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Inverse Margin Filtration Applied for Surface Water Treatment

Filtração em Margem Inversa Aplicada ao Tratamento de Água Superficial

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Abstract

Technologies to be applied under the context of protection and revitalization of surface water must be developed and improved in order to enhance the quality of aquatic ecosystems. In this way, this study aimed to evaluate the treatment performance of an inverse margin filtration system (IMF) applied in surface water treatment. The IMF was monitored during 1 year through the classic water quality parameters, and thus the treatment performance along the filtration path was identified. The results showed an average removal efficiency of 41% for turbidity, 35% for apparent color, 43% for true color, 26% for total suspended solids and total organic carbon, 53% for nitrogen, 46% for phosphorus, 91% for iron, 8% for manganese, and 100% for fecal coliforms. In this way, the IMF system proved to be a technology that can be applied in the treatment of water in lentic environments.

Keywords: Lentic ecosystems revitalization; Inverse margin filtration; Filtration distance

Resumo

Tecnologias para serem aplicadas sob o contexto de proteção e revitalização de corpos hídricos superficiais devem ser desenvolvidas e aperfeiçoadas, para assim melhorar a qualidade dos ecossistemas aquáticos. Nesse contexto, o objetivo desse estudo foi avaliar o desempenho de tratamento de um sistema de filtração em margem inversa (FMI) empregado no tratamento de corpo hídrico superficial. O sistema de FMI foi monitorado ao longo de 1 ano de operação por meio dos parâmetros clássicos de qualidade da água, e com isso o desempenho de tratamento ao longo do percurso de filtração foi identificado. Os resultados mostram uma eficiência média de remoção na ordem de 41% para turbidez, 35% para cor aparente, 43% para cor verdadeira, 26% para sólidos suspensos totais e carbono orgânico total, 53% para nitrogênio, 46% para fósforo, 91% para ferro, 8% para manganês, e 100% para coliformes fecais. A distância do percurso de filtração favoreceu o desempenho de tratamento, apresentando melhorias significativas na qualidade da água com o aumento do percurso de filtração. Nesse contexto, o sistema de FMI se mostrou uma tecnologia passível de ser aplicada para o tratamento de água de ambientes lênticos.

Palavras-chave: Revitalização de ecossistemas lênticos; Filtração em margem inversa; Distância de filtração

1 Introduction

In tropical countries, water bodies such as rivers, lakes and seas have always had multiple functions, acting as means of transport, in the production of food, and also as a direct source for public supply (Walsh, 2000). However, the urbanization and the development of cities are increasingly prevalent in these places. Thus, this dynamic makes it difficult to manage water resources, mainly due to the demand for water, both in terms of quantity and quality (Shamsuddin *et al*., 2014).

The recovery and renaturalization of rivers and lakes is possible, although in most cases with limitations, mainly in places where marginal areas are not available due to use and occupation and also to economic, financial and social costs. However, significant improvements can be obtained through new biotechnological technologies, starting with structural actions and the pre-treatment of the water (Missimer *et al*., 2013).

Recently, a technology widely used as water pre-treatment is riverbank filtration (RF) which refers to a relatively simple and economic process, applied in removing of suspended materials, organic carbonaceous matter, nutrients, microorganisms and a variety of organic contaminants present in surface water bodies (Hu *et al*., 2016). The RF has been showing positive results regarding water treatment. In some places, such as America, this technique is used as a preliminary treatment of water, while in the Europe, for example, this technology is used as the sole treatment of water supply public, plus chlorination only (Grünheid *et al*., 2005).

Due to several advantages of using RF systems for pre-treatment or even for the majority treatment of public water supply, the possibility of using RF with a new operational strategy, and for a new purpose it presents itself as an emerging technology. In this way, making a modification in the classic RF technology can be an interesting operational strategy, capturing the water from the source and infiltrating the margin, thus reversing the flow of treated water (source/margin). In this process, it is possible to perform the recovery of a superficial water body through the interaction between the soil and the microorganisms present around the source.

In this new approach known as inverse margin filtration (IMF), the margin sediment itself is used as a filtering medium through which water from the water body is infiltrated, were the filtration process takes place. Subsequently, the water is returned to the surface water body in a saturated zone through the action of gravity by the groundwater level, according to the hydrogeological conditions of the place. In this way, the IMF emerges as an alternative for water pre-treatment, providing the removal of suspended materials, pathogenic microorganisms, chemical and biological contaminants, incorporated into the liquid medium, carrying out the water body recovery process.

In this way, the aim of this study was to evaluate the treatment performance of a full-scale IMF system, applied to treat the water of the lake, taking into account the influence of the distance of the filtration path.

2 Material and Methods

The full-scale IMF system was constructed, operated and monitored along the Rio do Meio hydrographic basin in the Florianopolis city, south of Brazil (27º 25’ 44” S and 48º 31’ 03” W), as showed in the Figure 1. The lake studied is classified as an unnatural lentic environment and has an approximate surface area of 1,127.3 m² (27.20 m of length x 52.76 m of width x 1.5 m of deep), with an estimated volume of 1,690.95 m³.

2.1 Inverse Margin Filtration System Description

The system has been designed based on four related steps, first with the capture of the lake water, followed by an infiltration ditch, from where the water infiltrates and flows towards the lake, treating it through filtration in the soil sediments as well as microbial action. Moreover, a set of piezometers was installed to monitor flow and sample collection. In general, by means of a pumping system, the lake water to be treated is repressed and sent to the infiltration ditch, later it returns to the water body (lake) through the groundwater by gravity (Figure 2). The IMF system was implemented in March 2019, and its operation started in June 2019.

The sampling of lake water was carried out by a submersible motor-pump set (BCS -220 power of 1 VC) fixed to a metallic structure inside the lake. The water was pumped through an underground rigid polyvinyl chloride pipe (32 mm diameter) to the infiltration ditch. A hydrometer, with record and overflow was installed at the beginning of the discharge, to monitor the applied flow. To obtain a homogeneous supply throughout the system, the distribution entrance was projected in a median point of the infiltration ditch, that is, in the middle of the internal drainage pipe having 2.5 m for both sides. Subsequently to the treatment process, water returned to the lake where it was collected, by gravity the groundwater level.

The infiltration ditch has a cross-section of 1 m² and a length of 5 m, with a depth of 1.6 m from the surface. The entire vertical profile of the ditch was filled with a filtering mass formed by pebbles (average diameter of 70 mm) wrapped in a geotextile blanket for drainage. As the infiltration area of the ditch, the lateral and lower sides were considered in the total length, generating a useful area of 17 m². The ditch received a daily flow of 250 L d^{-1}, resulting in an application rate of 0.0147 m^3 m^{-2} d^{-1}. The specific physical and chemical characteristics of the soil used in the infiltration ditches are described in Table 1 and Figure 3.

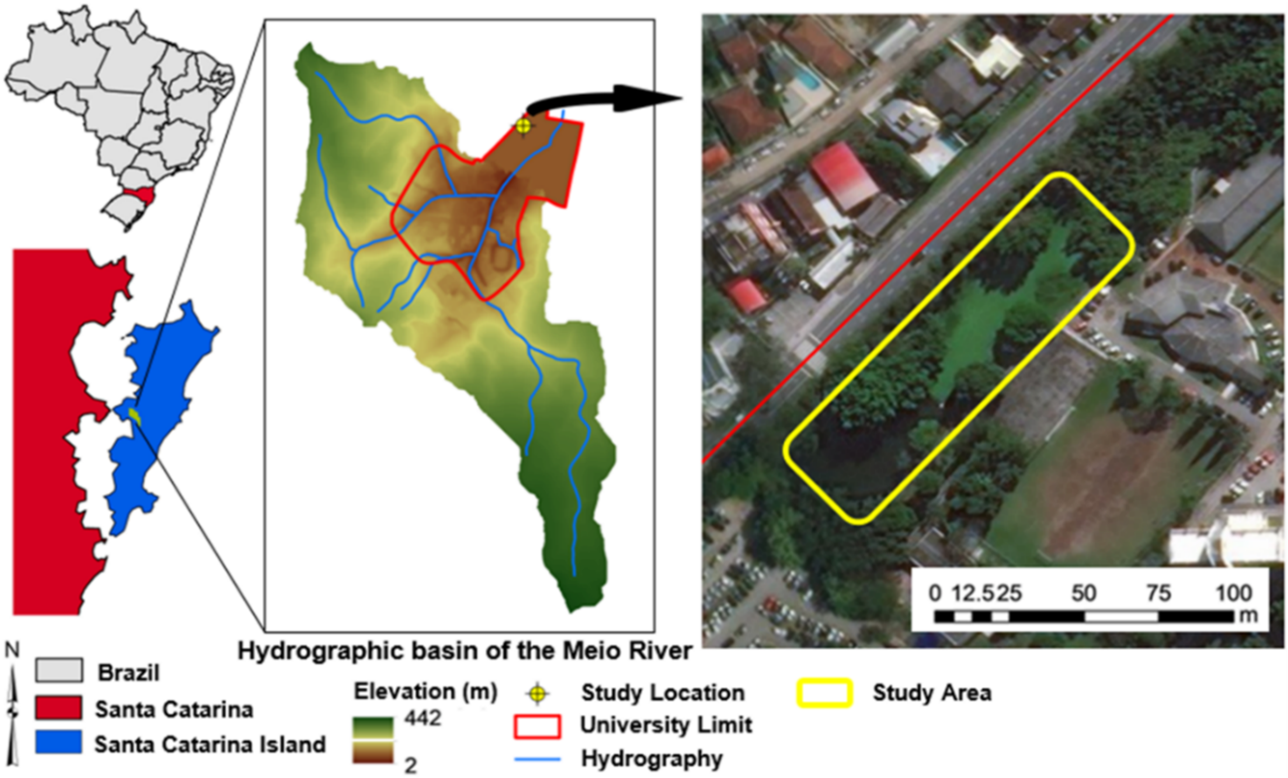

Figure 1 Location of the structure under study.

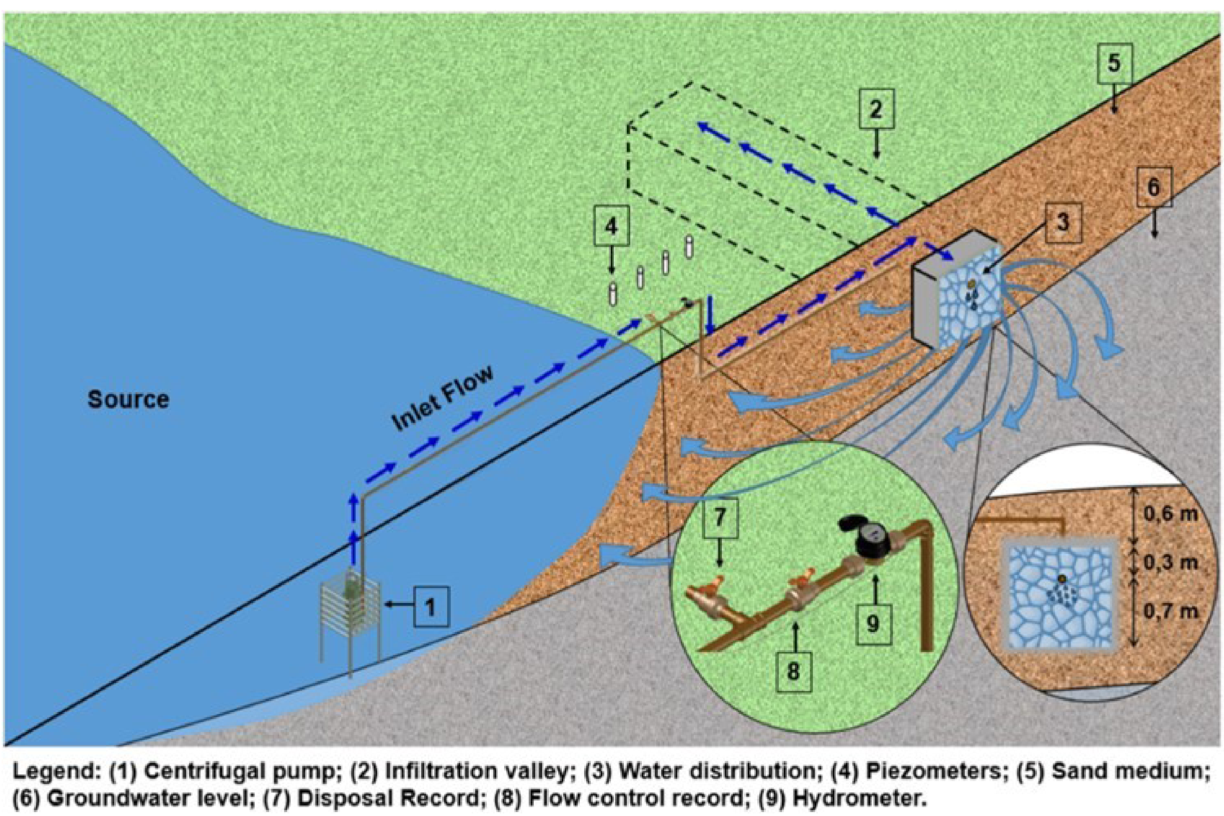

Figure 2 Scheme of the inverse margin filtration system for one water treatment.

Table 1 Physical and chemical characteristics of the soil.

Parameters	Values	Fraction distribution	Values (%)
Grain diameter D_{90} (mm)	1.76	Sand+clay	1.76
Effective porosity (%)	0.335	Fine sand	9.30
Uniformity coefficient	2.03	Medium sand	52.54
pH	5.65	Coarse sand	34.5
TOC ($g.Kg^{-1}$)	9.0	Fine gravel	1.90
TN ($g.Kg^{-1}$)	0.4		
I ($mg.dm^{-1}$)	456		
Mn ($mg.dm^{-3}$)	7.9		
TP ($mg.dm^{-3}$)	11.7		

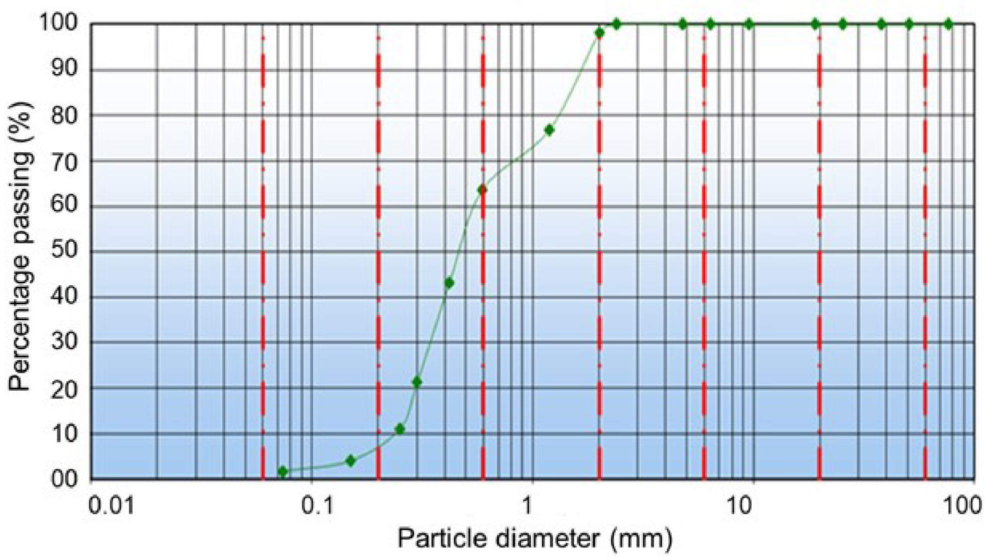

Figure 3 Granulometric curve constructed from the soil used in the inverse margin filtration system.

In order to monitor the water quality and the water level of the groundwater with the identification of its flow, 12 piezometers were installed between the infiltration ditch and the lake, strategically arranged in three equidistant rows, 1.5 m each. The piezometers were built following the recommendations of the Brazilian standard (ABNT, 2007).

2.2 Groundwater Level Stabilization Height Behaviour

The height of the groundwater and the waterflow after its entry into the infiltration ditch were monitored using piezometers. The height of the groundwater was measured using a water level indicator (audible, model EPP-10/6). The waterflow was determined with the system in operation through direct measurements at the groundwater level, obtaining the corresponding dimensions of each piezometer.

2.3 Monitoring the Treatment Performance of the Inverse Margin Filtration System

During the study period (July 2019 to August 2020) water sampling were carried out at four points in the system, one raw water (collected at the entrance to the system along with the intake) and at different filtration distances, being In the piezometers P1 (distance of 2 m of filtration), P5 (distance of 5.5 m of filtration) and finally, in the P12 (distance of 8.0 m of filtration), where the water after the treatment returned by the groundwater level to the lake, considered thus, the treated water.

The collections and analyses followed a weekly frequency and the parameters evaluated were: temperature, dissolved oxygen (DO), electric conductivity (EC), hydrogenionic potential (pH), redox potential (ORP), turbidity, true and apparent color, total organic carbon

(TOC), total suspended solids (TSS), total nitrogen (TN), ammonia nitrogen ($NH4^+$ -N), nitrite nitrogen (NO_2 -N), nitrate nitrogen (NO_3 -N), total phosphorus (TP), faecal coliforms (FC), manganese (MN), iron (I). All analyses were performed following recommendations by APHA (2017).

2.4 Statistical Analysis

The normality of the data regarding the chemical, physical and biological characterization of the water over the filtration distance (raw water, 2 m, 5.5 m, and 8 m) was evaluated by Shapiro – Wilk test. Given that the distribution occurred within the normal range, the ANOVA variance test (significance level of $p = 0.05$) was applied, in order to assess whether there was a statistical difference along the filtration distance.

3 Results and Discussion

3.1 Behavior of Groundwater Level Stabilization Height

The behavior over the monitored period showed the level of waterflow in the system with small variations provided by biological degradation, due to the bacterial action present in the filter media, pointing out the balance between the water volume of entered the system with the volume of water infiltrated (Figure 4). However, in some weeks (16, 19, 26, 30 and 47) significant point variations were observed, probably due to the precipitated volume. A very important characteristic of the groundwater level position is that the configuration varies according to the season, due to the recharge of groundwater, which is the addition of water above the surface of the saturated zone, and is related to the quantity and precipitation distribution (Arantes, 2003).

3.2 Treatment Performance of the Inverse Margin Filtration System along the Filtration Distance

Statistical differences ($p < 0.05$) between the different filtration distances (raw water, 2 m, 5.5 m and 8 m) were identified for all parameters evaluated, except for pH values. This behavior showed that the filtration distance influenced in the treatment performance of the IMF system. In general, the treatment performance of the IMF system varied along the filtration route. The greater distance filtration or greater the contact time between the water and the filter media higher was the treatment performance (Figure 5). Table 2 shows the average values and standard deviation of the results obtained, referring to the monitoring period of the physical-chemical and biological parameters identified at different filtration distances of the IMF system. Moreover, Table 3 showed the statistical results.

As the filtration path increases, lower were the turbidity values identified (mean removal efficiency of 5 ± 12 %, 25 ± 13 % and 41 ± 17 % for 2, 5.5 and 8 m of filtration, respectively), apparent color (mean removal efficiency of 8 ± 17 % for 2 m, 25 ± 13 % for 5.5 m and 35 ± 27 % for 8 m) and true color (mean removal efficiency of 28 ± 37 %, 38 ± 23 % and 43 ± 17 % for 2, 5.5 and 8 m of filtration, respectively). Moreover, EC increased along the route, mainly after 5.5 m of filtration. In this way, the decrease in the turbidity and color associated with the increase in EC values indicate a good sedimentation and filtration performance during water treatment process (Dash *et al*., 2008). This same behavior has already been reported in an RF system used for the water treatment of a pond in Florianopolis, Brazil (Romero-Esquivel, 2012).

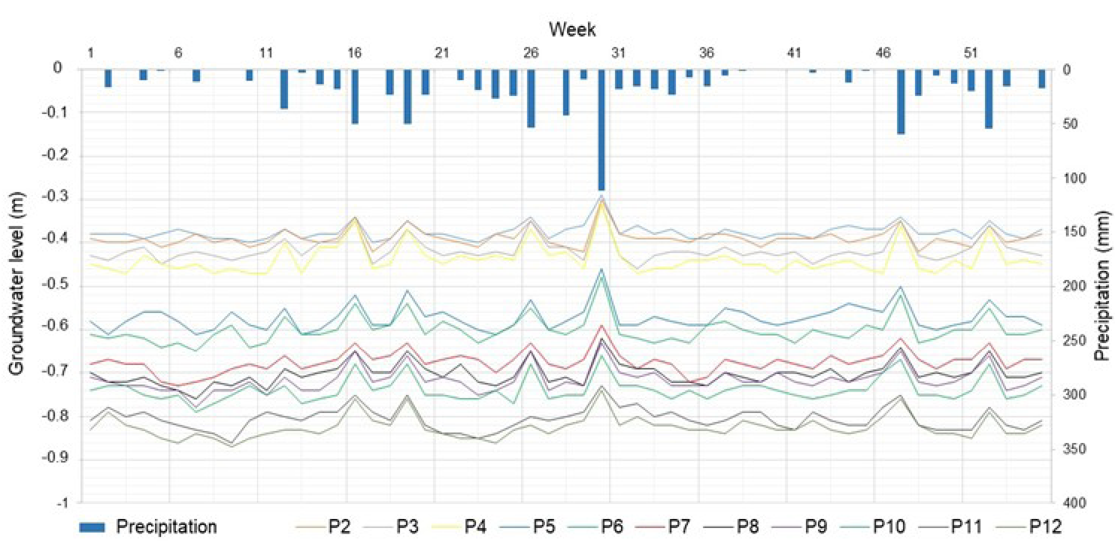

Figure 4 Groundwater level monitored in the piezometers in relation to precipitation.

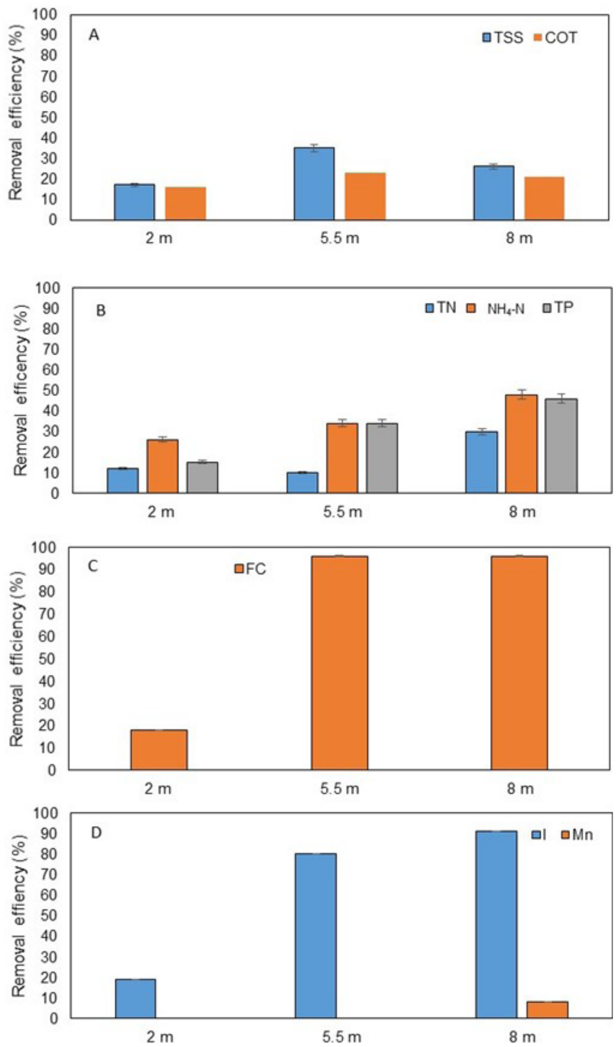

Figure 5 Average removal efficiency of pollutants at different points of filtration distances from the inverse margin filtration system. a) solids fraction b) organic matter. c) nutrients. d) pathogens. e) metals.

Regarding to the redox conditions present in the medium, at the same time that the pH values did not vary along the filtration path (6.29 to 6.59) and no statistic difference ($p > 0.05$) between the different collection points were identified (Table 2), the DO concentrations decreased with increase of filtration path (4.07, 0.98, 1.10 e 1.55 mg.L^{-1} in the raw water, for 2 m, 5.5 m and 8.8 m, respectively). This behavior showed the presence of predominantly reducing environments as the increased of filtration distance. This fact is associated is mainly associated with oxygen consumption by biochemical reactions developed by microorganisms (Weber, 2016). Therefore, the higher the filtration distance the more reduced the medium becomes.

In relation to TSS concentrations, interesting behavior was identified along the filtration path (Figure 6). Firstly, the mean removal efficiency at 2m of filtration was of 17± 10%. Subsequently, the removal efficiency gradually increased, reaching average values of 35 ± 12% at 5.5 m of filtration. After that distance, at 8 m of filtration, the average removal efficiency slightly decreases to 26 ± 39%. This fact is probably associated with a decrease in the hydraulic conductivity of the soil in this path, directly influencing the filtration process. The decrease of hydraulic conductivity, with the increase of the filtration distance in RB systems, has already been reported in other studies, being mainly this process linked to the amount of TSS present in the raw water, associated with the flow velocity of the system (Bertelkamp *et al*., 2016). In addition, another important characteristic that influences the TSS removal is the physical characteristics of the soil. The higher void rates of the soil, the greater the treatment performance of the system (Grischek *et al.,* 2007).

In relation to carbonaceous fractions, longer filtration distance associated with longer contact time of water inside the infiltration ditch, favoured the TOC removal process (Figure 5). The TOC mean removal efficiency was of 16 ± 9%, 23 ± 12%, and 26 ± 36% for, raw water, 2 m, 5.5 m and 8 m of filtration, respectively. The TOC removal can be associated with microbial activity and in a second moment, with sedimentation process (Maeg *et al*., 2008). In addition to carbonaceous fractions, the increase of filtration distance also favoured nitrogen transformations. The concentration of the different nitrogen forms identified along the filtration path is presented in the Figure 7.

NH_4^+-N mean removal efficiency was of 26 ± 23% to 2 m and 34 ± 18% for 5.5 m of filtration. After this filtration path, the NH_4^+-N mean removal efficiency remained increasing, with average two mechanisms, being the adsorption in the soil, despite being limited, as showed by Massmann *et al*. 2008 and the nitrification process. The oxidized nitrogen (NO_x-N) production was similar to the 2 m and 5.5 m of filtration distance (about 1.5 mg.L^{-1}), showed a low decreased at 8 m of filtration (0.73 mg.L^{-1}). On the other hand, the TN mean removal efficiency increased along the filtration distance (28 ± 12 %, 40 ± 20% e 53 ± 18% from 2, 5.5 and 8 m of filtration, respectively) (Figure 5). In this way, the sequential nitrification and denitrification process is evident, especially after 2 m of filtration. Therefore, when the ultimate aims are to avoid eutrophication of water bodies, derived from nitrates, IMF systems must be designed with a filtration distance greater than 5 m.

Table 2 Mean values and standard deviation identified at different filtration distances from the inverse margin filtration system.

Parameters n= 55	Raw water	2 m of filtration	5,5 m of filtration	8 m of filtration
Turbidity (NTU)	21.02 (7.41)	20.22 (4.65)	15.8 (3.10)	12.44 (3.92)
Apparent color (uH)	250.33 (75.88)	230.13 (66.78)	188.93 (27.91)	162.09 (33.12)
True color (uH)	40.38 (14.59)	29.04 (5.13)	25.0 (4.33)	23.07 (7.40)
Temperature (°C)	21.04 (4.57)	22.27 (4. 88)	22.49 (4.66)	21.93 (4.43)
pH	6.59 (0.64)	6.29 (0.39)	6.41 (0.42)	6.25 (0.40)
DO (mg.L^{-1})	4.07 (2.16)	0.98 (0.39)	1.1 (0.41)	1.55 (0.71)
ORP (mV)	62.20 (6.02)	123.7 (9.0)	-136.5 (8.5)	-117.44 (8.75)
EC (µS.cm^{-1})	211.17 (24.04)	232.02 (28.04)	226.8 (26.11)	249.23 (47.11)
TSS (mg.L^{-1})	154.82 (53.91)	111.53 (29.34)	86.7 (22.6)	118.11 (107.85)
TOC (mg.L^{-1})	17.44 (2.93)	14.85 (3.26)	13.5 (3.5)	12.61 (6.89)
TN (mg.L^{-1})	8.32 (4.56)	6.00 (1.14)	5.01 (2.0)	3.98 (1.87)
NH_4^+-N (mg.L^{-1})	4.86 (1.85)	3.36 (1.56)	3.0 (1.3)	3.11 (2.58)
NO_2^- -N(mg.L^{-1})	0.06 (0.03)	0.05 (0.01)	0.04 (0.01)	0.05 (0.04)
NO_3^- -N (mg.L^{-1})	1.33 (0.57)	1.25 (0.30)	0.89 (0.29)	0.73 (0.35)
TP (mg.L^{-1})	2.62 (0.58)	2.29 (0.46)	1.7 (0.4)	1.82 (1.09)
I (mg.L^{-1})	1.90 (0.46)	1.57 (0.57)	0.38 (0.16)	0.18 (0.09)
Mn (mg.L^{-1})	0.05 (0.01)	0.06 (0.01)	0.06 (0.06)	0.05 (0.01)
FC (MPN / 100 mL^{-1})	1.26×10^{-4} (8.84×10^{-3})	1.02×10^{-4} (6.92×10^{-3})	2.57×10^{-2} (2.51×10^{-2})	3.39×10^{-1} (4.17×10^{-1})

Table 3 Statistical results identified at different sampling points.

Parameters	p value
Turbidity (NTU)	0.0345
Apparent color (uH)	0.0234
True color (uH)	0.0123
Temperature (°C)	0.0324
pH	1.2341
DO (mg.L^{-1})	0.0214
ORP (mV)	0.0321
EC (µS.cm^{-1})	0.0213
TSS (mg L^{-1})	1.32×10^{-6}
TOC (mg L^{-1})	1.862×10^{-6}
TN (mg.L^{-1})	5.32×10^{-6}
NH_4^+-N (mg.L^{-1})	2.52×10^{-6}
NO_2- N (mg.L^{-1})	4.12×10^{-6}
NO_3- -N(mg.L^{-1})	7.33×10^{-6}
TP (mg.L^{-1})	3.32×10^{-6}
I (mg.L^{-1})	8.92×10^{-6}
Mn (mg.L^{-1})	7.52×10^{-6}
FC (NPN / 100 mL^{-1})	0.0874

For TP, firstly, a gradual increase in the mean removal efficiency was identified with an increase in the filtration distance (15 ± 14% at 2 m, 34 ± 18% at 5.5 m and 46 ± 20% at 8 m of filtration) (Figures 5 and 8). In the RB system, TP removal are associated with adsorption in the soil (Hu *et al*., 2016). However, it is necessary to take into account that the TP soil adoption process is temporary storage and is not a removal mechanism (Hu *et al*., 2016). Thus, the longer the filtration distance coupled with the longer contact time of the water to be treated with the soil, the greater the efficiency of removing due to the adsorption process (Hu *et al.,* 2016).

The FC mean removal efficiency was of 18 ± 17%, 97 ± 3% and 100 ± 1 % for 2, 5.5 and 8 m of filtration respectively (Figure 5). Moreover, log removal was less than 1 (0.1) at 2 m, 1.7 at 5.5 m and 2.57 at 8 m of filtration. This behavior made evident the importance of the filtration distance for CF removal. In the RB systems the removal of pathogens is mainly associated with predation by other organisms Grünheid *et al*. (2005).

As for metals, an interesting dynamic was identified in the removal of these elements, along the filtration distance (Figure 9 and 10). For iron, the mean removal efficiency was of 19 ± 14%, 80 ± 7% and 90 ± 1% at 2, 5.5 and 8 m of the filtration respectively. This fact showed that the filtration distance, mainly after the 2 m of filtration, was beneficial for the removal of iron. This treatment performance may be linked to microbial metabolism, due to the fact that iron is used as an electron acceptor, in reducing environments, for the degradation of carbonaceous organic matter (Grünheid *et al.,* 2005). In addition to this mechanism, the iron removal may also be linked to the formation of insoluble sulphides.

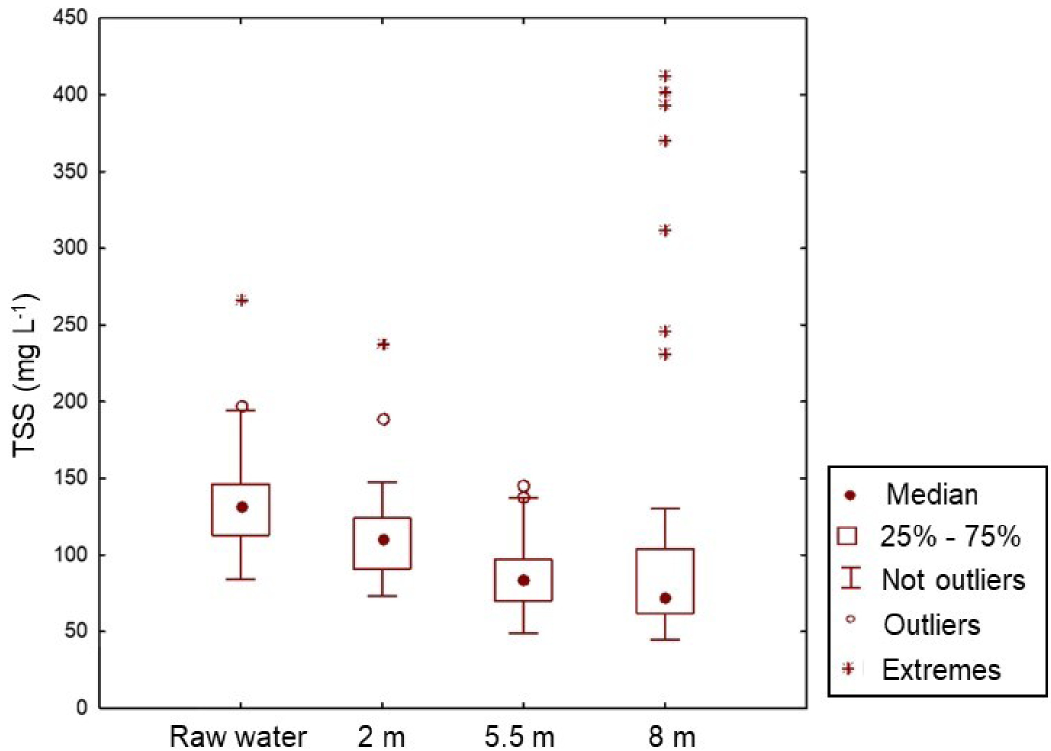

Figure 6 TSS concentrations along the filtration distance of the inverse margin filtration system.

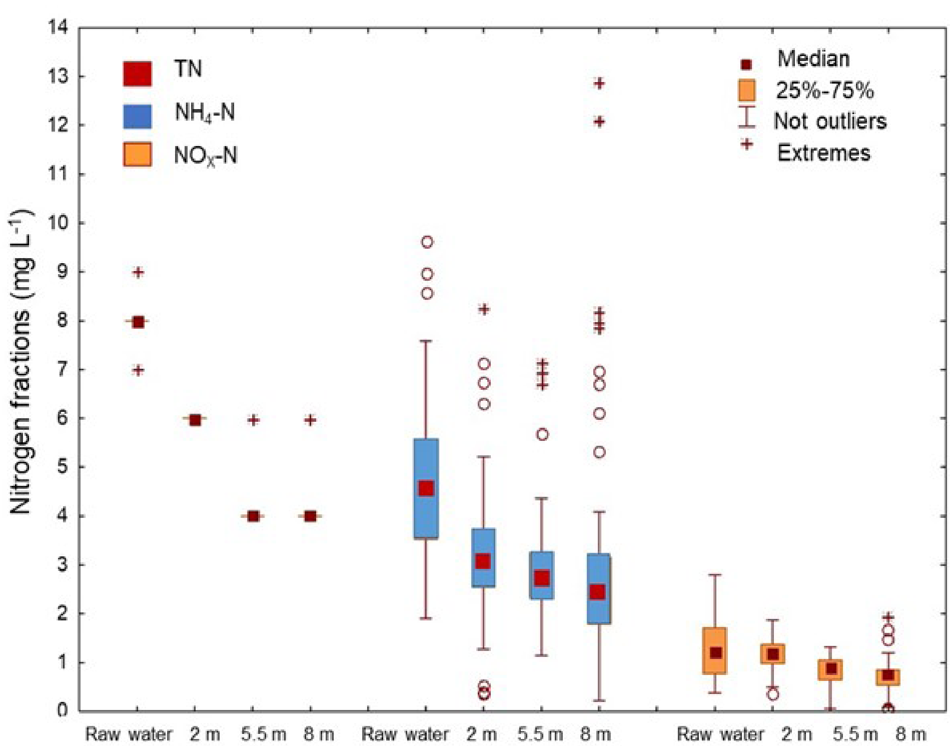

Figure 7 Nitrogen fractions along the filtration distance of the inverse margin filtration system.

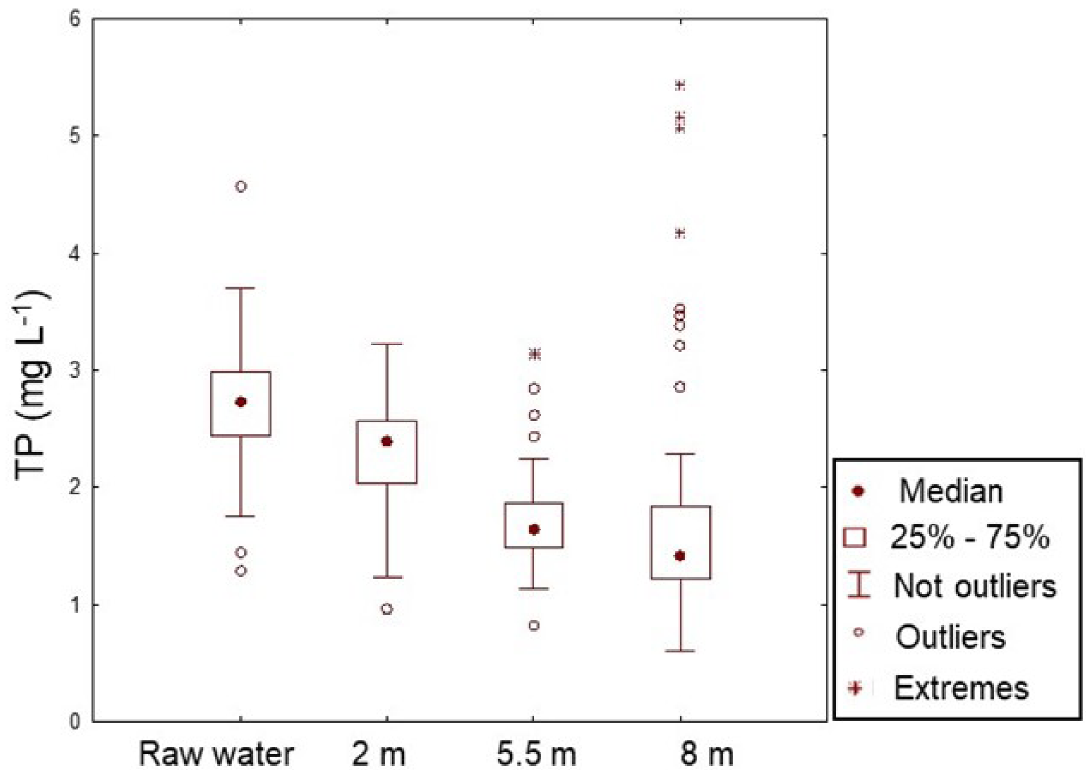

Figure 8 Total phosphorus concentrations identified over different filtration distances in the inverse margin filtration system.

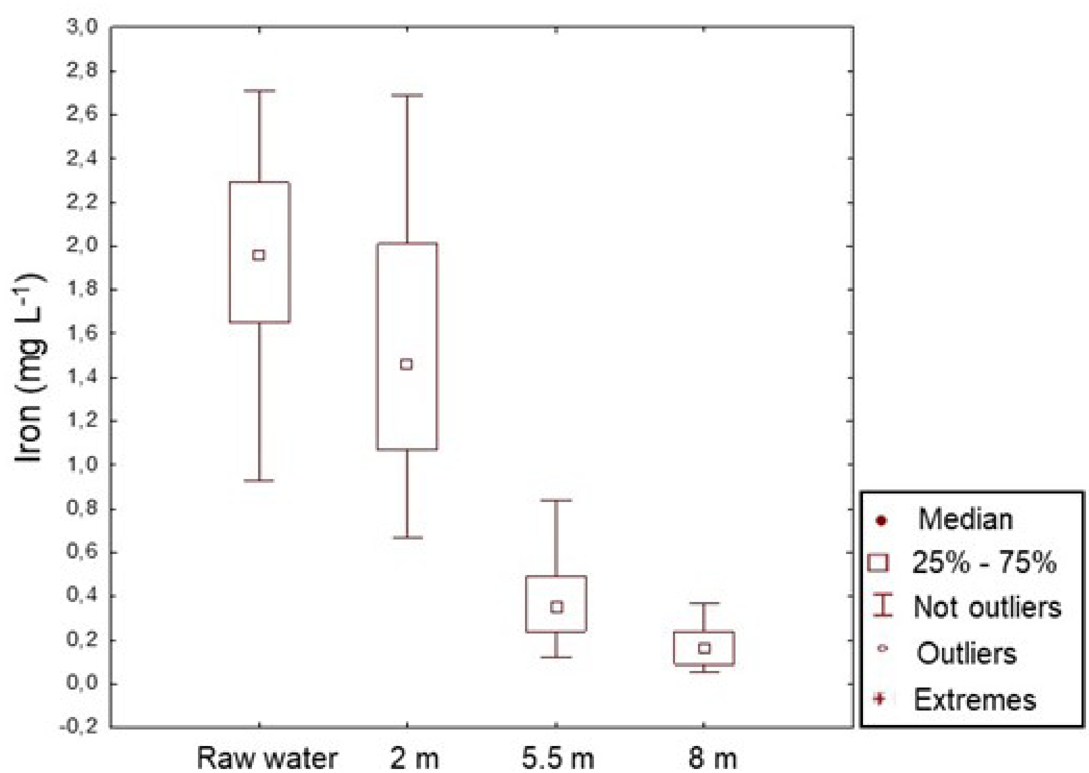

Figure 9 Iron concentrations identified over different filtration distances in the inverse margin filtration system.

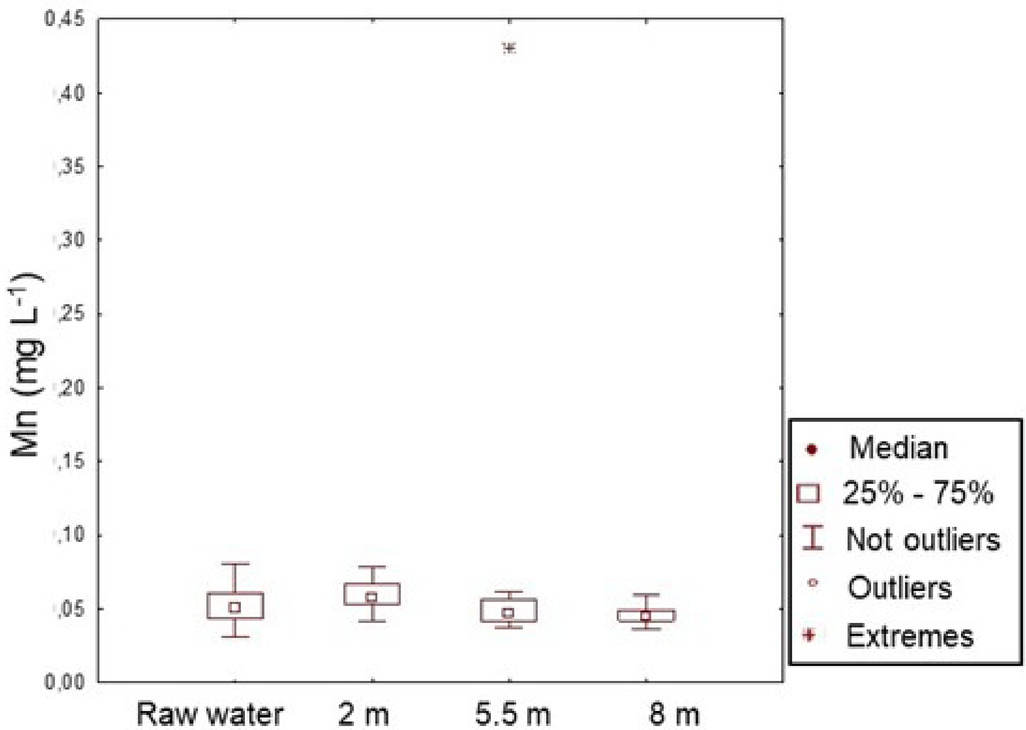

Figure 10 Manganese concentrations identified over different filtration distances in the inverse margin filtration system.

However, they can be inhibited by the formation of by-products of organic matter (Bourg *et al*., 2002).

In relation to Mn, removal efficiency was identified only at 8 m of filtration distance (Figure 10). Even so, the removal efficiency was only 8 ± 25%. This behavior showed the influence of the oxidizing conditions of the medium. The Mn can also be used as an electron acceptor for microbial activity during the process of removing carbonaceous organic matter. However, for this to occur, anoxic and / or anaerobic conditions must prevail in the environment. The more reducing the environment, the greater the efficiency of Mn removal (Bourg *et al.,* 2002).

Another factor that corroborates the low Mn removal in the IMF system is that there may be an increase in the Mn concentrations in the treated water. This fact is associated with the presence of low DO concentrations, which causes the process of releasing this element in water (Kuehn and Muller, 2000).

Table 4 show average values of concentration identified in the treated water for IMF system along with the classifications according to the Brazilian legislation (CONAMA RESOLUTION 357/2005). the treatment performance of the IMF system, provided a treatment level for lake water compatible with Class 3 of Conama Resolution 357/2005. This same behavior was just not identified for TP, indicating the need for additional treatment, especially when trying to avoid eutrophication.

Table 4 Concentrations of pollutants identified in the water treated by the inverse margin filtration system together with the reference values of CONAMA Resolution 357/2005.

Parameters	Treated water	Conama 357/2005 Class III
True color (uH)	23.07	75
Turbidity (NTU)	12.44	100
pH	6.25	6.0
TSS (mg.L^{-1})	118.11	500
DO (mg.L^{-1})	1.55	4.0
NH_4-N (mg.L^{-1})	3.11	13.3
NO_3-N (mg.L^{-1})	0.73	10.0
NO_2-N (mg.L^{-1})	0.05	1.0
TP (mg.L^{-1})	1.82	0.05
I (mg.L^{-1})	0.18	5.0
Mn (mg.L^{-1})	0.05	0.5

4 Conclusion

Based on the monitoring over a year of operation of an IMF system, used for the treatment of surface water, taking into account the distance of the filtration, it is concluded:

The IMF system showed a significant improvement in the quality of the lake water, presenting average removal efficiencies in the order of 41% for turbidity, 26% for TSS and TOC, 53% for TN, 46% for TP and 100% for FC;

The distance of the filtration path, and consequently, the time of contact of the water with the soil directly influenced the treatment performance of the IMF system. The removal efficiency of all evaluated parameters increased significantly after 2 m of filtration. Thus, the filtration distance from to 5.5 m was fundamental in the treatment process. In this sense, a minimum filtration distance of 5.5 m is indicated;

The IMF system proved to be a technology that can be applied in the treatment of water in lentic environments, significantly improving the quality of the water body, giving a final quality to treated water compatible with Class 3 of Conama Resolution 357/2005.

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