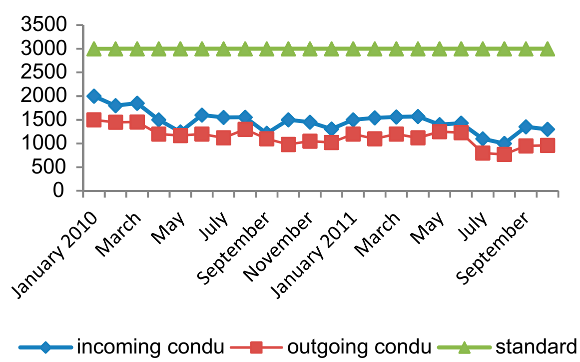

Fig. 12. Changes in electrical conductivity for El Maleh.

In our study, we analyzed the incoming and outgoing wastewater during the years 2010, 2011, and 2012 for the following parameters: alkalinity (pH), total suspended solids (TSS), biological oxygen demand (BOD5), chemical oxygen demand (COD), $N\text{-}NH_4^+$, $N\text{-}NO_3^-$, dissolved oxygen, electrical conductivity, and microbiological parameters.

3. Results and discussion

The results are shown in the figures, and the critical values (average incoming and outgoing, maximum value incoming and outgoing, incoming and outgoing minimum values, average performance for each parameters) are summarized in the tables.

3.1. Results of pH

pH is the hydrogen ion concentration $[H_3O^+]$ in a liquid. In water, pH plays an important role in both the physicochemical properties and microbiological parameters. For the four lagoons the pH is located between the values limited by the standards. As can be seen in Figs. 1–4 and Table 6, there is a slight increase in pH outgoing water compared to the incoming one, but it remains consistent with the standards. We can justify this increase in pH by H ions generated during the operation of nitrification.

Table 8
Critical values of conductivity

	Sidi Senoussi	Amir Ebdel Kader	Sidi Safi	El Maleh
Average concentration incoming/outgoing (µs/cm)	1,279.84/979.47	1,342.31/1052.45	1,238/895.38	1,469.27/1142.04
Max incoming/outgoing (µs/cm)	1,849.66/1,289 1,289	1,684/1,289	2,610/1,201	2,000/1,500
Min incoming/outgoing (µs/cm)	686.7/642.5	810/641	154/584	1,000/770
Average yield (%)	24.59	21.59	27.69	22.27
Standard	3,000 µs/cm			

Table 9
Critical values of TSS

	Sidi Senoussi	Amir Ebdel Kader	Sidi Safi	El Maleh
Average concentration incoming/outgoing (mg/l)	450.86/66.04	421.9/195.4	443.2/190.2	494.8/235.3
Max incoming/outgoing (mg/l)	594.5/106.5	800/ 457	800/368	1,018/446
Min incoming/outgoing (mg/l)	311/30.5	150/93	130/100	200.5/91
Average yield (%)	85.35	53.68	57.08	52.44
Standard	30 mg/l			

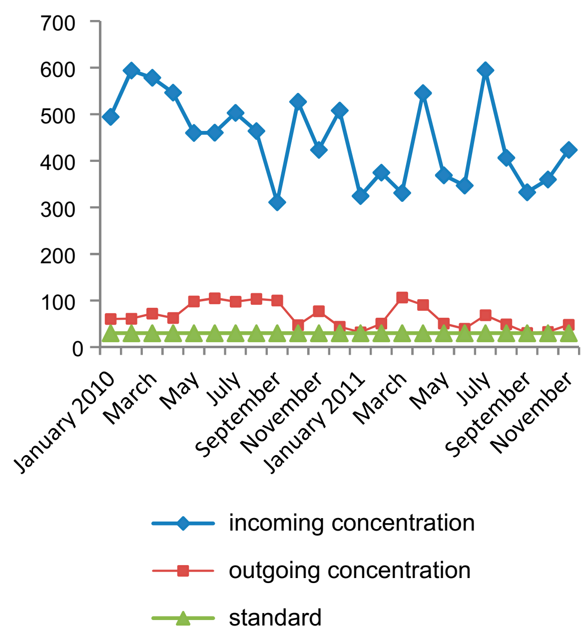

Fig. 13. Changes in TSS Concenration for Sidi Senoussi.

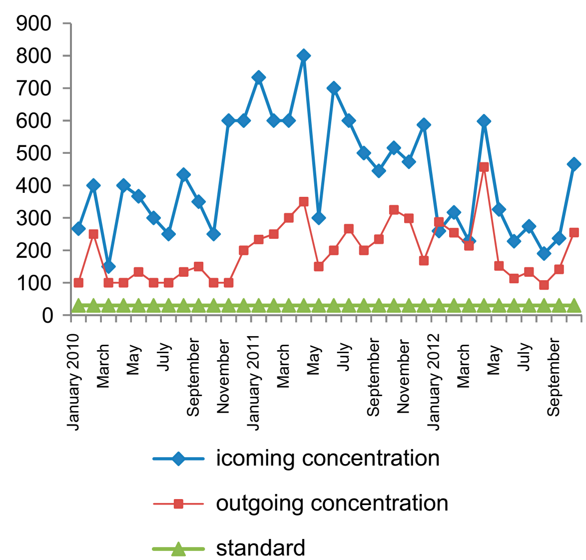

Fig. 14. Changes in TSS Concenration for Amir Ebdel Kader.

3.2. Results of dissolved oxygen

The concentrations of dissolved oxygen in the raw water of the studied lagoons varied between 0.18 and 1.5 mg/1, which explains the high pollution. The concentration of dissolved oxygen in the discharged water increased (between 3.1 and 5.3 mg/l). The cause of this excess of oxygen is because of the diffusion of air from the atmosphere, which is added to the amount of O_2 produced by algae during the operation of the photosynthesis (Figs. 5–8 and Table 7).

3.3. The results of electrical conductivity

Conductivity is the rate of the presence of minerals in the water. Conductivity of the incoming and outgoing wastewater was measured. The values of the

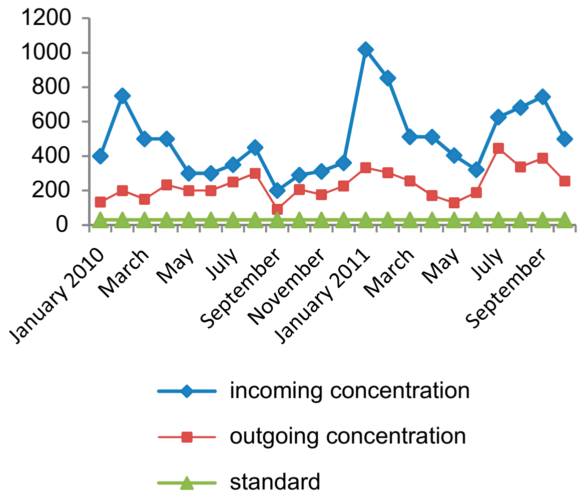

Fig. 15. Changes in TSS Concenration for El Maleh.

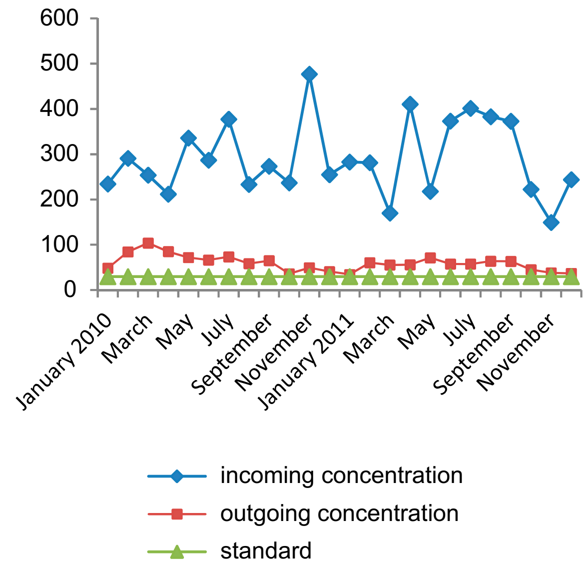

Fig. 17. Changes in BOD5 Concentration for Sidi Senoussi.

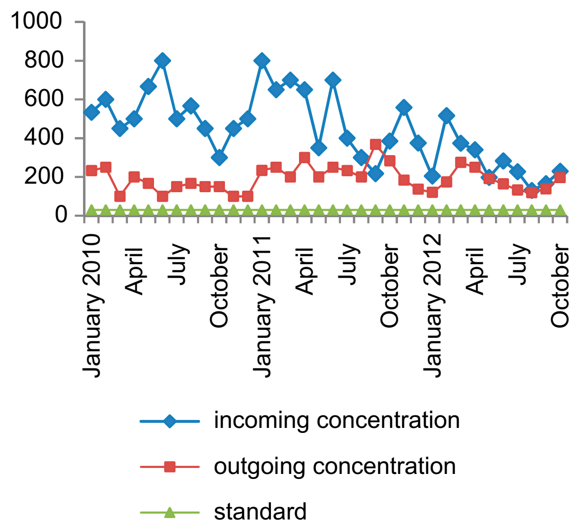

Fig. 16. Changes in TSS Concenration for Sidi Safi.

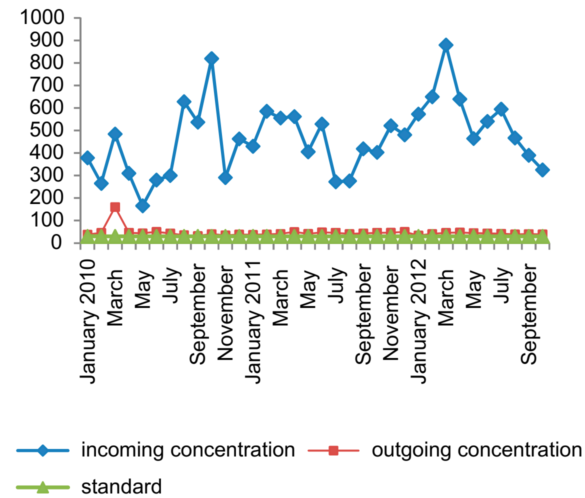

Fig. 18. Changes in BOD5 Concentration for Amir Ebdel Kader.

Table 10
Critical values of results of the BOD5

	Sidi Senoussi	Amir Ebdel Kader	Sidi Safi	El Maleh
Average concentration incoming/outgoing (mg/l)	290.74/59.36	467.27/45.46	420.17/40.74	340.86/43.96
Max incoming/outgoing (mg/l)	477/104	880/160	945/47.5	695/133
Min incoming/outgoing (mg/l)	149.5/34.5	165.7 /31.45	133.5/29.5	126.5/31.5
Average yield (%)	79.58	90.27	90.29	87.10
Standard	30 mg/l			

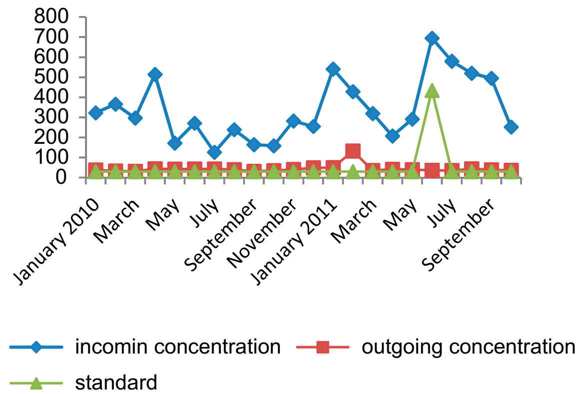

Fig. 19. Changes in BOD5 Concentration for El Maleh.

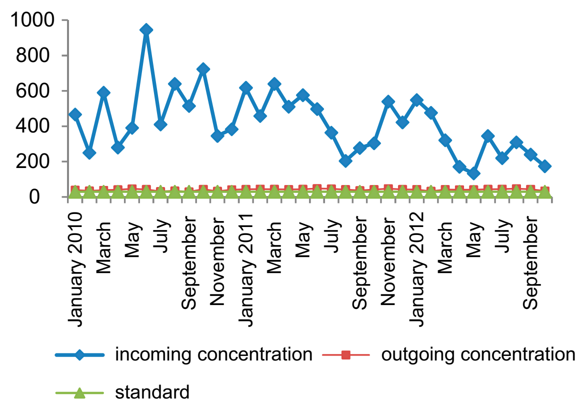

Fig. 20. Changes in BOD5 Concentration for Sidi Safi.

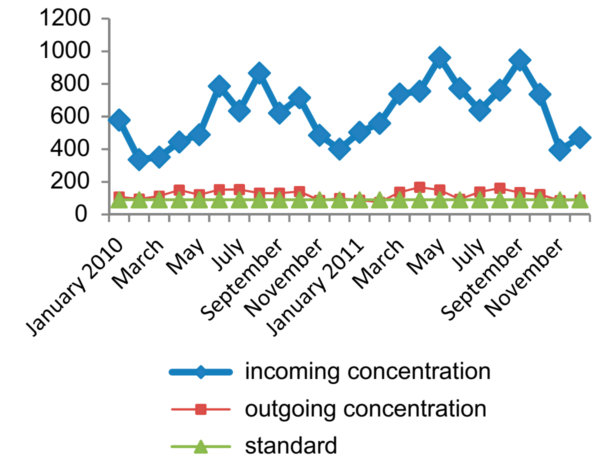

Fig. 21. Changes in COD Concenration for Sidi Senoussi.

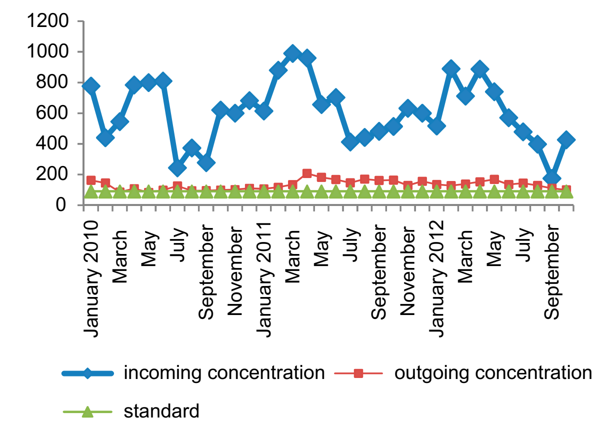

Fig. 22. Changes in COD Concenration for Amir Ebdel Kader.

rejection conductivity were inferior to the input wastewater (Figs. 9–12 and Table 8). This decrease leads us to consider that the quantity of dissolved salts in wastewater has been degraded by the presence of micro-organisms (phytoplankton) that use it for photosynthesis. The conductivity values of the outgoing water are all lower relative to the standards.

3.4. Results of TSS

According to the yields of allowance recorded in Table 9, we notice that there was an average degradation in all the lagoons, except in the lagoon of Sidi Senoussi, where the degradation is significant.

Table 11
Critical values of COD

	Sidi Senoussi	Amir Ebdel Kader	Sidi Safi	El Maleh
Average concentration incoming/outgoing (mg/l)	623.28/121.72	606.95/132.24	514.86/132.63	381.31/118.23
Max incoming/outgoing (mg/l)	962/167	990/208	1,111/256	690.7/146
Min incoming/outgoing (mg/l)	337/74.5	175/83.66	124.5/74	208/36.5
Average yield (%)	80.46	78.21	74.23	68.99
Standard	90 mg/l			

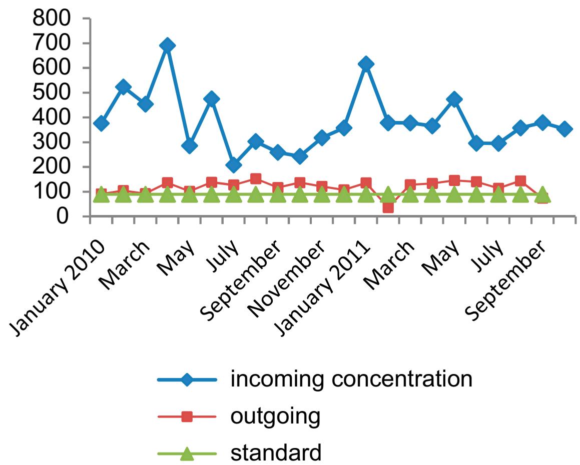

Fig. 23. Changes in COD Concentration for El Maleh.

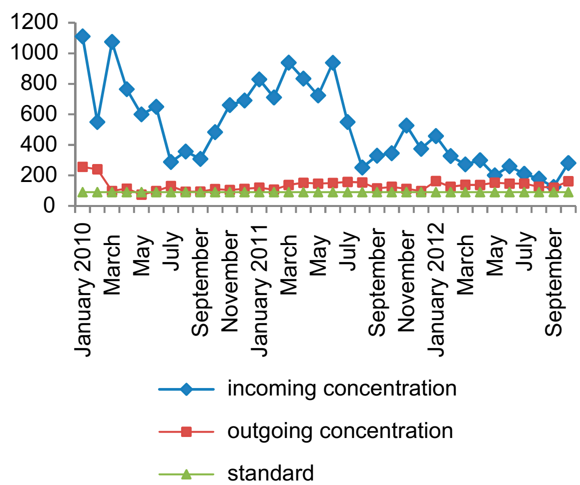

Fig. 24. Changes in COD concentration for Sidi Safi.

The average concentrations in treated waters are higher than the limited value by the standards. We also notice that the yields of degradation and the concentrations of purified water are all close to each other, except those of Sidi Senoussi which have a very significant yield and the lowest outgoing concentration

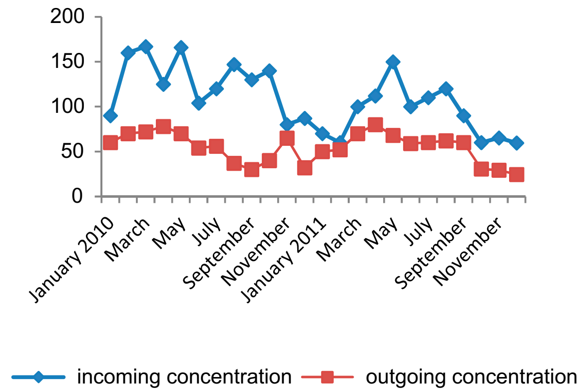

Fig. 25. Changes in NH_4^+ for Sidi Senoussi.

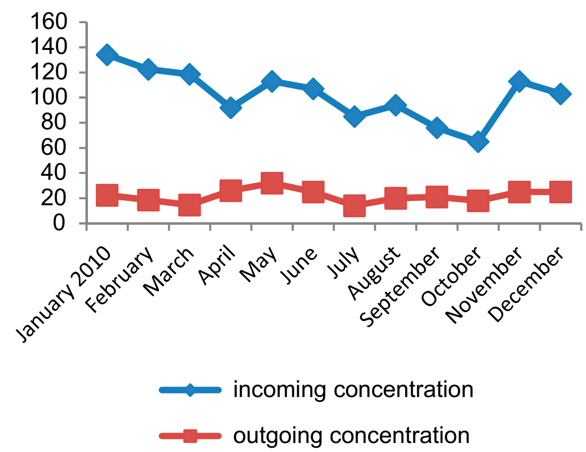

Fig. 26. Changes in NH_4^+ for Amir Ebdel Kader.

(Figs. 13–16). This can be explained by the dilution caused by water infiltrated groundwater in the lagoon of Sidi Senoussi. Natural lagoons in general are not sufficient for the removal of suspended solids.

3.5. Results of the BOD5

In Table 10, we notice that all lagoon yields were good and even better than those of TSS. We had the

Table 12
Critical values of ammonium (NH_4^+)

	Sidi Senoussi	Amir Abdel Kader	Sidi Safi
Average concentration incoming/outgoing (mg/l)	108.8/54.5	101.93/41.8	106.5/52.7
Max incoming/outgoing (mg/l)	167/80	134.15/32	140/32
Min incoming/outgoing (mg/l)	59.6/24.5	65/14	65/14.6
Average yield (%)	49.88	58.99	50.51

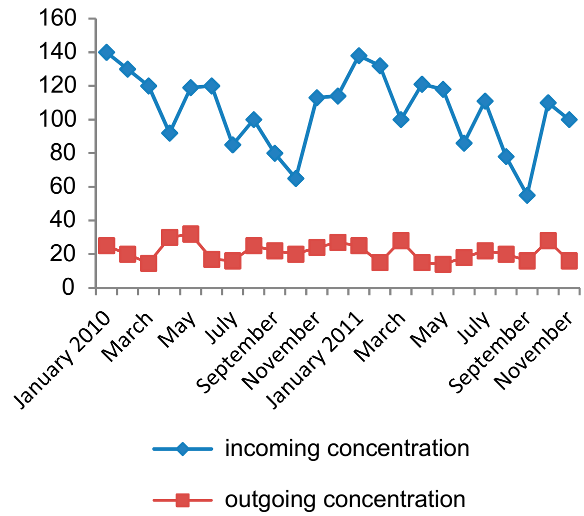

Fig. 27. Changes in NH_4^+ for Sidi Safi.

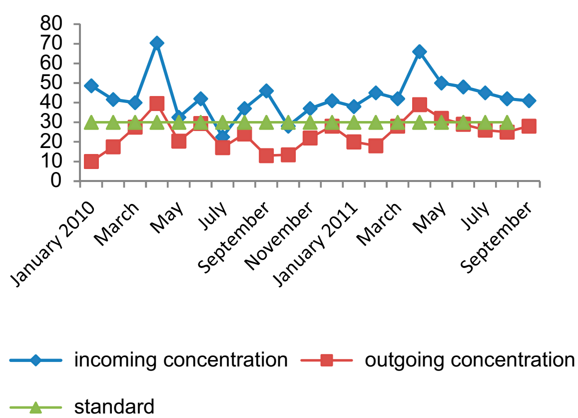

Fig. 28. Changes in nitrate concentrations for Sidi Senoussi.

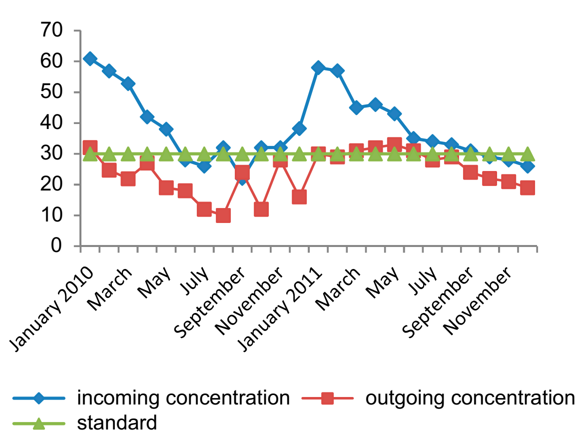

Fig. 29. Changes in nitrate for Amir Ebdel Kader.

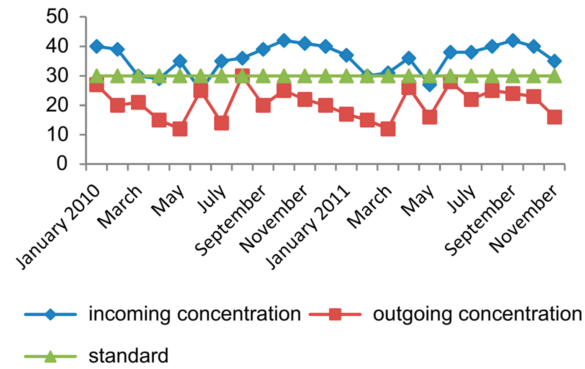

Fig. 30. Changes in nitrate concentrations for Sidi Safi.

Table 13
Critical values of nitrate (NO_3^-)

	Sidi Senoussi	Amir Ebdel Kader	Sidi Safi
Average concentration incoming/outgoing (mg/l)	32.748/24.3	38.4/20.38	41.54/22.16
Max incoming/outgoing (mg/l)	45/39.6	60.89/32.01	62.89/33
Min incoming/outgoing (mg/l)	19.2/8	22/10	25/12
Average yield (%)	25.72	46.67	46.64
Standard	45 mg/l		

best reduction performance in the lagoons Amir and Sidi Safi and lowest in those of Sidi Senoussi and El Maleh (Figs. 17–20). In summary, the lagoon that has the most important volume of incoming water is the one with the lowest yield (such as the lagoons of Sidi Senoussi and El Maleh). Nevertheless, for all lagoons, the concentration in the treated water remains above the standard value.

3.6. Results of the COD

From Table 11 and Figs. 21–24 we notice that the COD concentration decreased in all four lagoons. The order of performance in decreasing order is as follows: Sidi Senoussi, Amir, Sidi Safi, and El Maleh. This is the reverse order inflow, except for the lagoon of Sidi Senoussi which scored the best performance value despite that its inflow is the most important one. This can be explained due to the fact that the lagoon of Sidi Senoussi has three floors, each one equipped with two ponds. As for the lagoon of Amir there are only two basins. Despite these good yields, the COD

Table 14
Results of microbiological analysis

	May 2010				August 2010				November 2010			
	Total coliforms		Faecal streptococci		Total coliforms		Faecal streptococci		Total coliforms		Faecal streptococci	
	Incoming	Outgoing	Incoming	Outgoing	Incoming	Outgoing	Incoming	Outgoing	Incoming	Outgoing	Incoming	Outgoing
Sidi Senoussi	1.9×10^7	4.2×10^6	1.3×10^6	4.9×10^5	2.3×10^7	3.8×10^6	1.5×10^6	4.5×10^5	1.4×10^7	4.5×10^6	1.1×10^6	5×10^5
Amir Ebdel Kader	1.4×10^7	2.9×10^6	0.5×10^6	1.6×10^5	1.6×10^7	2.5×10^6	0.4×10^6	1.3×10^5	1.1×10^7	3×10^6	0.3×10^6	2×10^5
Sidi Safi	1.6×10^7	3.6×10^6	0.9×10^6	2.5×10^5	2.2×10^7	2.9×10^6	0.7×10^6	2.3×10^5	1.2×10^7	3.1×10^6	0.7×10^6	2.8×10^5
El Maleh	2.2×10^7	4.4×10^6	1.6×10^6	5×10^5	2.6×10^7	4×10^6	1.2×10^6	4.2×10^5	2.1×10^7	4.2×10^6	1.3×10^6	5.5×10^5

concentrations in the outgoing water lagoons are not in conformity with the value limits of the standards.

3.7. Results of the ammonium (NH_4^+)

In Table 12 we see that yields are good for the studied lagoons. The average concentrations of ammonium in outgoing water are 54.4, 41.8, and 52.7 mg/l (Figs. 25–27). For agricultural reuse the Algerian standards do not limit the value for ammonium because plants need this fertilizer.

3.8. Results of nitrate (NO_3^-)

For nitrates we find that yields were low (Figs. 28–30), but the concentrations in the outgoing water are adequate with the standards of reuse as shown in Table 13.

3.9. Results of microbiological analysis

The bacteriological parameters were carried out for three months (twice a month in May 2010, August 2010, and November 2010). The average concentrations of germ tests for fecal contamination (total coliforms, faecal streptococci) in incoming and outgoing wastewater lagoons studied are presented in Table 14. They are expressed by the number of bacteria in a sample of 100 ml.

The raw wastewater had higher average concentrations in the four lagoons. After the passage of wastewater in the lagoons the concentrations decreased. Unfortunately the wastewater treated by lagoon systems studied did not meet the required bacteriological quality for irrigation of crops that are intended to be eaten raw. No station provided treated water according to the Algerian standard for effluent discharges into the aquatic environment. In general, the elimination of different bacteria sought in treatment systems is favorably influenced with the combined effects of various environmental factors such as temperature (>25℃), the alkaline pH, the solar radiation, and nutrients. Despite the favorable situation (long duration of sunshine and high temperatures) the elimination of bacteria remained limited, particularly influenced by the organic matter and turbidity caused by the strong presence of suspended solids, these two factors that minimize the bactericidal effect of solar radiation.

4. Conclusion

From this study we concluded that the treatment performance of waste stabilization ponds have a very strong relationship with the inflow of wastewater. According to concentrations in treated wastewater by lagoons studied, it is clear that the natural lagoon in general is not sufficient to have purified water in conformity with the required quality for agricultural reuse. As a recommendation we suggest adding a planted filter pond downstream to the natural lagoons. These are resistant to alternate between periods of immersion and dry [7]. There are three application types: (1) the beds planted in horizontal flow below the surface, (2) the beds planted in vertical flow, and (3) the mixed or hybrid systems [8]. Clean water produced through any filter-type planted has an adequate quality standard for agricultural reuse (for example: the mean concentrations of purified water through the filters planted with vertical flow are: 30 mg/l BOD5 and 140 mg/l for COD and 20 mg/l TSS) [9]. Therefore, we suggest the installation of a purification system of filter planted in rural areas that are not yet equipped with a purification system, and for areas that already have a purification system by natural lagoon, we propose to add filter planted ponds.

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