Diffuse pollution in Oxford (Ohio, USA) watershed and performance of 'street sweeping' as a 'best management practice' (BMP)

Nur Muhammad and Anne Morris Hooke

ABSTRACT

Experimental results are described to evaluate the diffuse pollution profile according to land use in the catchments and street sweeping as a best management practice (BMP). We studied the variation of pollutant concentrations in outfalls discharging runoff from residential, commercial and high-traffic areas and in street sweeping. Pollution profiles varied with the land use in the catchments and seasons along with other factors such as rainfall intensity, construction works and street maintenance. Microbial indicator organisms were relatively high in all three outfalls. Heavy metal concentrations were low with lead (Pb) as the predominant heavy metal. The organic and solid contents were low but non-degradable and persistent. Relatively high quantities of pollutants were found in street sweeps in all catchments suggesting street sweeping as an effective measure to control diffuse pollution. Regular and frequent sweeping is important as a BMP.

Key words | diffuse pollution, heavy metals, indicator organisms, non-biodegradable, particulate-bound, persistent, street sweeping

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INTRODUCTION

Pollution sources are generally categorized as point source and non-point source. Point source refers to the polluted effluent from a point or an extremely small area, such as domestic and industrial wastewater; the route and the quantity of such pollution sources are easily measured or controlled. On the other hand, non-point source pollution, also known as 'diffuse pollution' arises when it rains and the pollutants are discharged from a wide area. As the treatment facilities for point sources expand, the relative importance of the treatment of non-point sources is increasing (Choe *et al.* 2002). Discharges of urban water have numerous adverse effects on urban areas and receiving waters, including flooding, sedimentation, temperature rise, dissolved oxygen depletion, eutrophication, toxicity, reduced biodiversity and associated impacts on beneficial water uses (Marsalek 1998). Increased concerns about such impacts led to the introduction of storm water management, a system of control and treatment strategies designed to mitigate such impacts either fully or partly. Such storm water management measures are also referred to as best management practices (BMPs). The US Environmental Protection Agency (EPA) has mandated that most municipalities in the United States with populations larger than 10,000 obtain a storm water run-off permit. One of the requirements of this permit program is the use of non-structural and structural BMPs appropriate to local conditions (USEPA 1999).

Diffuse pollution is a complex mixture of different pollutants. Whilst there are innumerable pollutants in storm water runoff, the most common ones are suspended solids, persistent organic matter, nutrients, hydrocarbons, pathogenic bacteria and heavy metals (ASCE 2002). Harmful poly aromatic hydrocarbons (PAHs) and the potential carcinogen benzo(a) pyrene have been reported

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in runoff and sediments (Yamane *et al.* 1993; Asada & Ohgaki 1996). Several recent studies have identified pathogenic microorganisms in storm water runoff (Mallin *et al.* 2000; Noble *et al.* 2000; Lipp *et al.* 2001). The concentrations of different heavy metals in runoff and sediments have been well established by different researchers (Mangur *et al.* 1995; Sansolane & Buchberger 1997; Pettersson 1998; Hares & Ward 1999; Buffleben *et al.* 2002; Choe *et al.* 2002; Farm 2002) and total suspended solids and organic matter indices such as Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) are often used to estimate storm water runoff quality (Shinya *et al.* 2003).

Concentrations and loading rates of contaminants in storm water are highly site-specific due to wide variations in dustfall, average daily traffic and land use in surrounding areas (Buren *et al.* 1996; Legret & Pogotto 1999; Farm 2002). It is difficult to establish a standard process to control diffuse pollution because of the uncertain load and characteristics and further studies are required. The primary objective of this study was to determine the types and concentrations of diffuse pollutants in the Oxford watershed during the course of storm events and to evaluate the variation of pollution profile according to the land-use pattern in the catchments. To achieve this objective, we monitored the pollutants in the surface runoff generated in residential, commercial and high traffic zones for nine months.

Different structural and non-structural BMPs are used to reduce the pollutants from storm water. The use of ponds, wetlands, swales and other structural treatment facilities is difficult in densely populated urban areas (German & Svensson 2002). Different source control strategies, such as street sweeping, are of interest. Some earlier studies in the USA found street sweeping effective in removing litter and coarser fractions of sediments, but the effect on urban runoff was not satisfactory (Bender & Terstriep 1984; Sartor & Gaboury 1984). Since these studies were performed, new street sweepers have been developed and some recent studies indicate that street sweeping can be an effective method to reduce pollutant transport from streets (Sutherland & Jalen 1997; German & Svensson 2001). German and Svensson (2002) observed that the removal of finer particles was important for controlling diffuse pollution. The effectiveness of street sweeping as a BMP is however, not clear and further studies are required for proper evaluation. The secondary objective of this study was therefore, to evaluate the performance of 'Street Sweeping' as a non-structural BMP. To achieve this objective, we monitored the associated pollutants in the street sweeps for four months.

METHODS AND MATERIALS

Site description

To evaluate the runoff characteristics in the Oxford watershed, samples were taken from three different locations covering residential, commercial and high-traffic zones. The residential zone covers high-density multi-family and single-family houses, local roads and car parks. The commercial zone covers a number of supermarkets, filling stations and car parks. The high-traffic area covers the busiest roads of the city (High Street and State Route 27) and small roads in the university. Samples were collected from the outfalls. The outfalls covering the residential, commercial and high-traffic catchments are referred to as Outfall 1, Outfall 2 and Outfall 3 respectively.

Sampling procedures

Grab samples were collected from all three outfalls within 30 minutes of the storm events. Three 500 ml samples from each outfall were taken at intervals of 3 minutes and mixed thoroughly to prepare a well-mixed sample at the time of sampling.

The City of Oxford watershed is divided into different zones and the street maintenance authority carries out the sweeping at least once in every zone every week. Residential, commercial and high traffic zones are referred to as catchment 1, catchment 2 and catchment 3 respectively in this research. We collected the sediment samples for the three zones on three separate dates during the spring and summer of 2003. Grab samples were taken from different locations at the dumping area and mixed thoroughly to prepare a well-mixed 500 ml sample.

Pollutant parameters and analysis

Pathogenic microorganisms

Water samples were analyzed for three sets of indicator organisms: total coliforms (TC), fecal coliforms (FC) and fecal streptococci (FS). We used standard membrane filtration technique to determine their numbers in runoff samples (AWWA 2001). The samples were serially diluted to minimize the turbidity problem in membrane filtration and because of the high numbers of organisms in each sample. Duplicate samples were analyzed for each dilution of samples. Table 1 describes the culturing media, incubating temperature and duration for analyzing the indicator organisms.

Heavy metals

Water samples were analyzed for both total and dissolved concentrations of five different heavy metals: copper (Cu); chromium (Cr); zinc (Zn); lead (Pb) and cadmium (Cd). Total metal concentrations were determined by the standard nitric acid digestion technique (AWWA 2001). Dissolved metal concentrations were determined after passing the water sample through 0.45 μm filters (AWWA 2001). The Inductively Coupled Plasma (ICP) method was used to determine the heavy metal concentrations (AWWA 2001).

Organic matter

Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) were measured to determine the organic content of the runoff samples. COD was measured by the standard closed reflux colorimetric method (AWWA 2001). We digested the samples in standard Hach COD tubes and measured the COD by comparing the absorbance at 600 nm in a spectrophotometer (HACH Model: M00485). BOD samples were incubated in standard BOD bottles at 20°C for five days and the initial and final dissolved oxygen (DO) were measured with the standard DO meter (Yellow Spring Model: 58).

Total solids and volatile solids

We determined total solids (TS) and volatile solids (VS) by filtering the sample through Whatman grade 934AH glass-fiber filter paper and drying the residue at between 103°C – 105°C and 550°C respectively (AWWA 2001).

RESULTS AND DISCUSSION

Microbiological pollutants

Figure 1 demonstrates that the TC, FC and FS in runoff from all three outfalls are high. The residential zone (outfall 1) contains the highest number of all three indicator organisms followed by the high-traffic zone (outfall 3) and the commercial zone (outfall 2). The number of indicator organisms in all three outfalls was the lowest in winter, as expected due to the lower temperature. The indicator organisms were generally very high in early spring, perhaps due to the sudden temperature rise after months of freezing conditions and minimum filtration effects in the catchments because of less vegetation cover. Although the temperature is high in summer, the indicator organisms were relatively low (with some exceptions in the residential area) because of good vegetation cover and better street maintenance (street sweeping) in the catchments. In the residential area, the indicator organisms were also relatively high, perhaps due to more outdoor pets in comparison to commercial and high-traffic areas.

Table 1 | Summary of membrane filtration procedure used for enumeration of the indicator organisms

Microorganism	Medium and indicator	Incubating temperatures (°C)	Incubation duration (hours)	Positive reaction
Total coliforms	m-endo and ethyl alcohol	35 ± 0.5	24	Metallic green colonies
Fecal coliforms	m-FC and rosolic acid	45 ± 0.5	24	Deep blue colonies
Fecal streptococci	KF agar and triphenyl-tetrazolium chloride (TTC)	35 ± 0.5	48	Deep red colonies

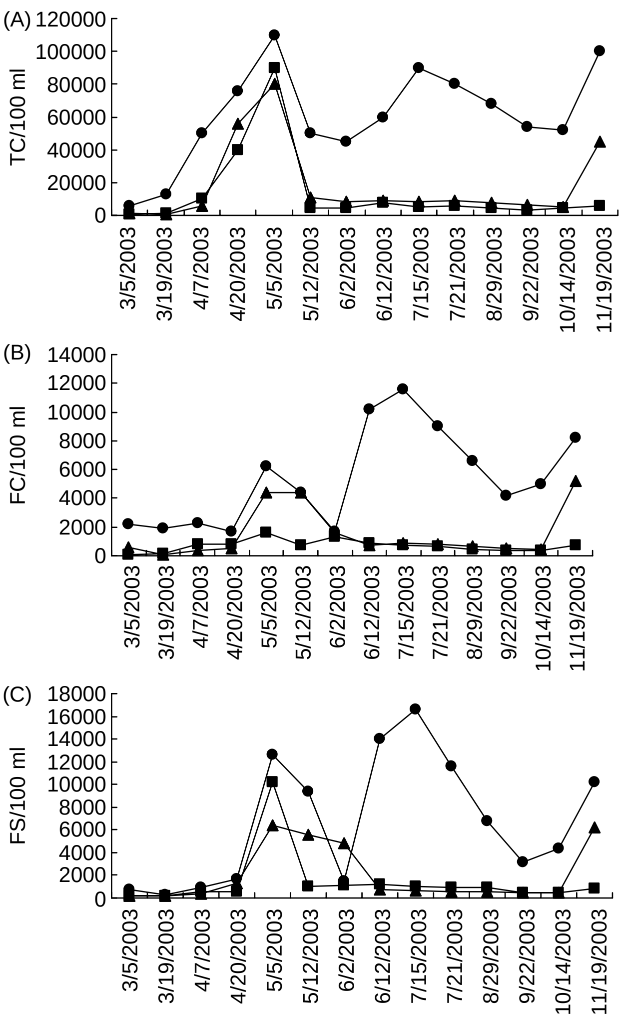

Figure 1 | Variation of (A) Total Coliforms, (B) Fecal Coliforms and (C) Fecal Streptococcai in different outfalls over nine months ● – Outfall 1 (residential area), ■ – Outfall 2 (commercial area) and ▲ – Outfall 3 (high-traffic area).

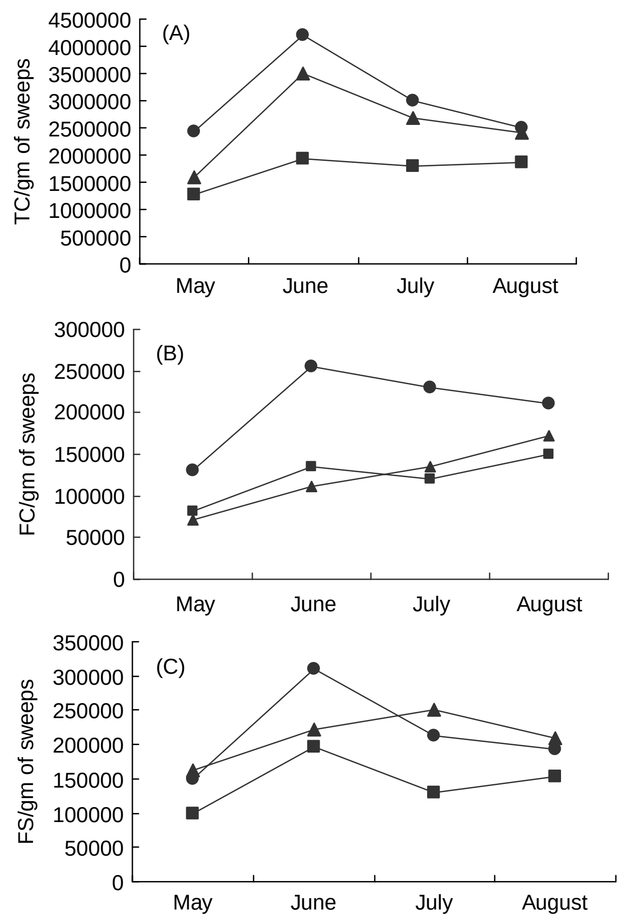

Figure 2 | Variation of (A) Total Coliforms, (B) Fecal Coliforms and (C) Fecal Streptococcai in street sweeps in different catchments during spring and summer, 2003. ● – Catchment 1 (residential area), ■ – Catchment 2 (commercial area) and ▲ – Catchment 3 (high-traffic area).

Figure 2 shows that the street sweeping from all three catchments contained a large number of indicator organisms. This indicates street sweeping as a preventative measure to control micro-pollutants entering the surface water. The number of indicator organisms in the street sweep varied over time, probably due to a number of rainfall events in between the sweepings.

Heavy metals

Figure 3 demonstrates the total and dissolved concentration of heavy metals in different outfalls. The total concentrations of the selected heavy metals were relatively low in the runoff in all outfalls. The concentrations of Pb were higher than the other heavy metals in all outfalls. In general the high-traffic zone contained the highest concentration of the selected heavy metals. The concentrations of heavy metals in the outfalls for the commercial and residential zones were not significantly different. The dissolved concentrations of all five heavy metals were negligible. The differences in the total and dissolved concentrations of heavy metals emphasized the importance of particle removal to control heavy metal pollution confirming the observations of other researchers (Sansolane & Buchberger 1997; Pettersson 1998). Figure 4 shows that street sweeping removed significant amounts of heavy metals from all catchments. The relatively higher concentrations of Pb, both in the runoff and in the street sweeps indicate that Pb

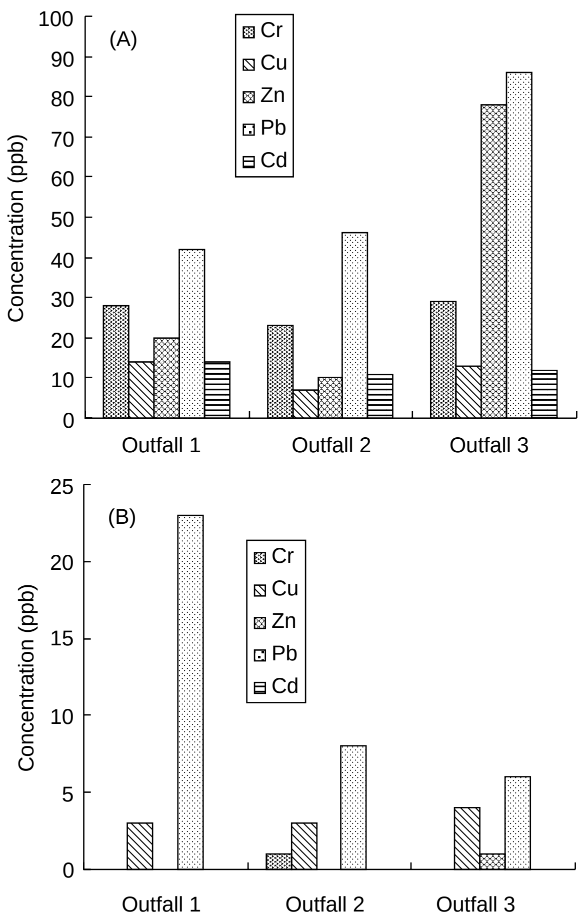

Figure 3 | Mean concentrations of (A) total and (B) dissolved heavy metals in different outfalls over nine months.

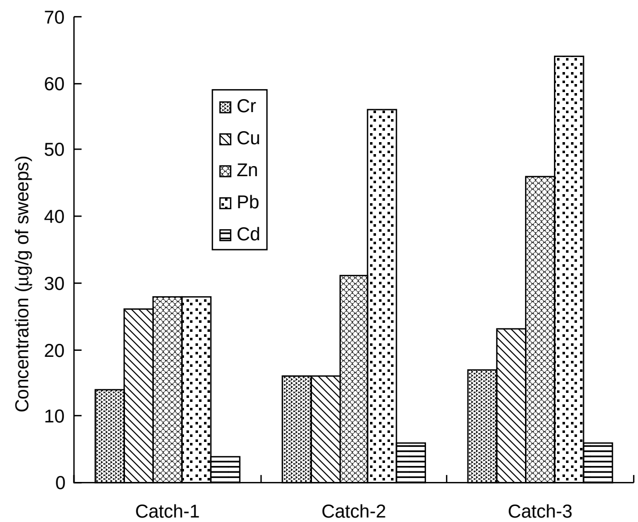

Figure 4 | Mean concentrations of heavy metals in street sweeps in different catchments during spring and summer, 2003.

is the predominant heavy metal in the Oxford watershed. The high concentrations of the selected heavy metals in the street sweep indicate the particulate bound tendency of these heavy metals as well as the importance of street sweeping to control heavy metal pollution.

Organic content

The BOD and COD represent the organic content of the runoff. Figure 5 shows the variation of BOD, COD and COD/BOD ratios in the outfalls. The BODs for the residential and high-traffic zones were more or less similar except for the two storm events when the BOD for the high-traffic zone was relatively higher perhaps due to maintenance work in the area. The BOD in the commercial zone was relatively low. The COD for the high-traffic zone was the highest followed by the residential and commercial zone. The COD/BOD ratios indicate that organic waste in the high-traffic zone was the least degradable followed by the residential and commercial zones. The organic pollutants in all three zones were the most non-degradable during winter because of accumulated hydrocarbon and de-icing agents. The COD/BOD ratios were close to the standard value (2–3) during spring and early summer and rose again during late summer due to construction activities.

Figure 6 shows the extracted BOD and COD per gram of the street sweeps in different catchments. Street sweeping removed a large amount of organic matter from the catchments.

Solid contents

Figure 7 shows the variation of TS, VS and VS/TS ratios in the different zones. Both the TS and VS were the highest in the high-traffic zones, followed by the residential and commercial zones. Like the BOD and COD, the TS and VS also varied with time, the highest in winter and the lowest during spring and early summer. The VS/TS ratios were always relatively high indicating the higher concentrations of hydrocarbon and other non-degradable organic matter in the runoff.

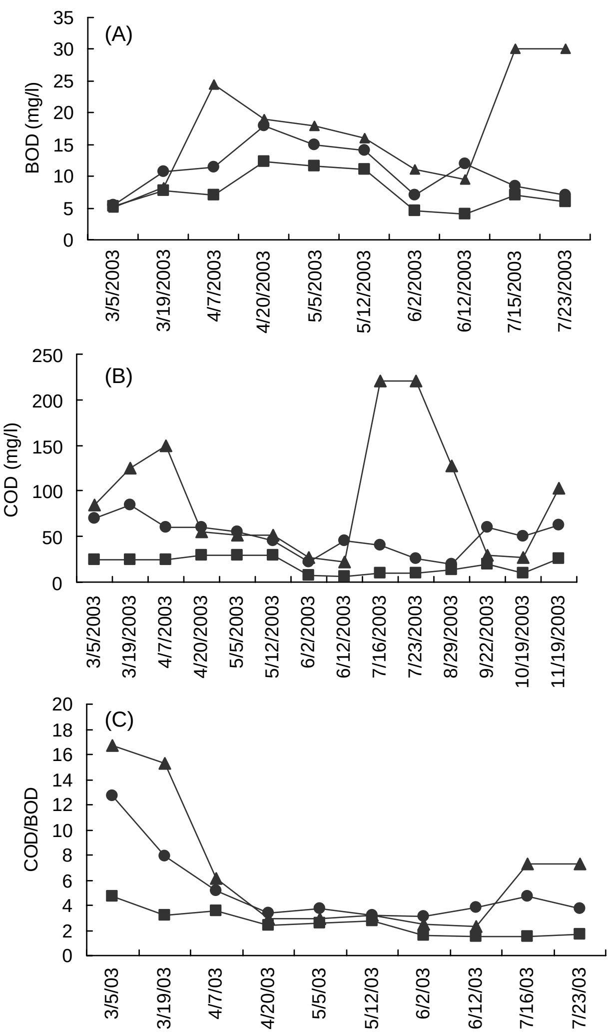

Figure 5 | Variation of (A) BOD, (B) COD and (C) COD/BOD ratios in different outfalls for five months (COD for nine months) ● – Outfall 1 (residential area), ■ – Outfall 2 (commercial area) and ▲ – Outfall 3 (high-traffic area).

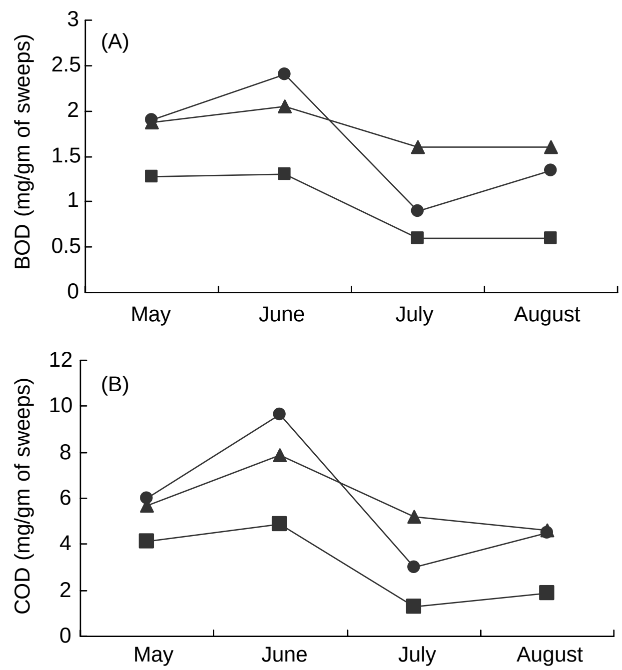

Figure 6 | Variation of (A) BOD and (B) COD in street sweeps in different catchments during spring and summer, 2003. ● – Catchment 1 (residential area), ■ – Catchment 2 (commercial area) and ▲ – Catchment 3 (high-traffic area).

CONCLUSIONS AND RECOMMENDATIONS

- Diffuse pollutants in the Oxford watershed varied with land use in catchments and seasons along with other factors such as maintenance works, vegetation covers, outdoor pets and street maintenance.
- Microbial indicator organisms were relatively high in residential and high-traffic zones in the Oxford watershed whereas those in the commercial zone runoff were relatively low.
- Heavy metal concentrations were relatively low in all three outfalls in the Oxford watershed. Pb is the predominant heavy metal in the Oxford watershed. All the heavy metals considered in this research possess high particulate bound tendency.
- The BOD and COD were relatively low in all outfalls. They varied with land use, with the highest values in the high-traffic area followed by the residential and commercial areas. The COD values during some storm events in the high-traffic zone exceeded the effluent quality normally recommended for wastewater treatment plants. The COD/BOD ratio was high indicating the higher percent of non-degradable organic matter in the runoff.
- The solid contents were high in the high-traffic outfall followed by the residential and commercial outfalls. The higher VS/TS values indicated a larger percent of persistent organic matter in the runoff.
- Street sweeping was found effective in controlling the diffuse pollutants as relatively high quantities of all pollutants were found in the street sweeps from all catchments. Regular and frequent sweeping is important to remove particles. The solids, organic and heavy metals content were relatively high in winter, partly because of irregular sweeping in extreme winter conditions.

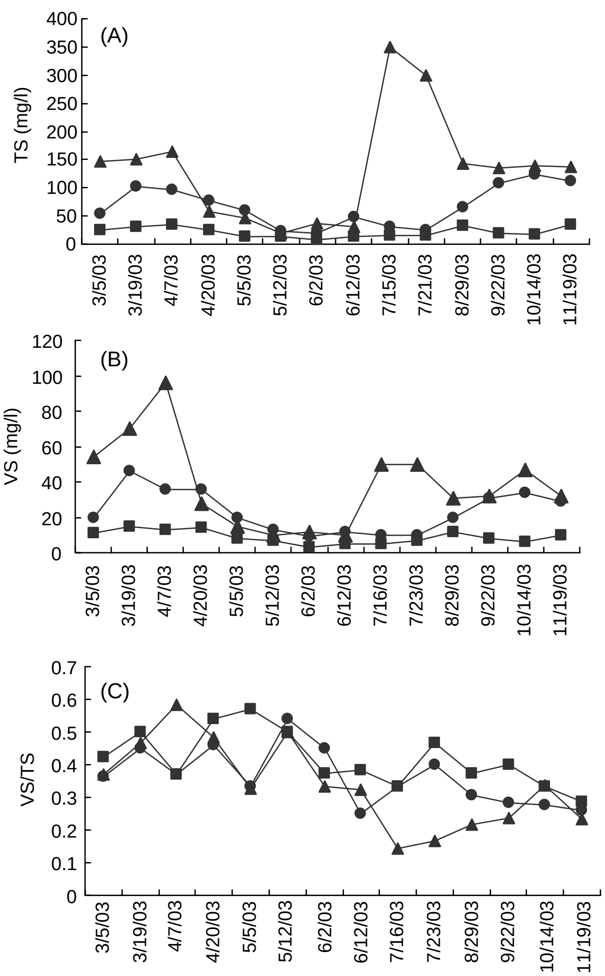

Figure 7 | Variation of (A) TS, (B) VS and (C) VS/TS ratios in different outfalls for nine months ● – Outfall 1 (residential area), ■ – Outfall 2 (commercial area) and ▲ – Outfall 3 (high-traffic area).

- There was a high percent of non-degradable and persistent organic matter in the catchments. Further research is necessary to identify the components of persistent organic matters in the runoff as well as in the street sweeps.
- This research was mainly focused on identifying the pollutant profile according to land use during rainfall only. A long-term study considering rainfall intensity, duration and detailed catchments characteristics is necessary to further establish the pollutant profile. The results of this study were not compared with the surface water quality standards, as this would require regular monitoring of the surface water. A follow-up study is necessary to determine the pollutant concentration in the receiving water body where the values are expected to be much lower because of dilution and self-purification in the stream.
- This study has identified the importance of particle removal by street sweeping in controlling diffuse pollution. A follow-up study considering a control catchment, frequency of sweeping and rainfall events between sweeping is necessary to further establish the efficiency of street sweeping in controlling diffuse pollution.

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