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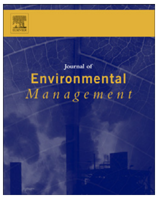

Research article

Urban rainwater runoff quantity and quality – A potential endogenous resource in cities?

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ABSTRACT

Rainwater harvesting might help to achieve self-sufficiency, but it must comply with health standards. We studied the runoff quantity and quality harvested from seven urban surfaces in a university campus in Barcelona according to their use (pedestrian or motorized mobility) and materials (concrete, asphalt and slabs). An experimental rainwater harvesting system was used to collect the runoff resulting from a set of rainfall events. We estimated the runoff coefficient and initial abstraction of each surface and analyzed the physicochemical and microbiological properties, and hydrocarbon and metal content of the samples. Rainfall intensity, surface material and state of conservation were essential parameters. Because of low rainfall intensity and surface degradation, the runoff coefficient was variable, with a minimum of 0.41. Concrete had the best quality, whereas weathering and particulate matter deposition led to worse quality in asphalt areas. Physicochemical runoff quality was outstanding when compared to superficial and underground water. Microorganisms were identified in the samples (>1 CFU/100 mL) and treatment is required to meet human consumption standards. Motorized traffic mostly affects the presence of metals such as zinc (31.7 μg/L). In the future, sustainable mobility patterns might result in improved rainwater quality standards.

1. Introduction

Water supply is a major challenge in terms of quantity and quality. Water management is a priority in cities, where population is expected to rise up to 70% by 2050 (UN, 2012) and water must be accessible without compromising sustainability. In addition, urban growth fosters artificial land covers and hinders stormwater infiltration. Worldwide, there are more than 500,000 km^2 of impervious surfaces (e.g., roads, streets, parking lots and sidewalks), being larger than the area of Spain (Elvidge et al., 2007). In this context, artificial urban areas can provide alternative water sources through rainwater harvesting systems, which might help to reduce the transport and treatment of drinking water and wastewater and to control floods (Fletcher et al., 2008; van Roon, 2007; Zhu et al., 2004).

However, stormwater quality has become of great interest for sanitary institutions and a barrier to rainwater harvesting systems, mainly motivated by the microbial presence in runoff (Adeniyi and Olabanji, 2005; Simmons et al., 2001). As a result, the end use of the runoff (e.g., street cleaning, irrigation, etc.) might vary depending on the stormwater quality and quantity, which can be related to the features of the harvesting site. So far, roof covers were the main surfaces assessed to deal with the potential rainwater provision to households or services (Adeniyi and Olabanji, 2005; Angrill et al., 2016; Belmeziti et al., 2013; Farreny et al., 2011; Huang et al., 2015; Meera and Mansoor Ahammed, 2006; Melidis et al., 2007), probably because of the implementation of rainwater harvesting

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systems at a building scale. Nevertheless, superficial runoff might be equally valuable to reduce potable water consumption (Antunes et al., 2016). Further, urban patterns are evolving towards more sustainable cities. As a result, rainwater quality might improve because of an increasing implementation of electric and pedestrian mobility and a reduced fossil fuel consumption. Hence, it is interesting to assess the quality and quantity of harvested rainwater in different types of cities and urban surfaces.

Regarding quantity, the rainwater harvesting potential of a surface can be estimated by multiplying the annual rainfall, the catchment area and the runoff coefficient (McCuen, 2004; Viessman and Lewis, 2003). The runoff coefficient is the amount of water that becomes runoff with respect to the total incident rainfall volume. The difference is lost because of leakages, surface material retention and evaporation (Singh, 1992). Therefore, the runoff coefficient can be used to determine the rainwater harvesting potential of a certain surface. So far, reported values for roads, streets and other urban areas range from 0.5 to 0.95 (Butler and Davies, 2000; Liaw and Tsai, 2004; Ragab et al., 2003). However, surface materials and local features might affect these results and specific analyses are needed.

In the case of quality, the most influential factors are the surface geometry and material, location and maintenance of the catchment area, climatic features and pollutant concentration (Abbasi and Abbasi, 2011). For instance, seasonality might affect the concentration of suspended solids in the runoff, especially in areas with snowy winters and melt period (Westerlund et al., 2003). Surface material and land use might play an important role in the case of paved urban areas. In this context, Drapper et al. (2000) found no significant correlation between the traffic volume and the pollutant concentrations in road runoff. In contrast, Apul et al. (2010) detected a significant contribution of the daily traffic to the concentrations of certain heavy metals. This might also depend on the frequency and intensity of rainfall events.

In this context, we studied different artificial urban areas to find out whether these are significantly different in terms of runoff quality and quantity. To this end, our goal was to evaluate the rainwater runoff quantity and quality in pedestrian and motorized areas and to determine their suitability as rainwater harvesting sites that meet quality standards. We based our assessment on an experimental case study in Barcelona (Spain) that is representative of the Mediterranean climate.

2. Materials and methods

2.1. Case study area

The campus of the Autonomous University of Barcelona (UAB), located in Cerdanyola del Vallès (Barcelona, Spain), was selected for the assessment. This area presents a semi-wet Mediterranean climate with an average annual rainfall and temperature of 514 mm and 15.5 °C, respectively (SMC, 2013). The campus is located in a green environment near Collserola hills and less than 1 km away from a motorway with dense traffic. The area includes different types of pedestrian and motorized public spaces, seven of which were selected for the quantity and quality surface analysis. Catchment areas were selected according to two criteria i.e., surface material and function. These seven surfaces were grouped into three functional types (Table 1) i.e., pedestrian areas, traffic roads and parking lots. At the same time, each functional type was divided into surface materials i.e., asphalt, concrete and precast concrete slabs (the latter only apply to pedestrian areas). The characteristics of each surface are shown in Supporting Information 1.

2.2. Experimental design

A rainwater harvesting conveyance and storage system was installed in each study surface. The storage tank was located at a lower elevation to obtain a gravity flow and avoid major civil works. The experimental design consisted of delimiting the catchment area and installing a gutter and downpipe that conducted water to one or two polypropylene tanks with a capacity of 1 m^3 (Fig. 1). This tank volume was selected considering the expected amount of water that might be collected during a rainfall event, which depends on the catchment area, runoff coefficient and maximum rainfall. A common membrane filter (1.5 mm pore diameter) was located at the entrance of the storage tank to prevent leaves and other large objects from entering the tank. No first flush diversion was installed and there was no maintenance of the catchment surface during the experimental period. However, pipes and gutters were frequently cleaned out of sand, leaves and other pollutants, and the storage tanks were rinsed with pressurized water twice a year. After collecting two homogenized unitary samples for the analysis, the storage tank and rainfall gauge were emptied and cleaned. We took samples at three different tank levels after agitation.

The experimental campaign took place from June 2011 to April 2013 (22 months). Throughout this period, we collected quantity and quality data for 25 different rainfall events. Local rainfall was monitored with a rain gauge set near each catchment surface. Rainfall events of less than 2.4 mm were excluded because of insufficient runoff.

2.3. Runoff quantity assessment

2.3.1. Data collection

A set of variables was needed to perform the quantitative assessment. Rainfall height was locally monitored using rain gauges and contrasted with the measurements of a nearby weather station located in Cerdanyola del Vallès. We gathered data on the amount of harvested runoff, duration of the event, minimum and maximum temperatures, predominant wind orientation and speed, and antecedent dry weather period (ADWP). Table 2 presents the number of valid events used in the calculations for each catchment surface and their main features. A maximum of 16 events could be assessed out of 25, as in these cases runoff was generated but did not exceed the tank capacity.

2.3.2. Estimation of the runoff coefficient

Equation (1) was the linear regression model considered to estimate the runoff coefficient, although more complex models could be studied using a larger set of variables. A p-value lower than 0.05 indicated a significant correlation.

$$\begin{aligned} \textit{Harvested runoff}\ (mm) = {} & \textit{Runoff coefficient}\left(mm^{-1}\right) \times \textit{Rainfall height}(mm) \\ & + \textit{Initial abstraction}\ (mm),\ \forall \textit{rainfall height} > \textit{initial abstraction} \geq 0 \end{aligned} \tag{1}$$