

Article

The efficiency of household sewage treatment by Wastewater garden technique in arid regions, case of WWG of Temacine, Algeria

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Abstract : The objective of present research was to describe the performance of wastewater garden (WWG) of Temacine through physico-chemical analysis for the removal of organic matter and nutrients pollutants from water in two consecutive operating years (2012-2013). The WWG located in Touggourt was used as a first pilot plant in Algeria for a natural technology of wastewater treatment with horizontal flow, usually applied for the treatment of domestic wastewater in rural areas. This system demonstrated that average removal efficiencies were almost even higher than expected: more than 90% for biochemical oxygen demand (BOD₅), chemical oxygen demand (COD) and total suspended solids (TSS). Mean decrease of nitrogen (NO₂-N, NO₃-N) and phosphorus (PO₄-P) were 73, 76 and 80%, respectively. These results obtained from this pilot during the study period showed that WWG rejects purified water of satisfactory quality against objectives set for the removal efficiency of the elements responsible for the pollution.

Keywords : Wastewater treatment; Constructed wetland; Macrophytes; water quality; arid area

1. Introduction

The shortage, water pollution and degradation of water resources has become an issue aggravating worldwide [1] especially in dry climate regions [2-5], as a result of accelerated industrialization and urban growth as well as changed climatic conditions [6]. The use of treated wastewater is an extended practice worldwide, as a viable alternative especially in arid and semiarid countries [7,8]. In many zones, as a result of the anthropogenic influences urban, industrial and agricultural activities wastewater are discharged in natural areas or reused in agriculture without any treatment is the cause of many human and animal health risks, the treatment of this potential resource becomes imperative before use [9].

There are a wide range of treatment technologies are available for use in the treatment of domestic sewage effluents. The treatment of wastewater using Constructed Wetlands (CWs) is one of the suitable treatment systems, Nowadays, constructed wetlands are recognized as a reliable wastewater treatment technology and they represent a suitable economical and ecological solution for the treatment of various forms of wastewater [10]. A constructed wetland system is fully human-made shallow basin filled with substrate (usually of sand, soils and/or gravel) and planted with vegetation (i.e reeds, duckweed, cattail) that has tolerance to saturated conditions [11]. This system is a wastewater treatment method that mimics and improves the effectiveness of the natural wetland processes. Thus, CWs are engineered systems that have been designed and constructed to

utilize the natural processes involving wetland vegetation, soils, and their associated microbial assemblages to assist in treating wastewater [12]. Constructed wetlands are based upon the symbiotic relationship between the micro-organisms and pollutants in the wastewater. These systems have potential to treat variety of wastewater by removing organics, suspended solids, pathogens, nutrients and heavy Metals [11]. The design of the constructed wetland can be adjusted according to the type of wastewater to be treated and it can be used for secondary or tertiary wastewater treatment [13]. The mechanisms that are available to improve water quality within a constructed wetland system are numerous and often interrelated. The mechanisms involve the settling of suspended particulate matter; the filtration and chemical precipitation through contact of the water with the substrate and litter; chemical transformation; adsorption and ion exchange on the surfaces of plants, substrate, sediment, and litter; the breakdown and transformation of pollutants by microorganisms and plants uptake; and transformation of nutrients by microorganisms and plants as well as the predation and natural die-off of pathogens [14]. The most common systems are designed with horizontal subsurface flow (HF CWs) but vertical flow (VF CWs) systems are getting more popular at present [11]. These technologies are very effective in removing organics and suspended solids from wastewater, whereas the removal of nitrogen is relatively low, but could be improved by using a combination of various types of constructed wetlands meeting the irrigation reuse standards. The removal of phosphorus is usually low, unless special media with high sorption capacity are used [15-17]. In general, the constructed wetland system has proven to constitute an appropriate ecotechnology for wastewater treatment and reuse in small communities of warm climate areas [4,18]. Wetlands are considered low-cost alternatives for treating municipal wastewater, industrial and agricultural [19]. In Algeria, this purification technique was performed for the first time in 2007 in Temacine (province of Ouargla) that has no sewage system, where wastewater from houses is discharged directly without any treatment in the Oued Righ channel or in the lake.

The objective of this work is to describe the purification performance of artificial wetland system with horizontal flow in two consecutive years operating in arid regions, using physicochemical and biological processes for the removal of organic and inorganic pollutants from wastewaters. The treated wastewater can be used for agricultural land irrigation, aquaculture, landscape irrigation, urban and industrial applications, recreational and ecosystem purposes, and artificial recharging of ground water.

2. Materials and Methods

2.1. Presentation of the pilot unit for wastewater treatment (WWG) of Temacine

The pilot plant is located near the old Q'sar Temacine in South-East Algeria (33°01'06.947' N, 6° 01' 09.44''E) (Figure 1), it has a single treatment basin with a total volume of 400 m³, and it is filled with a layer of gravel with a thickness of 70 cm in wherein the top level of the water is 10-15 cm below the gravel. The WWG was built in 2007, it was commissioned in 2008 and treats wastewater from urban sources by macrophytes, this station was sized to treat wastewater volume of 15 m³ per day, corresponding to the production of about 100 people at a rate of 150 l/ person / day with continuous flow. Before the arrival of the raw water in the secondary treatment tank (WWG basin) water passes through a septic tank to retain coarse particles, finally, the water treated by the sewage system is used to irrigate some plants and green spaces.



Figure 1. Localization of wastewater treatment (WWG) of Old Q'sar Temachine

2.2. Sewage flow to the WWG

The supply of the pilot plant is provided by two sources of wastewater, those are taken from homes of the Q'sar by gravity, and those brought by pumping placed in the pumping station, the two meet in a manhole and flows by gravity to the septic tank (primary treatment), then, the wastewater is still flowing by gravity to reach the WWG purification tank which is filled with gravel (260 m^3) and planted with plants where wastewater takes only 88 m^3 of tank volume. At the exit, the clean waters flow into the control box which is connected directly with the underground drainage system (468 m long with a slope of 3/1000). This box is equipped with a safety water pipe used to drain water in case of malfunction or saturation of the drainage network, led to the canal nearby as shown in Figure. 2. In this system (WWG), the total hydraulic retention time was 5 days.

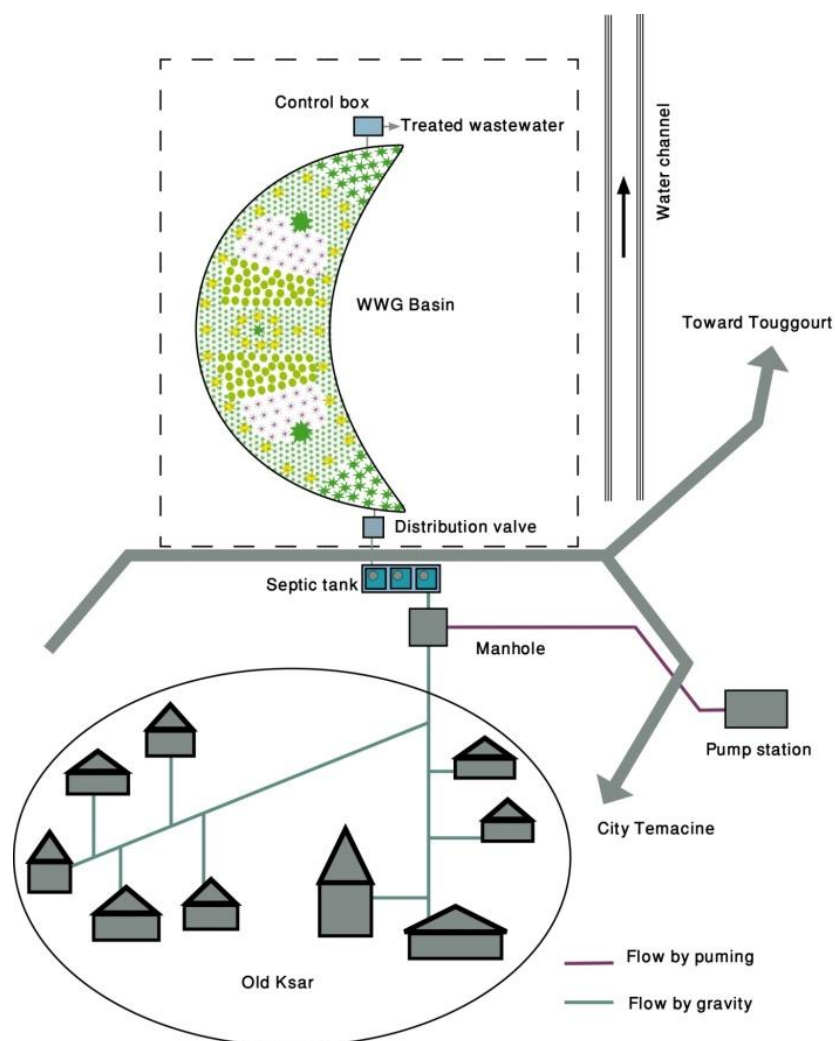


Figure 2. Schematic diagram of the sewage flow to the WWG of Temacine

2.3. Spatial distribution of plants used in the WWG

For this pilot plant, large plant diversity was investigated. According to the report of the manufacturer, virtually all of the species, 95% of plants are known for their ability to live in an environment saturated with water and can withstand the local climatic conditions, and 5% are plant-test. Special attention was devoted to the introduction of high value crops such as vetiver which was imported from Morocco, and the other species from northern countries. Thus, 941 plants divided into 23 species were installed between April and May 2007, planting was done by INRA Touggourt (National Institute of Agronomic Research) that controls plants in each month. The wrong choice of planting date (late April, early May), caused the death of most plants respond to high temperatures and the sirocco summer. Currently, the treatment basin contains six plant species known for their ability to live in a water-saturated environment: *Juncus maritimus*, *Typha angustifolia*, *Canna indica*, *Cyperus papyrus*, *Nerium oleander*, *Washingtonia robusta*, the plants are planted as eyelashes eye and Figure 3 below shows the arrangement of these plants in the wastewater treatment pond.

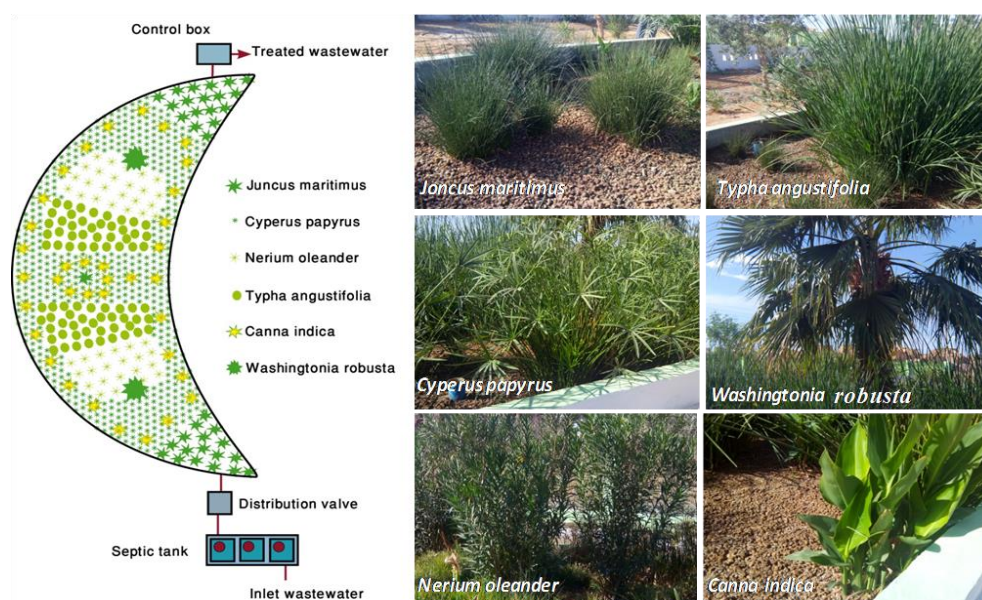


Figure 3. Spatial distribution of plants used in the WWG

2.4. Samples collection and physicochemical analysis

Samples were collected at the inflow and outflow of WWG, with weekly measurement for the biochemical oxygen demand in five days (BOD₅) and daily measurements for the other physicochemical parameters (pH, Temperature (T°), electrical conductivity(EC), suspended solids (SS), nitrites (NO₂-N), nitrates (NO₃-N), Orthophosphate (PO₄-P), and chemical oxygen demand (COD)). The analyses of the physicochemical parameters of the water are carried out in the laboratory of wastewater treatment plant (WWTP) of Touggourt over two operating years from January 2012 to December 2013. Sampling, preservation and transportation of the water samples to the laboratory were as per standard method. The treatment efficiency of each element measured is shown in Table 2 after the application of the following formula:

$$\text{Performance (\%)} = \left(\frac{X_{\text{Inlet}} - X_{\text{Outlet}}}{X_{\text{Inlet}}} \right)$$

X Inlet: Concentration of the parameter considered at the entrance to the station in mg /l.

X Outlet: Concentration of the parameter considered at the exit to the station in mg /l.

All samples were manually collected, handled and analyzed following [20]. approved standard methods

3. Results and discussion

3.1. Physicochemical quality of treated wastewater by WWG

In this study, the means concentrations of water quality parameters with a special focus on physicochemical parameters between influent and effluents of WWG (Table 1) and the means values of the removal efficiency of contaminant (Table 2) were evaluated.

Table 1. Average concentrations of the influents and effluents water quality parameters

Parameters	2012		2013	
	Inlet	Outlet	Inlet	Outlet
Temperature C°	27.20±6.23(a) (15.55-34)(b)	23.37±7.60 (13.25-35.75)	25.54±5.12 (16.45-32.40)	24.26±5.65 (12.90-29.75)
pH	7.39±0.42 (6.84-7.99)	7.17±0.47 (6.50-7.85)	7.19±0.15 (6.87-7.38)	6.94±0.16 (6.75-7.30)

Conductivity ms/cm	3.02±0.16 (2.78-3.27)	3.08±0.52 (2-3.55)	3.04±0.29 (2.52-3.50)	4.03±1.18 (2.28- 6.26)
SS mg/l	251.96±157.43 (113- 599.50)	26.29±3.23 (23-33)	290.36±141.84 (21.50- 488.50)	23.95±7.97 (12-39)
COD mg/l	324.20±54.42 (260-386)	33.20±2.07 (30-35)	322.5±98.09 (179.50- 500)	32.14±6.62 (21- 43.50)
BOD ₅ mg/l	200.56±61.26 (140-300)	19.92±10.98 (5-40)	277.86±69.62 (155- 365)	25±4.58 (18.50- 33.50)
N-NO ₂ mg/l	0.044±0.028 (0.020- 0.107)	0.014±0.011 (0.002- 0.032)	0.072±0.028 (0.040- 0.130)	0.017±0.014 (0.001- 0.040)
N-NO ₃ mg/l	17.11±8.79 (6.60-32.00)	4.13±3.08 (1.30-10)	28.241±12.447 (13.10- 49.00)	6.795±5.057 (0.70-13.35)
P-PO ₄ mg/l	14.27±7.92 (6-29.4)	2.85±2.62 (0.50- 7.50)	/	/

^a Mean ± Standard deviation, ^b Min – Max.

Table 2. Performance of purification physicochemical parameters measured in time

Months	Monthly treatment performance %										
	SS		COD		BOD ₅		NO ₂ -N		NO ₃ -N		PO ₄ -P
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012
J	84.21	87.91	/	90.15	92.50	90.37	82.24	75.00	40.56	79.05	72.22
F	90.21	90.05	/	87.62	96.43	88.06	93.33	69.23	21.88	94.97	36.71
M	90.58	86.82	/	92.11	96.80	92.00	62.26	62.50	85.87	96.90	68.22
A	93.43	92.81	/	91.14	92.94	91.56	47.54	57.14	31.82	93.13	89.80
M	89.89	93.63	/	89.26	89.67	89.80	50.00	62.50	71.76	61.08	90.00
J	95.16	91.67	/	89.57	81.82	90.78	33.33	66.67	75.00	56.89	92.22
J	74.34	90.26	/	89.70	85.71	91.83	79.17	66.67	40.00	64.87	60.12
A	71.79	90.87	89.55	75.77	88.42	82.13	90.00	98.00	90.26	87.25	94.89
S	86.77	93.87	88.21	90.25	80.65	93.53	77.78	95.00	95.31	71.26	85.37
O	87.17	95.10	88.46	90.86	85.71	92.29	80.00	95.00	95.67	82.24	88.33
N	92.10	95.80	90.28	94.20	91.67	92.88	75.00	95.00	70.98	73.81	88.33
D	85.98	92.22	91.45	90.04	93.45	91.00	71.74	75.70	90.40	75.94	91.67
Min	71.79	86.82	88.21	75.77	80.65	82.13	33.33	57.14	21.88	56.89	36.71
Max	95.16	95.80	91.45	94.20	96.80	93.53	93.33	98.00	95.67	96.90	94.89

3.1.1. Variation of Temperature, pH and EC

▪ Temperature (T °C)

The temperature is one factor that influences the rate of chemical reactions and plays an important role in increasing the chemical activity and especially bacterial. As shown in Figure. 4a, the evolution of the water temperature at the outlet during the two years is generally characterized by two phases: (1) A growing phase from January to July to reach the maximum value of 35.75 °C for 2012, and variable from January to August of the year 2013, where the temperature has reached maximum value of 29.75 °C. (2) A decreasing

phase from July to December during which the temperature value drops to near 14.7 °C for 2012, and in 2013, the value of temperature decrease from August until December (24.26 °C). All temperature values have the same tendency to change over time for two years, except in some cases where the exit temperature slightly above the temperature at the inlet as in July 2012, in April and June 2013 due to the influence of the air temperature.

- pH:

Means values and standard deviations of the influent and effluents water quality parameters are shown in Table 1. The influent wastewater pH was ranged between 6.84 and 7.99 with an average of 7.39 ± 0.42 in 2012 and 7.19 ± 0.15 in 2013. The measured of pH values in the effluent indicated a slight decrease of the pH from influent to effluents in both years, and these values are found in the standard interval (6.5 to 8.5) but with varying values between 6.5 - 7.85 for 2012 and 6.75 - 7.3 for 2013. The pH decrease in WWG could be related to the nitrification which during this process H^+ ions are released. In addition, these results may be also related to the production of organic acids by fermentation under anoxic conditions [21], generated inside the wetland during the growth and death of the plant, and by the mineralization of organic matter [22]. Although, it has been reported that the presence of plants in WWG are responsible for slightly modifying the pH conditions in the rhizosphere [10,23]. During the two years, the pH varies in the same way with the values in the effluents as the influent; this can be explained by the maintenance of a balance between the chemical compounds during processing time.

- Electrical conductivity (EC)

The average EC value in the influent was 3.02 ± 0.16 ms/cm in 2012 and 3.04 ± 0.29 ms/cm in 2013. The measured values of treated wastewater were ranging from 2 to 3.55 and 2.28 to 6.26 ms/cm respectively in 2012 and 2013. The average variation was almost similar to the influent wastewater, respectively (3.08 ± 0.52 and 4.03 ± 1.18 ms/cm). According to the monthly variation of EC, the highest values are recorded in April and May in both years of the study (Figure. 4c), and measured values of the conductivity of treated water were slightly higher than those of the raw water at the entrance to the station in almost the measurement period, and this may be due to the high concentration of soluble salts in the basin as a result of a strong evapotranspiration, caused by high temperatures [24,25]. This could be also partly attributed to the mineralization of the organics and dissolution of the bed granules [24].

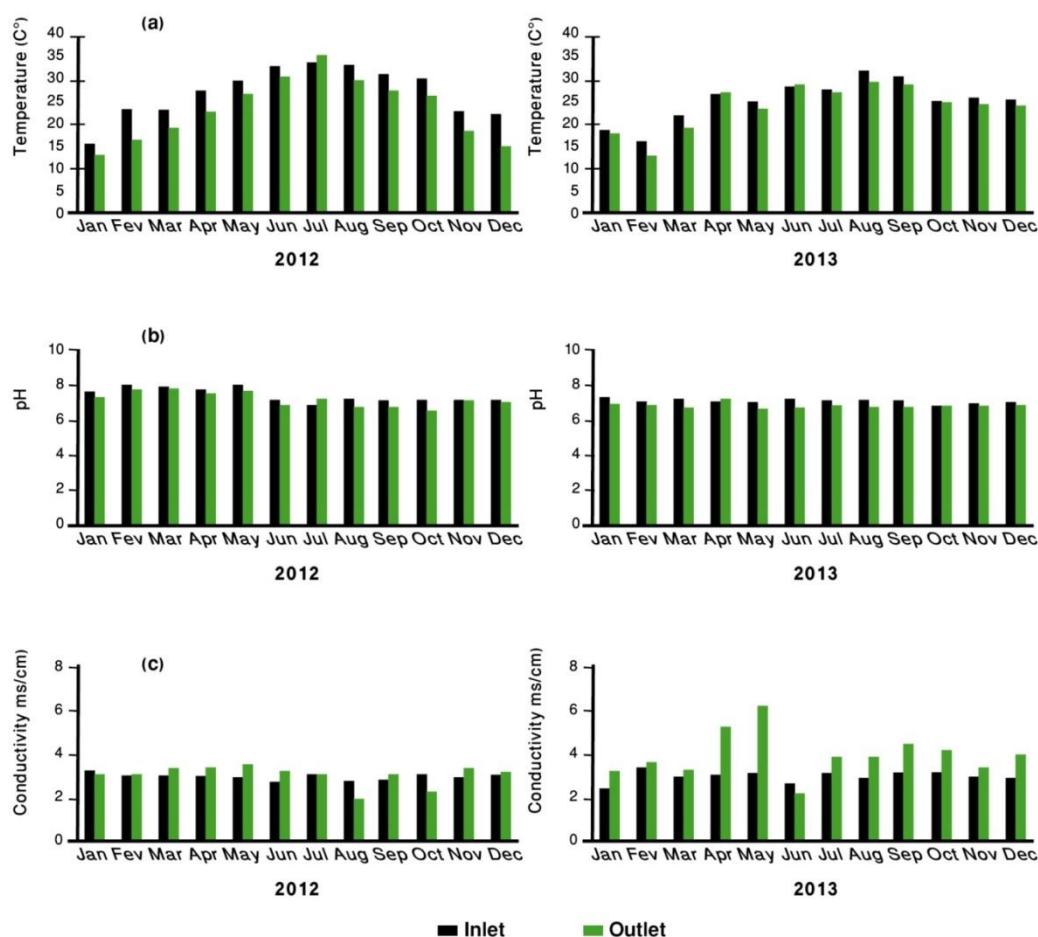


Figure 4. Evolution of the temperature, pH, and conductivity in different months over 2012 and 2013 of treatment

3.1.2. Suspended solids and organic matters removal

▪ Suspended solids (SS)

Throughout the study period, The WWG has received a large amount of suspended solids at the entrance; the means SS inflows concentrations were 251.96 ± 157.43 and 290.36 ± 141.84 mg/l respectively for 2012 and 2013. This mass of SS was decreased by the passage of water through the treatment basin to be around 26.29 ± 3.23 and 23.95 ± 7.97 mg/l for 2012 and 2013 respectively (Table 1). This decrease in concentration mainly due to the type of filter used (Liff) in the output of the septic tank that can hold a large amount of SS. In addition, the presence of gravel and the roots of plants in the water treatment basin serve as a physical obstacle with a degradation of the organic material in the presence of microorganisms. As shown in Figure. 5a, the removal efficiency of SS in WWG was higher in both years reach to 95%. In addition, the WWG provided the highest removal of SS in 2012 compared to the 2013. These results are similar to [26]., who indicated the removal efficiency of SS in a wetland treatment system is typically in the range of 80-90%. According to [27]., the SS removal can be attributed to the physical processes occurring in the wetland, such as sedimentation, filtration and adsorption. Filtration occurs by impaction of particles in the roots and stems of macrophytes or in gravel particles in subsurface flow [28]. Moreover, [29,30]. Reported also that the voids and media grain structure which is clearly visible in gravel, has remarkable impact on suspended solids and trapping during the flow path.

▪ Biochemical oxygen demand (BOD₅)

During the study period, the influent BOD₅ values were widely varied between 140 and 365 mg/l with an average concentration of 200.56 ± 61.26 mg/l for 2012 and 277.86 ± 69.62 mg/l for 2013. Whereas, the effluent values were ranged from 5 to 40 mg BOD₅ /l for 2012 and from 18 to 33 mg BOD₅ /l for 2013 (Table 2). As shown in Figure. 5b, there was a high reduction in the concentration after wastewater treatment in the two years, where the BOD₅ average removal efficiencies exceeded 80% (Table 3). The reduction of BOD₅ is very important in the control box, due mainly to aerobic and anaerobic microbial biodegradation processes supported by macrophytes transferring oxygen to the water within the rhizosphere [31,32] and also to physical processes, such as sedimentation and filtration [24,33]. According to [34], the reduction of the organic load was made by the presence of microorganisms in the treatment basin intervening in the process of degradation and mineralization of organic matter in the water.

- Chemical oxygen demand (COD)

For the COD concentrations, the analysis were carried out on all 2013 period, while in 2012; they were measured only from August to the end of the year. The COD concentrations variations of the WWG are shown in Table 1. The average influents water concentrations were 324.20 ± 54.42 mg/l in 2012 and 322.5 ± 98.09 mg/l in 2013. The high values of COD at the entrance of the WWG during the study period showed the presence of a large load of organic matter in household wastewater. In the outlet of the WWG, effluent mean concentrations for both years were around of 32 mg/l. The COD monthly removal efficiencies of WWG (Figure. 5c) were varying from 88 to 91% in 2012 and from 75% to 94% in 2013 (Table 2). The decrease of the pollutant load in the treated wastewater is probably related to the presence of plants that have created the physicochemical conditions for the oxidation of COD by microbial flora which facilitates its uptake by the plant. This drop can be explained also by the organic filler retained by the passage of the wastewater through the substrate (gravel) and the roots of plants in the treatment basin [35]. According to previous studies, the reductions of COD in CW due primarily to biological decomposition processes by various microorganisms attached to the filter medium under aerobic, facultative and anaerobic conditions [24,36,37]. This result indicated that the WWG was able to substantially decrease the concentration of COD in wastewater effluent.

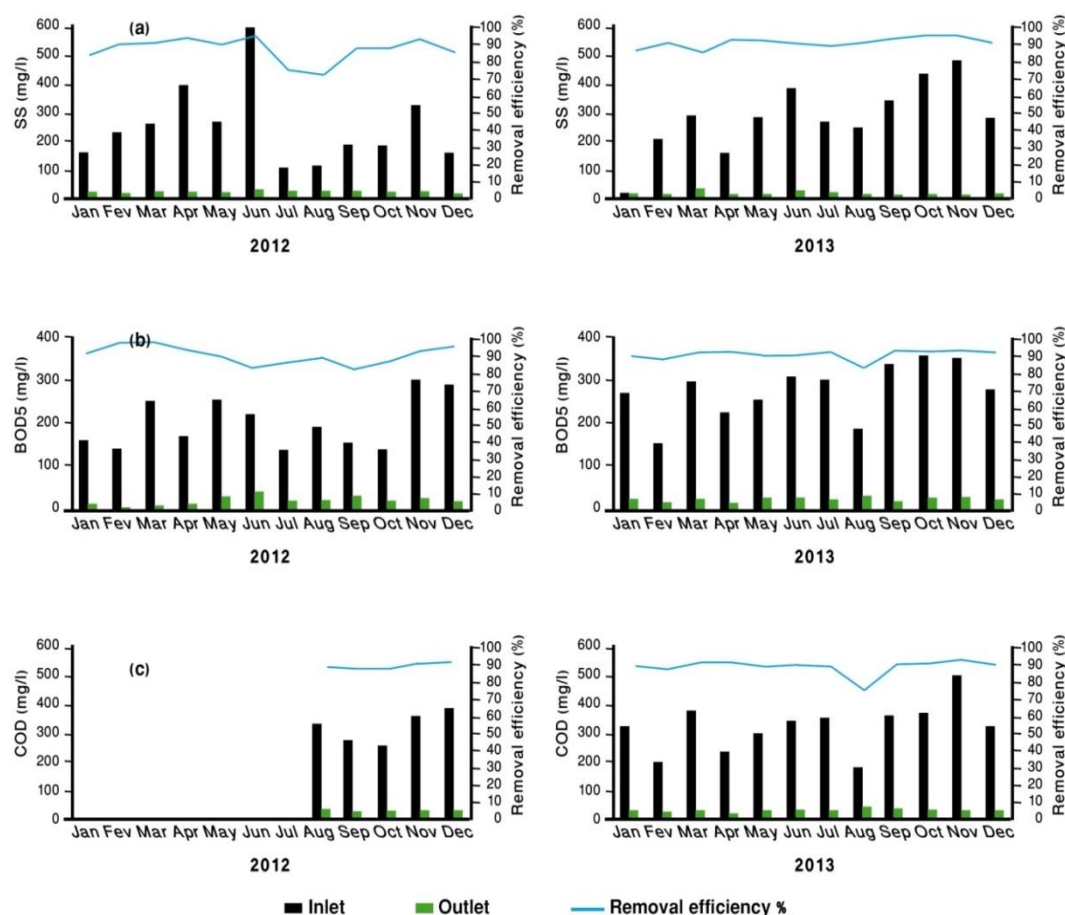


Figure 5. Average pollutants removal variation of SS, COD and BOD₅ in different months over 2012 and 2013 of treatment.

3.1.3. Nutrients removal

▪ Nitrate nitrogen (NO₃-N)

The average nitrate concentration obtained at sampling influent was 17.11 ± 8.79 mg/l in 2012 and 28.241 ± 12.447 mg/l in 2013 (Table 1). Whereas at effluent, the measured nitrate concentration values were decreased recording an average removal efficiencies of 67% and 78% (Table 2) in 2012 and 2013, respectively. In this case, the nitrate could be reduced in anoxic conditions by denitrification process, which is considered the main mechanism for nitrogen removal [38,39]. Denitrification is one of the key processes in biological nitrogen removal from wastewater. Through denitrification, oxidised forms of nitrogen, such as NO₃⁻ and nitrite (NO₂⁻), are converted to dinitrogen (N₂) and, to a lesser extent, N₂O gas. Denitrification is an anaerobic process that is carried out by denitrifying bacteria, which convert nitrate to dinitrogen [40]. However, denitrification in wastewater treatment plays a very beneficial role by removing unwanted nitrates from the wastewater effluent, thereby reducing the chances that the water discharged from the treatment plants will cause undesirable consequences (e.g., algal blooms).

▪ Nitrite nitrogen (NO₂-N)

The concentrations of NO₂-N in the influent were extremely low, which ranged between 0.02 and 0.13 mg/l during the entire experimental period (Table 1). However, the presence of NO₂-N in the effluents samples was lower than their corresponding concentrations in the influent, especially in the last months of both years (Figure. 6b). The removal efficiencies were varying from 33 to 93% in 2012 and from 57 to 98% in 2013 (Table 2). Nitrites may be encountered in the waters, but usually at low doses, they come either

from incomplete oxidation of ammonium, or a nitrate reduction under the influence of a denitrifying action [41]. Generally, low contents of nitrite in water at the inlet and the outlet may be explained by their oxidation to nitrate under biological action carried out by a biomass fixed on various media [42].

▪ Phosphate phosphorous $\text{PO}_4\text{-P}$

In this study, the phosphorus concentrations were measured only for 2012. Over the monitoring period, the mean value of the $\text{PO}_4\text{-P}$ concentrations obtained in the influent was 14.27 ± 7.92 mg/l, these concentrations were ranging from 6 to 29.4 mg/l (Table 1). After wastewaters passing through the WWG, low $\text{PO}_4\text{-P}$ concentrations in the effluent than in the influent were observed, the average concentrations throughout the study period decreased to reach weak concentrations (Figure. 6c). These values were fluctuated between 0.5 and 7.5 mg/l which means a removal efficiency of over 36 and 94% (Table 2). The decrease of the phosphate concentration in this investigation may be explained by the mechanisms responsible for phosphorus removal which are commonly substrate adsorption, plant and microorganism uptake and precipitation at high pH of 9–11 [38,43,44]. However, as pH was not high enough in this study to trigger precipitation, the bacterial activity and plants uptake of phosphate may be the only mechanisms for phosphorous removal. According to [45], phosphorous removal in constructed wetland systems occurs principally by substratum, while plant uptake has minimum role in phosphate removal.

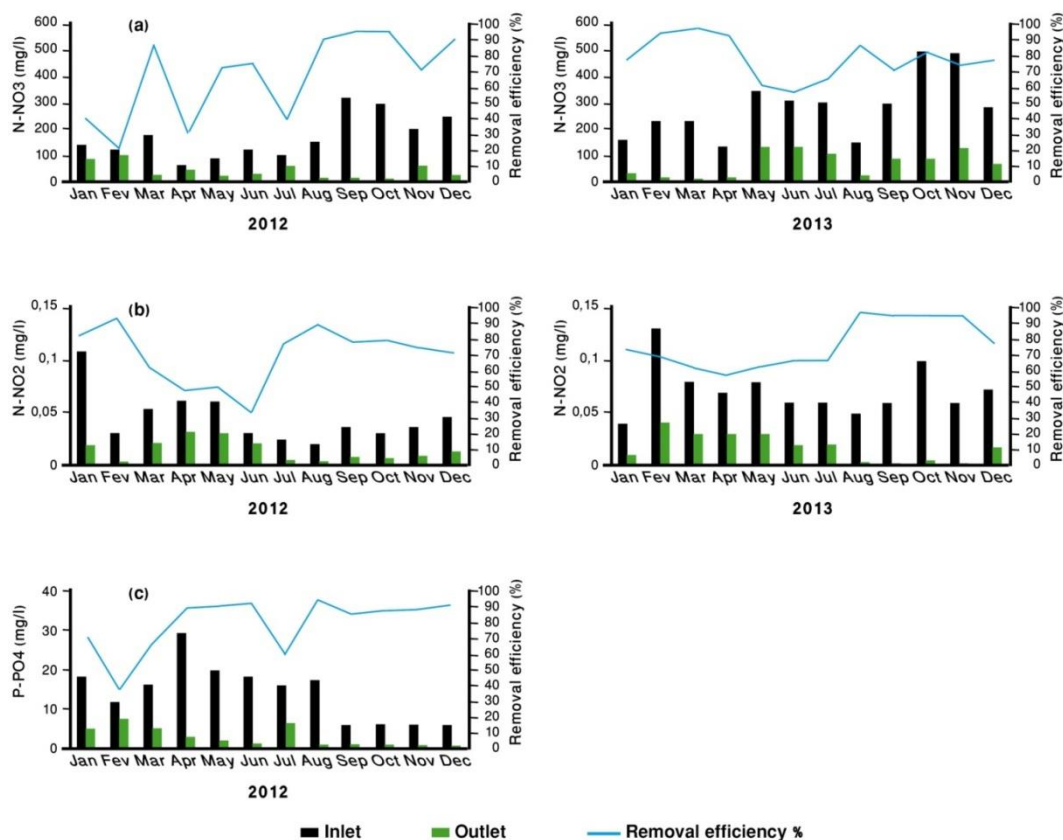


Figure 6. Average pollutants removal variation of $\text{NO}_3\text{-N}$, $\text{NO}_2\text{-N}$ and $\text{PO}_4\text{-P}$ in different months over 2012 and 2013 of treatment

4. Conclusion

Our research aimed to determine the performance of macrophyte-based wastewater treatment plant (WWG) in arid area by analyzing overall parameters of the organic and nutrients pollution of domestic wastewater in two consecutive operating years (2012–2013). The results of the analysis of the physicochemical quality of raw water at the inlet and treated water at the outlet showed that WWG of Temacine rejects a purified water of

satisfactory quality against objectives set for the removal efficiency of the elements responsible for the pollution. With respect to the reduction of the pollution load related to purification efficiency of elements responsible for pollution, purified wastewater is considered only if it satisfies the discharge standards, this is the case for all parameters studied in the treated water resulting from WWG of Temacine except in the salinity of treated wastewater that requires organizing the installation of plants in the basin according to their degree of tolerance to pollution and salinity (the most resistant plants in the front of the basin followed by less tolerant in the rear). The data collected from this WWG system represent an exceptional case study, which may be potentially transferred to other rural communities that lack sanitation and reclamation systems. Moreover, the option of wastewater reuse and zero discharge is particularly attractive for arid areas.

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