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Comparison of strategies to fit raw water treatment in French system for water reuse purposes in warm climate conditions

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Abstract: In order to investigate the elimination of Helminth ova and bacterial indicator organism of raw domestic wastewater, an adapted French System was studied in the National Agrarian University in Lima, Peru. The system was composed by a 1st stage gravel filter, divided in 2 alternating operated lines and a vertical sand filter as 2nd stage. The raw domestic wastewater had average concentrations of 1,9 x10^8 Thermotolerant Coliform bacteria (MPN/100ml) and 942 Helminth ova/L. The two stage system had an excellent treatment capacity, independent of increasing hydraulic loads Helminth ova were removed completely in the 1st stage and the still high concentration of Thermotolerant Coliform bacteria of around 2x10^6 MPN/100ml in the effluent of the 1st stage was reduced to 8x10^3 MPN/100ml in the 2st stage. Other parameters of the final effluent were constantly low as well (11 mg COD/L; 10 mg N_{Total}/L; 2,2 mg SS/L and 0,7 NTU). As there is hardly any sludge accumulation under tropical condition on the 1st stage, the surface of one of the two lines was covered with an artificial filtration layer of organic matter (a mixture of sawdust and chopped plants) in order to investigate ae possible positive treatment impact. During the investigation, there were no statistically significant differences between the effluent concentrations of both lines, nevertheless, slightly lower concentrations of SS and Turbidity in the effluent of the filter with organic layer (87 NTU, 10 mg SS/ L) in comparison to the line without layer (107 NTU, 18 mg SS/L) indicated better conditions for the application of additional disinfection technology, if the 1st stage is used as single treatment for production of water for reuse.

Keywords: French System; tropical arid climate; water reuse

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Introduction

More than 70% of the Peruvian population lives in the extremely arid costal area where also the capital Lima and other major cities are situated. The very high demand for reuse of treated wastewater for irrigation of agricultural land or green areas offers a great potential to introduce simple and efficient low-tech technologies such as constructed wetlands in general and the French system in especial. Studies in warm climate have already shown, that general quality standards for wastewater treatment can be complied with this simple, low impact technology (Molle et al., 2015; Platzer et al., 2016).

On the other hand, the reuse of treated wastewater is often the main motive at all to invest in wastewater treatment especially in warm regions with water scarcity, and exactly this aspect of effluent´s reusability has not completely studied yet for the French system. Peruvian quality standards for discharge of treated wastewater are 10.000 MPN/100 ml for Thermotolerant coliforms, 100 mg BOD_5/L and other parameters (MINAM, 2010). As there is no national standard for reuse, WHO guidelines are applied.

The WHO (1989) established for all kinds of reuse of treated wastewater (unrestricted irrigation) a limit for Helminth ova of <1 Helminth ova/L. Thermotolerant coliforms have to be reduced to ≤10^3 MPN/100ml only in case of indication of direct contact with persons, as irrigation of sports fields, public parks, and crops for direct consumption, while no limits for Thermotolerant coliforms are required for irrigation of cereals, industrially processed crops or trees in reforestation areas (restricted irrigation).

Material and Methods

The investigations were carried out in the pilot wastewater treatment plant (**Figure 1**) of the National Agrarian University La Molina (UNALM), Lima – Peru. The system received domestic wastewater from the public sewer system. The 1st stage with gravel as filter material and a 36 m² surface area was planted with *Cyperus alternifolius* and divided into two lines of 18 m² each. The two lines were operated alternately for 72 h (3 days) with one pump per line (Tank 1). The effluent drained to Tank 2, from where it was pumped according to the water level to the 2nd stage, a vertical flowed wetland with coarse sand as filter material. The 2nd stage had a total area of 30 m² and was divided into two parallel operated filters, one was also planted with *Cyperus alternifolius* but in the present study was only investigated the final effluent of the other filter, planted with *Chrysopogon zizanioides*.

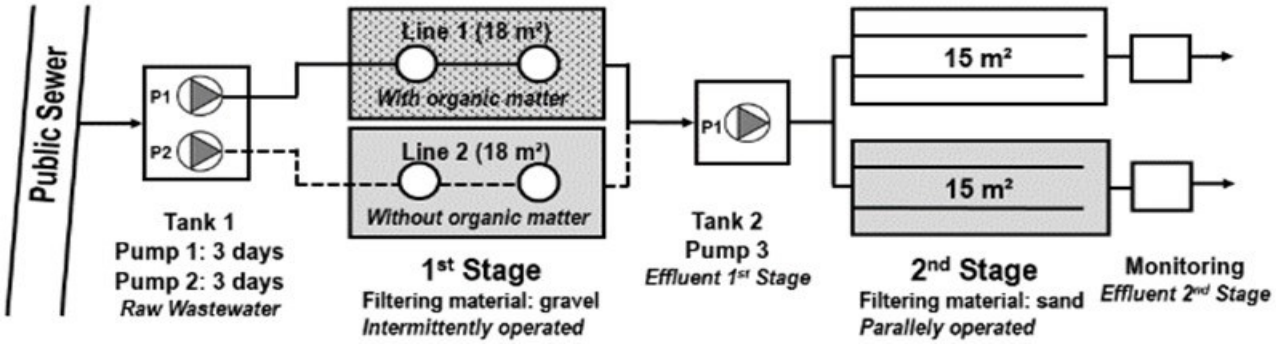

Figure 1: Outline of the pilot plant for the two-stage treatment of raw wastewater in Lima/Peru.

In order to investigate the elimination of helminth ova and termotolerantes coliforms, 2 design and operational options were investigated. The first option consisted in increasing the hydraulic loads in 3 phases (time for each phase: 8 weeks each) from 0.12 m/d to 0.25 m/d and 0.33 m/d (related to active surface area of the 1st stage). The second option investigated the effect of an artificial filtration layer of sawdust and plants chippings on the surface of one of the two lines of the 1st stage (**Figure 1**).

The effluent concentrations for the two lines of the 1st stage were tested for normality (Shapiro-Wilk-test) and homogeneity of variances (F-test). If both conditions were fulfilled, the t-test was used, otherwise Mann-Whitney-U test was carried out. All tests were run at the 5 % significance level.

Results and Conclusions

Raw wastewater concentrations (Table 1) are within the normal range for a sewer without infiltration by storm- or groundwater. The concentration of helminths ova is significantly high, as it is typical for tropical countries and the reason why the reuse of treated wastewater and sludge must be regulated.

Table 1: Arithmetic mean of the raw wastewater characteristics during the whole investigation

	BOD_5 (mg/l)	**COD** (mg/l)	**Turbidity** (NTU)	**SS** (mg/l)	**NH_4-N** (mg/l)	**N_{total}** (mg/l)	**PO_4-P** (mg/l)	**TtColif.** (MPN/100ml)	**Helm.** (ova/l)
Influent	**429**	**781**	**545**	**682**	**39.6**	**60**	**9.8**	**$1.9x10^8$**	**942**

Table 2 compares effluent concentrations and removal efficiency for each parameter between the 3 phases (increasing loads) and separated according to the line of the 1st stage that was covered with the

layer of organic material and those without such a layer. This table shows furthermore the quality of the final effluent (1st + 2nd stage) and the total treatment efficiency.

Table 2: Arithmetic means of outlet concentrations and removal efficiencies

		1st stage with layer		**1st stage without layer**		**1st + 2nd stage**	
		outlet concentration (mg/l)	**removal efficiency (%)**	outlet concentration (mg/l)	**removal efficiency (%)**	**outlet concentration (mg/l)**	**removal efficiency (%)**
COD	phase 1	68	**86**	107	**81**	12	**98**
	phase 2	100	**85**	88	**91**	11	**99**
	phase 3	89	**89**	79	**92**	11	**99**
BOD_5	phase 1	33	**86**	52	**84**	5.0	**98**
	phase 2	48	**90**	32	**95**	10.4	**98**
	phase 3	27	**95**	32	**92**	6.2	**99**
SS	phase 1	15	**96**	22	**90**	2.0	**99.7**
	phase 2	18	**95**	15	**98**	5.0	**99.4**
	phase 3	14	**99**	14	**98**	1.3	**99.9**
		(ova/l)	**(%)**	(ova/l)	**(%)**	(ova/l)	**(%)**
Helm.	phase 1	< 1	**100**	< 1	**100**	< 1	**100**
	phase 2	< 1	**100**	< 1	**100**	< 1	**100**
	phase 3	< 1	**100**	< 1	**100**	< 1	**100**
		(MPN/100ml)		(MPN/100ml)		(MPN/100ml)	
TtCol.	phase 1	$5.0x10^6$		$4.5x10^5$		$2.5x10^3$	
	phase 2	$7.1x10^6$		$6.4x10^6$		$3.4x10^3$	
	phase 3	$2.4x10^6$		$3.5x10^6$		$2.0x10^4$	

Figure 2: Pilot in Lima/Peru plant with 1st stage for raw wastewater treatment, the left line is covered with a layer of sawdust and shopped plants, and in the background 2nd stage, two parallel operated vertical flow filter

Figure 3: Samples of Raw Wastewater and Effluent of the 1st stage and 2nd stage

Comparison of the parameter between the 3 phases: the results in **Table 2** demonstrate a complete elimination of Helminth ova in the 1st stage, nevertheless the elimination of Thermotolerant coliforms in the 1st stage was limited. In the 2nd stage the efficiency of Thermotolerant coliform elimination was far better, efficiency of COD; BOD_5 and SS removals of the two stage treatment system were close to 100%. **Figure 3** proves the excellent quality of the final effluent.

Comparison of the 1st stage lines with and without the organic layer: The values in the **Table 2** do not indicate a clear positive treatment effect of the organic layer. This was confirmed by a statistical evaluation of all parameters and for all phases. According to **Table 3** there was no statistical significance difference between both lines. There was even detected a slight tendency towards higher COD and DBO_5 values in the filter with the organic layer, which could have been the effect of the outwash of complex organic substances, like lignin, from the sawdust. On the other hand, the concentrations of SS and turbidity have shown a tendency to be lower in the effluent of the filter with the organic layer. **Figure 4** shows a clear difference in sludge accumulation on the filter surfaces for the filter with and without organic layer after an operation of 6 months. Obviously, the formation of a compost layer on the surface of the 1st stage can be supported, but so far there is no clear effect on the effluent quality.

Table 3: Comparison of the median values of the effluent concentrations by means of statistical hypothesis tests (Höllmann, 2018)

	With layer Median	Without layer Median	statistical significance
COD (mg/L)	96	85	no
BOD_5 (mg/L)	40	35	no
TSS (mg/L)	10	16	no
N_{total} (mg/L)	20	22	no
NH_4-N (mg/L)	19	17	no
PO_4-P (mg/L)	5.0	4.7	no
Turbidity (NTU)	87	107	no

Figure 4: sludge deposition during 3rd phase on the line with layer (left) and on the line without layer (right)

Evaluation of reuse aspects: Despite the very high treatment efficiency of the two stage system, the final effluent does not meet WHO (1989) guidelines for unrestricted irrigation (Thermotolerant coliform bacteria $\leq 10^3$ MPN/100 ml). However, the application of additional disinfection technologies would be possible without any problems. The WHO (1989) condition for restricted irrigation (<1 Helminth ova/L) was even complied by treatment of raw wastewater in the 1st stage, independent of the hydraulic load and the existence of an organic layer on the surface. Further research on more economic options of the French System with regard to the reuse of treated wastewater is ongoing at UNALM.

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