Pollutant loads of surface runoff in Wuhan City Zoo, an urban tourist area

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Abstract
The pollutant loads of surface runoff in an urban tourist area have been investigated for two years in the Wuhan City Zoo, China. Eight sampling sites, including two woodlands, three animal yards, two roofs and one road, were selected for sampling and study. The results indicate that pollutants ranked in a predictable order of decreasing load (e.g. animal yard > roof > woodland > road), with animal yards acting as the key pollution source in the zoo. Pollutants were transported mainly by particulate form in runoff. Particulate nitrogen and particulate phosphorous accounted on average for 61%, 78% of total pollutant, respectively, over 13 monitored rainfall events. These results indicate the treatment practices should be implemented to improve particulate nutrient removal. Analysis of the M(V) curve indicate that no first flush effect existed in the surface runoff from pervious areas (e.g. woodland, animal ground yard), whereas a first flush effect was evident in runoff from impervious surfaces (e.g. animal cement yard, roof, road).

Key words: surface runoff; stormwater pollution; urban tourist area; impervious/pervious surface; M(V) curve

Introduction
Urban runoff is an important source of pollution responsible for impairing water quality (USEPA, 2002). Urban runoff carries high pollutant loads, including sediment, nutrients, heavy metals, oils and hydrocarbons, and oxygen-demanding substances. Further, urban surfaces are characterized by a high proportion of imperviousness, resulting in flashier hydrographs with higher, earlier peaks (Wanielista and Yousef, 1993; Gupta and Saul, 1996).

Several studies have reported surface runoff pollution in urban-residential and industrial dominated (Gromaire-Mertz et al., 1999; Lee and Bang, 2000; Choe et al., 2002; He et al., 2005). However, there are very few studies reporting water quality and quantity characterization of urban zoos. In urban zoos, the ratio of pervious surface (value for urban zoo ratio) is larger than in urban residential (value for urban residential ratio) and industrial areas (value for industrial ratio), reflecting the higher vegetation coverage in zoos. The drainage system in zoos is also distinct from other urban areas because it is shallower than that of other areas. These hydrologic features of zoos make the investigation of the pollution process and runoff characteristics important for determining appropriate strategies to control surface pollutants in these areas.

1 Methods

1.1 Study sites
The study was conducted from May 2004 to August 2005 in the Wuhan City Zoo, China. Wuhan City is situated in a subtropical area of China, with continent monsoon climate that generates intensive rainfalls in the summer. The mean annual temperature is 15.9°C and the annual precipitation is approximately 1300 mm, two-thirds of which falls from April to August.

The experimental catchment in the Wuhan City Zoo drains 26 hm² (Fig.1) of (sandy, silty, clayey) soils. The main landuses within the catchment include woodland (WD), animal yard (AY), roof (RF) and road (RD) in the zoo. The animal concrete yard, roof and road surfaces are all essentially impervious and account for 24% of the entire catchment. The animal ground yard, woodland surfaces are pervious. The pervious surface is divided into many fragments by animal yard, road, and buildings.

Eight sampling sites, including all main landuses, were selected for investigation (Table 1). The main pollutants in the runoff from animal yards are animal waste. Despite a daily cleaning schedule, some pollutants remain available for transport by surface runoff. All roads in the zoo are cleaned thoroughly once a day.

1.2 Experimental methods
Runoff samples were taken manually. All water samples were collected in plastic bottles, beginning at the initiation...
Table 1 Summary of characteristics of studied catchments at different sites in Wuhan City Zoo (see Fig.1)

<table>
<thead>
<tr>
<th>Sampling site</th>
<th>Land use</th>
<th>Area (m²)</th>
<th>Percent of impervious area (%)</th>
<th>Type of surface</th>
<th>Land slope (%)</th>
<th>Percent of vegetation (%)</th>
<th>Arbor</th>
<th>Grass</th>
</tr>
</thead>
<tbody>
<tr>
<td>WD1</td>
<td>Woodland</td>
<td>4085</td>
<td>11.8</td>
<td>Pervious</td>
<td>8.3</td>
<td>73</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>WD2</td>
<td>Woodland</td>
<td>5167</td>
<td>14.1</td>
<td>Pervious</td>
<td>4.4</td>
<td>76</td>
<td>68</td>
<td></td>
</tr>
<tr>
<td>AY1</td>
<td>Animal ground yard</td>
<td>220</td>
<td>0</td>
<td>Pervious</td>
<td>0</td>
<td>9</td>
<td></td>
<td>68</td>
</tr>
<tr>
<td>AY2</td>
<td>Animal ground yard</td>
<td>808</td>
<td>0</td>
<td>Pervious</td>
<td>9.3</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AY3</td>
<td>Animal cement yard</td>
<td>1120</td>
<td>100</td>
<td>Impervious</td>
<td>3.2</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>RF1</td>
<td>Roof</td>
<td>27</td>
<td>100</td>
<td>Impervious</td>
<td>10.6</td>
<td>22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RF2</td>
<td>Roof</td>
<td>15</td>
<td>100</td>
<td>Impervious</td>
<td>0</td>
<td>51</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RD</td>
<td>Road</td>
<td>20</td>
<td>100</td>
<td>Impervious</td>
<td>5.1</td>
<td>43</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1 Map of experimental area and location of sampling sites.

of the runoff and ending when the runoff ceased. Samples were collected at the outlet of each site with an interval of 5 min in the first 30 min followed by 10 min intervals until runoff ceased. Time of sampling and runoff volume were recorded simultaneously. Runoff volume was measured using calibrated polythene barrel with 20 L for higher volumes and 5 L for smaller volumes. Rainfall intensity data was recorded by an automated gauge in the zoo. The rainfall patterns are summarized in Table 2.

Suspended solids (SS) and chemical oxygen demand (COD) were measured according to Standard Methods of APHA (1998). All the samples were filtrated with 0.45 µm millipore filter. The filtrate was used for measuring constituents of dissolved nitrogen (DN) and dissolved phosphorus (DP). All the filtered and unfiltered water samples were digested simultaneously for determination of nitrogen and phosphorus concentrations (Ebina et al., 1983). The particulate nitrogen (PN) and particulate phosphorus (PP) concentrations were determined as the difference between total nitrogen (TN) and DN, and that between total phosphorus (TP) and DP, respectively.

1.3 Data analyses

Event mean concentrations (EMC), a single index to characterize pollutant in runoff (Novotny and Olem, 1994; Sansalone and Buchberger, 1997), was used to estimate pollutant loads in the runoff from eight sampling sites. The EMC is a flow-weighted average of constituent concentration, and can be represented as

\[
EMC = \frac{\int C(t) \times Q(t) dt}{\int Q(t) dt}
\]

where, EMC is the event mean concentrations (mg/L); \( C(t) \) is the time variable concentration (mg/L); \( Q(t) \) is the runoff flow rate discharged at time \( t \) (m³/min).

The export of pollutants was assessed by the unit pollutant loading rate. The following equation can be used to calculate this index (Lee and Bang, 2000):

\[
L = KC_i \times \Delta Q_i \times \Delta t_i \times R / (\sum \Delta t_i \times A_i \times I_i)
\]

where, \( L \) is the unit pollutant loading rate (kg/(hm²·a)); \( K \) is the conversion constant (10⁻³); \( C_i \) is the average concentration of the composite sample during the \( \sum \Delta t_i \) interval (mg/L); \( \Delta Q_i \) is the runoff in \( \Delta t_i \) interval (m³/h); \( \Delta t_i \) is the sampling time interval (h); \( \sum \Delta t_i \) is the rainfall

Table 2 Patterns of rainfall event sampled

<table>
<thead>
<tr>
<th>Date</th>
<th>Rainfall depth (P, mm)</th>
<th>Rainfall duration (T_r, h)</th>
<th>Ave. rainfall intensity (I, mm/h)</th>
<th>Max. rainfall intensity (I_max, mm/h)</th>
<th>Days since last storm (d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11 May 2004</td>
<td>13.6</td>
<td>3.1</td>
<td>4.4</td>
<td>22.8</td>
<td>3</td>
</tr>
<tr>
<td>14 June 2004</td>
<td>20.1</td>
<td>3.6</td>
<td>5.6</td>
<td>33.6</td>
<td>10</td>
</tr>
<tr>
<td>18 June 2004</td>
<td>12.3</td>
<td>3.1</td>
<td>4.0</td>
<td>13.2</td>
<td>4</td>
</tr>
<tr>
<td>23 June 2004</td>
<td>55.3</td>
<td>3.8</td>
<td>14.6</td>
<td>69.6</td>
<td>5</td>
</tr>
<tr>
<td>14 Aug. 2004</td>
<td>78</td>
<td>4.2</td>
<td>18.6</td>
<td>66</td>
<td>3</td>
</tr>
<tr>
<td>8 Apr. 2005</td>
<td>18.8</td>
<td>1.8</td>
<td>10.4</td>
<td>40.8</td>
<td>52</td>
</tr>
<tr>
<td>1 May 2005</td>
<td>10.5</td>
<td>2.3</td>
<td>4.6</td>
<td>31.2</td>
<td>15</td>
</tr>
<tr>
<td>17 May 2005</td>
<td>32.0</td>
<td>2.5</td>
<td>12.8</td>
<td>32.4</td>
<td>3</td>
</tr>
<tr>
<td>10 June 2005</td>
<td>35.0</td>
<td>3.1</td>
<td>11.3</td>
<td>40.8</td>
<td>23</td>
</tr>
<tr>
<td>26 June 2005</td>
<td>78.0</td>
<td>7.9</td>
<td>9.9</td>
<td>46.8</td>
<td>15</td>
</tr>
<tr>
<td>10 July 2005</td>
<td>30.1</td>
<td>4.0</td>
<td>7.5</td>
<td>54.0</td>
<td>13</td>
</tr>
<tr>
<td>22 July 2005</td>
<td>27.0</td>
<td>1.2</td>
<td>22.5</td>
<td>82.8</td>
<td>12</td>
</tr>
<tr>
<td>3 Aug. 2005</td>
<td>41.3</td>
<td>4.8</td>
<td>8.6</td>
<td>45.6</td>
<td>8</td>
</tr>
</tbody>
</table>
duration (h); $R$ is the annual total rainfall intensity (mm/a); $A_i$ is the watershed area (hm$^2$); $I_i$ is the rainfall intensity (mm/h).

First flush effect is a common phenomenon in urban runoff pollution (Gupta and Saul, 1996; Lee and Bang, 2000). To evaluate if the first flush phenomenon was exhibited at these sites, $M(V)$ curves were developed. The following $M(V)$ curve can be drawn (Deletic, 1998):

$$M(V) = \frac{\int_0^T C(t) \times Q(t) \, dt}{\int_0^T C(t) \times Q(t) \, dt}$$

(3)

where, $C(t)$ is the time variable concentration (mg/L); $Q(t)$ is the runoff rate (m$^3$/min); $t$ is the time elapsed from the start of the event (min); $T_{run}$ is the duration of runoff (min).

2 Results and discussion

2.1 Effects of land surface properties on the pollution process

Pollutant loads were largely influenced by the activities and surfaces of the sites. Fig.2a illustrates that pollutant concentrations in the impervious surface runoff were high only at an initial stage and decreased gradually with the rainfall duration. However, pollutant concentration in pervious surface runoff had a positive relation to flow rate and rainfall intensity, as shown in Fig.2b.

Pollutant concentration of runoff from impervious surface quickly decreased after the peak value appeared. This pollution process is similar to the process occurring in other urban watersheds with a high impervious ratio (Characklis and Wiesner, 1997). In contrast pollutant concentration of runoff from pervious surface increased with rainfall density increasing in the zoo. This pollution process is similar to that of agriculture area (Fraser et al., 1999; Hammad et al., 2006), because the removal of pollutants from pervious surface depends heavily on the rainfall pattern (Novotny and Olem, 1994). The primary differences in mechanism regulating pollutant concentrations in impervious and pervious surfaces are in the quantity of pollutant in surface and capability of rain to erode the soil surface. High volumes of runoff are generated rapidly over impervious surfaces because precipitation can not infiltrate into soil. Pollutants that have built up on this surface are easily washed off by runoff during the rising limb of the hydrograph. In contrast, pervious surface can be penetrated by water more easily so that only rainfall with high intensity can form sufficient runoff to remove pollutants. Furthermore, pervious surfaces at these sites are composed of soil particles that act as pollutant sources by releasing stored pollutants.

2.2 Pollutant load from different landuses

Animal yards were the heaviest pollution sources in the zoo because of animal breeding. The highest pollutant concentrations were measured at the animal yard runoff in all 13 rainfall events (Table 3). The analyses indicate that the mass loading rate was in the following order: animal yard>roof>woodland>road (Table 4).

The pollutant concentration of roof runoff in the zoo is higher than the concentrations at roofs in other urban areas (Gromaire-Mertz et al., 1999). Accumulated vegetation on the roofs is suspected as the source of pollutants on the roofs at our study sites. Vehicles are prohibited in the zoo and road management is good. Consequently, the runoff pollution from the roads was the lowest in that of all the sampling sites. Woodland with less grass growth (WD1) had a higher pollutant export than the one with more grass coverage (WD2).

2.3 Pollutant form in the runoff

Nitrogen and phosphorus were predominantly in particulate form in the runoff of Wuhan City Zoo (Fig.3). PN
and PP accounted for 71% and 89% of the TN and TP in runoff from pervious surface, 50% and 66% in runoff from impervious surface.

Some studies indicated that DN is the main form of N in urban runoff. Uunk and Ven (1987) reported that PN was below 33% of the TN in urban runoff, while Taylor et al. (2005) reported that PN accounted for only around 20% of the total in urban runoff. This study found PN to be higher in comparison with these studies, with a mean of 61% PN for all sampling sites. The portion of PP in this study was 78% and it is similar to the result of US EPA's survey in which PP accounted for 70% in nationwide urban runoff (Smullen et al., 1999).

Because particulate nutrient dominates runoff in the zoo, it is suggested that runoff treatment practices should be designed to improve retention of particulates removal. Wet detention pond, infiltration basin and constructed wetland with good performance on particulate removal may be perfect choice in the zoo.

2.4 First flush phenomenon

The $M(V)$ curves developed of pervious and impervious surface runoff in the zoo are shown in Fig.4. Deviation of the $M(V)$ curve above the bisector is an indicator of first flush. The $M(V)$ curves in Wuhan City Zoo indicate that no first flush existed in pervious surface runoff, but this phenomenon was very clear in impervious surface runoff.

Some researchers considered that the concentration of pollutants in the first flush is positively related to rainfall intensity and percent of impervious area, but negatively related to the watershed area (Lee et al., 2002). Our findings support Lee et al., indicating that the first flush phenomena from the impervious surface runoff in the zoo was caused by intensive rainfall, a highly impervious surface, and the small runoff area.

3 Conclusions

In Wuhan City Zoo, a typical urban tourist area, pollutant concentration was positively relationship to flow rate and rainfall intensity in runoff from the pervious surface. However, the impervious surface runoff peaked only initially, reflecting the phenomenon of the first flush. The pollution loads were dominated by the particulate forms of N and P, 61%, 78% of the total, respectively, emphasizing the importance of management strategies that...
target these pollutant forms.

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**References**


