Bulletin de l'Institut Scientifique, Rabat, Section Sciences de la Vie, 2020, n° 42, 43-50 ***e-ISSN : 2458-7184***

Wastewater treatment efficiency by natural lagooning in new station of Aïn Chiffa at Sefrou city-Morocco

Efficacité de traitement des eaux usées par lagunage naturel dans la nouvelle station d'Aïn Chiffa, Séfrou, Maroc

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Abstract. Land availability and climatic condition encouraged by geographical situation of Morocco, have promoted the country to adopt since the 1990s natural lagooning technique as a solution best adaptated to the economic and climatic context from the country. Many pretreatment stations of the wastewater by natural lagooning are been constructed. Objective of this work is to measure the physico-chemical and biological parameters of treated wastewater by natural lagooning in the center of Aïn Chiffa, Sefrou-Morocco. Water samples were taken during the period January-May 2016, from four locations of the station **(i)** entrance, **(ii)** bottom of basin, **(iii)** surface of basin and **(iv)** exit. Water quality characterization is realized by (1) analysis of physico-chemical parameters: Temperature, pH, Electrical Conductivity, Dissolved Oxygen, five-day Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Suspended Matter (SM), phosphorus concentration, nitrogen compounds concentration (NH_4^+ & NO_3^-) and Chlorophyll (a) concentration and by (2) enumeration of total germs, fecal coliform and fecal enterococci. Treatment efficiency, expressed as abatement rate (%), values are 83% for BOD5, 30% for COD and 50% for SM. Purification performance for phosphorus is low, of which average abatement rate is 18%. Analysis of chlorophyll (a) concentration, from basin until exit of station, shows a remarkable decrease the values ranging between 41% and 92%. Microbiological analyses show that pretreatment by natural lagooning allows a considerable elimination of bacterial germs, with abatement rate of 96% for facal enterococci, 75% for total germs and 30% for fecal coliform.

Keywords: Wastewater, Natural lagooning, Purification effectiveness, Aïn Chiffa, Sefrou, Morocco.

Résumé. La disponibilité du foncier et les conditions climatiques, encouragées par la situation géographique du Maroc, ont poussé ce pays à adopter depuis les années 90 le lagunage naturel comme étant une solution technique la plus adaptée au contexte économique et climatique, ainsi, de nombreuses stations de traitement des eaux usées ont été déjà réalisées. Le présent travail a pour objectif, d'effectuer un suivi et une analyse des performances épuratoires de la station d'épuration par lagunage du centre Aïn Chiffa, dans la province de Séfrou. Cette étude est basée sur des prélèvements qui ont été effectués durant la période Janvier-Mai 2016 au niveau des eaux **(i)** de l'entrée, **(ii)** de fond, **(iii)** de surface et **(iv)** de sortie de la station. Cette étude concerne l'analyse des paramètres physico-chimiques (température, pH, Conductivité électrique, Oxygène dissous, DBO5, DCO, MES, Quantité du phosphore et Quantité des composés azotés (NH_4^+, NO_3^-)), l'évaluation de la quantité de la chlorophylle a et la recherche des indicateurs bactériens classiques de contamination fécales (germes totaux, coliformes fécaux et entérocoques fécaux) en vue de caractériser la qualité des eaux de la station. Le rendement épuratoire observé pour la station d'épuration est de 83% comme abattement pour la DBO5, 30% pour la DCO et 50% pour les Matières en suspension (MES). La performance épuratoire est faible pour le phosphore dont l'abattement moyen observé est de 18%. L'analyse de la quantité de la chlorophylle au niveau de bassin et à la sortie montre une diminution remarquable pour laquelle les abattements moyens observés varient entre 41% et 92%. Les résultats des analyses microbiologiques montrent que la station d'épuration assure une élimination importante des germes bactériens qu'est de 96% comme abattement pour les entérocoques fécaux, 75% pour les germes totaux et 30% pour les coliformes fécaux.

Mots Clés : Eau usée, Lagunage naturel, Efficacité d'épuration, Aïn Chiffa, Sefrou, Maroc.

INTRODUCTION

Urban residual water (or wastewater) is charged with polluting compounds, soluble or not, resulting mainly from human activity (Rejsek 2002). Therefore, wastewater contains a wide variety of waters, which have lost their purity and natural properties by effect of pollutants after being used in various domestic, industrial or agricultural activities (Grosclaude 1999). They include domestic wastewater, runoff waters and industrial effluents (Baumont et *al*. 2004).

Lagooning treatment consists of a series of artificial basins, forming of impermeable barriers, where the wastewater are unloaded during a long residence times and it successively and naturally pass from one basin to other by gravitation. Several assemblages or combinations of lagoon basins are possible, depending on local conditions, requirements on final quality of effluent and on flow rate to be treated (Chaib 2004).

Lagoon basins function as ecosystems with symbiotic relationships between different populations (bacteria, fungi, protozoa, metazoans, algae, fish, plants, etc) (Seidl & Mouchel 2003). These various microorganisms assure an elimination of pollutants contained in wastewater. Natural lagooning is an economical and efficient process for biological treatment of wastewater. It is effective in small agglomerations (Ruochuan & Heinz 1995) and advised in areas with hot climate (Gloyna 1972, Sauze 1973, Vasel & Jupsin 2007). Its efficiency is considerable for elimination of pathogenic germs, which makes natural lagoon a very suitable technique for reuse of wastewater in agriculture.

In order to treat wastewater of rural centers, the Sebou hydraulic basin agency of Fez has built a natural lagooning pretreatment station in center of Aïn Chiffa at Sefrou city-Morocco. The aim of this work is to evaluate the purification capacity of this station, physico-chemical, biological and microbiological parameters measurement.

MATERIALS AND METHODS

Study site and sampling

Aïn Chiffa center is located in north (8 km) of Imouzer Kandar city and south (20 km) of Fez city. Pretreatment station of wastewater by natural lagooning is located at 5°01'W and 33°46'N at altitude of 950 m. Weather is typically mediterranean, semi-arid, with an average rainfall of 465 mm/year and annual temperature of 13.5 °C (Fig. 1). Water samples were collected during period of January-May 2016 from four locations in pretreatment station: **(i)** entrance, **(ii)** bottom of basin **(iii)** surface of basin and **(iv)** exit. The water samples were deposited in glass bottles, preserved in ice-boxes and analyzed within 12h.

Physico-chemical analysis

Physico-chemical analyses were carried out according to protocols described by Rodier et *al.* (2009). The analyzed parameters were temperature, pH, electrical conductivity, dissolved oxygen, five-day biological oxygen demand (BOD_5), chemical oxygen demand (COD), suspended matter (SM), phosphorus concentration and nitrogen compounds concentration (ammonium and nitrates ions). Pollution elimination by pretreatment station was expressed as abatement rate (%) and determined according to formula:

$$Abatement\ (\%) = \frac{Ci - Cf}{Ci}\ X\ 100$$

Ci. initial concentration at station entrance.
Cf. final concentration at station exit.

Spectrophotometric determination of chlorophyll (a) concentration

Chlorophyll (a) concentration per unit of water volume was determined according to the method described by Plante-Cuny (1974). A volume sample (100 ml) was filtered with a Whatman GF/C filter (Ø = 0.45 µm). After, filter was ground in acetone (90%) and was stored in the dark for 12 h. Filtrate was centrifugated (4000g/5min) and the optical density of supernatant was measured by spectrophotometer at wavelengths 630, 645 and 665 nm. Chlorophyll (a) concentration (µg/l) was determined by formula :

$$\text{Chlorophyll (a) } (\mu g/l) = \left(\frac{11.64\ E1 - 2.61\ E2 - 0.1\ E3)\ X\ V}{L\ X\ Vg}\right)$$

E1. Wavelength 665 nm, **E2**. Wavelength 6 45 nm, **E3**. Wavelength 630 nm, **V**. Volume of acetone (ml), **L**. Diameter of the cuvettes (cm), **Vg**. Volume of filtered water (l)

Bacteriological analysis

Culture media

Luria Bertani agar medium (LB agar) (Peptone 10 g/l; Yeast Extract 5 g/l ; Sodium Chloride 10 g/l and Agar 18 g. pH 7) was used for culture of total germs. Tergitol agar medium (Peptone 10 g/l ; Meat extract 5 g/l ; Yeast Extract 6 g/l ; Lactose 20 g/l ; Tergitol7 0.1 g/l ; Triphenyl Tetrazolium Chloride (TTC) 25 mg/l ; bromothymol blue 50 mg/l and agar 10 g/l. pH 7.2) was used for culture of fecal coliform (Rodier 1984). Slanetz & Bartley agar medium (Tryptose 20 g/l ; Yeast Extract 5 g/l ; Glucose 2 g/l ; Phosphate dipotassium 4 g/l ; sodium azide 0.4 g/l ; Triphenyl Tetrazolium Chloride (TTC) 0.4 g/l and agar 12 g. pH 7) was used for culture of fecal enterococci (Slanetz & Bartley 1957).

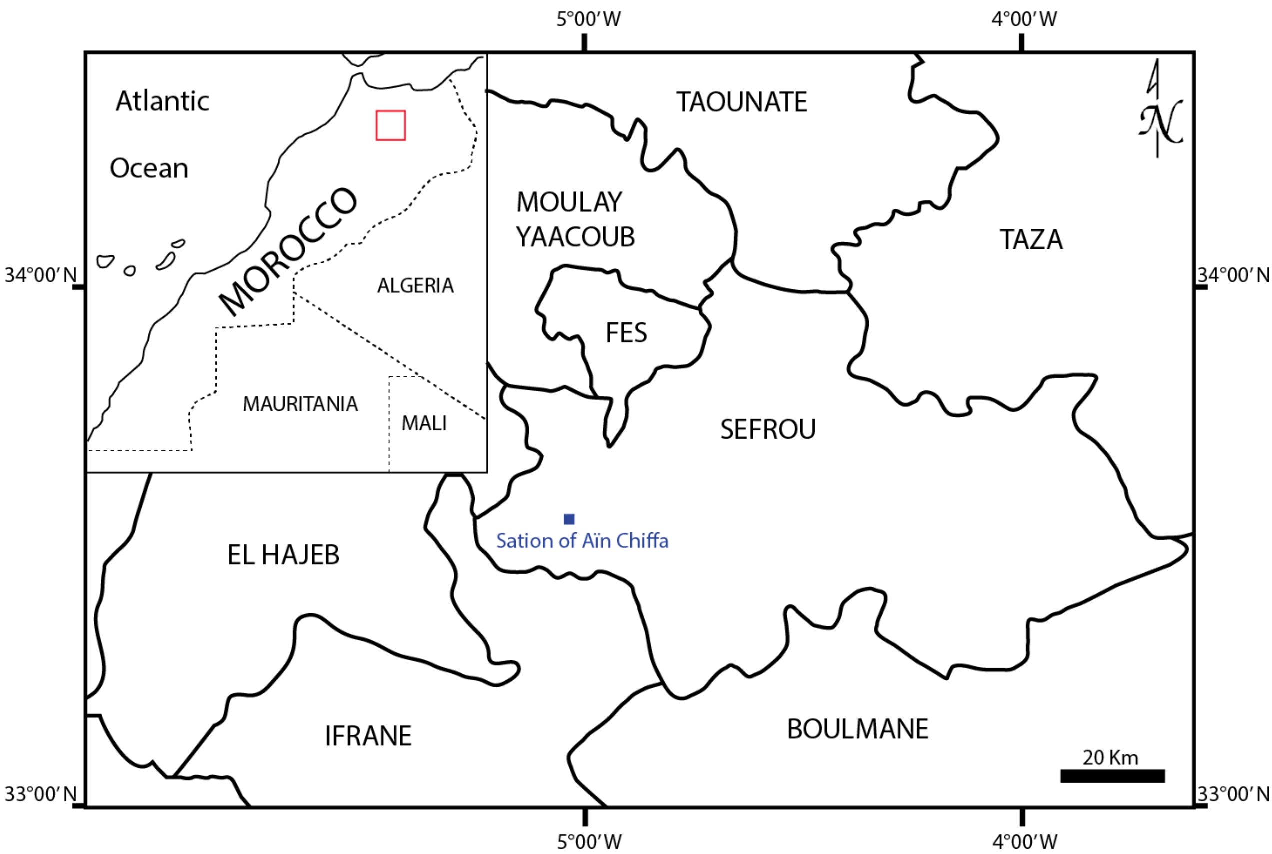

Figure 1. Geographical location of study site.

Enumeration of microorganisms

Serial 10-fold dilutions of each water sample were prepared in sterile physiological water (0.85% NaCl in distilled water). Dilutions was then plated on suitable culture medium and incubated during 24h at 37°C for total germs, during 24h at 45°C for fecal coliforms and during 48h à 37°C for fecal enterococci. After incubation, bacterial colonies were recognized by their morphological aspects and enumerated by the formula:

$$N = \frac{n}{(V\ X\ d)}$$

N. Number of germ in colony-forming units per ml (CFU/ml), **n**. Number of colony developed on surface of culture medium, **V**. Spread volume (0.1 ml), **d**: Dlution.

RESULTS AND DISCUSSION

Wastewater pretreatment station by natural lagoon should be monitored to evaluate its purification performance, since it's based on a natural system that can be influenced by variations of biotic and abiotic factors according to seasons.

Physico-chemical analysis

Temperature

The temperature affects physico-chemical properties of treatment basins, as well as the biological reactions. It significantly influences purification performance of these basins. The recordes values vary between 4°C and 29°C (Fig. 2). Also, the temperature of the samples analysed increases over time (February-June) in agreement with the increase of the temperature of the region.

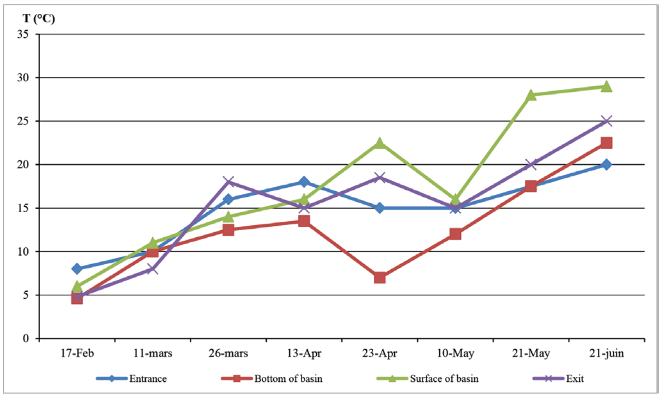

Figure 2. Spatio-temporal trends in temperature values of water samples collected from four locations of treatment station during study period.

pH

This parameter affects several physico-chemical reactions. pH values show a small variation with a tendency to be basic, at entrance of station, who's a minimal value is 7.8 and a maximum is 8.2 and at exit, values vary between 7.4 and 8.7 (Fig. 3). Throughout purification process of wastewater by lagooning, there is development of microorganisms and micro-algae that contribute to alkalinization of the environment. Also, greater the development of phytoplankton, more pH values tends to increase. During hot period, the pH has reached its maximal level following the development of phytoplankton. On the other hand, in winter and when micro-algae are not very abundant, pH values of waters remains close to neutrality in basins of station. This difference in pH values shows that different compartments of station operate differently. Several authors relate pH variations in wastewater stabilization basin to biological and biochemical activities, including photosynthesis (Davoust et *al*. 1985, Chifaa 1987, Oudra 1990).

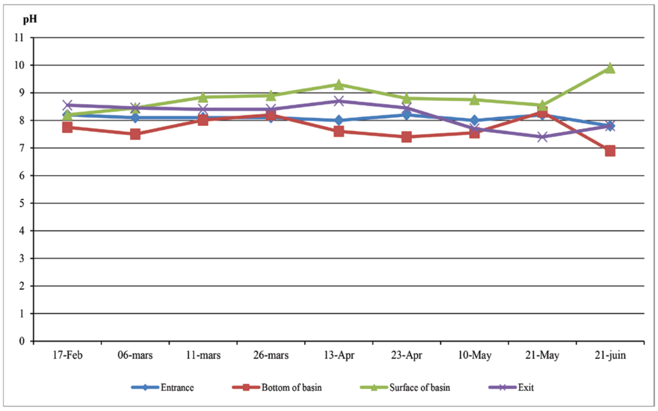

Figure 3. Spatio-temporal trends in pH values of water samples collected from four locations of treatment station during study period.

Elecrical conductivity

Electrical conductivity is one of means to validate physico-chemical analyzes of water. This parameter makes it possible to assess dissolved salts quantity in water (Pescod 1985, Rodier et *al*. 1996). As a matter of fact, contrasting measurements on a medium make it possible to highlight existence of pollution, mixing or infiltration zones (Ghazali & Zaid 2013).

Wastewaters at entrance of station are weakly mineralized during the month of February and beginning March with values between 380 µS/cm and 630 µS/cm (Fig. 4). These values recorded in period of return of rains could be attributed to precipitations which led to phenomenon of water dilution. These values are increased since end of March until end of June; they can reach 1000 µS/cm (Fig. 4). This increase in values of electrical conductivity during this period can be attributed to evaporation of water by heat.

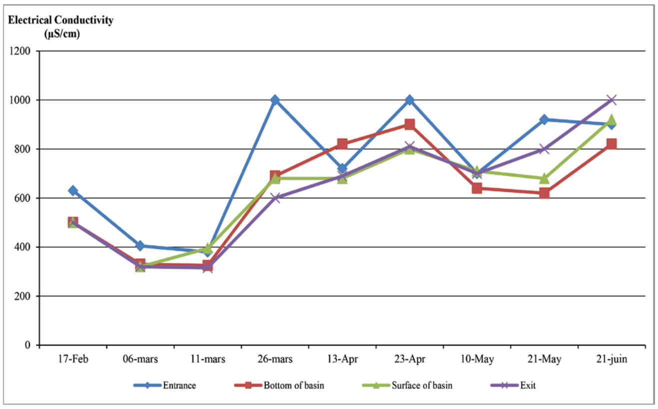

Figure 4. Spatio-temporal trends in Electrical Conductivity values of water samples collected from four locations of treatment station during study period.

Electrical conductivity values obtained during hot period are high compared to values obtained during cold period. During its passage in station basins; since entrance until exit; electrical conductivity of water decreased slightly. This decrease can be due to the decrease in dissolved salts quantity in water by different physicochemical and biological processes.

Dissolved oxygen

Dissolved oxygen measures dissolved oxygen (O_2) concentration in water (Rodier 1996). It participates in majority of chemical and biological processes in aquatic environment. It comes in fact from mixing of the atmosphere with water by diffusion, or from photosynthesis of autotrophic organisms, mainly algae. It is consumed during respiration of organisms present in water in euphotic zone, during decomposition organic matter by aerobic microorganisms and oxidation of certain chemical substances. Its concentration in aquatic ecosystems is function of several factors: temperature, atmospheric pressure, salinity or intensity of photosynthetic activity of algae.

The results obtained are summarized in Figure 5. At Surface, dissolved oxygen concentrations vary between 7 mg/l and 17 mg/l. At bottom of basin, dissolved oxygen levels are always zero, which shows installation of anaerobic conditions. At Exit of station, concentrations of oxygen in treated water are between 3.5 mg/l and 10.5 mg/l.

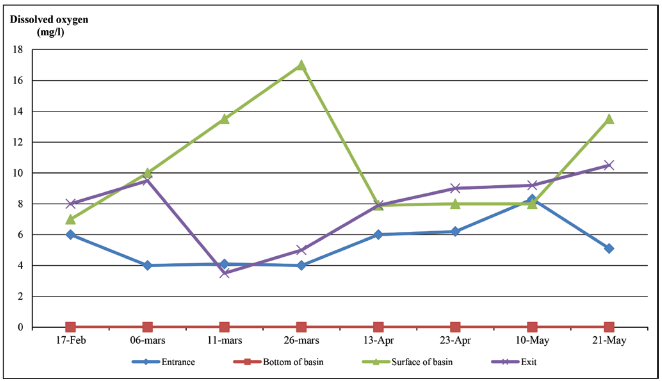

Figure 5. Spatio-temporal trends in dissolved oxygen values of water samples collected from four locations of treatment station during study period.

Biochemical Oxygen Demand (BOD_5)

Biochemical Oxygen Demand (BOD) is expressed in mg of oxygen per liter. It expresses quantity of biodegradable organic matter present in water. Specifically, this parameter measures oxygen quantity necessary for destruction of organic matter by aerobic oxidation. To measure this parameter, we take as reference the amount of oxygen consumed after five days: it is Biochemical Oxygen Demand over five days (BOD_5) (Rodier 1996).

The organic load received by the treatment station is 385 mg/L. At the exit, the removal of organic matter is 83.5% (Fig. 6).

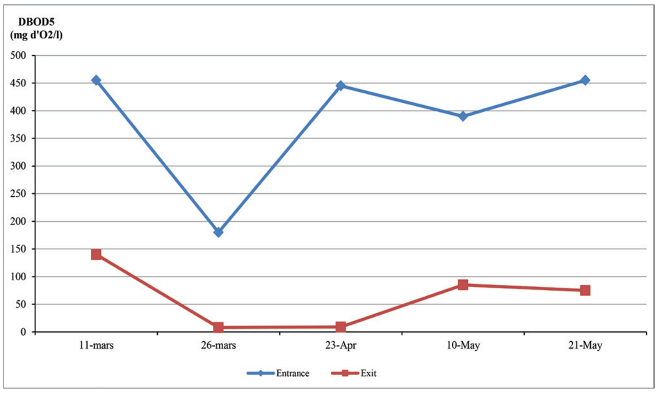

Figure 6. Spatio-temporal trends in five-day Bichemical Oxygen Demand values of water samples collected from two locations of treatment station during study period.

Chemical Oxygen Demand

The chemical oxygen demand (COD) is expressed in mg of oxygen per liter. It represents total content of oxidizable materials in water. This parameter corresponds to oxygen quantity that must be supplied to chemically oxidize these materials.

According to obtained results of the figure 7, recorded values at entrance of station vary from 280 mg/l to 380 mg/l. At to exit of station, these values show a slight decrease and vary between 215 mg/l and 245 mg/l. The abatement rates are low and vary between 23% and 35.5%.

Chemical oxygen demand values obtained are high and exceed discharge standards fixed at 120 mg/l (Decree ministerial: N° 2943-13 of 2013. Legal texts code for the water resources in Morocco).

BOD_5/DOC ratio accounts for fraction of readily biodegradable materials among all oxidizable material. Average value obtained from this ratio is 1.3, which is significantly greater than 0.6. This result leads to the conclusion that effluent is character domestic dominant (Bechac *et al*. 1987).

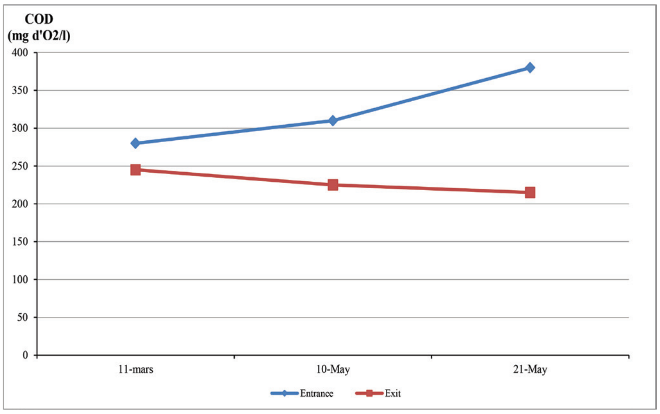

Figure 7. Spatio-temporal trends in Chemical Oxygen Demand values of water samples collected from two locations of treatment station during study period.

Suspended Matter

Suspended matter (SM) is expressed in mg per liter. These are undissolved materials with diameters exceeding 1 µm. They contain both mineral and organic elements and decant spontaneously.

Suspended matter concentration at the entrance of the station varies between 60 mg/l in January and 170 mg/l in April (Fig. 8). From entrance of station to exit, these concentrations undergo a decreasing gradient where they vary between 30 mg/l and 50 mg/l.

Presence of organic matter in wastewater does not constitute an obstacle to reuse these waters. On the contrary, it contributes to soil fertility. Performance of treatment station in terms of organic pollution is evaluated by calculating the abatement rate of BOD_5, COD and SM expressed in percentage. The results obtained are 83,5% for BOD_5, 29,5% for COD and 68,5% for SM.

Phosphorus and nitrogen concentrations

Nitrogen and phosphorus concentrations are very important because they contribute to water eutrophication in case of excessive releases. This phenomenon is characterized by an algal proliferation and during night by a decrease of dissolved oxygen, which impoverishes fauna and flora of superficial waters.

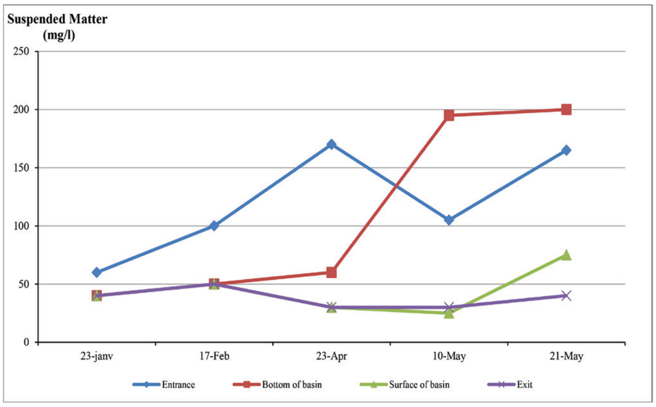

Figure 8. Spatio-temporal trends in suspended matter concentration of water samples collected from four locations of treatment station during study period.

1. Phosphorus concentration. Phosphorus assimilation by algae is essentially an active phenomenon, implement temporary links between PO_4^{3-} ion and transport enzymes at the cell membrane (Feuillade & Feuillade, 1972 ; Fogg, 1973 ; Nalewajko & Lean, 1980 ; Oudra, 1990). Rate of assimilation of this element increases with temperature, whereas it is independent of luminous intensity. What is more, this assimilation is subject of algo-bacterial competition (Jones & Tasfi, 1987). However, it is important to note that removal of phosphorus in lagoon basins involves processes other than algae assimilation, namely, chemical complexation and sedimentation processes (Oudra 1990, El Halouani *et al.* 1993).

Phosphorus concentrations at station entrance vary between 0.8 mg/l and 2.35 mg/l. At exit, phosphorus concentrations vary between 0.4 mg/l and 1.45 mg/l (Fig. 9). These phosphorus concentration respect Moroccan normes of rejection fixed 2 mg/l (Ministerial decree n° 2943-13 of 2013. Legal texts code for the water resources in Morocco).

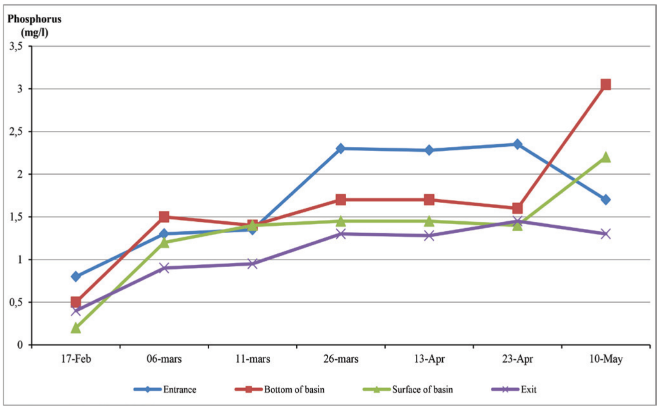

Figure 9. Spatio-temporal trends of phosphorus concentration in water samples collected from four locations of treatment station during study period.

2. Ammonium ion concentration. Ammonium ion is producted by reduction of nitrogenous organic substances and inorganic matter in water and in soil. It also comes from excretion of living organisms and reduction or biodegradation of waste, without neglecting agricultural and industrial sources.

At entance of station, average concentration of ammonium ions is 2 mg/l (Fig. 10). The low concentration suggests that this element does not pose a risk of pollution to waters in this station. Values obtained are close to those obtained by El Halouani 1995 and remarkably lower than those reported by El Hamouri *et al.* 1987 and Bouhoum *et al*. 1995b.

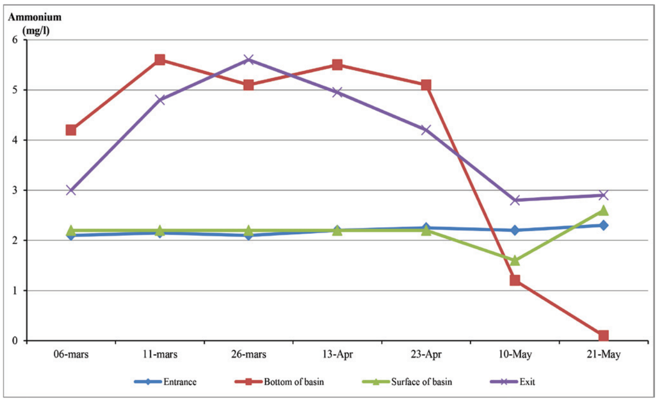

Figure 10. Spatio-temporal trends of ammonium concentration in water samples collected from four locations of treatment station during study period.

3. Nitrate ions concentration. Nitrate ions present in natural state and soluble in soil. They penetrate in soil and groundwater and flow into streams. However, they are also synthetically provided by fertilizers (Chapman & Kimstach 1996) and constitute a factor of degradation of water quality. They generally come from organic matter decomposed by bacterial oxidation of nitrite and thus constitute ultimate product of nitrification.

At station entrance, nitrate ions concentrations vary between 0.38 mg/l and 0.72 mg/l (Fig. 11). These values remain below of 30 mg/l fixed by Moroccan standards.

Values obtained are in most cases less than 0.5 mg/l, consistent with results found by Ouazzani (1987) who reported that nitrite and nitrate concentrations in lagooning basins was insignificant. Also, Oudra (1990) reported that evaluation of ammonium concentrations alone is sufficient to trace evolution of nitrogen in a lagooning station.

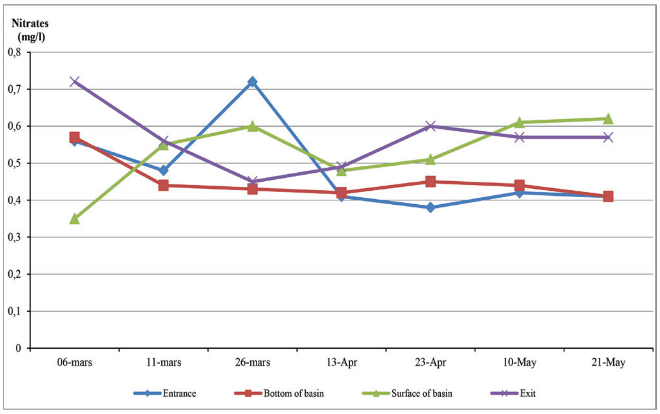

Figure 11. Spatio-temporal trends of nitrate ions concentration in water samples collected from four locations of treatment station during study period.

Chlorophyll (a)

Determination of chlorophyll (a) concentration is often used as index of algal prolifération. Obtened results are shown in figure 12. Highest chlorophyll (a) concentration (>

6000 µg / l) is detected in May known by increase in duration of sunshine and of temperature which favors the algal proliferation. At station basin, chlorophyll (a) concentrations ranged between 242 µg/l and 6100 µg/l. At station exit, they vary between 140 µg/l and 470 µg/l.

Chlorophyll allows micro-algae to use sunlight as source of energy by photosynthesis process. In presence of light, they assimilate carbon dioxide and mineral salts dissolved in the water and release of oxygen. They are the main producers of oxygen in lagooning basins. This production occurs mainly in surface layer of the water (0-50 cm deep).

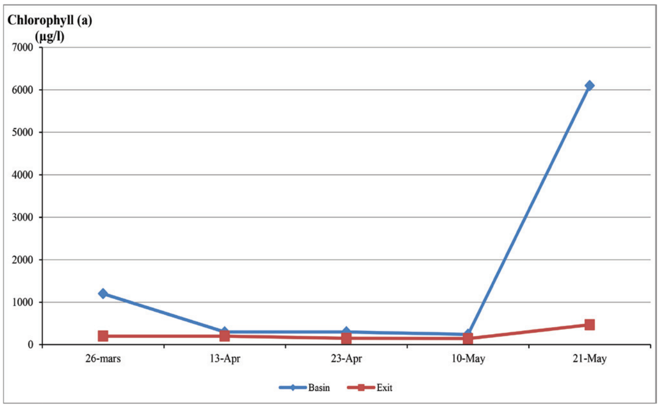

Figure 12. Spatio-temporal trends of chlorophyll (a) concentration in water samples collected from four locations of treatment station during study period.

Bacteriological analysis

Bacteriological analysis of water is aimed at enumeration of following microorganisms: total germs, fecal coliforms and fecal enterococci. The following results were obtained:

Total germs

Results of enumeration of total germus are grouped together in figure 13. Wastewater at station entrance is loaded with pathogenic germs compared to station exit. It is will significantly reduced from station entrance to exit for all analyzed samples. This number is remarkably high during the month of May. At station entrance, it varies between 3.10^{+6} CFU/ml and $22.5.10^{+6}$ CFU/ml. While at exit, this number varies between $0.2.10^{+6}$ CFU/ml and 5.10^{+6} CFU/ml, with a mean abatement rate of 31%. It can be concluded that the treatment station of Aïn Chiffa is effective for the elimination of total germs.

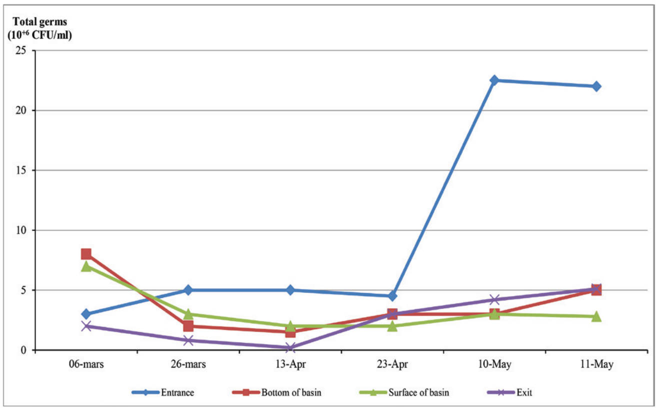

Figure 13. Spatio-temporal trends of number of total germs in water samples collected from four locations of treatment station during study period.

Fecal coliforms

From the results of Figure 14, untreated wastewater (at entrance) is loaded with fecal colifoms and this microbial load is slightly decreased at station exit. At station entrance, faecal coliforms numbers vary between 43.10^{+3} CFU/ml and 76.10^{+3} CFU/ml. At exit, it varies between 31.10^{+3} CFU/ml and 50.10^{+3} CFU/ml (Fig. 14), with a mean abatement rate of 31%.

Results obtained show that number of faecal coliforms detected is low simultaneously at station entrance and bottom of basin, that exceeds Moroccan standards of water quality (NM 03.7.001 (2006) Moroccan Standard) limited at 0/100 ml.

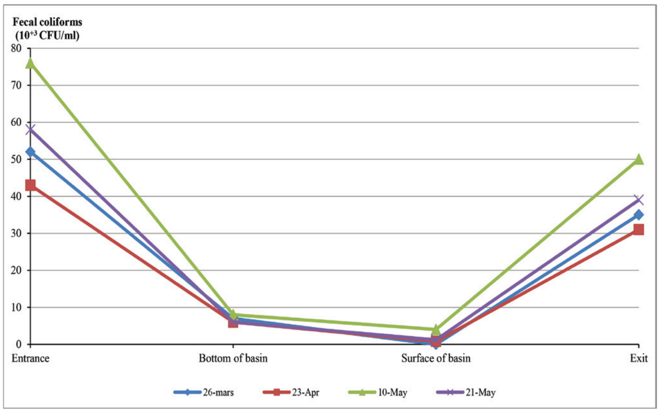

Figure 14. Spatio-temporal trends of number of fecal coliforms in water samples collected from four locations of treatment station during study period.

Fecal enterococci

Microbiological analysis shows presence of fecal enterococci in water samples studied. These microorganisms are intestinal origin, naturally present in human and animal faeces, can end up in water following spills and spraying. Isolation and enumeration of fecal enterococci is very useful for quality control of treated wastewater.

Results show a very high decrease of number from treatment station entrance to exit, with reduction of 95% ((Ni - Nf) / Nf) X 100 = ((47.10^{+3} - 2.10^{+3}) / $47.10^{+3)}$ X 100 = 95, 74%. At station entrance, it varies between 17.10^{+3} CFU/ml and 77.10^{+3} CFU/ml. At exit, it varies between 1.10^{+3} CFU/ml and 3.10^{+3} CFU/ml (Fig. 15).

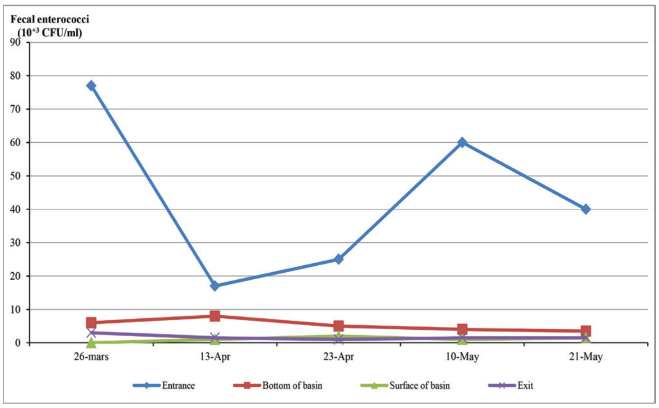

Figure 15. Spatio-temporal trends of number of fecal enterococci in water samples collected from four locations of treatment station during study period.

It is important to mention that value ratio of fecal colifoms/ fecal enterococci is an indicator of the contamination origin. When it is greater than 1, the pollution is of human origin, when it is lower than 0.7 it is animal origin (Geldreich & Kenner 1969). In this work, the ratio equal to 2, meaning that faecal pollution in that station is of human origin.

CONCLUSION

Biological treatment of wastewater by natural lagooning technique seems to be a very good solution and efficient to purify the growing amount of wastewater produced by our society. This technique has four particular advantages: (1) economic, (2) ecologic, (3) educational and (4) urban planning. First, maintenance of lagooning station is less expensive and does not require qualified personnel. Secondly, lagoon basins develop an entire ecosystem, where aquatic plants serve as support and food for fauna, which contributes to increase biodiversity. Thirdly, lagoon could be considered as a support for very diversified educational topics (water, sanitation, aquatic fauna and flora). Finally, rural communities are more and more attentive to regional planning, to ensure a perfect integration of landscape (Eau en couleur 2006). There are other advantages of natural lagooning technique: absence of energy and chemical consumption, possibility of developing by-products (planktonic biomass, aquatic plants, farmed fish) and use purified water for fertilization and irrigation the fields (Globenet 2000). Another important feature is its high buffering capacity to handle fluctuations in organic load or hydraulic load variations by high hydraulic retention time in comparison with others wastewater treatment techniques (CNRC 2004).

Biodegradability coefficient of effluents shows that waters studied are purely domestic and favorable for a natural lagoon treatment. Purification performance of treatment station is satisfactory for organic pollution with a higher efficiency greater than 80%. Residual concentrations of nitrogen and phosphorus remain important for potential reuse in agriculture. However, microbiological analysis of fecal coliforms and fecal enterococci show that treated water slightly exceeds standards imposed for reuse in agricultural irrigation (Ministerial decree n°1276-01 of 17 October 2002. Legal texts code for the water resources in Morocco).

ACKNOWLEDGEMENTS

This work was supported by the Sidi Mohamed Ben Abdellah University, Fez, Morocco. We would like to thank the staff of the station of Aïn Chiffa for their precious technical support.

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Manuscrit reçu le 16 / 02 /2018
Version révisée acceptée le 12/11/2020
Version finale reçue le 16/11/2020
Mise en ligne le 16/11/2020