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Hydraulic load rates effect on the performance of Horizontal Multi-Soil-Layering to treat domestic wastewater in rural areas of Morocco

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Abstract

The objective of the present study was to investigate an environmental and economically sustainable technic to treat domestic wastewater in rural areas of Morocco. To do this , a pilot-scale treatment system, horizontal multi-soil-layering (H-MSL) measuring 0,5 m × 0,3 m × 0,55 m (L ×W× H), was designed, constructed and operated to treat domestic wastewater, using natural substrate. A feeding tank (100L) was used to store prescreened wastewater from the inlet of the household wastewater using submersible pump. Three hydraulic loading rates (HLRs) were tested: 0.25, 0.35 and 0.50 m/day. This pilot-scale treatment was exposed to the environmental conditions and it does not include any pretreatment. Several water quality parameters including BOD_5, COD, TSS, NH_4^+, NO_3^- and PO_4^{3-} were monitored. The ANOVA test showed a significant difference between the means of these parameters at ($p < 0.05$) for the influent and the effluent, except ammonium. Moreover, it showed a difference between the values of organic mattersat0.25m/d and 0.5m/d. However, it did not show any significant differences between each type of nutrients for all HLRs tested. The main treatment performance results showed the following average removal rates: BOD5 (66±13 %), COD (68±12 %) and TSS (75±14%), NH_4^+(29.2±14.1%) and PO_4^{3-} (45.2±27.3%). The quality of the treated wastewaters was under to Moroccan Reject Limit Value (RLV).

1. Introduction

Rural water pollution has attracted greater attention over the past few decades [1]. In developing countries like Morocco, water pollution loads caused by rural activities are becoming cumulatively prominent because of lacking applicable sewage management [2-4]. These practices still pose a major risk to public health and the environment; exposing many people to infection and dangerous diseases [5-7]. In order to overcome this situation, most decentralized wastewater treatment systems including conventional septic tank-soil trench systems, land treatment systems, sand filter systems etc., can provide advanced treatment for rural wastewater. However, it would be important to develop an effective wastewater treatment system adapted to Moroccan context with a low cost, because the main barriers to access to the sanitation service in these areas are mainly in terms of investment and operating costs. Indeed, the lack of financial resources and the high cost of existing technologies in the sanitation market (intensive systems) are considered among the main reasons for inadequate wastewater treatment in rural areas of Morocco. Currently, an alternative technique that holds interesting potential for decentralized sewage treatment is multi-soil-layering (MSL) system. The first MSL system had been used for domestic wastewater treatment in Japan since July 1990[8].The technology of decentralized wastewater treatment has been gaining popularity as a low-cost, low-maintenance and effective alternative in vast rural areas. Furthermore, it has been successfully used for treatment of other types of wastewater [9-11]. MSL system typically comprises layers of soil mixture blocks (SMBs) alternating with permeable layers (PLs) (Figure 1). MSL system is extremely economical because the constituents of the system, including soil, coal, sawdust and metal, are locally available. Chen et *al*.[12] analyzed the cost of materials in China and pointed out that to construct an MSL system with a municipal wastewater treatment capacity of 100 m^3/day at an HLR of 1 m^3/m^2/day, this required an area around 100 m^2, with a depth of 1 m. Therefore, the whole cost for constructing such as MSL system can be less than US$10,000. Compared to conventional sewage systems and sewage treatment plants, the cost of operating and maintaining MSL systems is extremely low. Therefore, this type of natural treatment system is an economical solution. Moreover, the homogeneous coarse particles of PL enhance wastewater distribution and prevent clogging [13,14].

The main objective of the present is to develop a very simple MSL system that will be economic, ecologic and effective to treat domestic wastewater for single household, a few households or a public building in rural areas of Morocco. The specific objective was to evaluate the effect of three hydraulic loading rates (250, 350 and 500 L/m^2/day) on the performance of the filter H-MSL.

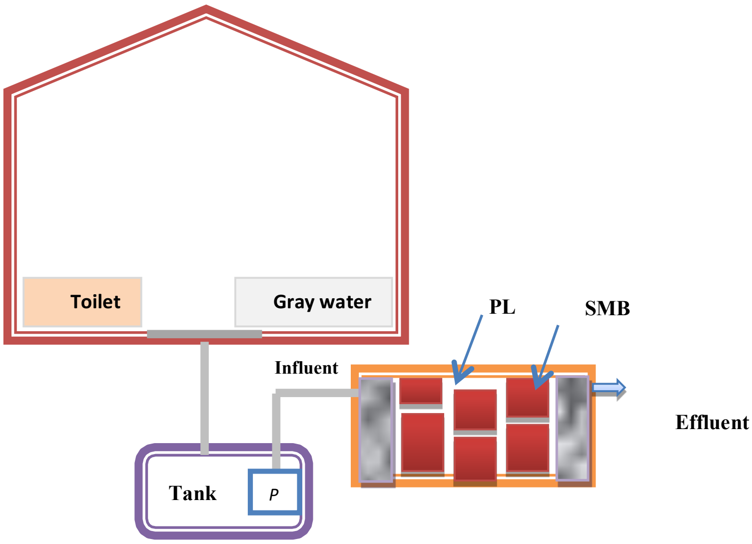


Figure 1. Schematic representation of Horizontal Multi-Soil-Layering (H-MSL) for a single household

2. Material and Methods

2.1. Description of the treatment unit

This study was carried out in a guardian's household of a middle School (Razi), Meknes, Morocco; where the climate is classified as warm temperate. The pilot-scale system was designed, built and began to operate at the beginning of March 2017 and, this system was allowed to stabilize for three months. The pilot-scale treatment system is a Horizontal Multi-Soil-Layering (H-MSL) measuring 0,5 m × 0,3 m × 0,55 m (L ×W× H) (Table 1) with a feeding tank (100L) used to store prescreened wastewater from the inlet of the household wastewater using submersible pump.

Table 1: characteristics of the H-MSL

Surface (m^2)	0.15
Dimensions (mxmxm)	0.30x0.50x0.55
Feeding type	Continue
Direction of flow	Horizontal
Aeration	No

The pilot-scale treatment wetland was exposed to the environmental conditions. The substrates used in this study were gravel, iron sawdust, charcoal, wood sawdust and soil (Table 2). These materials are abundant and inexpensive in Morocco.

Table 2:Horizontal Multi-Soil-Layering (H-MSL) composition

Layer name	thickness / layer (cm)	composition	Ø (mm)	% by weight	weight of a brick
3 SMB layers	5	- Soil - Wood sawdust - Charcoal - Iron sawdust	≤ 2	60% 20% 10% 10%	1.75 kg
4Permeabe Layers (PL)	4	- Fine gravel	3 -5 mm	100%	
2 laterallayers	10	- pebble	20-40 mm	100%	

The H-MSL was feeding continuously by a network of perforated tube provides the uniform distribution of the wastewater into the lateral surface (Figure 1). Indeed, the wastewater is fed via an inlet that continues its way under the surface of the bed in a horizontal path until it reaches the outlet zone. On the other hand, three hydraulic load rates were tested in this study: 0.25 m /d, 0.35 m /d and0.5 m /d.

2.2 Measurement of water quality parameters

After the stabilization period, the samples were collected and analyzed monthly for the duration of one year from June 2017 to May 2018. Physico-chemical analyses were carried out for raw and treated wastewater. They covered: Temperature, pH, chemical oxygen demand (COD), biological oxygen demand (BOD), total suspended solids (TSS), ammonia-nitrogen (N-NH4), Nitrate-nitrogen ($N-NO_3$), Orthophosphate (PO_4^{3-}) and total suspended solids (TSS). Some parameters such as temperature, pH, EC and dissolved oxygen (DO) are measured in the field by a multi-parameter device; the other physicochemical parameters are carried out within the Laboratory of Natural Resources Management and Development Team, Health and Environment, Faculty of Science for analysis [15].

2.3. Data analysis

Statistical analyses of the collected data were carried out using software: Microsoft Excel 2010 and SPSS 20 (included analysis of variance (ANOVA)).

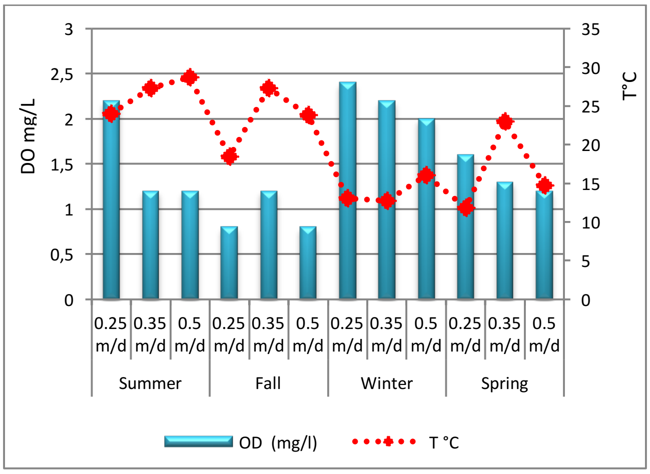
3. Results and discussion

3.1 Trend temperatures and dissolved oxygen concentrations

The average values of influent and H-MSL water temperatures are 20.3±6.1 °C and 20.1±6.3°C, respectively. The highest temperatures (influent: 29.1°C, effluent: 28.7°C) were reached in summer (July–August), and the lowest values (inflow: 11.6°C, outflow: 11.8°C) were recorded in March. The DO content of the influent and H-MSL averaged 1.2 ± 0.5 mg/L and 1.5 ± 0.6 mg/L respectively (Figure 2).On the other hand, in H-MSL, the dissolved oxygen reached the highest value in winter (December: 2.4 mg/L) and at the beginning of the monitoring period(June: 2.2 mg/L)with a HLR 0.25 m/d(Figure2).This parameter presented an inverse variation with temperature. The ANOVA test showed a significant difference between the temperature means of different seasons at ($p <0.05$) except between summer and fall for the influent and effluent; however, it did not show any significant differences between the raw and treated temperatures (Table 3). In addition, the ANOVA test did not show any significant differences between the dissolved oxygen means of the seasons at ($p <0.05$) for the influent and effluent and for all season.

3.2 Trend of electrical conductivity and pH

The pH values of the treated water are between 7 and 8 units (Figure 3), indicating optimal conditions in the treatment system during the study period; the averages of this parameter in influent and effluent were 7.0 ± 0.6 and 7.2 ± 0.4, respectively. Indeed, pH is a fundamental factor for the quality of the water, exerting a great influence on the aquatic system, because it is a fundamental parameter in many chemical reactions in living organisms. The pH of the effluent reached the highest value in September and May with a maximum of 7.7 (Figure 3). The EC mean of treated wastewater (1.043 ± 0.31 mS/cm) was almost equal to influent values (1.05 ± 0.38 mS / cm) during the study period (Figure3). The ANOVA test did not show any significant differences between the EC means of different seasons at ($p < 0.05$) for the influent and effluent. The same result was obtained for the pH because the probability was higher than 5% (Table 3).



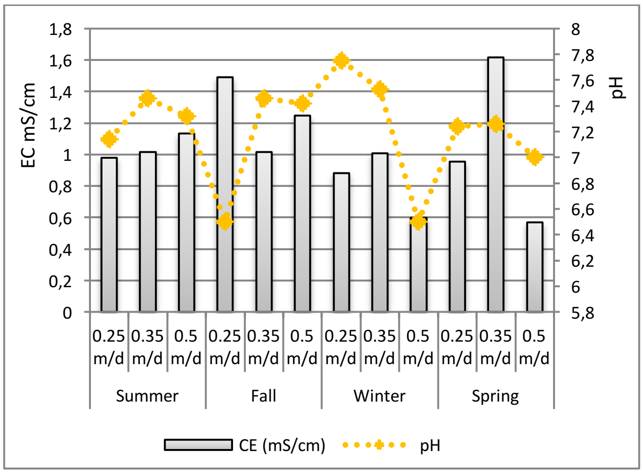


Figure 2: Trend of DO and temperature in H-MSL **Figure 3**: Trend of EC and pH in H-MSL

3.3 Reduction of BOD5, COD and TSS

The concentrations of BOD5, COD and TSS in influent and H-MSL during the study period are shown in figures 4, 5 and 6. The averages of their concentration in the influent were 186.7±42.9, 386.8±84.1 and 371±102.7mg/L, and those of the effluent were 65.5±31.3, 123.7±52.9 and 87.3±43.3, respectively. The values of these parameters increase as the values of the hydraulic load rate (HLR) increase (Figures 4, 5 and 6). The ANOVA test shows that there is a significant difference between the BOD, COD and TSS averages in influent and effluent at $p < 0.05$ (Table 3). Moreover, it showed a difference between the values of these parameters at0.25m/d and 0. 5m/d (Table 4), but there is no difference between 0.25m/d and 0.35m/d. The main treatment performance results showed the following average removal rates: BOD5 (66±13 %), COD (68±12 %) and TSS (75±14%). The results obtained by our pilot unit were similar than those reported by Molle et *al*. [16] in terms of COD and TSS reduction, which are 68% and 74%, respectively.

Table 3. ANOVA test of treatment (influent and H-MSL)

Variable	(I) Treatment	(J) Treatment	Différence des moyennes (I-J)	Signification (P)
T °C	Influent	H-MSL	.208	.935
pH	Influent	H-MSL	-.183-	.404
EC	Influent	H-MSL	-13.500-	.925
DO (mg/L)	Influent	H-MSL	-.333-	.125
BOD_5 (mg/L)	Influent	H-MSL	121.158*	**.000**
COD (mg/L)	Influent	H-MSL	263.083*	**.000**
TSS (mg/L)	Influent	H-MSL	284.000*	**.000**
$P0_4^{3-}$ (mg/L)	Influent	H-MSL	2.492*	**.000**
NH_4^+ (mg/L)	Influent	H-MSL	-1.067-	.800
NO_3^- (mg/L)	Influent	H-MSL	9.550*	**.000**

* Significant difference at $p < 0.05$

Table 4. ANOVA test of organic matters in different HLRs

Variable	(I) HLR	(J) HLR	Difference of averages (I-J)	Signification (P)
BOD5 mg/l	0.25m/d	0.35m/d	-22.2000-	0.338
		0.5m/d	-56.0000-*	**0.019**
	0.35m/d	0.5m/d	-33.8000-	0.123
COD mg/l	0.25m/d	0.35m/d	-41.7500-	0.209
		0.5m/d	-94.5000-*	**0.011**
	0.35m/d	0.5m/d	-52.7500-	0.109
TSS mg/l	0.25m/d	0.35m/d	-30.2500-	0.126
		0.5m/d	-75.5000-*	**0.003**
	0.35m/d	0.5m/d	-45.2500-*	**0.03**

* Significant difference at $p < 0.05$

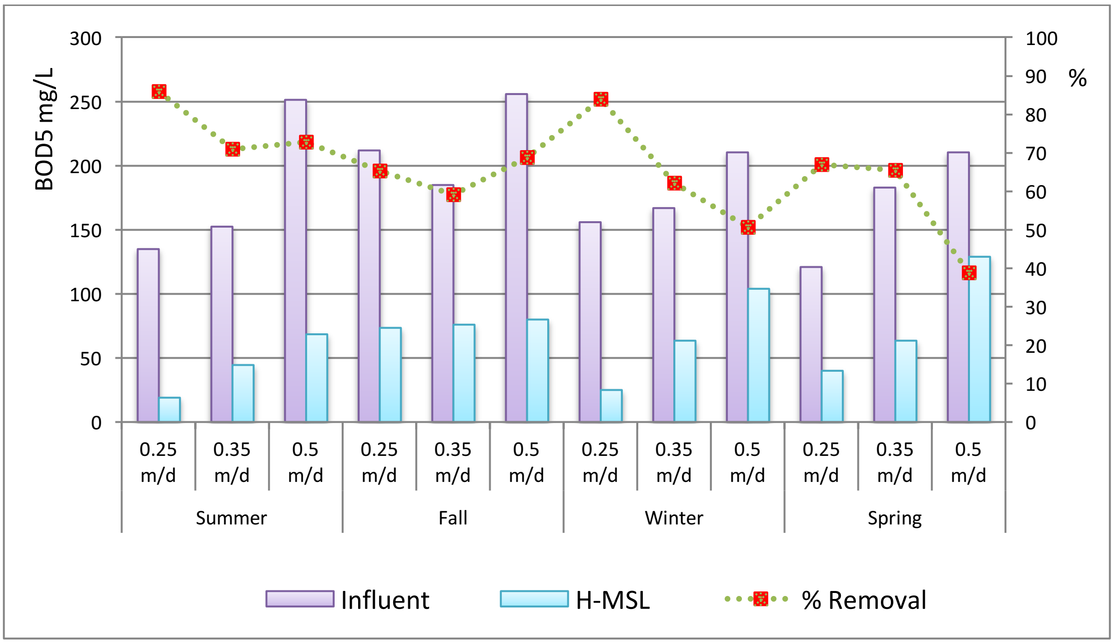


Figure 4. Trend of BOD5 concentrations according to HLR

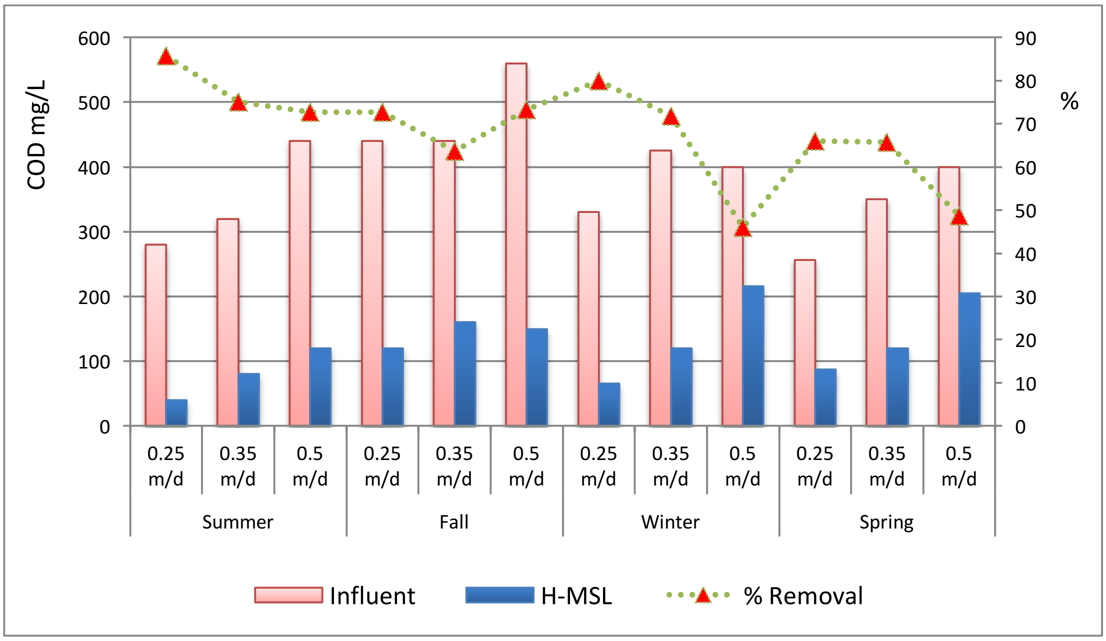


Figure 5. Trend of COD concentrations according to HLR

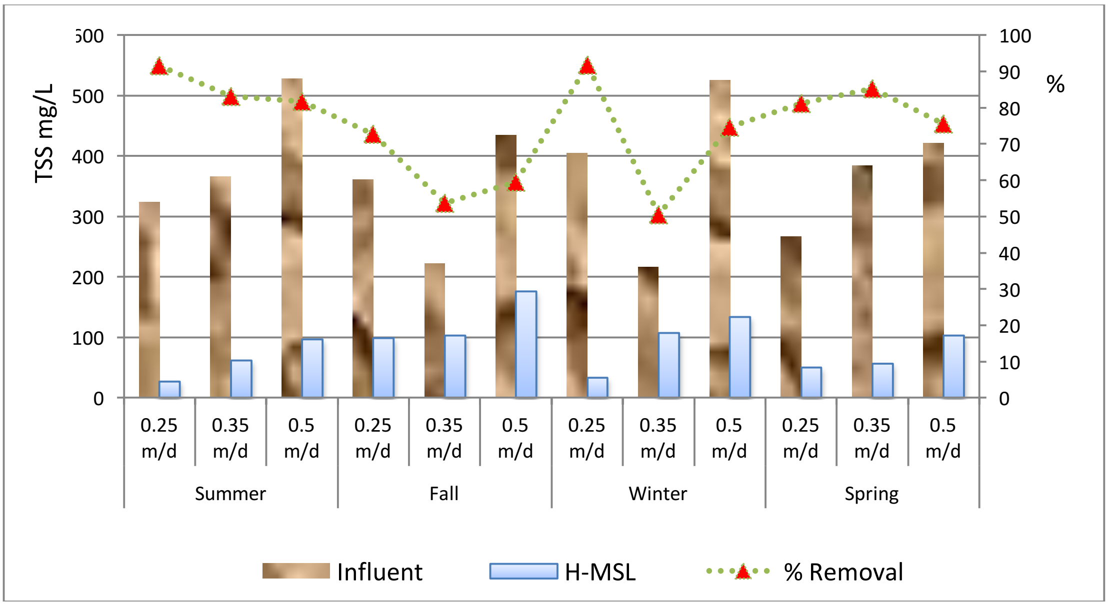
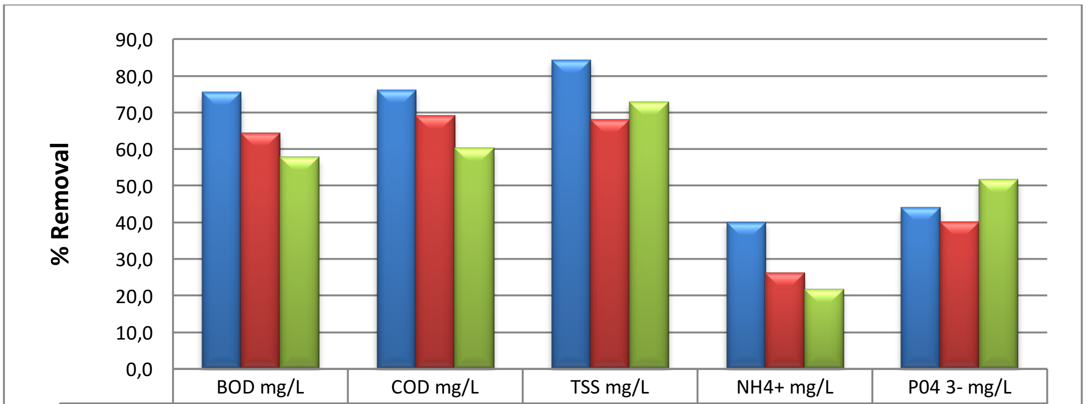


Figure 6. Trend of TSS concentrations according to HLR

Figure 7 shows the BOD, COD and TSS removal efficiency under various HLR conditions . The results indicated that the BOD, COD and TSS removal rate increased as the HLR decreased. This is because the retention time of the wastewater within the system increased as the HLR decreased, thus providing the system with sufficient time to adsorb, react, and remove the organic pollutants from the wastewater and consequently enhancing the removal efficiency[17]. In general, when the HLR was increased, the filter performance decreased. However, the ANOVA test did not show any difference of the removal performance of BOD, COD and TSS between the three hydraulic load rates tested (Table 4).In addition, the BOD_5 removal by H-MSL system under HLR = 0.25, 0.35 and 0.5 m/d conditions were 75.5%, 64.4% and 57.7% respectively, and those of COD under the same HLR were 76.1%, 69% and 60.2%, respectively. The same results were reported by Ho and Wang[18]; they indicated that the average COD removal efficiency of the four MSL samples under HLR = 0.5 $m^3/m^2/d$ is 77.8%, 69.8%, 54.1%, and 74.4%, respectively. On the other hand, Boonsook et *al*.[19] developed MSL systems and used zeolite, zeolitised perlite, perlite, gravel, and charcoal as the PL materials. They subsequently conducted a series of indoor tests and discovered that under an HLR of 0.096–0.346 $m^3/m^2/d$ and under nonaerated conditions, all the PL materials achieved a COD removal rate of 79.0%–98.1%.



	BOD mg/L	COD mg/L	TSS mg/L	NH4+ mg/L	P04 3- mg/L
0.25 m/d	75,5	76,1	84,3	40,0	44,0
0.35 m/d	64,4	69,0	68,1	26,1	40,1
0.5 m/d	57,7	60,2	72,8	21,6	51,6

Figure 7. Evolution of the performance of H-MSL according to HLR

3.4 Ammonia removal and nitrate transformation

The variations of ammonia and nitrate concentrations during the study period are illustrated in figure 8. The results showed that the average concentrations of the ammonia and nitrate concentrations in H-MSL were 14.1±4.5 mg/L and 4.6±4.3 mg/L, respectively; While, the average concentrations of ammonia and nitrates in raw water were 19.8 ± 5.4 mg/L and 4.9 ± 2.7 mg/L, respectively. The average removal rate of NH_4^+ was low 29.2±14.1% (Figure 7), due to anaerobic conditions in the filter. Moreover, the ANOVA test shows that there is not a significant difference between the NH_4^+ means of the H-MSL and the influent at $p < 0.05$ (Table 3).The lower nitrification capacity of the H-MSL can be attributed to anaerobic condition into this filter, favoring denitrification processes [20], since, in horizontal flow system, oxygenation of the matrix is lowest compared to the intermittent fed of vertical systems. According to Bezbaruah and Zhang[21], oxygen transporting into the saturated media of the horizontal flow systems is limited, so they are predominantly anaerobic systems. While this low level of oxygen availability largely restricts the nitrifying rates, such anoxic conditions can significantly facilitate denitrification achievable in these systems. Furthermore, the ANOVA test did not show any difference of the removal performance of NH_4^+ between the three hydraulic load rates tested (Table 5). The average removal rate of NH_4^+ was 29.2±14.1% during the study period. For the three HLRs tested (0.25 m/d, 0.35 m/d and 0.5 m/d), the average removal rates of NH_4^+ were 40.0%, 26.1%, 21.6%, respectively. This can be explained by the decrease of dissolved oxygen into the filter when increasing the hydraulic load which disadvantages nitrification.

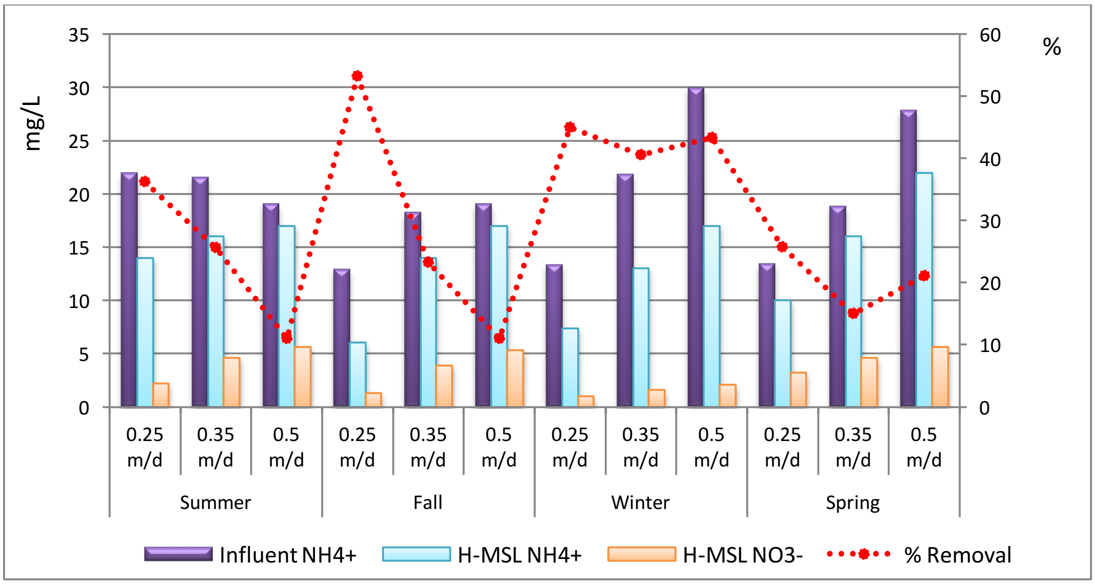


Figure 8. Trend of $NH_4^+$and NO_3^-concentrations according to HLR and season

Table 5. ANOVA test of nutrients

Variable	(I) HLR	(J) HLR	Difference of averages (I-J)	Signification (P)**
NH_4^+ mg/L	0.25m/d	0.35m/d	-9.8900-	0.333
		0.5m/d	-6.4400-	0.596
	0.35m/d	0.5m/d	3.4500-	0.854
NO_3^- mg/L	0.25m/d	0.35m/d	-1.2500-	0.904
		0.5m/d	-5.2000-	0.247
	0.35m/d	0.5m/d	-3.9500-	0.413
PO_4^{3-} mg/L	0.25m/d	0.35m/d	.2575	0.952
		0.5m/d	.6325	0.751
	0.35m/d	0.5m/d	.3750	0.902

** p>0.05 no significant difference

3.5Orthophosphateremoval

The average of influent and effluent concentrations of $P0_4^{3-}$ were 4.2 ± 1.7 mg/L and 2.2 ±1.3 mg/L, respectively(figure 9) with 45.2±27.3% as average removal rate of $P0_4^{3-}$ during the study period. On the other hand, the removal rates of $P0_4^{3-}$ for the three HLRs tested (0.25 m/d, 0.35 m/d and 0.5 m/d) were 44%, 40.1%, 51.6%, respectively. The ANOVA test shows that there isa significant difference between the $P0_4^{3-}$ means of the H-MSL and the influent at $p < 0.05$ (Table 3), but this test did not show any difference of the removal performance of $P0_4^{3-}$ between the three hydraulic load rates tested (Table 5). These results were similar than those obtained by Zurita et *al*. [22]on horizontal flow constructed wetlands (HFCW). They reported that only 44% of phosphate removal had been obtained in HFCW and that 50% had been eliminated in food-source water. In this study, the removal of orthophosphate ($P0_4^{3-}$) is probably related to its precipitation on the sawdust iron added to the soil mixture blocks (SMBs) (Table 2). According to several studies, the presence of iron (Fe) and calcium in the filter medium increase the adsorption and precipitation reactions of Phosphorus [23]. Many studies have previously reported that phosphorus can be absorbed chemically by Al and Fe hydroxides in filter media. The added iron, for example, will turn into ferrous iron (Fe^{2+}) and then be oxidized to ferric ion (Fe^{3+}), which will facilitate the fixation of phosphorus by the formation of a chemical precipitate [24].Sato et *al*. [25] concluded that phosphorus removal is mainly due to chemical precipitation, a process essentially limited by the contact time between ferric ion and orthophosphate.In addition, Zhang et *al*. [26] reported that iron debris.

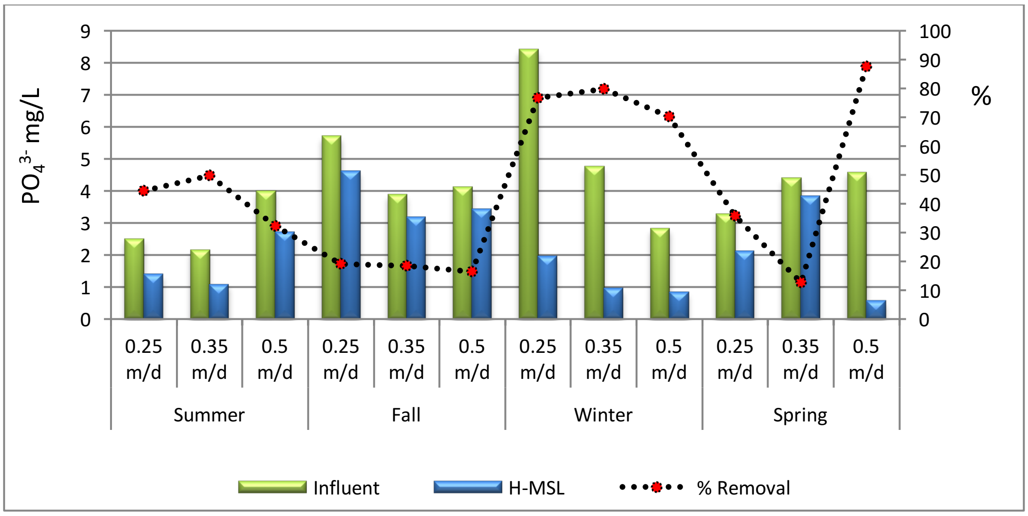


Figure 9. $P0_4^{3-}$ removal during the study period

paved in the aerobic vertical flow trickling filter (VFTF) had a much greater effect on phosphorus uptake than those added in SMBs in horizontal flow multi-soil-layering (HFMSL) since about 74.1% of the TP was removed on the upper level.This may be due to the fact that iron can more easily be converted to ferric ion under aerobic conditions [27].These results are consistent with our results, which show that the removal performance of PO_4^{3-} follows the trend of dissolved oxygen. Indeed, during the winter when DO is high the performance reaches maximum values and vice versa in fall (Figure 2and 9).

Conclusion

In this study, the horizontal multi-soil-layering filter was created to treat domestic sewage in rural areas of Morocco. This system showed a good ability to reduce BOD_5, COD, TSS, and a moderate removal efficiency of PO_4^{3-}. However, the removal rate of $NH_4^+$was lower due to anaerobic conditions. In addition, when the hydraulic load rate (HLR) was increased, the performance of the filter decreased. The ANOVA test showed a significant difference between influent and H-MSL system for organic matters and nutrients except ammonium. However, it did not show any difference between the three HLRs tested for all pollution parameters. The effluent quality was still in line with Moroccan standards. This makes this system even more suitable for single households in rural areas of Morocco. Consequently, this technology could be an alternative to conventional treatment systems, particularly for small and remote communities in Morocco.

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