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Wastewater Treatment Plant Performance Inside Multi-Soil-Layering System

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Abstract: Wastewater effluent disposal is a challenge in Moroccan rural area. Wastewater treatment is the only suitable solution to overcome these environmental constraints. Technology such as Multi-Soil-Layering (MSL) system is one of the most appropriate solution for the treatment of wastewater for small communities in rural areas. The MSL system overcomes many of the deficiencies of conventional soil treatment systems such as large land requirement clogging and low Hydraulic Loading Rate (HLR). The MSL systems are composed of Soil Mixture Blocks (SMB) arranged in a brick-like pattern and surrounded by Permeable Layers (PL). To investigate the efficiency of MSL systems in relation to HLR differences and the fluctuations in the wastewater contamination levels, three MSL pilot plants were alimented continuously by domestic wastewater, were constructed in three 36×30×65 cm plastic boxes, with different HLR of 250, 500 and 1000 $l/m^2/day$. The main removal rates of Biochemical Oxygen Demand (BOD_5) and Chemical Oxygen Demand (COD) were higher at higher HLR. However, the kinetic rate constant of the MSL process implemented under Moroccan conditions is 130 d^{-1} at 25°C.

Keywords: BOD_5, Kinetic, Morocco, Treatment, Wastewater

Introduction

The rural wastewater effluent characterized by very high concentrations of nutrients, organic contents and pathogens is a serious problem in Moroccan rural (El Hamouri *et al*., 2007). Actually, more than 90% of the population in the rural areas are connected to drinking water triggering a remarkable increase in wastewater production, which requires immediate intervention by collecting and treating wastewater in this region. Various convenient technologies can be applied in rural areas, such as MSL systems. The technique of Multi-Soil-Layering (MSL) is a new technology developed in Japan by Wakatsuki *et al.* (1993). Since, this technique has been enhanced, structured and adjusted. The use of MSL systems, for the treatment of domestic wastewater, has shown great success around the world. Many applications in Japan, China, Indonesia, Thailand and Hawaii have confirmed significant purification performance (Luanmanee *et al*., 2002).

MSL systems support higher Hydraulic Loading Rate (HLR) and pollutant loads than some other soil systems due to its structure. This technique can overcome many constraints in the operation of the conventional functioning sewage treatment with soil (Yi-Dong *et al*., 2013). The MSL system is also characterized by its high purifying ability by reducing levels of organic matter and nutrients (Yidong *et al*., 2012).

The main objective of this research is the study of the effects of HLR and the fluctuations in the wastewater contamination levels, to improve and adapt the performance of this system under climate and Moroccan socio-economics conditions. In the present study, the effects of three degrees of HLRs on the treatment efficiency in a MSL system were examined.

Science Publications

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Materials and Methods

Description of Experimental Conditions

Figure 1 (Lamzouri *et al*., 2016) shows the structure of the MSL systems used in this study. Three different HLR are used: 250, 500 and 1000 l/m^2/day. The MSL systems evaluated in this study were packed in three individual plastic boxes (36×30×65 cm). The MSL system is constituted of Soil Mixture Blocks (SMB) arranged in a brick-like pattern and surrounded by water-layers (PL). The SMB was composed of soil, sawdust, charcoal and granular metal iron at a ratio of 7:1:1:1 on a dry-weight basis and packed.

The mode of operation of the MSL is based on the percolation infiltration using the ground as purification means. The absorption, infiltration and biodegradation are the major processes occurring in the filter.

Sampling and Analyses

To investigate and quantify the effects of HLR in MSL systems, Raw and treated wastewater were collected, once per 2 weeks, at almost at the same time using plastic bottles for chemical assays and sterilized glass bottles for bacteriological studies. For physicochemical parameters, pH and temperature were measured in situ. The other parameters were measured according to French standard methods (AFNOR, 1997; Rodier, 1996). The experiment was conducted from 24 July 2014 to 18 June 2015.

Analysis of the Experimental Data

To quantify the HLR influence on MSL treatment efficiency for BOD_5 parameter, we used an exponential equation to express the experimental data. The starting point is the equation that manages the flow in this type of system. The kinetic model of the process is similar to that of a perfect mix (Fig. 2). This is due to the important role of the uniformity of the particles size and the uniform provision of permeable layers and filter layers. It may allocate wastewater properly between the bricks and the different parts of the filter, thereby reducing the percentage of the unsaturated zone. The concentration at the outlet is the same over the entire surface of the system.

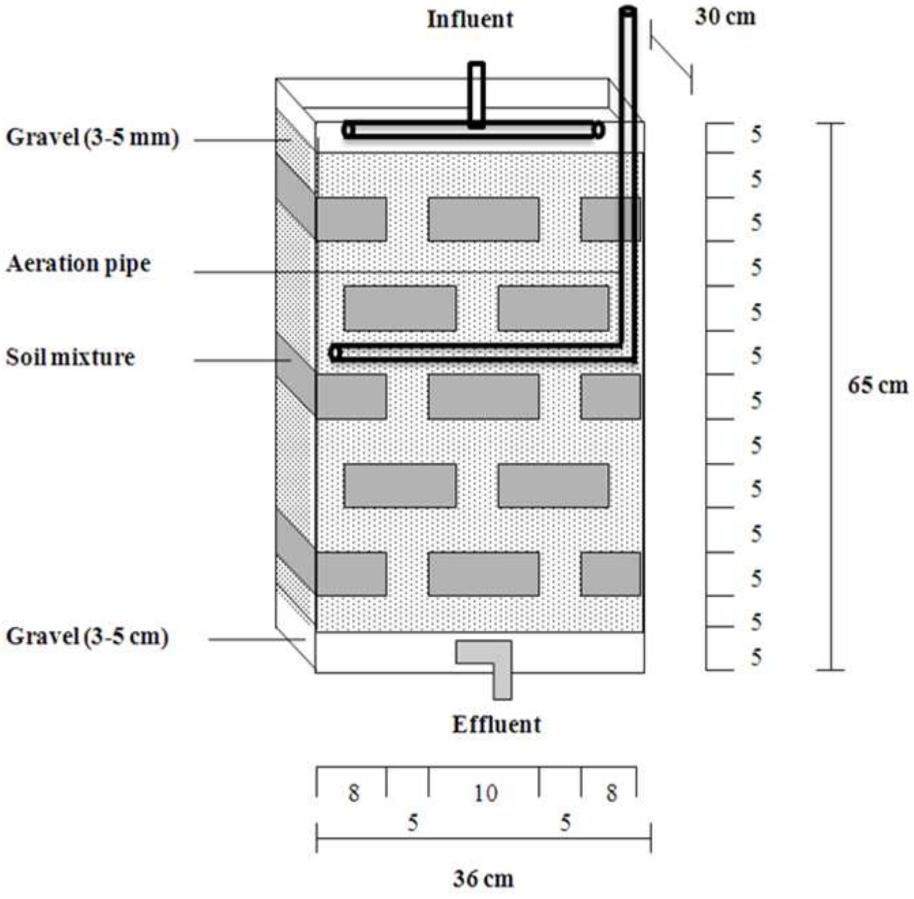

Fig. 1. Structure of MSL system

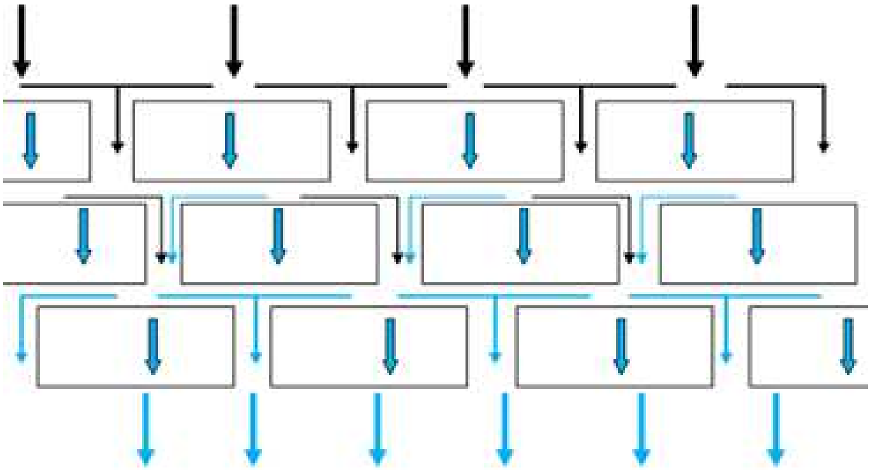

Fig. 2. Sewage infiltration inside the MSL system

The equation of the kinetic model of our system is:

$$E/H(1-E) = K * HLR^{-N} \tag{1}$$

Where:
E = Efficiency
H = Filter height in meter (m)
K = Kinetic constant (d^{-1})
HLR = Hydraulic loading (l/m^2*d)
N = Power factor

Introducing the common logarithm, the equation takes the following form:

$$Log\left(E/H(1-E)\right) = Log(K) - N * Log(HLR) \tag{2}$$

Where:
E = Efficiency
H = Filter height in meter (m)
K = Kinetic constant (d^{-1})
HLR = Hydraulic loading (l/m^2*d)
N = Power factor

Results and Discussion

Effect of HLR Difference on Parameters Removal

The series of characterization of wastewater at the input and at the output of the pilots include Biochemical Oxygen Demand (BOD_5) and Chemical Oxygen Demand (COD).

Three parallel similar MSL pilot are used in this experimental setup: 250, 500 and 1000 L m^{-2} day^{-1} respectively for each MSL system. The results showed average reduction efficiency for BOD_5 of 88 %, 86% and 80% for 250, 500 and 1000 L m^{-2} day^{-1} respectively (Fig. 3-5). At lower HLRs the mean removal percentage BOD_5 tended to be higher.

The results showed average removal efficiency for COD of 84, 80 and 76% respectively for 250, 500 and 1000 L m^{-2} day^{-1} (Fig. 6-8). At lower HLRs the mean removal percentage COD tended also to be higher.

During the entire experiment (329 days), the MSL system was able to treat organic matter and nutrients without clogging. The efficiency of the MSL systems on organic matter removal depends on the wastewater characteristics and HLRs applied. In the SMB, the efficiency was estimated by measuring the quality of outflow from all HLRs, the efficiency of the BOD_5 and COD removal were higher in each HLRs. Although, the results show also that the best removal rates of BOD_5 and COD were higher at higher HLR.

Quantitative Evaluation of HLR in the MSL Systems

Using the experimental data of MSL system, we can determine both kinetic parameters K and N. The values of BOD_5 at the entry and exit of MSL systems based on the HLR illustrated in (Fig. 3-5). Therefore, knowing the inlet concentration and outlet BOD_5, we were able to calculate the rate of the constant K and the factor N.

Using the above data, we get the number of points corresponding to the number of experiments on a landmark whose vertical axis is the log ($E/(H(1-E))$) while the horizontal is the log (HLR), the result is illustrated in (Fig. 9).

The determination of both unknown factors K and N can be done directly from the curve, which suggests following values: K = 130 d^{-1} and N = 0.46. The kinetic model of the system for an average temperature of 25°C:

$$E/\left(H*(1-E)\right) = 130 * HLR^{-0.46} \tag{3}$$

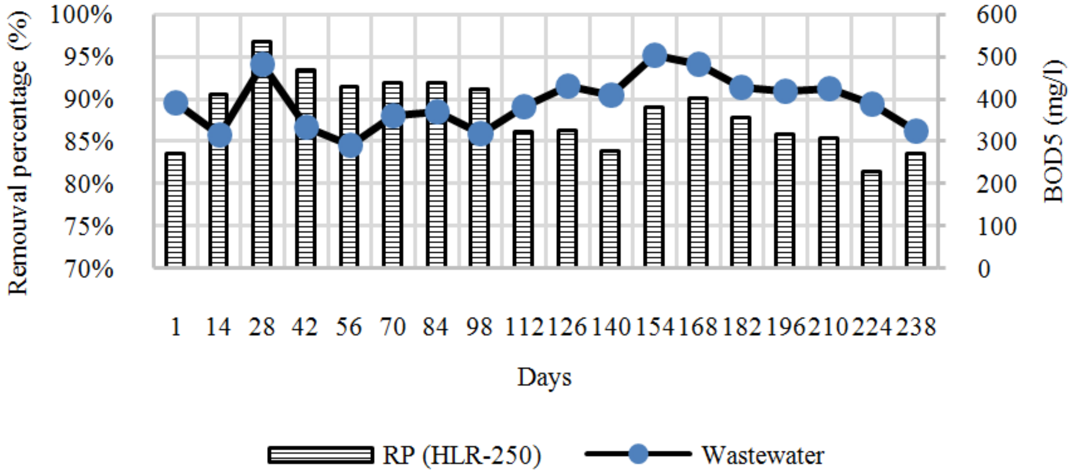

Fig. 3. Removal Percentage (RP) of BOD_5 under 250 L m^{-2} day^{-1}

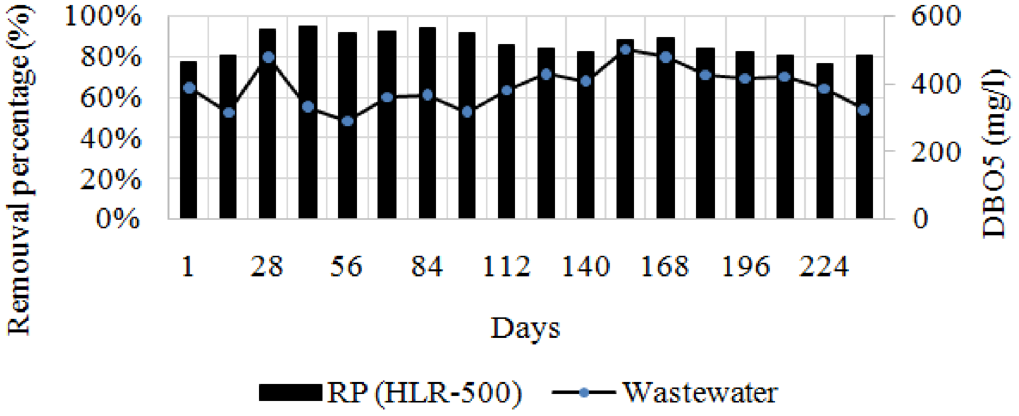

Fig. 4. Removal Percentage (RP) of BOD_5 under 500 L m^{-2} day^{-1}

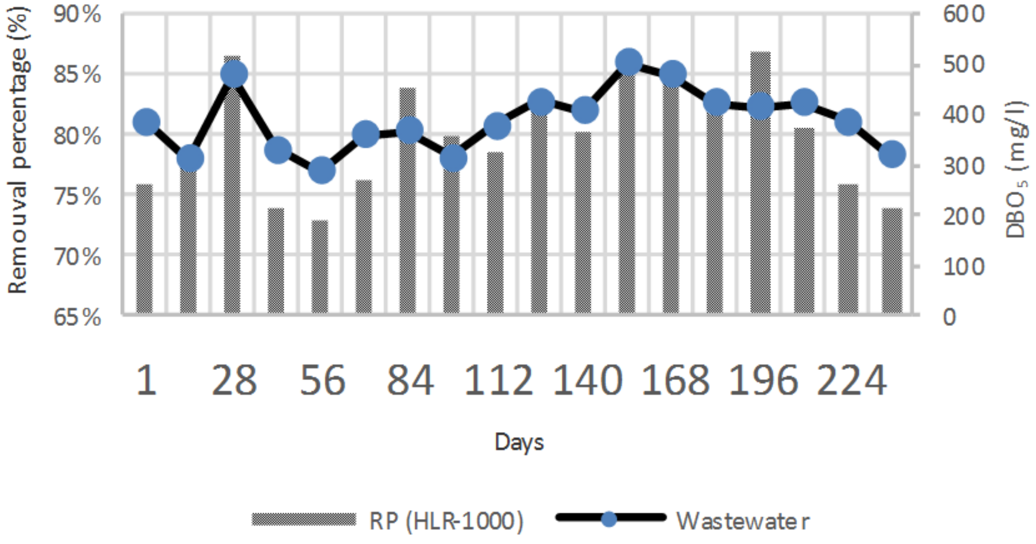

Fig. 5. Removal Percentage (RP) of BOD_5 under 1000 L m^{-2} day^{-1}

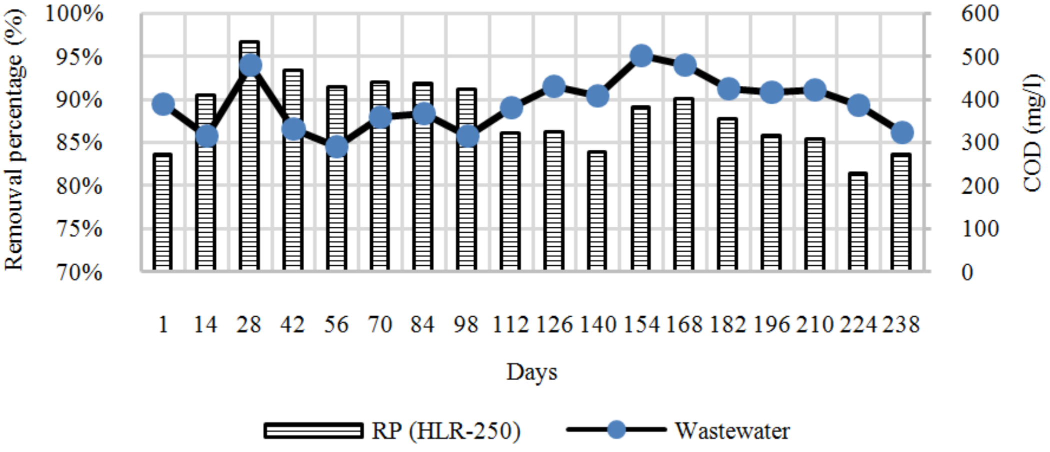

Fig. 6. Removal Percentage (RP) of COD under 250 L m^{-2} day^{-1}

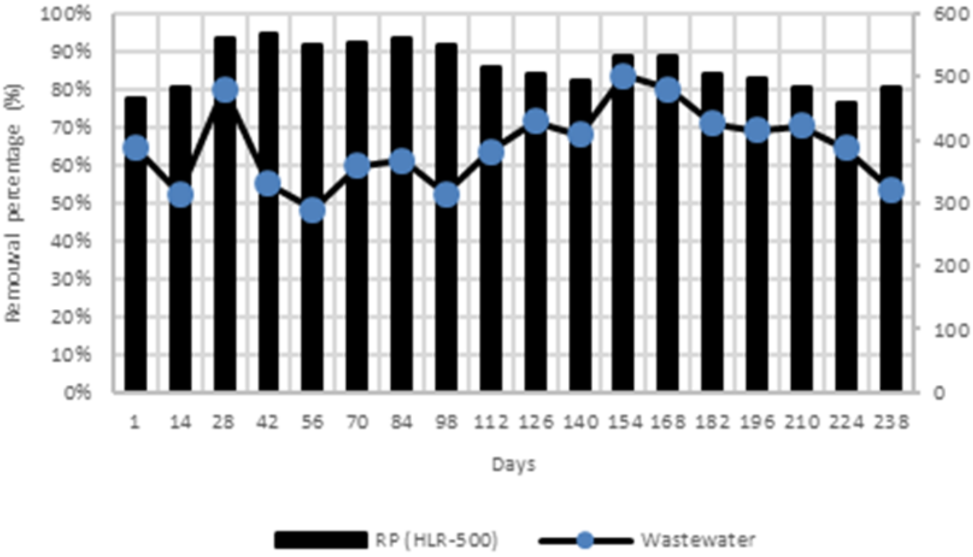

Fig. 7. Removal Percentage (RP) of COD under 500 L m^{-2} day^{-1}

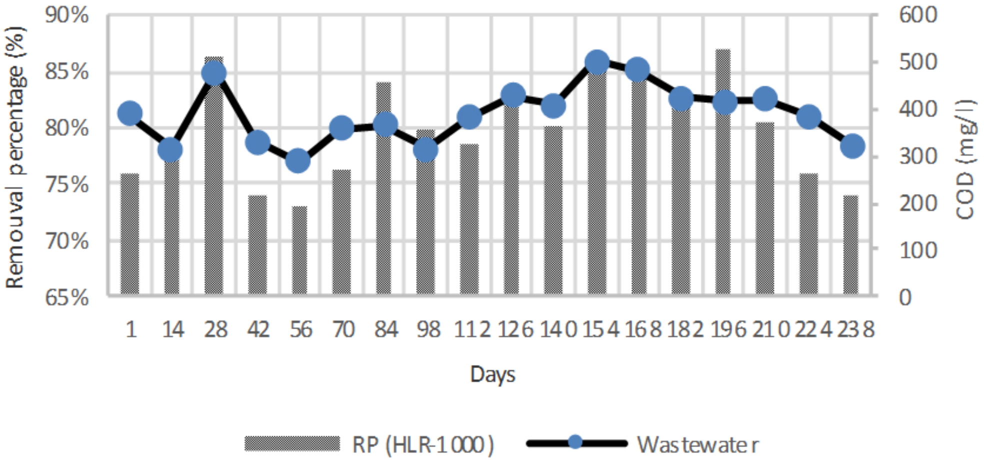

Fig. 8. Removal Percentage (RP) of COD under 1000 L m^{-2} day^{-1}

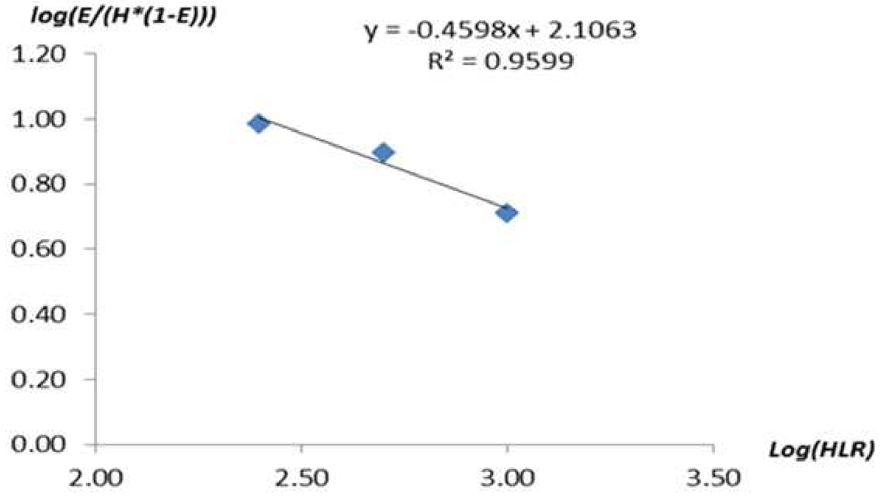

Fig. 9. Kinetic coefficients for BOD_5

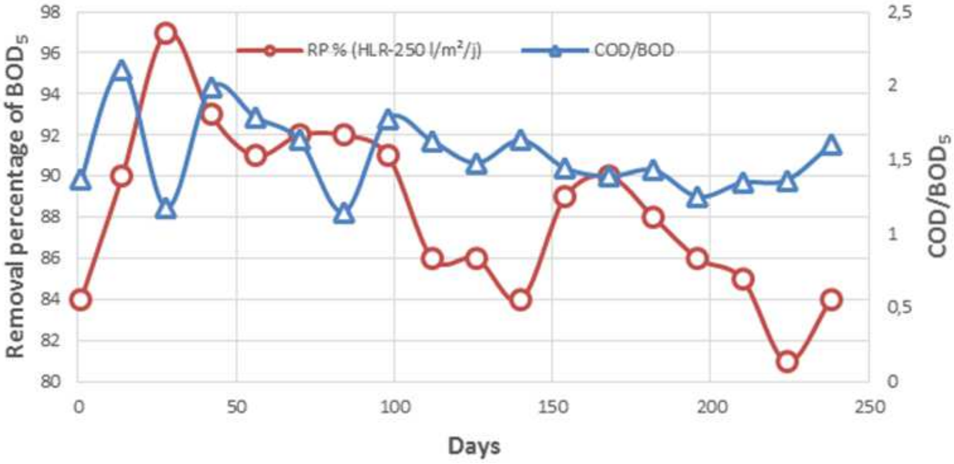

Fig. 10. Removal percentage of BOD_5 under HLR-250 Vs biodegradability (COD/BOD_5)

The kinetic coefficient performed for the MSL system, which was installed and adapted to the Moroccan conditions, is 130 d^{-1}.

The obtained value of k = 130 d^{-1} at 25°C, can be extended to 13°C which is the temperature in winter of our case study, taking into account the Arrhenius temperature coefficient, we get a value of k 75 d^{-1}, with:

$$K_t = K_{25} * 1,047^{(t-25)} \tag{4}$$

Based on these results we adopt 250 l/m^2/day to design MSL system for a village with 532 inhabitants located at Aghouatim community no far than Marrakech in south Morocco. Indeed, to ensure both a performance and stability of the system, during different seasons of the year, we have chosen a kinetic coefficient of 75 d^{-1} as a basic design for the construction of our full system.

Effect of the Fluctuations in the Wastewater Contamination Levels on Parameters removal

Figure 10 show the fluctuations in the COD/BOD_5 ratio and removal percentage of BOD_5 for 250 l/m²/d.

The COD/BOD_5 ratio is used to quantify the biodegradability of the wastewater. The non-biodegradable portion of the wastewater increases with the ratio COD/BOD_5. In our case study, the COD/BOD_5 ratio is between 1.15 and 2.10, with an average ratio of 1.53 for a HLR of 250 $Lm^{-2}day^{-1}$. As shown in Fig. 10, we note that the removal percentage of BOD_5 fluctuated widely during the experimental period with the variation of COD/BOD_5 ratio. Indeed, when the COD/BOD_5 ratio decreases, the biodegradability increases and therefore the removal percentage of BOD_5 increases also.

Biological process of BOD_5 and COD removal seemed to occur, in addition to the physic-chemical reaction. The existing of microbial activity, i.e., organic matter decomposition is enhanced with time and climatic condition through the accumulation of micro-organisms species. In fact, the accumulation, of organic matter, in upper layers of the MSL system, through to intensive biological activities at this level: The local temperature is very favorable to biological activity (average temperature of 25°C) and the low water consumption, 30 l/capita/day, filters intermittently feeding (30 liters spread over 24 h).

The results of this study showed, that the lifetime and the efficiency of the MSL system, are linked, organic, hydraulic load and the climatic conditions.

To ensure reliable performance of the system, it is proposed to cover the MSL system against the thermal shock of the cold period (insulation or heating using the outcome methane biogas production from anaerobic digester).

Conclusion

The hydraulic loading rate inside the Multi-soil-layering system revealed that the performance decreased with increasing loading rate. Indeed, the main removal rates BOD_5 parameter were higher at higher hydraulic loading rate. The relevant kinetic coefficient of the MSL system installed and adapted to the Moroccan terms gave a value of the constant rate of 75 d^{-1} at 13°C. It can be used, for all semi-arid zone under continental climate. The optimization of the kinetic coefficient affects the investment, the operating and the maintenance costs.

The knowledge of flow distribution in this process has a big benefit in practice. Using this study, we will be able to perform a dynamic simulation of the constant rate variation taking BOD_5 as an example of kinetic parameters.

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Author's Contributions

Lamzouri Khaoula: Did the research, analyzed and interpreted the result, prepared the manuscript and responsible for the manuscript correction, proof reading and paper submission.

Mahi Mustapha: Designed the work plan and organized the study, assisted in research work, provided the intellectual input and designs in the study and reviewed it critically for significant intellectual content.

Masunaga Tsugiyuki, Ouattar Said, Bartali El Houssine and Mandi Laila: Reviewing the work plan of the research.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

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