Adaptation of urban drainage system with infiltration trench for the removal of metallic ions

Adaptation du système de drainage urbain par infiltration pours l'élimination des ions métalliques

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RÉSUMÉ

Ce résumé décrit la pertinence d'une tranchée d'infiltration pour améliorer l'infiltration et la rétention des répondant ainsi aux défis courants des régions côtières : la faible profondeur des nappes phréatiques et les taux d'infiltration élevés. L'ancien fossé recevait des eaux de ruissellement contenant des ions métalliques, constituant un point d'injection de polluants dans le sous-sol. La conception du nouvel ouvrage comprend la fermeture complète du fossé, la mise en place d'un tuyau perforé pour le drainage et l'insertion d'une couverture de chitine (biosorbant) commerciale. Après la modification du fossé, des échantillons d'eaux de ruissellement, d'eaux souterraines, d'eaux ayant percolé à travers la couverture de chitine et de sol ont été prélevés afin de déterminer la concentration des métaux (Cr, Pb, Ni, Cu, Zn, Fe et Mn). Cette étude présentera des informations concernant les métaux présents dans les eaux de ruissellement de surface et les effluents de filtration. Les analyses et les procédures méthodologiques ont suivi le manuel de l'APHA (2012). Les résultats obtenus concernant l'élimination des métaux étaient excellents pour le Cr, le Pb, le Cu, le Zn et le Fe, améliorant ainsi la qualité des eaux de ruissellement atteignant la nappe phréatique. Cependant, les modifications apportées à la structure modifiée ont entraîné la rétention de matières solides et une réduction du volume de sol infiltré dans le sous-sol.

ABSTRACT

This abstract describes the adaptation of an infiltration swale to improve the infiltration and retention of metals, addressing common challenges in coastal regions characterised by shallow aquifers and high infiltration rates. The former infiltration swale received surface runoff containing metallic ions, thereby becoming a point source for the injection of pollutants into the subsoil. The design of the new structure includes the complete sealing of the swale, the installation of a perforated drainage tube, and the insertion of a commercial chitin (biosorbent) bedding. Following the modification of the swale, samples of surface runoff, groundwater, water percolated through the chitin bedding, and soil were collected to determine the concentrations of metals (Cr, Pb, Ni, Cu, Zn, Fe, and Mn). This paper presents information on the metals present in surface runoff and filtrated flow. The analyses and methodological procedures followed the APHA manual (2012). The results obtained for metal removal were excellent for Cr, Pb, Cu, Zn, and Fe, improving the quality of the runoff reaching the aquifer. However, the modifications to the structure led to the retention of solids and a reduction in the volume of soil infiltrated into the subsoil.

KEYWORDS

Biosorbents, chitin Commercial, infiltration swale, removal of metallic ions, surface runoff quality

1 INTRODUCTION

Aquifers located in coastal regions may exhibit greater vulnerability or sensitivity to human and/or natural impacts. Vulnerability can be characterised as intrinsic, depending on hydrogeological factors (such as the characteristics of the aquifer, soil, and geological materials), or specific, resulting from the potential impacts of particular land uses and contaminants (Ndifreke, Nyakno and Aniekan, 2024). The rate of groundwater contamination can be higher when an aquifer has shallow water levels, thin soil cover, and a high infiltration rate (Caprario et al., 2019a). There are several potentially polluting sources of groundwater, with pollutants originating mainly from urban, rural, and mining areas (Stagge et al., 2012; Braga, 2017). Among the pathways through which surface pollutants come into contact with the subsurface environment, the infiltration of surface runoff is notable. Each year, drainage techniques that promote the infiltration and retention of surface runoff are investigated in order to mitigate the effects of urbanisation and to restore or maintain the hydrological cycle in urban environments. Alternative or compensatory drainage techniques are practical and can be applied in commercial, residential, and industrial areas (Fletcher et al., 2014). However, some infiltration-structure models may pose a risk of pollutant loads reaching the aquifer via stormwater runoff. In this context, IMPs (Integrated Management Practices) have emerged—these are infiltration techniques associated with the use of vegetation, commonly referred to as bioretention.

In addition to the use of bioretention in infiltration techniques, natural biosorbents have high potential for retaining pollutants present in surface runoff (Rech et al., 2019). Biosorbents or residual/agro-industrial biomass are promising, low-cost, and have the potential to remove organic and inorganic pollutants from different polluting sources. Applying biosorbents in infiltration structures promotes integration between proper waste management and water pollution control, especially in locations where the structures are located in critical zones that require higher levels of water treatment. Considering this scenario, Rech et al. (2019) tested in the laboratory the efficiency of fresh shrimp shells for removing metals present in surface runoff, obtaining satisfactory results for the removal of Fe, Mn, Zn, and Cr ions. However, the biosorbent showed inefficiency in removing Pb, Ni, and Cu, indicating contamination of the shells in their natural state. Tests with commercial chitin showed well metal removal in laboratory batch test to all the aforementioned ions.

Therefore, this study explores the renovation of a compensatory infiltration technique that forms part of an urban drainage system in a region subject to environmental restrictions. The site is located in a coastal area characterised by a shallow, sandy, and highly infiltrating aquifer, where the removal of surface runoff pollutants is essential. The former structure, an infiltration swale, received surface runoff containing metallic ions, thereby becoming a point source of pollutant injection into the subsurface environment. Monitoring of the aquifer confirmed the presence of metal ions. The structure (Figure 01) had been in operation for more than 30 years, fulfilling its original purpose; however, modifications were required to prevent the percolation of pollutants into the soil and aquifer. The open swale was subsequently converted into a percolation drain, incorporating a chitin (biosorbent) bedding placed beneath the infiltration drains, enabling the removal of metallic ions. This structural modification provided a real-scale opportunity to evaluate the use of biosorbents in infiltration systems. The use of biosorbents may represent a viable alternative for addressing the environmental challenges faced in this region.

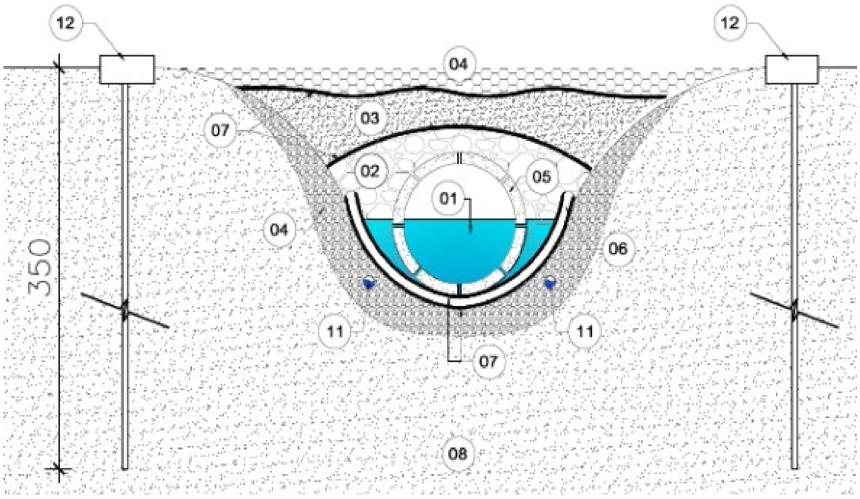
2 MATERIALS AND METHODS

2.1 Infiltration Swale

Hydrological monitoring of the infiltration swale, carried out by the Urban Stormwater and Compensatory Techniques Laboratory (Lautec) at the Federal University of Santa Catarina (UFSC), was conducted from 2014 to 2019. After detecting elevated concentrations of metals in surface runoff, soil, and groundwater, structural modifications to the infiltration swale were proposed so that it would continue to function as an infiltration system while reducing the metal load. The region in which the swale is located is a coastal plain that accumulates large volumes of water and is surrounded by hills that accelerate initial runoff (Caprario et al., 2019b). During high tides, drainage becomes more difficult. An additional aggravating factor is the presence of an unconfined aquifer (the Campeche Aquifer). This area also contains an intermittent drainage system and numerous active infiltration structures, all of which require evaluation to ensure their proper functioning.

The swale modification project (Figure 2) consisted of inserting a perforated concrete tube like a drain above a chitin biosorbent bedding surrounded by stone gravel. The bedding is composed of a two-sided geotextile fabric filled up with commercial chitin with flakes of 0.1 to 2 mm and a thickness of 3 to 5 cm. To allow the monitoring of the percolated water from the chitin bedding, two perforated drainage tubes were positioned to collect the filtered runoff (diameter 0.04m). The chitin bedding was installed along the length of the swale (approximately 10 m), in inspection boxes (0.8 m²), with a width at the bottom (1 m) and sides (0.50 m high). Ten kilograms of commercial chitin (Polymar, CE) were used to fulfil the bedding. The drained water was referred to in this research as filtered runoff collected in the inspection boxes. The constructed inspection boxes were 1 m deep, 0.80 m wide, and 1 m long. The execution phase of the modified swale project occurred in two days, involving 3 people for installation and construction activities, and 4 hours of machinery for relocating the drainage tubes within the structure. Figures 1 and 2 illustrate the project and construction process.

Figure 1 (a) Infiltration swale before modification, (b) Modification and construction of a drainage bedding made with chitin, (c) Modified swale in final stages of completion, and (d) Modified swale completed and sidewalk paving finished.



01 – Surface runoff
02 – Grain rock
03 – Sand
04 – Crushed stone
05 – Perforated concrete tube
06 – Chitin composite mattress
07 – Geotextile bedding
08 – Soil
09 – Concrete box
10 – Inspection box
11 – Polyethylene Vinyl Pipe (PVC)
12 – Groundwater monitoring wells

Figure 2 Swale modification project.

After the swale modification was completed, monitoring involved collecting samples of surface runoff, groundwater, water percolated through the chitin bedding, and soil to determine the concentration of metals (Cr, Pb, Ni, Cu, Zn, Fe, and Mn). The analyses and methodological procedures used the APHA manual (2012).

3 RESULTS AND DISCUSSION

The results demonstrate that the new structure allowed infiltration of 15.7% to 28.4% of the volume passing through the structure (table 1).

Table 1 Comparison of similar events from the original and modified swale.

Original swale			Modified swale			
Date	Prec. (mm)	% Infiltration	Date	Prec. (mm)	% Infiltration	Difference (%)
04/08/2015	10.40	39.00	20/05/2018	12.00	28.40	10.60
12/08/2015	16.00	75.00	05/06/2018	15.00	21.03	53.70
07/01/2016	19.80	34.00	19/05/2018	21.27	27.00	41.00
09/03/2015	97.60	14.00	25/07/2018	95.02	15.70	-1.70

The highest infiltration rates were recorded in May, with the smallest event lasting 6 hours (12 mm of precipitation and 28% infiltration). The infiltrated volume in 2015 and 2016 reached up to 78% of the runoff volume, whereas the infiltrated volume in the modified structure did not exceed 28.40%. It should be noted that each event occurring within the infiltration structure exhibits distinct hydraulic behaviour, influenced by soil saturation capacity and the accumulation of material at the base of the system. The new design demonstrated a reduced infiltration capacity during more intense rainfall events when compared with the previous swale.

Table 2, shows two sampling methods, allowing for comparison of metal concentrations in surface runoff and filtered runoff. Removal of metal concentrations in the percolated water from the chitin bedding showed values that varied from 50% until 96%. Only one sample for Pb presented 20%. Results were very promising.

Table 2 Removal of metals from surface runoff and filtration.

Metal (mg/L)	04.14.2018		% Removal	06.05.2018		% Removal
	Surface runoff	Filtered runoff		Surface runoff	Filtered runoff	
Cr	0.008	0.001	87.50	0.001	0.001	0.00
Pb	0.023	0.003	86.95	0.200	0.008	96.00
Ni	0,010	0.005	50.00	0.005	0.004	20.00
Cu	0.002	0.001	50.00	0.008	0.001	87.50
Zn	0.026	0.008	69.23	0.030	0.010	66.66
Fe	0.440	0.033	92.50	0.130	0.001	92.30
Mn	0.023	0.003	86.95	0.000	0.000	0.00

4 CONCLUSION

The proposed structural adaptation of an infiltration swale using biosorbent showed satisfactory results for infiltration and retention of pollutants present in surface runoff. According to the analysed events, the modified swale allowed infiltration from 15.7% to 28.4%, while the old structure allowed infiltration of up to 80% (Rech et al. 2022). When comparing events with similar rainfall between the original swale and the modified swale, there was a difference of 10.6% to 53.7% in the loss of infiltration capacity. In heavy rainfall events, both structures showed a low infiltration rate, acting as a passage channel. Despite the reduction in infiltration capacity, with the installation of the commercial chitin bedding, it was possible to retain the pollutants found in the surface runoff. There was metal retention from 50% to 96%of the quantity of each species present in the runoff.

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