Quantifying the performance of a SUDS treatment train. A case-study of San Cristobal Park, Bogotá (Colombia).

Quantification de la performance d'un enchainement de techniques alternatives. Étude de cas du parc San Cristobal, Bogotá (Colombie).

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RÉSUMÉ

L'augmentation rapide du nombre de zones urbanisées a entraîné une augmentation de la fréquence des inondations et une dégradation des masses d'eau réceptrices du fait des modifications du cycle hydrologique naturel. De plus, la gestion conventionnelle des eaux urbaines s'est concentrée sur l'évacuation des eaux de ruissellement le plus rapidement possible, ce qui accentue les effets négatifs du processus d'urbanisation. Pour prévenir et atténuer ces effets, les systèmes de drainage urbain durable (SUDS) constituent une approche alternative et globale de la gestion du ruissellement urbain. Néanmoins, le manque d'informations sur les performances de SUDS constitue un obstacle important à sa mise en œuvre. Cet article présente les performances hydrologiques et en matière de qualité de l'eau d'un train de traitement de type SUDS, composé d'un houle gazonnée et d'un bassin de rétention sec et prolongé. L'étude de cas est décrite avec un an et demi de données de surveillance. Les résultats ont montré un volume de ruissellement moyen et une réduction du débit de pointe de 55% et 75% respectivement. En outre, en analysant les échantillons de ruissellement recueillis à l'entrée et à la sortie du train de traitement, les résultats ont démontré la capacité du train de traitement SUDS à atténuer la pollution.

ABSTRACT

The rapid increase of urbanized areas has risen flooding events frequency and caused the degradation of the receiving water bodies due to changes in the natural hydrological cycle. Moreover, conventional urban water management has focused in evacuating the runoff as fast as possible, which increases the negative effects of the urbanization process. To prevent and mitigate these effects, Sustainable Urban Drainage Systems (SUDS) are an alternative and holistic approach for urban runoff management. Nevertheless, the lack of information regarding SUDS performance represents an important barrier for its implementation. In this article, the hydrological and water quality performance of a SUDS treatment train, composed of a grassed swale and a dry extended detention basin, is presented. The case study is described along with one year of monitoring data. The results showed an average runoff volume and a peak flow reduction of 55% and 75% respectively. Besides, by analysing the runoff samples collected at the entrance and exit of the treatment train, the results have demonstrated the capacity of the SUDS treatment train for pollution mitigation.

KEYWORDS

Dry extended detention basin, Grassed Swale, Monitoring, Performance, San Cristobal Park (Colombia), SUDS treatment train.

1 INTRODUCTION

The accelerated population growth in urban areas is becoming increasingly unsustainable, especially in those cities that do not have strong urban planning mechanisms and effective expansion control programs. Urbanization processes have generated the waterproofing of natural soil cover thus increasing the amount of runoff generated in the basin. This has affected the receiving water bodies' quality and overload the drainage systems, leading to more frequent flooding in different urban areas. To solve this problem the stormwater storage and conveyance capacity of the conventional urban drainage systems can be increased. However, problems related to runoff management are still producing significant economic losses and water quality deterioration of receiving water bodies.

The Sustainable Urban Drainage Systems (SUDS) offer alternative structures for urban runoff management and work as a complement of conventional systems (Fryd et al., 2012). These systems include a wide range of typologies, which promote water detention, retention, infiltration and evapotranspiration at different scales. This holistic approach, in addition to managing stormwater volumes and flow peaks, has the potential to improve water quality, and contributes to increase the healthier and liveable cities goal (Woods-Ballard et al., 2007). Nevertheless, the limited evidence on the performance of these systems represents an important barrier to their implementation (Perales-Momparler et al., 2016).

2 MATERIALS AND METHODS

2.1 Site description

By identifying critical areas of the city (considering runoff management, water quality improvements, amenity, urban restoration and re-naturalization/preservation of natural values) and, in order to evaluate the SUDS performance, the San Cristobal Metropolitan Park in Bogotá was chosen as one of the most suitable locations for the construction of a first full-scale pilot of SUDS in public space. The area surrounding the park primarily has a residential use. In early 2017, a SUDS treatment train was constructed for treating the runoff that is generated inside the upper area of the park and on the roads to the east side. This train is composed by a grassed swale (with a drainage area of 1.48 Ha, surface width of 2.80 m and length of 70 m), which treats and transports the volume of captured runoff to a dry extended detention basin (with a drainage area of 1.56 Ha, surface width of 16.33 m and length of 49 m). This last typology temporarily stores and treats the runoff volume and drains it across the soil layers (through infiltration) and throughout an outlet drainage system downstream the structure.

2.2 Monitoring of water quantity variables

The purpose of the water quantity monitoring was to evaluate the reduction capacity of both runoff volumes and peak flows. Tipping bucket rain gauges were used to measure rainfall. In addition, electronic water level sensors were used along with a weir control installed both at the entrance and at the exit of the system.

2.3 Monitoring of water quality variables

For the water quality monitoring three sites were selected for taking water samples in order to estimate event mean concentrations (EMCs): (a) at the entrance of the treatment train, (b) at the exit of the grassed swale (sedimentation forebay of the extended basin) and (c) at the exit of the treatment train. Total Nitrogen (TN), Total Phosphorus (TP), Total Suspended Solids (TSS), Total Solids (TS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Organic Carbon (TOC), Metals (i.e. Aluminum, Chromium, Zinc, Lead, Cooper, Magnesium and Manganese), Total Coliforms, E.coli, Sulfates, Soluble Phosphorus, Phosphates, Ammonia, Total Kjeldahl Nitrogen (TKN) and Nitrates concentrations were determined according to the Standard Methods for the examination of water.

3 RESULTS

During the monitoring period (May 2017 to May 2018), 14 rainfall events were recorded and further analyzed. Table 1 summarizes the key variables of the monitored events. According to the rainfall distribution, 50% of the rainfall depths were lower than 5.92 mm and only 3% exceed 10 mm. The rainfall duration varied from 1.85 to 6.63 hours, with maximal intensities from 6.5 to 60 mm/h. Moreover, the previous dry period, which influences the system's hydrological performance, fluctuated between 6.01 and 124.77 hours.

Table 1. Rainfall events characteristics

	Antecedent dry period (h)	Duration (h)	Rainfall depth (mm)	Max. 1-min intensity (mm/h)
Mean	32.57	1.85	5.92	21.09
Max.	124.77	6.63	15.60	60.00
Min.	6.01	0.1	0.60	6.50

The peak flow and the runoff volume reductions in each monitored precipitation event are presented in Table 2. In general, events with the lowest maximum intensity per minute were those with the greatest percentage flow peak attenuation. Besides, in events of greater magnitude (rainfall depth exceeding 9 mm), the volume draining to the sewer network downstream significantly reduced with volumetric efficiencies always greater than 39%. The volumetric efficiencies of some low magnitude events were affected by the antecedent dry period. For example, events 6, 9 and 11 had very similar rainfall depths: 4.70, 4.80 y 4.40 mm, respectively. However, event 11 produced larger overflow discharge where the antecedent dry period was 7.97 hours, whereas for events 6 and 9 the previous dry hours were 19.3 and 19.2, respectively.

Table 2. Water quantity results

Event	Date	Event rainfall depth (mm)	Volume reduction (%)	Peak flow reduction (%)
1	08/05/2017	0.6	100.0	100.0
2	12/05/2017	2.4	54.0	82.0
3	15/05/2017	5.4	Not measured	80.0
4	17/05/2017	1.8	10.0	69.0
5	08/06/2017	10.6	Not measured	94.0
6	09/11/2017	4.7	62.5	89.8
7	14/11/2017	15.6	60.8	69.5
8	23/11/2017	2.0	68.8	87.8
9	01/12/2017	4.8	58.3	83.3
10	09/12/2017	9.4	43.0	55.3
11	10/04/2018	4.4	-2.8	33.5
12	12/04/2018	6.8	67.7	71.8
13	13/04/2018	1.6	97.5	96.3
14	07/05/2018	12.8	39.5	37.7

Figure 1 compares the removal percentages in the SUDS treatment train for parameters that had the highest removal efficiencies (greater than 35% on average): Aluminum, TSS, Chromium, Total Solids, COD, Zinc, Lead and TP. Figure 2 presents parameters with positive reductions but that are below 35% on average (i.e. TOC, Sulphates, Copper, Magnesium, Ecoli, BOD, Nitrates, Nitrites, TN). Finally, Figure 3 summarizes those parameters whose output concentrations were higher at the exit than at the entrance (Total Coliforms, Soluble Phosphorus, Phosphates, Manganese and Ammonia). It can be identified a high variability in pollutant removals and, in some events, negative removal percentages are presented. The largest removals were carried out by the grassed swale instead of the dry extended detention basin. The phosphates in most events showed concentration increases at the exit possibly due to the presence of fertilizers in the park soil. In addition, it was detected that, in the majority of monitored events, the Total Coliform concentrations were greater at the SUDS treatment train's exit with a percentage of 74.18, probably due to the presence of pet waste inside the treatment train.

The relationship between the removal efficiencies of the water quality parameters and the rainfall event characteristics was estimated, giving as a result that the percentage removal of BOD increases with intensity, duration and precipitation depth increases, having correlation coefficients of 0.97, 0.83 and 0.79 respectively. In the case of COD occurs the same but the correlation coefficients found to be smaller. The TSS removals presented less evident changes regarding the characteristics of the evaluated events. The correlation coefficients indicate that the TSS removal efficiencies increase with event intensity and previous dry period (i.e. 0.43 and 0.42 respectively). In relation to TP, NTK and TN the association between the removal efficiencies and the intensity of the events is relevant, with correlation coefficients of 0.69, 0.49 and 0.56, respectively.

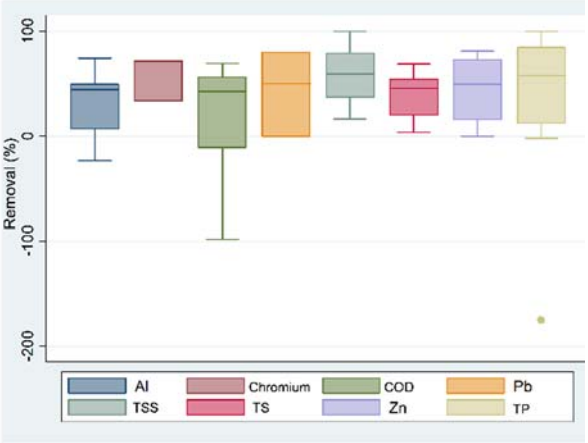

Figure 1. Boxplot of parameters with high percentage removals

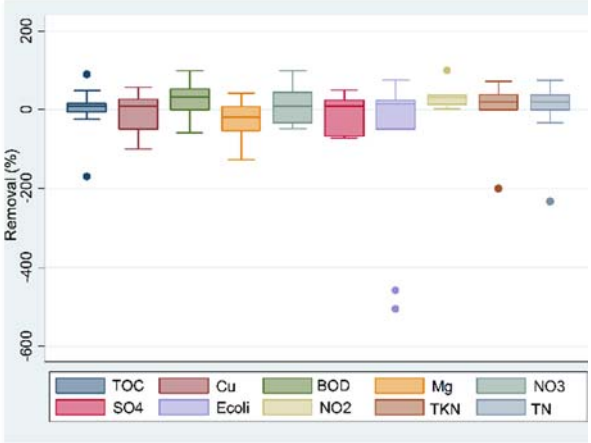

Figure 2. Boxplot of parameters with moderate percentage removals

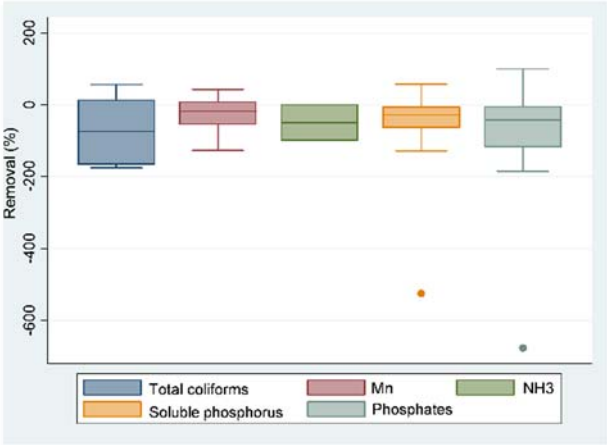

Figure 3. Boxplot of parameters with low percentage removals

4 CONCLUSIONS

All the monitored events presented peak flow reductions higher than 33.5% and, except for the event 11, volume reductions were higher than 10%. Pollutant concentration reductions in the SUDS treatment train were observed. The largest peak flow and volume reductions occur in the dry extended detention basin and the largest pollutant removals were carried out by the grassed swale. However, there are internal processes that can lead to exit concentrations increases of some pollutants (e.g. Total Coliforms). It was also evidenced that removals were greater for particulate pollutants compared with the dissolved pollutants. Further monitoring is being carried out to better understand the SUDS treatment train performance.

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