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Application of Multi-soil-layering technique for wastewater treatment in Moroccan rural areas: study of the operation process for an engineering design

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Abstract

In the Middle East and North Africa, small communities have virtually no access to centralized wastewater collection and treatment systems. In the absence of such services, sewage disposal is often left to the discretion of homeowners. In many cases, untreated sewage is discharged into surface waters or the landscape, contaminating already dwindling surface water and groundwater resources. This practice will continue unabated unless appropriate and affordable treatment systems are made available. The project will develop, test and promote low cost sustainable technologies for decentralized wastewater treatment through a partnership of local communities, research institutions, government and businesses. In order to study the multi-soil-layering system (MSL), which was installed for the first time in Morocco, four laboratory-scale MSL systems were built and monitored. The first small scale pilot, which was 30 cm deep, 36 cm wide, 65 cm high and a hydraulic loading rate (HLR) of 200 l/m^2/day. The three others were installed at the village Talat Marghen under the Aghouatim rural community in Marrakech governorate in Morocco. They are cylindrical plastics with a height of 65 cm and a diameter of 41 cm. with different hydraulic loads of respectively 250, 500, and 1000 l/m^2/day. The results of the technologies piloted implemented in Morocco will be study, according to technical criteria. The project asks for the best way to adapt the wastewater treatment systems for small communities in MENA region and some part in Africa.

Keywords: Domestic wastewater, Treatment, Multi-soil-layering, Rural areas, Morocco

1. Introduction

Treatment of wastewater by Multi-Soil-Layering (MSL) system could be beneficial for Morocco and MENA region. The technique of multi-soil-layering system (MSL) is a new concept in Morocco. This technique has been enhanced, structured and adjusted to have a service life, which is much broader than traditional sand filters [1]. The use of MSL systems for wastewater treatment technologies have shown great success and have confirmed significant high performance to treat of domestic wastewater [2].

MSL system is composed of locally available materials in rural areas such as soil, iron particles, jute or sawdust, charcoal and zeolite or alternative materials [3]. The MSL system constructed by two layers, permeable layer alternated with soil mixture blocks [4]. This technique came to overcome the many problems encountered in the conventional malfunctioning sewage treatment by the soil [5]. The system is, also characterized by several typical benefits such as small area demand, a simple maintenance, and the application of high hydraulic loads, no frequent clogging and their effective life that was estimated to be longer than 20 years for domestic

wastewater treatment [6]. Wastewater characteristics and hydraulic loading rate (HLR) are important factors that influence the treatment efficiency of the MSL systems [4].
The experimental setup included four parallel similar MSL pilot. Four HLRs were applied; 200. 250. 500 and 1000 L m^{-2} day^{-1} respectively for each MSL system.
The aim of this study is to analysis of the hydraulic behavior and to compare the performance of pilot scale and full scale, of MSL systems.

2. Experimental

The mode of operation of MSL is based on the percolation infiltration using the ground as a purification system. The adsorption, infiltration and biodegradation are the major processes occurring in the filter.
The wastewater treatment system with the MSL system is an aerobic purification process with layers, which are permeable to water, and soil mixture layers, which are arranged in blocks:

- Permeable gravel layers (PL): consists of gravel, pumice. perlite or zeolite with a small and uniform diameter of 1-5 mm, so as to improve the distribution of water and reduce the risk of clogging.
- Soil mixture blocks (SMB) consists of:
  - Soil
  - Charcoal
  - Sawdust: reported as an effective adsorbent because it contains a high concentration of cellulose, which irreversibly adsorbs the pollutants contained in wastewater. Furthermore, it could also function as a carbon source for the microorganisms [7].
  - Iron: when added to MSL, it gradually oxidizes into ferrous iron or ferric with time. As a phosphorus soil, adsorption capacity is positively related to its composition in active iron and aluminum. The iron addition could significantly increase the efficiency of adsorption of phosphorus MSL systems [8]. Similarly, Sakimoto and Mori (1999) reported that the addition of ferric chloride in wastewater has led to an improvement in the removal efficiency of COD chemical oxygen demand.

The technique is simple. It consists in mixing the materials constituting a substrate. In most cases. The substrate used is made of a material mixture consisting essentially of: silica sand, coal, iron and sawdust with a simultaneous mixing proportion of 70: 10: 10: 10 in the form of bricks [9].
The bricks are laid horizontally on floors and covered by gravel layers (30-50 cm in diameter), that are 5 cm thick. These gravel layers are permeable zones that enable to mitigate the risk of clogging by retaining a great deal of the surface suspended matter.
As previously, reported four experimental pilots have been installed in order to adapt and develop the system of filters embedded in the Moroccan rural areas [10]. One of these multi-soil-layering systems (pilot scale), was installed at Marrakech laboratory (Figure 1).

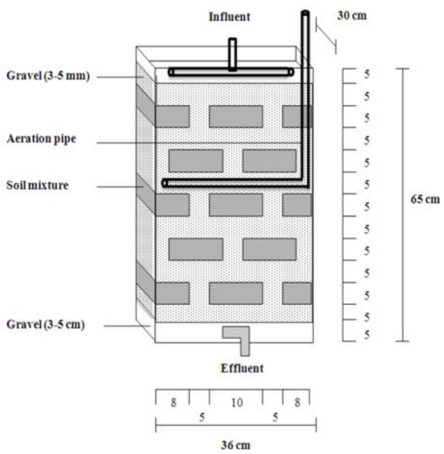

Figure 1: Structure of MSL pilot scale

The system is installed in a plastic box (65 cm high, 36 cm wide, 30 cm deep) made up of layers of soil mix and gravel with a diameter of 3-5 mm. The mixture of soil blocks consisted of local sandy soil mixed with sawdust, metallic iron and carbon at a ratio of 7: 1: 1: 1, respectively. These layers are arranged in a brick pattern, surrounded by gravel layers. The physical and chemical characteristics of the soil base used are listed in the table 1. According to the textural classification of [11], the soil used in this experiment was of a sandy texture. The size of the sawdust was smaller than 2 mm. The sawdust was made of certain species of trees such as Moroccan Quercus sp. and Fraxinus sp. The coal was made from Eucalyptus trees sp. The size of the metallic iron was 2 cm. The wastewater was deriving from a toilet of wastewater. This experiment was conducted from 17 February 2013 to 22 June 2015.

Table 1 : Physical and chemical properties of soil used in the study.

Parameters	Content
pH	8.15
Coarse sand (%)	48.42
Fine sand (%)	19.01
Silt (%)	23.99
Clay (%)	8.58
Total organic carbon (mg g^{-1})	13.10
Total Kjeldahl Nitrogen (mg g^{-1})	1.06

The three other pilots (large scale), were installed in 2013 at the Talat Marghen village (Figure 2). They are made of plastic, cylindrical, 65 cm high and 41 cm in diameter. Domestic wastewater come from 8 lived houses (72 inhabitants) and collected by a holding tank with a volume of 1 m^3 which used to feed the MSL pilots plant. The three MSL systems are of the same composition as the lab small-scale pilot. This experiment was conducted from 24 July 2014 to 18 June 2015.

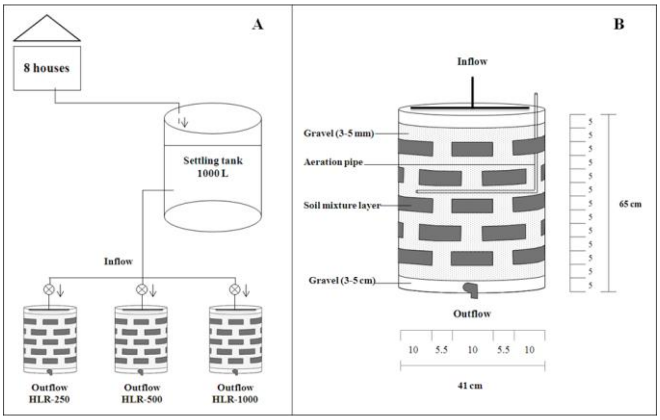

Figure 2: MSL full-scale plants (A: scheme of the MSL systems; B: detailed structure of the MSL system)

Wastewater and treated water were collected at almost the same time once per 2 week using plastic bottles for chemical assays, and in sterile glass bottles for bacteriological studies. Sampling was according the French standard methods [12; 13]. Wastewater was collected by a holding tank which used to feed continuous the MSL pilots plant.

3. Results and discussion

The series of characterization of wastewater at the input and at the output of the pilots include the following parameters: pH, temperature (T), total suspended solids (SS), biological oxygen demand (BOD_5), chemical oxygen demand (COD), ammonium (NH_4^+), total Kjeldahl nitrogen (TKN), total nitrogen (TN) and total phosphorus (TP).

3.1. *Pilot scale*

The quality of the parameters at the input and at the output of the pilot scale system is shown in table 2:

Table 2 : Wastewater quality at the input and at the output of the pilot scale, during the study period.

Parameters	Inflow average value	Effluent average value	Removal percentage (%)
pH	7.99 ± 0.014	7.28 ± 0.010	-
BOD_5 (mg/l)	204.44 ± 4.359	30.41 ± 2.708	85%
COD (mg/l)	494.59 ± 19.684	92.34 ± 13.228	81%
SS (mg/l)	160.01± 2.102	10.45± 0.262	93%
NH_4^+ (mg/l)	24.95 ± 0.625	3.02 ± 0.358	88%
NTK (mg/l)	60.59 ± 2.065	10.83 ± 1.290	82%
NT (mg/l)	92.86 ± 2.016	15.64 ± 1.372	83%
PO^-_4-P (mg/l)	1.40 ± 0.035	0.26 ± 0.021	82%
TP (mg/l)	3.10 ± 0.087	0.50 ± 0.052	84%

Results show a decrease in pH from 7.99 to 7.28 and a 93 % removal of total suspended solids. The MSL system treatment also led to important reductions in organic matter (85 % of total BOD_5 and 81 % of COD) and nutrients (88 % of NH_4^+-N, 82 % of TKN, 83 % of TN, 82 % of PO^-_4-P and 84 % of TP). The values are within the admissible limit for wastewater reject.

3.2. *Full scale*

Now analyze the characterization of wastewater at the input and at the output MSL system, for the three full scales with different hydraulic loading rate (HLR), implemented at the village Talat Marghen.
The quality of the main parameters that characterize the wastewater at the input and at the output of the full scale system is shown in the table 3:

Table 3 : Wastewater quality at the input and output of the three full scale, during the study period.

Parameters	Inflow	MSL 1: HLR-250		MSL 2: HLR-500		MSL3: HLR-1000	
		Effluent	PR	Effluent	PR	Effluent	PR
pH	8.17 ± 0.04	7.95± 0.122	-	8.23± 0.092	-	8.27± 0.103	-
BOD_5 (mg/l)	314 ± 5.359	43.20± 3.102	86%	52.24± 4.003	83%	70.24± 5.011	78%
COD (mg/l)	504 ± 21.014	91.21±12.231	82%	116.49±15.227	77%	144.32±15.106	71%
SS (mg/l)	279 ± 3.203	31.51± 0.433	89%	38.42± 0.566	86%	48.77± 0.955	83%
NH_4^+ (mg/l)	33 ± 0.902	4.99± 0.404	85%	9.62± 1.033	71%	12.98± 2.203	61%
NTK (mg/l)	23.10± 2.788	3.74± 1.053	84%	4.99± 1.902	78%	6.64± 2.102	71%
NT (mg/l)	80.28± 2.530	14.56± 1.225	82%	19.90± 2.256	75%	26.11± 4.056	67%
PO^-_4-P (mg/l)	4.87± 1.255	0.44± 0.021	91%	0.68± 0.098	86%	0.93± 0.121	81%
TP (mg/l)	7.40± 0.118	0.73± 0.192	90%	1.23± 0.255	83%	1.89± 0.504	74%

PR: Percentage Removal

The experimental setup included three parallel similar MSL pilot. Three HLRs were applied; 250, 500 and 1000 L m^{-2} day^{-1} respectively for each MSL system. The results showed average reduction efficiency for SS, BOD_5 and COD of 83-89, 78-86 and 71-82 %, respectively, and nutrients (61-85 % of NH_4^+-N, 71-84 % of TKN, 67-82 % of TN, 81-91 % of PO^-_4-P and 74-90 % of TP). The mean removal percentage of SS, BOD_5, COD and TP tended to be higher at lower HLRs.

According to the results, we note that the general tended of efficiency relative to each parameter remains more or less stable from the pilot scale to the large scale. Besides, the values are within the admissible limit for wastewater reject, as we can observe in the table 4.

Table 4 : Admissible limit for wastewater reject in Morocco

Parameters	Admissible limit for wastewater reject
BOD_5 (mg/l)	**120**
COD (mg/l)	**250**
SS (mg/l)	**250**

Moreover, by analyzing the treated wastewater characterization data and from the graph (Figure 3) we observe that efficiency tended to decrease with the increase of HLR.

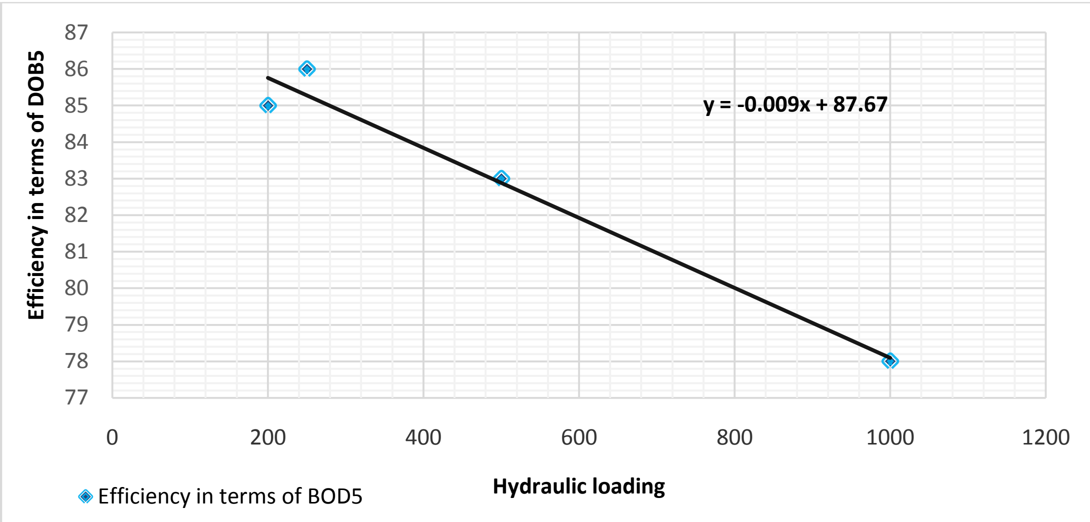

Figure 3: Relationship between the hydraulic loading and efficiency in terms of BOD_5 in the MSL

The percentage of elimination of BOD_5 is governed by the hydraulic load according to the following linear equation:

$$\textit{Equation 1 : } RP\ BOD_5 = 0.0096*HLR + 87.67$$

RP: Removal Percentage
HL: Hydraulic Loading rate

To determine which of the three pilots installed in the village Talat Marghen, under the same weather conditions, ensures system stability and therefore its stability, we had to study the performance in terms of BOD_5, during the study period ranging from the 24th of June, 2014 to the 18th of June, 2015. Below are three graphs (Figure 4, 5 and 6) summarizing the data characterization of waste and treated wastewater.

Highest yield was noticed at the full scale with a hydraulic load of 250 l/m^2/day, is more stable compared to other full scale with 500 and 1000 l/m^2/day under the same climatic conditions., Indeed, and from the figure 4, full scale with HL 250 l/m^2/day the most of the PR are above 80%, compared to the other hydraulics loadings 500 and 1000 l/m^2/day.

Based on these results we decided to adopt 250 l/m^2/day as HL for designing MSL system for the whole village with 532 inhabitants. Indeed, we have chosen a hydraulic loading of 250 l/m²/ day as a basic design for the construction of our expanded system, to ensure both a high yield and stability of the system, during different seasons of the year.

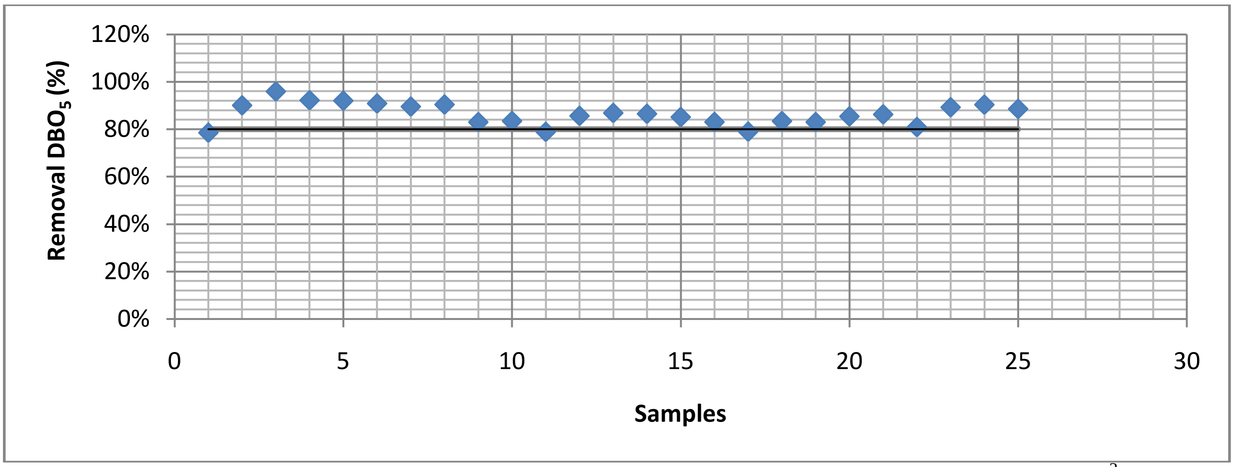

Figure 4: The efficiency in terms of BOD$_5$ during the study period for the pilot with HLR 250 l/m^2/day

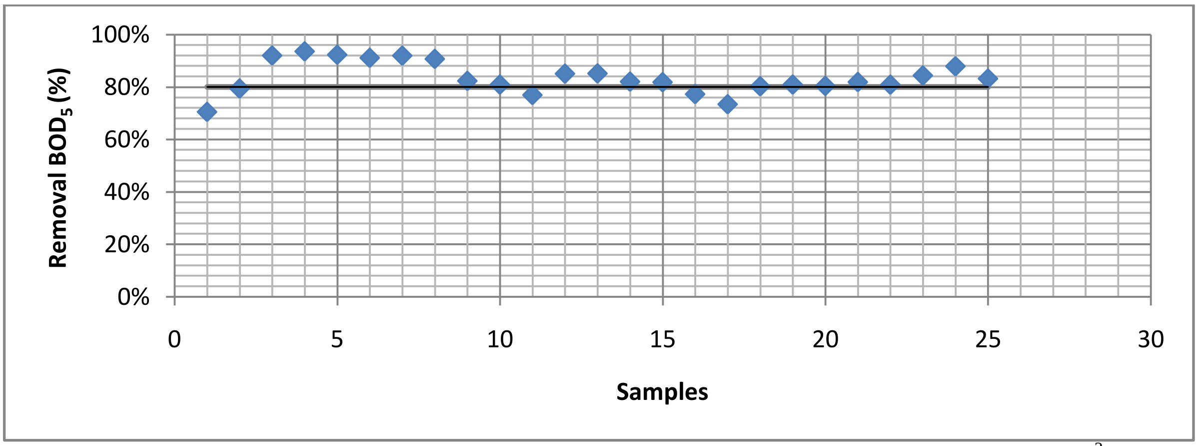

Figure 5: The efficiency in terms of BOD$_5$ during the study period for the pilot with HLR 500 l/m^2/day

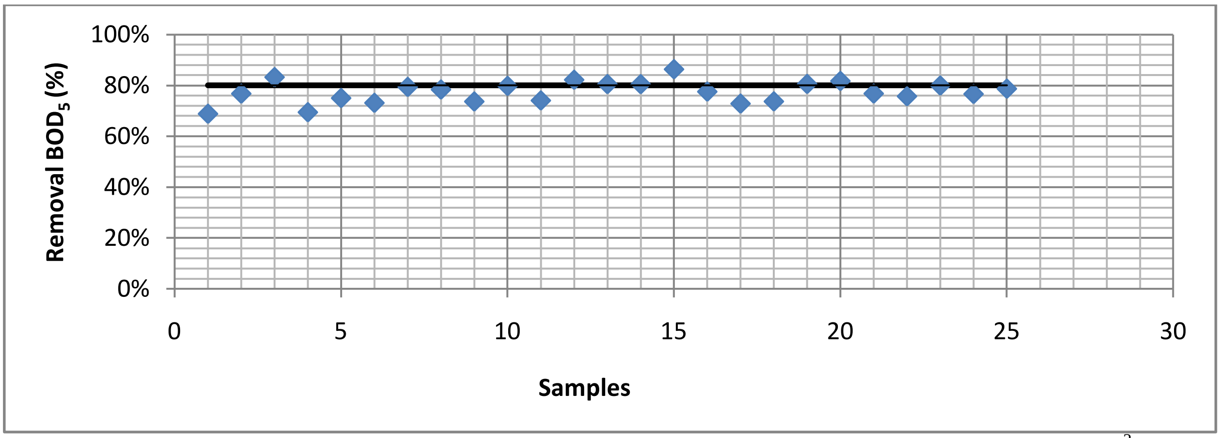

Figure 6: The efficiency in terms of BOD$_5$ during the study period for the pilot with HLR 1000 l/m^2/day

Conclusions

The objective of this study is to represent that multi-soil-layering technology successfully used in the pilot-scale and full-scale. In effect, excellent efficiency was obtained in the pilot and full-scale fed with real wastewater. Multi-soil-layering system could be feasible to apply in full-scale systems at rural area in Morocco and MENA region, if sufficient conditions were supplied.

Indeed, the hydraulic loading which allows both good removal efficiency of organic pollution and stability of the system and therefore its durability is that of 250 l/m²/day.

The choice of hydraulic load 250 l / m^2 / day allowed us to optimize cost investissement and operating the treatment plant by MSL. For a wrong choice of design load may induce either, oversizing of the station so an investment cost and high operating or under-sizing causing a malfunction of the station and thus major impact on 'environment.

The 250 l / m^2 / day, is confirmed also by other parameters including COD, NH_4^+ -N nutrients. NO_2^- - N, NO_3^- - N, TKN, TN, PO-4-P and TP. These key parameters will help engineers and design of wastewater treatment plant Type MSL north of Africa in general in the MENA region since they having the same climate and socio-economic context.

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