AN EFFICIENT APPROACH TO MANAGE DOMESTIC WASTEWATER IN SMART CITY

A.Taouraout[1,2,*], A. Chahlaoui[2], D. Belghyti[1], I. Taha[2], M. Lachhab[1]

[1]Laboratory of Agrophysiology, Biotechnology, Environment and Qualities, Faculty of Sciences, University IbnTofail of Kenitra, BP: 133, 14000 Kenitra Morocco.
[2]Laboratory of Natural Resources Management and Development Team, Health and Environment, Faculty of Science, Moulay Ismail University Meknes, Morocco.

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ABSTRACT:

The adoption of an ecological sanitation system, meeting the requirements hygienic and sanitary, constitutes a feasible and technically and economically acceptable solution in the future smart city. This new sanitation concept has the advantage of solving the problems of pathogens of human waste at source, thus offering the possibility of reusing them after treatment (recycling) in order to improve the standard of living of the population and protect the environment. The aim of this study is to evaluate the efficiency of a vertical Multi-Soil-Layering system (MSL) system to treat domestic wastewater under three hydraulic loading rates: 250 L/m^2/day, 350 L/m^2/day and 500 L/m^2/day, in Moroccan conditions. To do this, a vertical MSL system measuring 20cm x 60cm x 78cm (L ×W× H) was designed to treat domestic wastewater and his performance was investigated. The results showed high removal of organic matters and nutrients under the three hydraulic loads tested; the performance averages recorded are upper than 84 % for organic matters, 83.1±7.2 % for ammonium and 72.4±14.1 % for orthophosphate. The quality of the treated wastewater was evaluated according to Moroccan reject limit value. Consequently, this system could be considered an effective solution to be adopted for decentralized domestic wastewater treatment in Moroccan conditions.

1. INTRODUCTION

Currently, there is a risk that several cities will face water shortage, lack of water qu[1]ality, lack of sanitation and environmental pollution in general. The situation is further exacerbated especially in developing countries due to the combined effects of population growth and low socio-economic status (Vymazal, 2011; Wu et al., 2014); this is one of the factors behind population expansion is rural migration. People come to cities looking for employment opportunities. Unfortunately, in many cities of developing countries, people live and raise their children in a highly polluted environment. Moreover, there is the issue of weak or almost non-existent policies on more efficient water usage. Also, water management plans are not based on demand, reuse and recycling. Wastewater is often not given much importance. Consequently, in 2015, 2.4 billion people worldwide lacked improved sanitation (United Nations, 2016); and more than 2,000 million tons of human waste are discharged directly into the wild every year, without any treatment (UN-HABITAT, 2009). These practices still pose a major risk to public health and the environment; exposing many people to infection and dangerous diseases (Galloway et al., 2004; WHO, 2005; Sutton et al., 2011). In fact, human excrement can contain pathogenic agents such as bacteria and parasites capable of causing diarrheal diseases (cholera, typhoid, etc.) (Berrada, 2007). According to Jewitt (2011), food and drinking water can be contaminated with these pathogens through insects and human contact. This is why, in these countries, there is a high percentage of the population that is already attacked by waterborne diseases; this population becomes vulnerable to potential infections and malnutrition sulfur (Heinonen-Tanski, van Wijk-Sijbesma, 2005). As a

result, an estimated 1.5 million people die each year from lack of access to clean water and the presence of pathogens associated with human excrement (Farmer, 2001; UNICEF/WHO, 2008).

Rather than linear thinking about systems and technical solutions, smart city will need to think more about ecosystems and the 'water web'. This new approach integrates the social, cultural, economic and ecological aspects. Indeed, the ecosystem, social and resource problems in urban settings are all interrelated. In particular, better management of the water resource, storm water and wastewater can often be achieved by addressing the total urban water system. In addition, wastewater management is also about the wise use of our natural resources such as water, nutrients and even energy (Ferguson et al., 2003; Taouraout et al., 2020a; Taouraout et al., 2020b).

To compete effectively at an international level, cities will need to become more intelligent, innovative, and integrated. A Smart City will increase efficiency, productivity, ecological awareness; it will reduce pollution and improve quality of life in a world of increasing urban complexity. Smart cities concept is pragmatic and balanced combination of ecological, economical and other effective field for perfect sustainable development. Ecological cities enhance the well-being of citizens and society through integrated urban planning and management that fully harnesses the benefits of ecological systems, and protects and nurtures these assets for future generations (Taouraout et al., 2020a; Taouraout et al., 2020b).

In general, the sanitation concept to be adopted in smart cities must integrate not only the water aspect (transport, flow) but also the treatment in order to protect the receiving environment from the risks of contamination (Taouraout et al., 2020a;

*Corresponding author

Taouraout et al., 2020b). Indeed, the concept of the linear approach sanitation "end of pipe" (Figure 1), in which resources are used and converted into wastes, only to be disposed of, represents a failure in human ingenuity and a flaw in technology design.

The adoption of an ecological sanitation system (Figure 2), meeting the requirements hygienic and sanitary, constitutes a feasible and technically and economically acceptable solution in the future smart city (Taouraout et al., 2020a; Taouraout et al., 2020b). This new sanitation concept (ecological sanitation) has the advantage of solving the problems of pathogens of human waste at source, thus offering the possibility of reusing them after treatment (recycling) in order to improve the standard of living of the population and protect the environment (Ferguson et al., 2003; Taouraout et al., 2020a; Taouraout et al., 2020b).
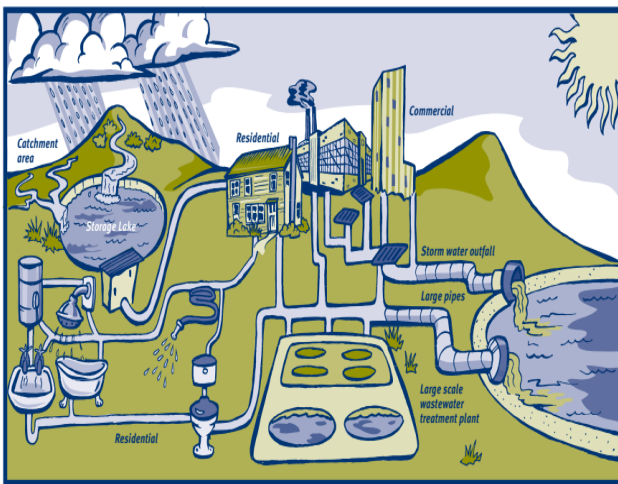

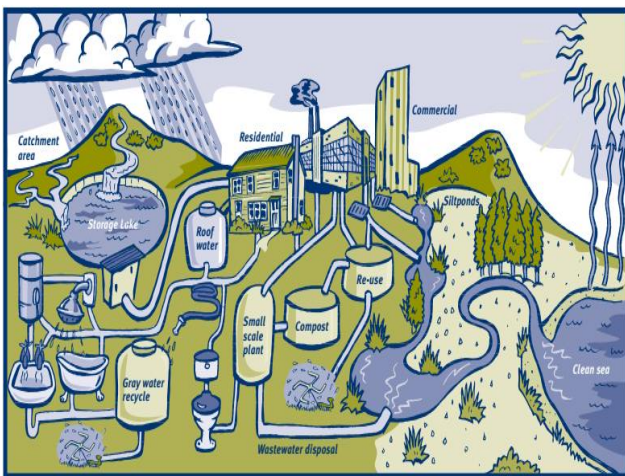Figure 1. Leaner sanitation "end of pipe" (Ferguson et al., 2003).

Figure 2. Ecological sanitation "treatment and recycling" (Ferguson et al., 2003)

One efficient approach to treat domestic wastewater is through an economic, ecological and sustainable technic called Multi-Soil-Layering system (MSL). The first MSL system was developed in Japan (1990), to treat wastewater. Compared with conventional soil treatment systems, this system could withstand a higher hydraulic loading rate (HLR) and was less prone to clogging (Masunaga et al., 2007; Ho, Wang, 2015). The MSL system uses high quantities of natural, unpolluted materials to produce reusable water for eco-environment or

agriculture, washing cars and toilet flushing (Chen et al., 2009). Contrary to the traditional system (e.g. lagooning), this system can be maintained and operated at a low cost, requires only a small land area, and is ideal for urban areas in developing countries (Luanmanee, et al., 2002). The MSL system primarily comprises soil mixture blocs (SMBs) and permeable layers (PLs). The aim of this study is to evaluate the efficiency of a vertical Multi-Soil-Layering system (MSL) system to treat domestic wastewater under three hydraulic loading rates: 250 $L/m^2/day$, 350 $L/m^2/day$ and 500 $L/m^2/day$, in Moroccan conditions.

2. MATERIEL AND METHODS

2.1 Description of the treatment unit

The pilot-scale treatment system used in this study is a Vertical Multi-Soil-Layering (V-MSL) measuring 20cm x 60cm x 78cm (L×W×H) with a feeding tank (100L) used to store pre-screened wastewater from the inlet of the household wastewater using submersible pump. Figure 3 shows a detailed description of this MSL structure. This pilot-scale was carried out in a single household (Meknes, Morocco); where the climate is classified as warm temperate. It was designed, built and began to operate at the beginning of March 2017 and, this system was allowed to stabilize for three months. This MSL system was composed of soil mixture blocks (SMBs) arranged in a brick-like pattern and surrounded by permeable layers (PL) composed by gravel (Ø=3-5 mm). The SMB comprised by sandy soil (60%), wood sawdust (20%), charcoal (10%), and iron sawdust (10%) at a dry weight. The mixture was packed into square Hemp bag (Block) measuring 20 cm in width and 4 cm in height. In this filter, we used two types of block which differed mainly in the width: 16cm for block A and 8 cm width for block B (Figure 3).
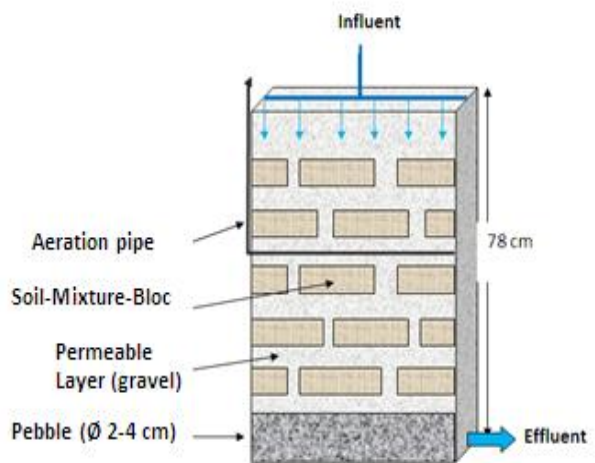

Figure 3. Schematic representation of Vertical Multi-Soil-Layering

The filling of the filter is done in the following order: the first layer (20 cm thick) is composed by the pebbles followed by the first permeable layer (5 cm thick of gravel) followed by the first layer of bricks (SMBs); the alternation of the permeable layers and the brick layers succeed one another until the sixth permeable layer. The bricks are arranged horizontally with a space of 5 cm between them.

2.2 Measurement of water quality parameters

After the stabilization period (three months), samples of raw and treated water were collected at the same time each month (from June 2017 until April 2018). Samples were analyzed for different water quality parameters using the French standard methods (Rodier et al., 2009). Temperature (T), pH, and Dissolved Oxygen (DO) were measured in situ using a multiparameter probe type PCE-PHD1 and turbidity by Turbidity meter (HI 93703 HANNA instruments). The other parameters were measured into Laboratory of Natural Resources Management and Development Team, Health and Environment (Faculty of Science Meknes). Biochemical oxygen demand measured in a 5 day test (BOD_5) was determined by the BOD Sensor (VELP SCIENTIFICA), and chemical oxygen demand (COD) was analyzed according to the dichromate open reflux method. Total suspended solids (TSS) concentration was determined by the filtration method, ammonium (NH_4^+) concentration by the indophenol method, and orthophosphate (PO_4^{3-}) concentration by the molybdate and ascorbic acid method.

2.3 Data analysis

Statistical analyses of the collected data were carried out using software: Microsoft Excel 2010, SPSS 20 (Analysis of variance test (ANOVA)). In this study, the objective of the ANOVA test is to investigate whether there is a significant difference between the characteristics of the sample before and after treatment with a significance level (p) and the effect of hydraulic load rates on the performance of V-MSL.

3. RESULTS

3.1 General parameters

The results in Table 1 showed an increase of turbidity values when HLR increased; in the contrary, dissolved oxygen decreased when HLR increased. The average values of DO for 250 L/m²/day, 350 L/m²/day and 500 L/m²/day were (4.5±0.5) mg/L, (4.4±0.6) mg/L and (3.5±1.5) mg/L, respectively. On the other hand, pH values are almost similar for all HLRs tested; however, the different values of temperature recorded for the HLRs are related to the month of the year. ANOVA test did not show any significant difference between the averages of these parameters for all HLRs tested.

HLR (L/m²/day)	T (°C)	pH	EC (mS/cm)	Turbidity	DO (mg/L)
250	20.9	7.4	0.87±0.2	17.9±9.6	4.5±0.5
350	17.6	7.3	1.03±0.1	19.8±6.5	4.4±0.6
500	22.0	7.5	0.97±0.4	25.6±6.5	3.5±1.5

Table 1. Temperatures, pH, EC, turbidity and DO values into the filter according to the HLR

3.2 Reduction of BOD_5, COD and TSS

The concentration of BOD_5, COD and TSS in the inlet and outlet and their removal efficiency, during the study period under various HLRs, are shown in Table 2 and Figures 4 to 6. The results indicated these parameters achieved (85.2±6.0)%, (83.8±7.5)%, (88.3±7.2)% removal, respectively, when the HLR1= 250 L/m2/day; with HLR2=350 L/m2/day, they achieved (85.9±5.5)%, (87.1±4.7)% and (87.9±4.4)%,

respectively, and with HLR3= 500 L/m2/day, they achieved (83.0±7.3)%, (82.1±8.3)% and (84.6±10.5)%, respectively.

HLR (L/m²/day)		BOD_5	COD	TSS
	Influent (mg/L)	156	326.5	339.1
250	V-MSL (mg/L)	21.5	49.9	36.5
	% removal	85.2	83.8	88.3
	Influent (mg/L)	171.8	383.8	297.3
350	V-MSL (mg/L)	23.5	48.5	36
	% removal	85.9	87.1	87.9
	Influent (mg/L)	232.1	450	477.6
500	V-MSL (mg/L)	39.07	79.2	71.76
	% removal	83.3	82.1	84.6

Table 2. Removal performance of organic matters under different HLRs

These results suggested that the removal rate of these parameters decreased as the HLR increased. 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 (Masunaga et al., 2007; Taouraout, et al., 2019).
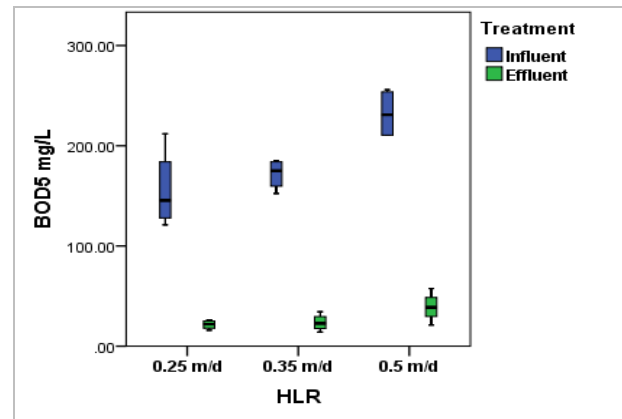

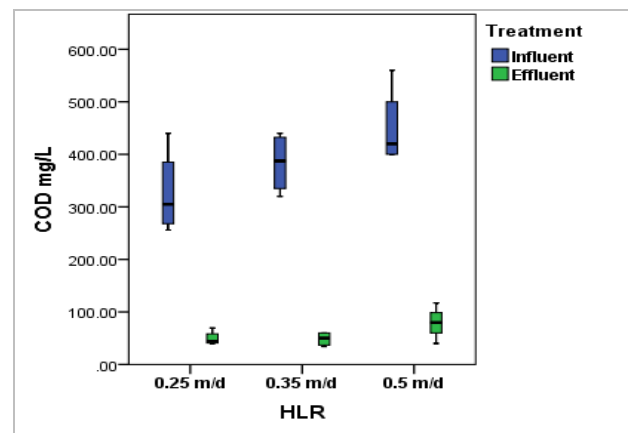Figure 4. Trend of BOD_5 according to HLRs
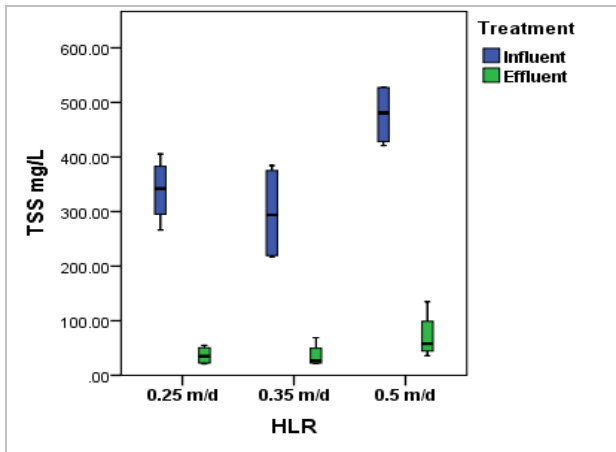

Figure 5. Trend of COD according to HLRs

Figure 6. Trend of COD according to HLRs

The differences between removal rates of organic matter (BOD5, COD and TSS) in our filter did not exceed 5%. This result can be explain by the V-MSL ability to treat domestic wastewater with hydraulic loading rates less than or equal to 500 L/m^2/day. Indeed, the high removal rates of organic pollutants (BOD5, COD and TSS) reported in this study, indicate the importance of physical (filtration, sedimentation), chemical (adsorption, precipitation) and biological (biodegradation) mechanisms occurring in our MSL system.

Moreover, it was suggested that effective contact between the wastewater and SMB was a major factor for MSL performance (Masunaga, et al., 2003; Sato et al., 2005).

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). However, this test ANOVA did not show any significant difference between the removal rates of these parameters in V-MSL for all HLRs tested at $p < 0.05$ (Table 4).

Similar results were reported by Lamzouri et al., (2016) that investigated the performance of three full-scale V-MSL (MSL1: HLR-250L/m^2/day, MSL2: HLR-500L/m^2/day and MSL3: HLR-1000L/m^2/day). They reported for COD, BOD5, TSS the following results (86%, 82% and 89%) for MSL1, respectively; (83%, 77% and 86%) for MSL2, respectively and (78%, 71% and 83%) for MSL3, respectively. In addition, Sato et al., (2011a) reported that in a pilot-scale study the removal rates were 91% for BOD5 and 85% for COD. Also, Masunaga et al., (2007) reported removal rates between 88% and 98% for BOD5. The reduction of organic matter is realized through biological degradation under oxygenated condition in the porosity of the MSL reactor (Chen et al., 2009).

On the other hand, the efficiency (per cent removal by mass) of the V-MSL to remove organic matters according to the seasons is showed in Table 5 and Figure 7. This filter showed a high performance to remove the BOD5, COD and TSS during all season with an average between 81.5% - 85% in summer, 84% - 87% in fall, 83% - 89% in winter and 84% - 88% in spring. These results show that the V-MSL filter shows certain stability to remove organic matter, this is might be related to the optimum temperatures (between 12°C and 29°C) and dissolved oxygen (with an average of 4mg/L) recorded during the study period (Table 1). According to Zhu and Chen (2002), biological reaction rates increase with rising temperature until an optimal temperature is reached; above the optimal temperature, enzymatic proteins denature and the rates decrease in fixed film processes. On the other hand, Latrach et al., (2018) reported that the efficiency of MSL technology to reduce contaminants is not sensitive to season and air temperature fluctuations.

Variable (mg/L)	(I)	(J)	Difference (I-J)	Signification (p)
BOD5	Influent	V-MSL	158.583***	.000
COD	Influent	V-MSL	327.617***	.000
TSS	Influent	V-MSL	323.229***	.000
PO_4^{3-}	Influent	V-MSL	3.149***	.000
NH_4^+	Influent	V-MSL	9.882***	.002

*** Significant difference at $p < 0.001$
I: concentration of a specified variable in Influent **J**: concentration of a specified variable in Effluent

Table 3. ANOVA test of organic matter between influent and effluent at $p < 0.05$

Variable	(I) HLR	(J) HLR	Difference (I-J)	Signification (P)
BOD5	0.25 m/d	0.35 m/d	-.5000	.994
		0.5 m/d	2.0000	.905
	0.35 m/d	0.5 m/d	2.5000	.857
COD	0.25 m/d	0.35 m/d	-3.2500	.785
		0.5 m/d	1.5000	.949
	0.35 m/d	0.5 m/d	4.7500	.606
TSS	0.25 m/d	0.35 m/d	.5000	.996
		0.5 m/d	3.7500	.790
	0.35 m/d	0.5 m/d	3.2500	.837
NH4+	0.25 m/d	0.35 m/d	2.7500	.850
		0.5 m/d	6.7500	.407
	0.35 m/d	0.5 m/d	4.0000	.714
PO43-	0.25 m/d	0.35 m/d	13.5000	.167
		0.5 m/d	26.2500*	.009

* Significant difference at $p < 0.05$ **I** and **J**: Removal rates of a specified variable at different HLRs (0.25 m/d = 250 L/m^2/day, 0.35 m/d = 350 L/m^2/day and 0.5 m/d = 500 L/m^2/day)

Table 4. ANOVA test of organic and nutrient pollutions removal rates according to HLRs

	Removal rates (%)				
	BOD5	COD	TSS	PO_4^{3-}	NH_4^+
Summer	81.5	82.9	85.7	71.85	84.4
Fall	87.3	87.1	84.1	65.4	84.7
Winter	83.3	82.9	89.7	76.9	83.7
Spring	86.8	84.4	88.3	75.5	79.6

Table 5. Efficiency of V-MSL to remove the pollutions according to the season

This is due to the capacity of MSL system materials to withstand the air temperature variation, which highlights one of the advantages of MSL's technology. Contrarily, according to Taylor et al., (2011) and Stefanakis & Tsihrintzis, (2012), the effect of season and temperature on organic matter removal efficiency in the constructed wetlands is reported with the worst performance occurring usually during the winter with low temperatures.
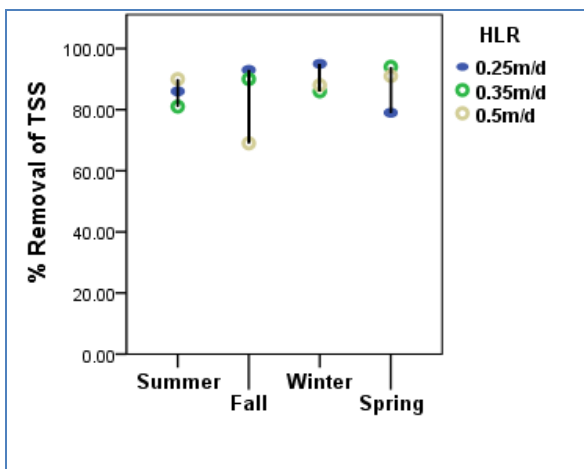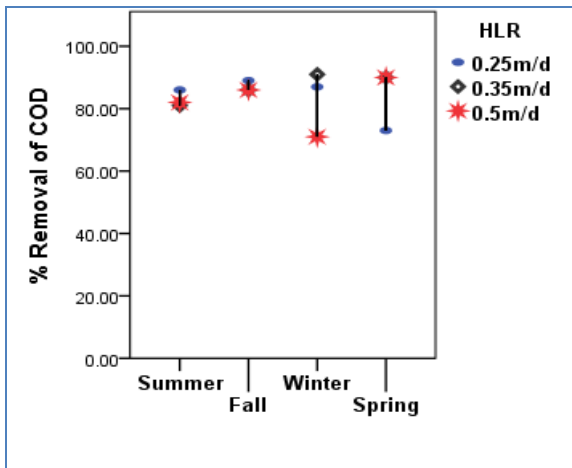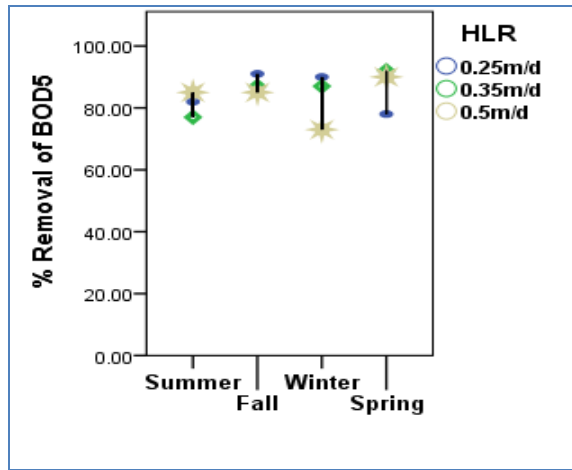
Figure 7. Performance of V-MSL to remove organic matters according to HLR and season

3.3 Ammonia removal and nitrate transformation

Table 6 and Figure 8 show the average concentrations of ammonia in influent and effluent during the study period according to the HLRs. With HLR1=250L/m^2/day, NH4+ concentrations were (15.4±4.4) mg/L and (2.1±1.6) mg/L, respectively. Under HLR2 =350L/m^2/day, NH4$^+$ concentrations were (20.1±1.8) mg/L and (3.4±1.4) mg/L, respectively. Finally, with HLR3= 500L/m^2/day, NH4$^+$ concentrations were (24.0±5.7) mg/L and (4.9±1.3) mg/L, respectively. This

indicates that the nitrification was effective due to aerobic conditions into the filter. The average removal rates of NH4+ were (86.3±10.7)%, (83.5±5.7)% and (79.5.±1.7) % for the three HLRs tested (HLR1, HLR2 and HLR3), respectively. Despite these differences between the three HRLs tested, ANOVA test did not show any difference of the NH4+ removal between the three HLRs at p <0.05 (Table 4). However, this test showed a significant difference between NH4+ averages in influent and effluent at p <0.001 (Table 3).

HLR (L/m^2/day)			NH4$^+$	PO4^{3-}
250	Influent(mg/L)		15.4±4	5.0±2.7
	V-MSL (mg/L)		2.1±1.6	0.70±0.3
	% removal		86.3±10	85.7±3.8
350	Influent (mg/L)		20.1±1	4.0±0.7
	V-MSL (mg/L)		3.4±1.4	1.1±0.5
	% removal		83.5±5	72.3±11.6
500	Influent (mg/L)		24.0±5	3.9±0.7
	V-MSL (mg/L)		4.9±1.3	1.6±0.7
	% removal		79.5.±1	59.5±11.2

Table 6. Removal performance of nutrients under different HLRs
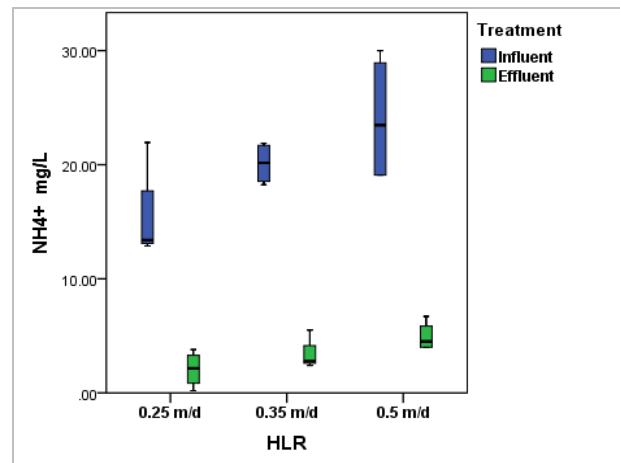

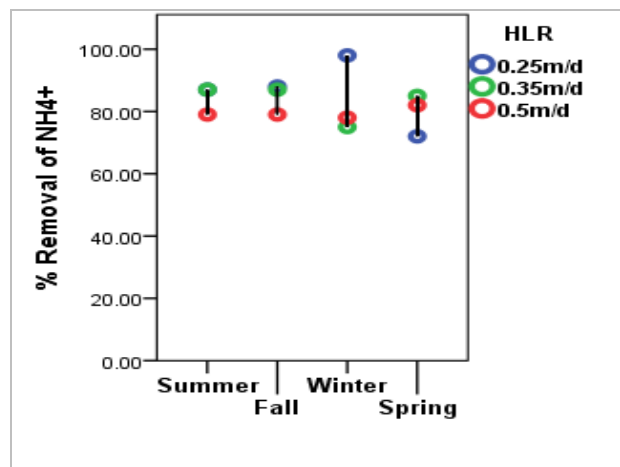Figure 8. Trend of Ammonia according to HLR

Figure 9. Performance of V-MSL

The high removal efficiency for nitrogen was due to the ability of the MSL materials to adsorb NH_4^+ and to the co-existence of aerobic and anaerobic conditions inside the MSL system that induce nitrification/denitrification processes. Sato et al., (2011b) showed that nitrification took place in permeable layers and SMBs in the top layers of MSL system. However, denitrification mainly occurred in the lower SMBs. Nitrates were produced in the upper part of the MSL system and its concentrations decreased in the lower part where anaerobic conditions were developed indicating that denitrification proceeded (Sato et al., 2011b).

In Moroccan conditions, Lamzouri et al., (2016) reported similar result for MSL1 (HLR-250L/m²/day) which reached 85% of NH_4^+ removal. However, our results are better for HLR= 500L/m²/day since they reported only 71% of ammonium removal. Also, Latrach et al., (2016) reported the same result for MSL pilot in term of NH_4^+ removal. On the other hand, the efficiency the V-MSL showed a good performance to remove ammonium according to the season (Table 5 and Figure 9). The average removal rates are 84.4±4.7%, 84.7±5%, 83.7±12.9% and 79.6±7% in summer, fall, winter and spring, respectively. This filter shows a certain stability to remove NH_4^+ during the study period (Latrach et al., 2018).

3.4 Elimination of orthophosphate

The PO_4^{3-} average concentrations in influent and effluent during the study period according to the HLRs were (5.0±2.7) mg/L and (0.70±0.35) mg/L, respectively (with HLR1=250L/m²/day); under HLR2 =350L/m²/day, the PO_4^{3-} concentrations were (4.0±0.7) mg/L and (1.1±0.5) mg/L, respectively; finally, with HLR3= 500L/m²/day, the PO_4^{3-} concentrations were (3.9±0.7) mg/L and (1.6±0.7) mg/L, respectively (Table 7 and Figure 10). The average removal rate of PO_4^{3-} during the study period was 72.5%, while their removal rates for the three HLRs tested (250 L/m²/day, 350 L/m²/day and 500 L/m²/day) were (85.7±3.8) %, (72.3±11.6) %, and (59.5±11.2) %, respectively (Table 7 and Figure 11). The ANOVA test showed that there is a significant difference between the PO43- means of the V-MSL and the influent at p <0.001 (Table 3), and between the hydraulic loading rates 250 L/m²/day and 500 L/m2/day; but it did not show any significant difference between 250 L/m²/day, 350 L/m²/day (Table 4).

Lamzouri et al., (2016) reported a high removal rates of PO_4^{3-} 91%, 86% and 81% for the three HLRs (250L/m²/day, 500L/m²/day and 1000L/m²/day), respectively, in Moroccan conditions. According to several studies, the MSL system was very effective in removing phosphorus, because of the capacity of the soil and iron existing into the SMB blocks to adsorb and/or precipitate phosphate from the wastewater (Drizo et al., 2006). Furthermore, it has been reported that phosphorus removal increases with increasing retention time, due to increased contact time (Lantzke et al., 1999; Taouraout, et al., 2019). This indicates that retention time is a crucial parameter for effective phosphorus removal (Drizo et al., 2006). In addition, according to Luanmanee et al., (2003), aeration of the system is also an important factor in improving phosphorus removal from wastewater. Indeed, aeration enhanced phosphorus removal by forming ferric hydroxides, which strongly fixed phosphate from the wastewater. After aeration was stopped, anaerobic conditions developed in the MSL system. This enhanced the formation of ferrous ions, which are not effective in fixing phosphate (Masunaga, Wakatsuki, 1999; Wakatsuki et al., 2000). Indeed, the iron added to the SMBs is

transformed into ferrous iron (Fe^{2+}), which is transported to the gravel layers and is oxidized under aerobic conditions to ferric ion (Fe^{3+}); then, PO_4^{3-} from wastewater precipitate with Fe^{3+} (Wakatsuki et al., 1993; Chen et al., 2009; An et al., 2016). The V-MSL showed a good performance to remove PO_4^{3-} according to the season (Table 5 and Figure 11). The average removal rates are 71.85±11.6%, 65.4±14.8%, 76.9±10.8% and 75.5±22.3% in summer, fall, winter and spring, respectively.
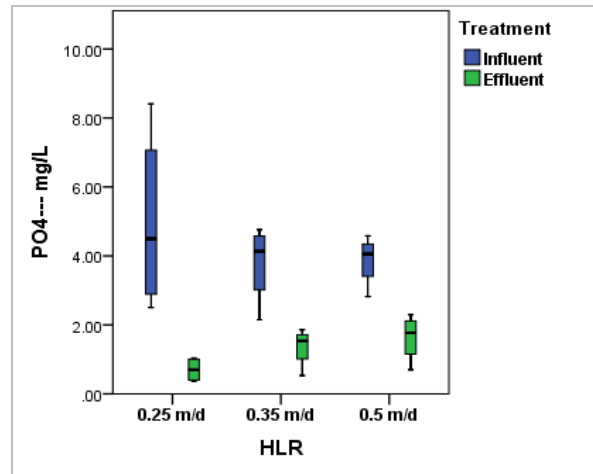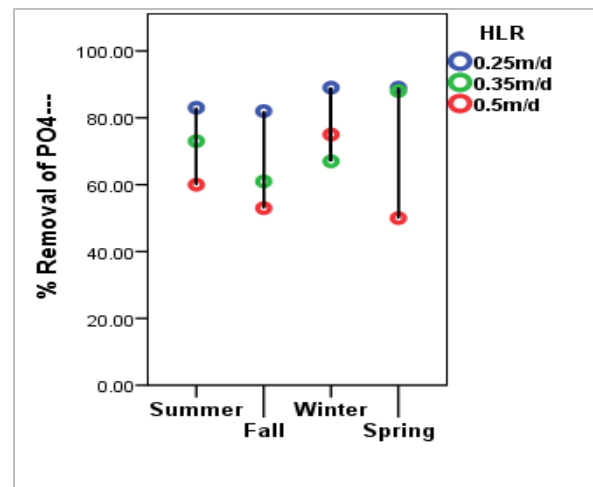

Figure 10. Trend of PO_4^{3-} removal

Figure 11. Removal rate of PO_4^{3-} according to season

4. CONCLUSION

The Vertical Multi-Soil-Layering system used in this study showed a good ability to reduce BOD_5, COD, TSS, NH_4^+ since the removal efficiencies of these parameters are over than 80% for all the three hydraulic load rates used. This system showed also a good performance to reduce PO_4^{3-} with HLR= 250 L/m²/day, but for the other HLRs tested, it recorded a moderate performance (between 60% and 72%). Furthermore, the efficiency of the V-MSL to reduce contaminants is not sensitive to season. In all, the effluent quality (physico-chemical) in this study was still in line with Moroccan standards. However, a study of the effectiveness of this system in eliminating faecal pollution and parasites would be necessary under Moroccan conditions.

In general, this system is assumed to be one of the alternative technologies for decentralized wastewater treatment in smart city.

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