



Mixed greywater treatment for irrigation uses

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ABSTRACT

Water contamination comes from many different sources, including, among others, factories, sewage treatment plants, mining activities (heavy metals), food-processing waste, agriculture runoff, animal waste, disposal of personal care products, and household chemicals. Therefore, the reuse of wastewater has become a fundamental strategy for sustainable water management and maintaining environmental quality. In this sense, this research presents a simple and economic alternative to solving the problems caused by greywater, resulting from laundry activities. This paper evaluates a mixed system for the treatment of greywater. The mixed system has physical filters that are composed of river stone, concrete, river sand, and coal. A bioremediation technique is also evaluated, involving two types of aquatic plants, watercress (*Nasturtium officinale* L.) and duckweed (*Lemna minor* L.). This study showed significant differences in pH reduction, from 9.56 to 7.50, total suspended solids (TSS), from 1742.00 mg/L to 298.50 mg/L, phosphates, from 1.12 mg/L PO₄³⁻ to 0.31 mg/L PO₄³⁻, and chemical oxygen demand (COD), from 472.38 mg/L to 8.52 mg/L. Thus, the results indicate that this system is efficient for the reuse of grey water for irrigation uses. Moreover, each parameter, with the exception of dissolved oxygen and total suspended solids (TSS), meets the maximum limits set by the Environmental Quality Standards for Category 3: irrigation water for vegetables and animal beverages and the FAO irrigation water standards.

Keywords: biological filter, detergents, macrophytes, physical filter, water quality.

Sistema misto de tratamento de águas cinzas para irrigação

RESUMO

As atividades pelas indústrias, população urbana e rural, são fontes mais frequentes na poluição de água, devido nisso tem se tornado necessário, principalmente a reutilização das águas residuais como uma estratégia fundamental. Nesse sentido esta pesquisa apresenta uma alternativa simples e econômica para solucionar os problemas causados pela água cinzas das atividades de lavanderia doméstica, com o objetivo de avaliar um sistema misto de tratamento de água cinza. Para isso foi estabelecido um sistema misto com filtração física, compostos de pedra de rio, concreto, areia de rio e carvão, seguido pela Biorremediação com duas plantas



aquáticas, agrião (*Nasturtium officinale* L.) e lentilha d'água (*Lemna minor* L.). Os resultados tiveram diferenças significativas na redução do pH de 9.56 até 7.50, os sólidos suspensos totais (SST) de 1742.00 mg/L até 298.50 mg/L, os fosfatos de 1,12 mg/L PO_4^{3-} até 0,31 mg/L PO_4^{3-} e demanda química de oxigênio (DQO) de 472,38 mg/L até 8,52 mg/L, por tanto indicam que o sistema é eficiente para o reuso da água cinzas com fim de irrigação. Finalmente, todos os parâmetros, a diferença do oxigênio dissolvido e os sólidos suspensos totais (SST), cumprem com os limites máximos permitidos pelos padrões de qualidade ambiental para a categoria três: água de irrigação para vegetais e bebidas de animais e os padrões para irrigação pela FAO.

Palavras-chave: detergentes, filtro biológico, filtro físico, macrófitas, qualidade da água.

1. INTRODUCTION

Water is one of the essential resources for the development of natural life in all its forms (Cai *et al.*, 2016). However, the importance of this resource has not been taken into account until the end of the 19th century, when it was discovered as the origin of numerous water-related infectious diseases (Abellán, 2017). Moreover, the scarcity and deterioration of water resources have been related to anthropological activities, for example, poor agriculture practices, livestock, and mining, along with accelerated industrial development and rapid population growth (Bwapwa, 2018). All these factors lead to health problems due to deficient water consumption (Guzmán *et al.*, 2016). In developing countries, such as Peru, most diseases are caused by poor water supply (Ferro-Mayhua *et al.*, 2019).

The service of water supply and sanitation is a major problem in Peru (Calzada *et al.*, 2017). Accordingly, by the beginning of 2018, an estimated 10.6% of the Peruvian population lacked access to drinking water services in the public system. Furthermore, the inadequate disposal of greywater outside the sewerage system is of great concern. As a result, there is an increase in the proliferation of vector-borne diseases that affect the most vulnerable population (Gutierrez-Espino and Romero-Cóndor, 2018). Greywater or sullage is the result of laundry activities, showers, baths, hand basins, and washing machines. These waste waters usually have hazardous contaminants such as phosphate, a typical compound in detergents, which causes the eutrophication of water bodies (Fowdar *et al.*, 2017; Pérez-Díaz *et al.*, 2019).

Those water issues are a major concern in the search for new supply sources and treatment systems, as well as finding alternatives to mitigate the environmental impacts caused by the inadequate disposal of greywater. In fact, water is a valuable resource that must be preserved in order to ensure a permanent supply for a sustainable use. There are a large number of techniques for treating wastewater, which range from conventional techniques, mostly physical and chemical, such as sedimentation, filtration or chlorination, to alternative techniques, generally physical and biological, such as bioremediation or filtration involving inert material such as sand or gravel (Gheraout *et al.*, 2017; Poirier *et al.*, 2019). Alternative techniques, although not generally used by both national and local government bodies, may be part in the response to greywater treatment in rural or low-finance areas, as they are proven to be efficient in removing organic and inorganic pollutants and pathogenic organisms (Boczka and Fernandes, 2017).

Regarding alternative treatments, bioremediation is one of the most important techniques that is increasingly used due to its easy and simple use and its friendliness to the environment (Azubuike *et al.*, 2016). These techniques usually involve planting emergent plants, such as watercress (*Nasturtium officinale* L.); but in some cases, organisms such as worms have also been considered. It has been proven that the use of Californian worms (*Eisenia fetida*, Savigny, 1826) or water hyacinth (*Eichhornia crassipes* (Mart.) Solms) is highly effective in treating and purifying greywater, especially in terms of organic matter parameters which include

biochemical oxygen demand (BOD₅) or chemical oxygen demand (COD) (Reyes Farje and Morales Rojas, 2019).

In this sense, this work proposes a mixed treatment system based on bioremediation and filtration techniques to treat greywater which is generated in a building, testing the evolution of the physicochemical parameters throughout the system. Furthermore, we analyze the spatial variation of the physicochemical parameters in the system and, finally, determine whether the parameters meet national and international regulations and standards regarding water usage in the irrigation of vegetables.

2. MATERIALS AND METHODS

2.1. Study Area

The experiment was conducted in the building "La Alianza Alemana", with an average population of 18 people and an age distribution of the occupants above 18 years. This building is located in the province of Chachapoyas, Amazonas in northern Peru. It is located at an altitude of 2483 meters above sea level, between the coordinates 6°13'00" S and 77°51'00" O.

2.2. Mixed system design

The mixed treatment system for the purification of greywater has two parts, which are connected to each other. The first one is a grey water collection system, with a capacity of 100 litres, with the purpose of adequately feeding the filter systems of the following component. The second part has three mechanical filters, each with a capacity of 600 litres, and whose measurements are 100 cm in width per 100 cm in length and 60 cm in depth. Each filter's base is composed of three layers; the first layer has 0.24 m³ of 1" river stone, the second one of 0.04 m³ of concrete, and the last one of 0.24 m³ of sand mixed with 0.06 m³ of coal generated from wood. Furthermore, in the third filter, we also included two bioremediation plants, duckweed (*Lemna minor* L) and watercress (*Nasturtium officinale* L), which were distributed in equal parts. It was taken an average height of 10 centimetres into account for the aforementioned plants, thus ensuring their proper development (Figure 1).

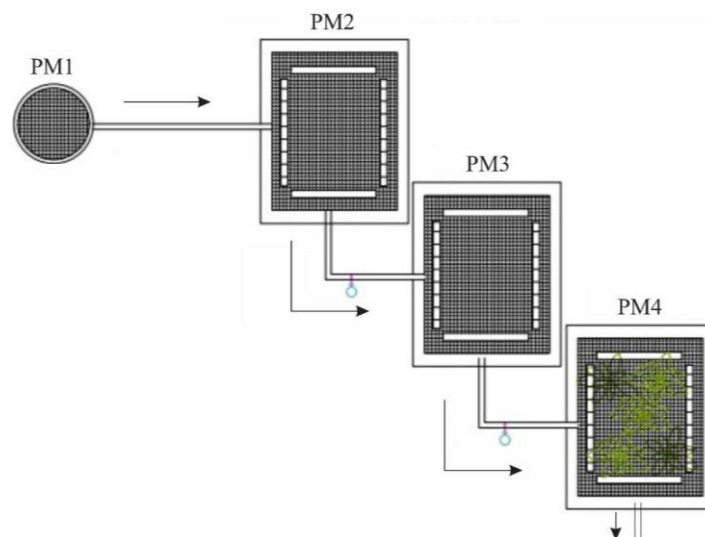


Figure 1. Design of the mixed treatment system based on filtration and bioremediation techniques (PM1: Collection, PM2: Filter 1, PM3: Filter 2, PM4: Filter 3)

2.3. Methodology

Sampling was carried out every 15 days between June and July 2018. For each established sampling point (PM1, PM2, PM3 and PM4) we collected four samples. The collection, storage,

and transfer of samples, including laboratory analysis, were done according to APHA *et al.* (2017). Moreover, data collection of pH and Dissolved Oxygen (DO) was performed on-site using a Hanna Model HI 98194 multiparametric water test. The samples to determine biochemical oxygen demand (BOD₅) and chemical oxygen demand (COD), parameters that establish the contamination of organic matter in water bodies, were collected in dark plastic containers and transparent plastic bottles, thereby allowing the physicochemical analysis of electrical conductivity (EC), total dissolved solids (TDS), total suspended solids (TSS), alkalinity and phosphates. Such analyses were performed at the Soil and Water Laboratory of the Research Institute for the Sustainable Development of the “Ceja de Selva” (INDES-CES) from the National University Toribio Rodríguez de Mendoza de Amazonas.

2.4. Statistical analysis

First of all, a graphic analysis of the box and whiskers of each parameter per sampling point was created to study the behaviour of the parameters in each part of the system. Likewise, a Kruskal-Wallis analysis of each parameter was made and subsequently a post-hoc test, a Mann-Whitney test with the Bonferroni adjustment method, was carried out on the parameters that showed significant differences, in the interest of identifying the existence of differences between individual parts of the system, and thus being able to compare the behaviour and interrelationship at the inflow and outflow stages of the system. To understand the relationship between the studied parameters, a Spearman correlation analysis was performed. Finally, it was verified graphically whether all the parameters met the maximum permitted limits for pH, DO, EC, Alkalinity, BOD and COD, set by the Environmental Quality Standards (EQS) of Water for Category 3: irrigation water for vegetables and animal beverages, established by the Ministry of Environment, Peru (2017). Due to the fact that the parameters of TDS, TSS and phosphate are not included in the EQS, they were tested with standards established by the Food and Agriculture Organization of the United Nations (FAO) for water quality in agriculture (Ayers and Westcot, 1994). All statistical analyses were performed at a significance level of $p < 0.05$ with the statistical software R v. 3.6.3 (R Development Core Team, 2020).

3. RESULTS AND DISCUSSION

3.1. Performance of the physicochemical parameters in the mixed treatment system

We found that the parameters that showed a reduction throughout the treatment system are pH ranging from 9.56 to 7.50, DO from 6.58 mg/L to 3.13 mg/L, TSS from 1742.00 mg/L to 298.50 mg/L, alkalinity from 106.06 mg/L to 76 mg/L, phosphates from 1.12 mg/L to 0.31 mg/L, BOD from 28.13 mg/L to 12.31 mg/L and COD from 472.38 mg/L to 8.52 mg/L. On the other hand, the parameters that experienced an increase are EC rising from 186.75 $\mu\text{S}/\text{cm}$ to 328.25 $\mu\text{S}/\text{cm}$ and TDS from 112.05 mg/L to 196.95 mg/L (Figure 2).

It should be noted that pH is one of the parameters which is most affected by the mixed treatment system, as it has been reduced from alkaline to almost neutral (Figure 2A). This performance can also be observed in fast, slow and mixed sand filters for obtaining drinking water (Laghari *et al.*, 2018). In fact, this parameter has enormous importance in wastewater treatment, due to the high influence on biological, chemical or physical treatments (Aelterman *et al.*, 2006; Issabayeva and Dih, 2019). As an example of this, it is relevant in the ammonium oxidation process (Tomaszewski *et al.*, 2017), in advanced oxidation processes (Boczka and Fernandes, 2017), as well as in microbiological processes for the elimination of phosphorus (Stokholm-Bjerregaard *et al.*, 2017).

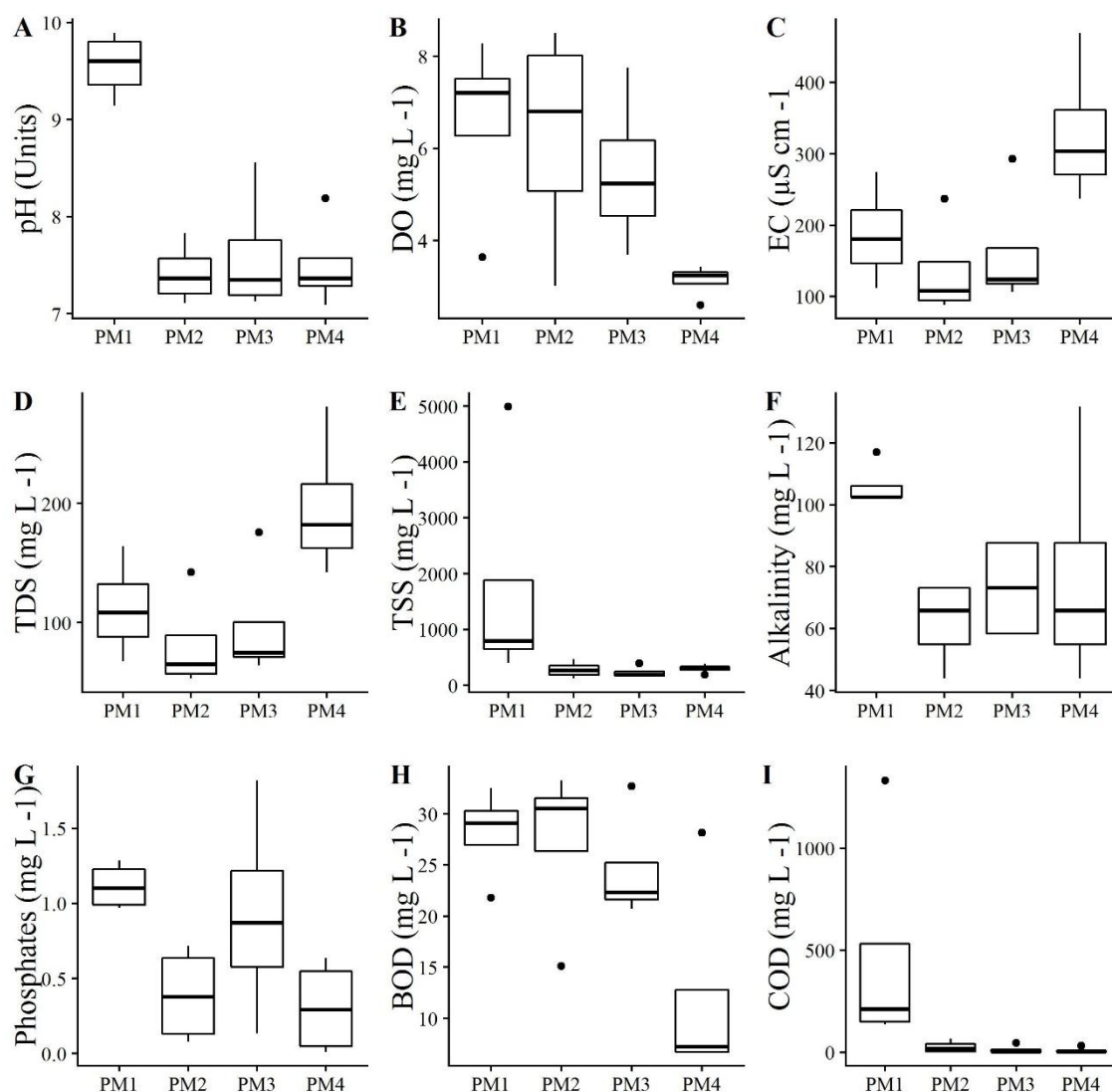


Figure 2. Average values of pH (A), DO (B), EC (C), TDS (D), TTS (E), Alkalinity (F), Phosphates (G), BOD (H), COD (I) at the different sampling points in the system.

In contrast, regarding DO, it was negatively affected since it had a significant decrease (Figure 2B). Usually this is typical at the bottom of oxidation ponds (Noikondee *et al.*, 2019). However, DO reduction is very common in biological treatments, since oxygen consumption is an excellent indicator that the system works properly (Harja *et al.*, 2016). Nevertheless, it would be ideal to include an additional method in this system to increase DO, given that it is essential to biodegrade contaminants, especially organic matter (Radzi *et al.*, 2020).

In relation to EC and TDS parameters, which are directly related to each other, they experience an increase along the treatment system points (Figure 2C and 2D). These parameters usually decrease when biological treatments are applied (Duque-Sarango *et al.*, 2018). This behavior is due to the dragging of particles in the system when the filters contain sand and carbon (Pompei *et al.*, 2017). Nevertheless, just the opposite occurs with TSS (Figure 2E), owing to the fact that there are seasonal phases in the filter, and in the absence of pumps, sedimentation processes, therefore take place, leading to a settling of solid particles to the bottom (Merizalde *et al.*, 2019).

The alkalinity decreased from Point PM1 to Point PM2 of the treatment; however, it was constant in the remaining points (Figure 2F). Alkalinity is an important parameter, not only because it varies according to the type of treatment and temperature, but also because it is an indicator for making pH adjustments in the systems, as it is strongly related to it, and thus

prevents corrosion or incrustation in the treatment systems (Silva-Teira *et al.*, 2018). The reduction of phosphate (Figure 2G) is mainly due to assimilation by aquatic plants, since it is an important nutrient for their growth (Delgadillo-Mirquez *et al.*, 2016).

The organic matter, BOD and COD parameters showed a large decrease throughout the mixed system (Figure 2H and 2I). The same inclinations are found in other water treatments, for instance, stabilization or oxidation ponds, which, by degrading organic matter and oxygenating it, have proven to be efficient, reducing up to 82% of organic matter (Peña *et al.*, 2018). Similarly, it has been shown that aquatic plants are efficiently removing organic matter in the range of 70-86% when using *Eichhornia crassipes* (Mart.) Solms, and about 58% when using *Lemma minor* L, both of which are used in this research (Rodríguez-Miranda *et al.*, 2010).

3.2. Spatial dynamics for the mixed treatment system

The Kruskal-Wallis analysis for the nine physicochemical parameters showed significant differences for pH, TSS, Phosphates and COD (Table 1). After applying the post-hoc test (Mann-Whitney test), it was found that point number one of the systems differs from the rest of the treatment system

Table 1. Kruskal-Wallis analysis and post-hoc test (Mann-Whitney test) for the analyzed physicochemical parameters.

Parameters	Kruskal-Wallis		Post-hoc	
	χ^2	Sig.	Different PM	Same PM
pH (Units)	8.54	0.036*	1	3,4,2
DO (mg/L)	6.77	0.079 ^{ns}		Same
EC (μ S/cm)	7.48	0.057 ^{ns}		Same
TDS (mg/L)	7.48	0.058 ^{ns}		Same
TSS (mg/L)	8.25	0.041*	1	3,4,2
Alkalinity (mg/L)	6.55	0.088 ^{ns}		Same
Phosphates (mg/L)	8.76	0.033*	1	2,4,3
BOD ₅ (mg/L)	5.87	0.118 ^{ns}		Same
COD (mg/L)	10.41	0.015*	1	2,3,4

*Significant ($P < 0.05$), ^{ns} not significant ($P > 0.05$).

As for the pH, TSS, phosphates and COD parameters, those parameters have been affected by the mixed treatment system (Table 1). Both pH and TSS are significantly affected by the action of mechanical filters, due to the retention of particles larger than 0.45 μ m (Laghari *et al.*, 2018) and the effect of calcium carbonate that is usually found in the sand (Holtman *et al.*, 2018). The significant effects on phosphates are due to the action of aquatic plants when using them as a nutrient (Delgadillo-Mirquez *et al.*, 2016), whereas the effects on COD are mainly due to the path taken by the water through the various mechanical filters, which promotes oxygenation and thus the degradation of organic matter (Achak *et al.*, 2019).

3.3. Water quality testing of the mixed treatment system

Regarding water warmth evolution, it is noted that at the beginning, all parameters meet the regulations, but pH, TSS, BOD and COD. On the other hand, at the end of the treatment, the only parameters that fail to meet the regulations are the DO and the TSS (Figure 3).

If we compare the final values of pH, OD, EC, Alkalinity, BOD and COD parameters with the Environmental Quality Standards (EQS) for Water, Category 3: irrigation water for vegetables and animal beverages, established by the Peruvian Ministry of the Environment (Peru, 2017), we find that they all meet the standard, except for the DO. TDS, TSS and

phosphate parameters were compared with the standards established by the FAO, for water quality in agriculture, given that Peruvian regulations do not include them within the RCTs (Figure 3). Although pH is not widely used to assess irrigation water quality, it is important to establish the relative concentrations of dissolved carbonate species, which affect plant nutrient uptake (Jaramillo and Restrepo, 2017).

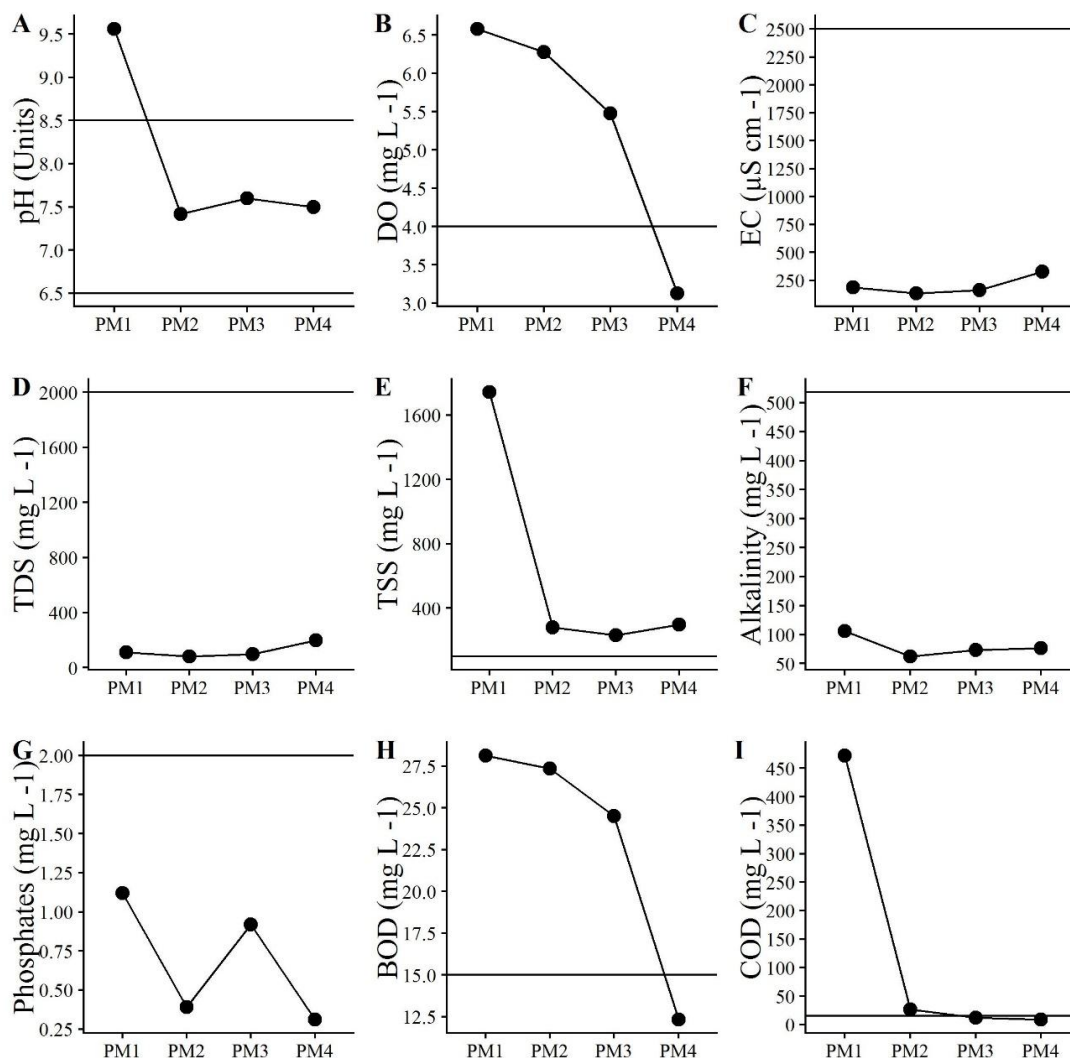


Figure 3. Comparison of average values of pH (A), DO (B), EC (C), TDS (D), TTS (E), Alkalinity (F), Phosphates (G), BOD (H), COD (I) regulations.

Parameters which are of primary importance for irrigation include phosphates and organic matter (BOD and COD), due to their strong influence on plant growth (Da Silva Gomes *et al.*, 2019). Nevertheless, low DO concentration has a major disadvantage, since values found to be lower than 3.0 mg/L make biota survival impossible (Rubio Arias *et al.*, 2014). Therefore, one option may be the implementation of air pumps, in order for the DO values to be increased. Both TDS and phosphates meet the limits established by the FAO. However, TSS exceeds the maximum limit allowed. Nevertheless, that limit is only for drip irrigation to avoid clogging (Ayers and Westcot, 1994). This means that we can use them for direct irrigation.

4. CONCLUSIONS

Our results demonstrated that the mixed treatment system improved greywater quality for irrigation uses, notably by reducing levels of pH, TSS, phosphates, BOD and COD. As a result,

these parameters were favourably influenced in each system filter. Nevertheless, the EC and TDS parameters were negatively affected by the sediment carry-over in the treatment system, as well as the DO reaching lower values for the development of biota.

Finally, all final values of parameters meet the FEA and FAO standards for irrigation water, except the DO. Therefore, we suggest implementing an aeration system within the treatment.

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