Performance of vegetated infiltration swales for treatment of zinc roof runoff

Performance des fossés d'infiltration engazonné pour le traitement des eaux de ruissellement provenant de toitures en zinc

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RÉSUMÉ

Les noues d'infiltration engazonné peuvent constituer une alternative durable et attrayante pour le traitement des eaux de ruissellement fortement polluées provenant des toits en zinc. Le but de cette étude était d'évaluer les risques de contamination des sols et des eaux souterraines par ces eaux de ruissellement. La distribution horizontale et verticale de la teneur en zinc a été étudiée dans quatre noues d'infiltration engazonné servant au traitement des eaux de ruissellement d'un toit en zinc. Des teneurs allant jusqu'à 27,9 g de zinc par kg de sol ont été mesurées uniquement dans les zones d'entrée de chaque fossé d'inflitration. La quantité de Zn retenue a été comparée à la quantité totale ruisselée à partir du toit afin d'évaluer l'efficacité du Systèmes de Drainage Urbain Durable (SDUD) à l'aide d'un bilan de matière. La conclusion principale est que les fossés d'infiltration sont souvent mal conçus et qu'une distribution inégale des eaux de ruissellement à leur surface conduit à des zones fortement concentrées. L'épaisseur de la couche superficielle du sol étant souvent trop faible, cela peut conduire à une contamination en zinc des eaux souterraines par percolation des eaux de pluie insuffisamment traitées. Pour protéger les eaux souterraines, il est donc important de procéder à un entretien régulier des fossés, de contrôler leurs performances hydrauliques, et de remplacer régulièrement les sols en surface dans les zones hautement contaminées.

ABSTRACT

Vegetated infiltration swales as an example of decentralized Sustainable Urban Drainage Systems (SUDS) can offer a viable and attractive alternative to treat highly polluted stormwater runoff of zinc roofs. The aim of this study was to assess the risks of soil and groundwater contamination, which can be caused by this application. The horizontal and vertical distribution of zinc content in four vegetated infiltration swales treating runoff of a zinc roof was analyzed and evaluated. Up to 27.9 g zinc (Zn) per kg soil have been measured only for spatially limited areas at the inflow zones of each infiltration swale. In addition, the retained Zn mass was compared with the total roof runoff load to determine the efficiency of the SUDS by a mass balance. The principal conclusion is that infiltration swales are often built incorrectly, and that uneven distribution of the runoff on the swale surface leads to heavily loaded zones. Further, the topsoil layer depths are often too shallow, therefore rainwater with high concentrations of Zn can percolate into the groundwater without sufficient treatment. Consequently, it is important to undertake regular maintenance and to monitor the hydraulic performance of the swales to protect the groundwater. In addition, topsoil in highly contaminated zones needs to be replaced regularly.

KEYWORDS

Infiltration swale; groundwater protection; sustainable urban drainage systems; zinc roof runoff; heavy metals

1 INTRODUCTION

Vegetated infiltration swales as an example of decentralized Sustainable Urban Drainage Systems (SUDS) mitigate contaminants emission to groundwater as they are used as treatment systems for contaminated stormwater runoff [Dierkes et al., 2015]. In Germany the thickness of the topsoil of such swales must be 20–30 cm for the effective treatment of metal roof runoff [DWA-A 138 E, 2005]. The increasing usage of vegetated infiltration swales raises concerns about the content and fate of contaminants within these devices and their potential threat to groundwater quality. In addition, the potential needs for topsoil maintenance or remediation to ensure a proper and sustainable functioning are not clearly identified [Tedoldi et al., 2016].

The aim of this study was the evaluation of four 15 year old vegetated infiltration swales treating the runoff of a square, symmetrical zinc (Zn) roof with four similar areas and inclinations but different orientations. In particular, the horizontal and vertical distribution of Zn at each swale was analyzed. Finally, the retained Zn mass was compared with the total roof runoff load to determine the efficiency of the swales and the risk of groundwater contamination by a mass balance.

2 MATERIAL AND METHODS

2.1 Sampling site and sampling process

The 25 year old roof consisting of titanium Zn (1,037 m^2) which discharges its runoff symmetrically into four vegetated infiltration swales is located at Campus Garching of the Technical University of Munich, Germany. Since the four infiltration swales were installed about 10 years later than the roof itself, a stable roof patina had already been formed with an estimated Zn runoff rate of 3.7 g/(m^2·yr) at the point of the swales' installation [Schriewer et al., 2008]. Each quarter (259 m^2) of the roof area is drained to a separate downspout and onto a round stone plate of 2 m diameter at each of the four infiltration swales. The areas of the swales varies from 76 m^2 to 124 m^2 (North East (NE): 109 m^2, North West (NW): 124 m^2, South East (SE): 80 m^2, South West (SW): 76 m^2). The swales were not maintained during the last 15 years, except for lawn mowing. The mean annual precipitation at the sampling site is 745 mm with the highest precipitation in summer and the main wind direction is West.

A stainless steel soil sampler with 1.8 cm diameter was used to take topsoil samples of the vegetated infiltration swales in different depths in steps of 5 cm depending on the thickness of the topsoil layer as well as at different distances from the point of inflow distribution. For each swale, the samples were taken in a radiating pattern with increasing distances from the rim of the round stone plate outlets.

2.2 Chemical and data analyses

The samples were dried at 60°C ±1 °C until their weight was constant. The dried samples were homogenized using a ball mill. After an *aqua regia* digestion of the samples, the total amount of Zn was determined by flame atomic absorption spectrometry (Varian Spectrometer AA-240FS) according to Standard Methods No. 3111 and No. 3113, respectively [Baird et al., 2017]. To illustrate the spatial distribution of Zn in the topsoil layer, contour plots were created using OriginPro 2017. For mass balance, the area from each contour line was multiplied with 5 cm depth and a soil bulk density of 0.83 g/cm^3. For box and whisker plots, the bottom and top of each box are the first and third quartiles and the band inside the box is the median. The whiskers represent 1.5 times the interquartile range (IQR). Outliers (>1.5 times IQR) are marked as small crosses.

3 RESULTS AND DISCUSSION

Table 1 presents a summary of the measured topsoil Zn contents. The low median values indicate that several areas of the infiltration swales have a low hydraulic loading. Therefore, the spatial horizontal and vertical distribution of the Zn contents of each infiltration swale varies considerably.

Table 1. Median, Mean, Min, Max, and n of the measured Zn contents for the four infiltration swales

Parameter		NE	NW	SE	SW
Zn [g/kg dry mass]	**Median**	0.094	0.179	0.598	0.378
	Mean	2.25	2.03	2.92	3.63
	Min	< 0.060	< 0.060	0.065	<0.060
	Max	20.1	25.0	27.4	27.9
	n	64	68	74	63

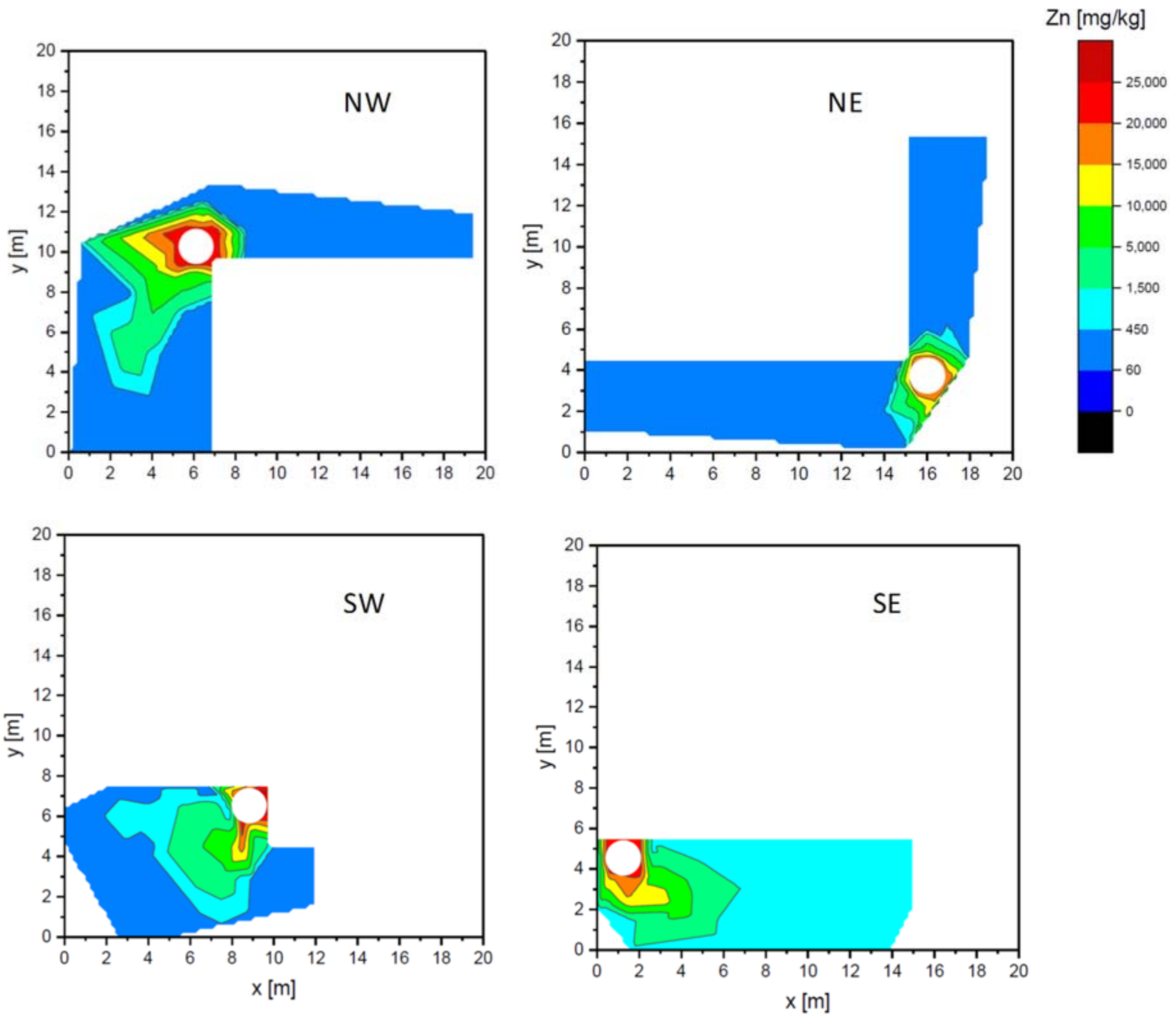

Figure 1. Horizontal and vertical distribution of Zn in the soil of the different infiltration swales in the layer 0-5 cm.

The highest Zn content (maximum values) can be found in all swales in the top layers (0-5 cm) and directly at the inflow points. The Zn concentration decreases rapidly from the inside to the outside of the swale. The horizontal distributions within the various swales were found to be different. At the NW site, the runoff can spread over the surface in one direction because the inlet area is relatively flat, whereas the inflow area at the NE site is extremely low directly at the plate and rises steeply in all directions. Moreover, the SE swale is flatter compared to all other swales, which is also evident in the Zn distribution over the complete topsoil layers.

With an estimated annual average runoff rate of 3.7 g Zn/(m^2·yr) [Schriewer et al., 2008] and a total roof area of 1,037 m^2 theoretically 57.5 kg of Zn was washed off the roof within the last 15 years. The calculation of all Zn contents of the various layers and the mass of the layers results in 35.5 kg Zn retained by all four swales, which is 22.0 kg less than the assumed total mass of Zn wash-off. The difference of Zn retention in the different swales is significant. One reason that the NW swale is the most heavily loaded (15.4 kg Zn) may be due to the roof facing into the prevailing wind and weather direction.

4 CONCLUSION

The study shows that the horizontal distribution of zinc in the soil of vegetated infiltration swales treating zinc roof runoff varies significantly due to unevenness of the surface. In some swales there was a preferential flow direction, in others, the water remained in the inflow zone. The Zn content decreases vertically in the topsoil layer. There was no regular inspection and maintenance of the topsoil layer. As a result, it can be assumed that Zn has already been discharged into the groundwater for some time.

Regular inspection and maintenance is recommended. If contaminated zones are identified, only these hot-spot areas should be exchanged to minimize the amount of waste. Thus, a better protection of the groundwater is achievable.

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