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Research article

Improving stormwater quality at source using catch basin inserts

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ABSTRACT

Stormwater runoff transports contaminants, including gross pollutants (GPs) accumulated on surfaces to nearby receiving water bodies. These may clog storm drainage systems, seal side entry pits and increase dissolved pollutants in receiving water bodies. Best management practices (BMPs) such as oil and grit separators, grassed swales, vegetated filter strips, retention ponds, and catch basin inserts (CBIs) are implemented to reduce stormwater pollutants in urban runoff. However, the information on physicochemical characteristics of the pollutants are still few in literature but important to improve the design of BMPs, considering qualitative aspects, and their operation. CBIs are devices used to remove GPs at source without requiring any extra land use because they are typically mounted within a catch basin (e.g. side entry pit) or existing drain. In this study, improvement of stormwater quality was investigated at two different sites (Subiaco, a residential area and Hillarys Boat Harbour, a commercial-marine-recreational area; Western Australia) where a new CBI made of non-woven polypropylene geotextile was installed in side entry pits to capture GPs at source. Influent and effluent water from the CBIs was collected and analyzed for BOD, COD, TSS and PO_4-P with maximum improvements in water quality of 90%, 88%, 88% and 26% respectively. The heavy metals in influent and effluent water were found very low and below the guideline values. Analysis of particle size distribution, specific surface area of solids, SEM images and heavy metal content (Cu, Fe, Ni, Pb, Zn, Cd) in solids showed that the residential area contained more finer particles than the commercial area but that solids in the commercial area contained greater concentrations of heavy metals than those from the residential area. The specific surface area was found to be higher in the residential area and particles were thought to be largely sourced from traffic. However, these characteristics may be monitored for longer term for more CBIs installed in different locations.

1. Introduction

Urban development (e.g., urbanization) has significant effects on the water quality of nearby water bodies receiving urban runoff (Miguntanna et al., 2010). Urbanization alters the natural surface, transforming pervious to impervious surfaces. It has been found that impervious surfaces can lead to reducing infiltration and increasing surface runoff (USEPA, 2012). The surface runoff consists of various pollutants including gross pollutants (debris and litter), suspended solids, nutrients, oxygen demanding substances, heavy metals and hydrocarbons (oil and surfactants). Excessive nutrient levels in water bodies can result in growth of algae, and other aquatic plants that clog waterways. Eutrophication, the phenomenon of excessive aquatic plant growth such as macrophytes and algae, has become a serious environmental threat in urban areas (Lewitus et al., 2008). The presence of heavy metals in urban stormwater runoff is of concern due to their potential toxicity level in receiving waters. Reddy et al. (2014) reported that heavy metals such as lead (Pb), cadmium (Cd), zinc (Zn) and copper (Cu) are the most prevalent metals in urban stormwater runoff and mercury (Hg), chromium (Cr) and nickel (Ni) are found to a lesser extent. Heavy metals in urban stormwater runoff originate from traffic-related sources such as brake linings, tires, pavement wear and automobile exhaust (Gunawardana et al., 2012). Corrosion of building materials and atmospheric deposition are also potential sources of heavy metals in urban stormwater runoff (Gunawardana et al., 2012; Amato et al., 2011).

Various researchers showed that stormwater from different catchments consist of different levels of pollutants (Zhao et al., 2007; Kim et al., 2005; Lee and Bang, 2000). Nazahiyah et al. (2007) and Lee et al. (2002) reported that total suspended solids (TSS) and chemical oxygen demand (COD) are the primary pollutants which can result in degradation of water quality in residential areas. Zhang et al. (2010) verified that vehicular traffic density in commercial and industrial areas is higher than in residential areas. This implies that the characteristics of pollutants and their accumulation level depend on the number of people that utilize the area and also the types of activities carried out.

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Again, rainfall characteristics such as runoff volume, antecedent dry weather periods and rainfall intensity are the major factors affecting the magnitude of stormwater pollutants in receiving waters (LeBoutillier et al., 2000). Huang et al. (2007) reported that the strongest rainfall event following the longest period of dry days can result in the highest concentration of TN, TSS and COD in urban waterways.

Based on the regulations, proper stormwater management must be undertaken to remove pollutants to the required levels. Best management practices (BMPs) for stormwater management include bioretention devices, swales, infiltration basins, stormwater ponds, engineered wetlands, gross pollutant traps (GPT) and catch basin inserts (CBIs). Among these practices, CBI is a device that can be used to remove pollutants at source without requiring any extra land use because it is typically mounted within a catch basin (e.g. side entry pit drain). A few studies have focused on capturing pollutants using CBI in side entry pits before they enter the drainage system (CIWMB, 2005; GeoSyntec and UCLA, 2005; ICBIC, 1995; MacLure, 2009). Kostarelos and Khan (2007) and Kostarelos et al. (2011) evaluated pollutant removal efficiency of six CBIs under laboratory and field conditions. They studied the removal of TSS, total nitrogen (TN), total phosphorus (TP), total petroleum hydrocarbon (TPH), and biochemical oxygen demand (BOD_5) at three different flow rates with three contaminant concentrations. Their study focused on the installation characteristics, durability and maintenance of CBIs. The authors concluded that these CBIs can be used as a pre-treatment device with other stormwater structural practices. Their field studies revealed that these CBIs were easy to operate and maintain and have comparable annual maintenance cost (approximately $640 per year) except one CBI (i.e., Passive Skimmer). A similar study was performed by GeoSyntec and UCLA (2005) to remove oil and grease in four CBIs. Chrispijn (2004) did a field survey for 63 "at source stormwater pollutant traps" (ASPT) out of 300 SEPT in Hobart, Tasmania. Three different ASPT namely Enviropod Filter, Ecosol RSF 100 and SEPTs (designed by Hobart City Council) were used in this study and a small number of traps from each type were installed in comparable locations in and around Sullivans Cove, Hobart, Tasmania Australia. A wet weight of 2.25 tons of polluted materials was captured in the 63 traps with variable retention capacity of pollutant materials. Lau et al. (2001) performed field and laboratory tests on CBIs in the City of Santa Monica, USA, collecting the GP from CBIs twice during their testing period to determine the pollutant size distribution. Recently, Alam et al. (2017a) carried out a field survey on UST (Urban Stormwater Technologies Pty Ltd.) CBIs through a period of one year and found efficient for capturing gross pollutants, mainly vegetation ($> 90\%$). The study of Alam et al. (2017a) was conducted in a commercial land use type site located in the vicinity of a market and library surrounded by trees. As reported by Alam et al. (2017a) and (2017b), the UST CBIs (made of non-woven polypropylene geotextile) can capture sediments down to 150 µm. However, although different types of trapping devices are now available there is a lack of information on physio-chemical characteristics and removal efficiencies of captured pollutants in CBIs. Pollutant characteristics captured in CBIs have not been fully tested in field conditions under the influence of seasonal variations especially for a Mediterranean climate (such as Perth, Western Australia) where high rainfall intensity in short duration prevails. Therefore, the quality of stormwater and physio-chemical characteristics of captured solids in CBIs were investigated in this study for a variety of both physical and chemical environmental parameters.

2. Materials and methods

2.1. Selection of study area

In this study, two different sites (i) Olive Street, Subiaco and (ii) Southside Drive, Hillarys in Western Australia were selected where UST has installed CBIs in the side entry pits to capture GP at source (Fig. 1). A total number of 17 and 14 CBIs were installed in Olive St and Southside Dr respectively. Among them, 2 CBIs (S1 and S2) from Subiaco and 4 CBIs (H1, H2, H3 and H4) from Hillarys were selected based on the criteria of receiving maximum amount of stormwater runoff. The CBIs in Hillarys were selected at the junction of roads and near the car park area as shown in Fig. 1. Similarly, the CBIs in Subiaco were selected near the end and middle of the side road (Fig. 1) with relative downward slope considering that these will receive all kinds of pollutants. The CBI may therefore represent the outlet points of the basin. A detailed description of UST CBIs and its solid removal characteristics can be found in Alam et al. (2017a) and (2017b). The selected catchments are mixed land use type areas. The land use in Subiaco catchment (25.5 ha) is mostly residential with high vegetation waste (such as leaves and twigs) and located 3 km from Perth CBD (central business district). Hillarys is located on the coast approximately 18 km northwest of the Perth CBD. Hillarys is a recreational and commercial area that includes more than 2700 car parking bays. The catchment area of Hillarys is approximately 45.5 ha. The city of Subiaco and Hillarys provides comprehensive street sweeping (weekly), butt out bin and street bin cleaning (fortnightly), as well as litter control services (City of Subiaco, 2017; City of Joondalup, 2017). Similarly, street sweeping practices are monitored and audited to ensure that street waste is kept out of drains.

2.2. Method of sampling

Duplicate sets of water and solid samples were collected from 2 CBIs at Subiaco (S1 and S2) and 4 CBIs at Hillarys (H1, H2, H3 and H4) during the wet season of 2014. Solid samples or samples of material which was drifted from soil but mostly consisting of soil particles; hence it was considered as soil in this study. Two most wet months (June and July 2014) were targeted to collect the samples matching with the CBI servicing schedule for those months. The monthly servicing and meteorological data during sampling times are shown in Table 1. These two months were selected because of the high road runoff volume containing high washed load (Alam et al., 2017a). The number of rain events between two successive servicing dates varied between 13 and 20 in the study sites. However, the sampling dates were selected following a large storm event occurred in that month. The washed road runoff first enters into the side entry pits. These pits are designed to operate as soak wells but in practice, many of them were found to be sealed due to accumulation of GPs and other pollutants because of insufficient maintenance. The water inside the CBIs was considered as influent and water outside the CBIs was considered effluent in this study. The influent and effluent stormwater samples were collected from different sampling points at both study sites. The samples were collected after few rain events on the basis of the assumption that after successive rain events these CBIs act as a permeable reactive filter due to the accumulation of different sizes of soil/wood particles (0–10000 µm). The accumulated fine particles within the CBI may act as an adsorbent medium for dissolved pollutants and thus releasing the cleaner water outside of CBI. However, solid particles in CBIs could also release pollutants by desorption.

The influent and effluent water samples were collected in 1 L polyethylene bottles from selected CBIs at both sites and were kept below 4 °C to minimize any changes in water characteristics. Solid samples were collected at a depth of 0–5 cm from within the CBIs and stored in a polystyrene bag in ice boxes to maintain the temperature below 4 °C. The collected samples were immediately transferred from the site to the laboratory for analysis. The collected water samples were analyzed for TSS and PO_4-P at water laboratory of civil engineering department, Curtin University while BOD, COD, heavy metals (HMs) and particle size distribution (PSD), density, specific surface area and scanning electron microscope (SEM) analyses were performed at the CSIRO Laboratory.