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Uncertainties in stormwater runoff data collection from a small urban catchment, Southeast China

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Abstract

Monitoring data are often used to identify stormwater runoff characteristics and in stormwater runoff modelling without consideration of their inherent uncertainties. Integrated with discrete sample analysis and error propagation analysis, this study attempted to quantify the uncertainties of discrete chemical oxygen demand (COD), total suspended solids (TSS) concentration, stormwater flowrate, stormwater event volumes, COD event mean concentration (EMC), and COD event loads in terms of flow measurement, sample collection, storage and laboratory analysis. The results showed that the uncertainties due to sample collection, storage and laboratory analysis of COD from stormwater runoff are 13.99%, 19.48% and 12.28%. Meanwhile, flow measurement uncertainty was 12.82%, and the sample collection uncertainty of TSS from stormwater runoff was 31.63%. Based on the law of propagation of uncertainties, the uncertainties regarding event flow volume, COD EMC and COD event loads were quantified as 7.03%, 10.26% and 18.47%.

Key words: urban stormwater runoff; *in-situ* monitoring data; uncertainty; data collection

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Introduction

With the effective management of industrial wastewater and municipal sewage pollution, non-point source pollution from stormwater runoff is recognized as one of the major causes for the deterioration of receiving water bodies (US EPA, 2007). In the United States, urban stormwater runoff is the third largest pollution source of streams and lakes (Deletic and Maksimovic 1998). As a developing but booming country, China has suffered from an accelerated urbanization process in recent years. The proportion of percentage imperviousness of land cover increased inevitably resulting in water quality degradation in the urban areas. It is reported that 90% of the water bodies in urban areas in China are seriously polluted (Yin, 2006).

In-situ monitoring is the direct method to characterize urban stormwater runoff, and can also provide field data for calibrating models (Freni et al., 2009). Although urban stormwater runoff monitoring programs began in the late 1970s (US EPA, 1983), practical information on stormwater data collection methodology has only recently been developed (Leecaster et al., 2002; Harmel et al., 2003, 2006a; Haggard et al., 2003; Gillespie et al., 2004). However, the data collected are often used without any consideration of the large uncertainties involved in such environmental measurements (Harmel et al., 2006a; Bertrand-Krajewski, 2007; McCarthy et al., 2008). Haydon and Deletic (2009) point out that the uncertainty of modeled output data is partly due to the uncertainty in the model data input. Obviously, the issue of uncertainty associated with stormwater data collection not only exerts significant influence on the identification of urban stormwater runoff characteristics and stormwater modelling, but also has implications for consequent stormwater management decisions (Harmel et al., 2006b; McCarthy et al., 2008).

Previous research has produced valuable knowledge of the uncertainties related to various sampling procedures (Leecaster et al., 2002; Harmel et al., 2006a; McCarthy et al., 2008). However, there are still few reports regarding the systematic quantification of the uncertainties involved in monitored stormwater runoff data, including discrete sampling uncertainty, flow measurement and error propagation analysis on a small urban catchment scale. The aim of this study was to estimate the uncertainties which exist in monitored stormwater runoff data in an urban lawn catchment, Southeast China. The monitored data of five wet weather events were used to quantify the uncertainties of discrete chemical oxygen demand (COD), total suspended solids (TSS) concentration, stormwater flowrate, stormwater event volumes, COD event mean concentration (EMC), and COD event loads in terms of flow

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measurement, sample collection, storage and laboratory study, integrated with discrete sample analysis and error propagation analysis.

1 Materials and methods

1.1 Description of the study catchment

The study catchment, covering 3.26 ha, is located on the north bank of the Yundang lagoon in Xiamen, Fujian Province, Southeast China (Fig. 1). Yundang lagoon was built for reclamation in the 1970s. Although the treatment project for Yundang lagoon was regarded as a demonstration project of PEMSEA (the GEF/UNDP/IMO Regional Program on Building Partnerships in Environmental Management for the Seas of East Asia), the water quality of Yundang lagoon has been seriously contaminated in recent years.

Given that the greenland including lawn & park is one of the important land cover types in Xiamen City, accounting for over 37% of total area (XMEPB, 2009), this study chose a catchment with predominant land use of lawns. The study catchment consists of lawns (65%), and has an impervious area of roads (20%) and roofs (15%). The sewer network is separate.

1.2 General description of data collection

A rain gauge was set up near the study catchment to measure the amount of rainfall during rainfall events. A manual volumetric method and a flowmeter (SIGMA 910, HACH, USA) were coupled to measure the rainfall runoff flowrate at the outlet of the catchment. Sampling was carried out by a manual grab at different time intervals, namely, sampling intervals was 5 min in the first 30 min, 10 min in 30–60 min of the rainfall event, and then 30 min for the receding flow stage. Five rainfall events were monitored and sampled over the period November, 2008

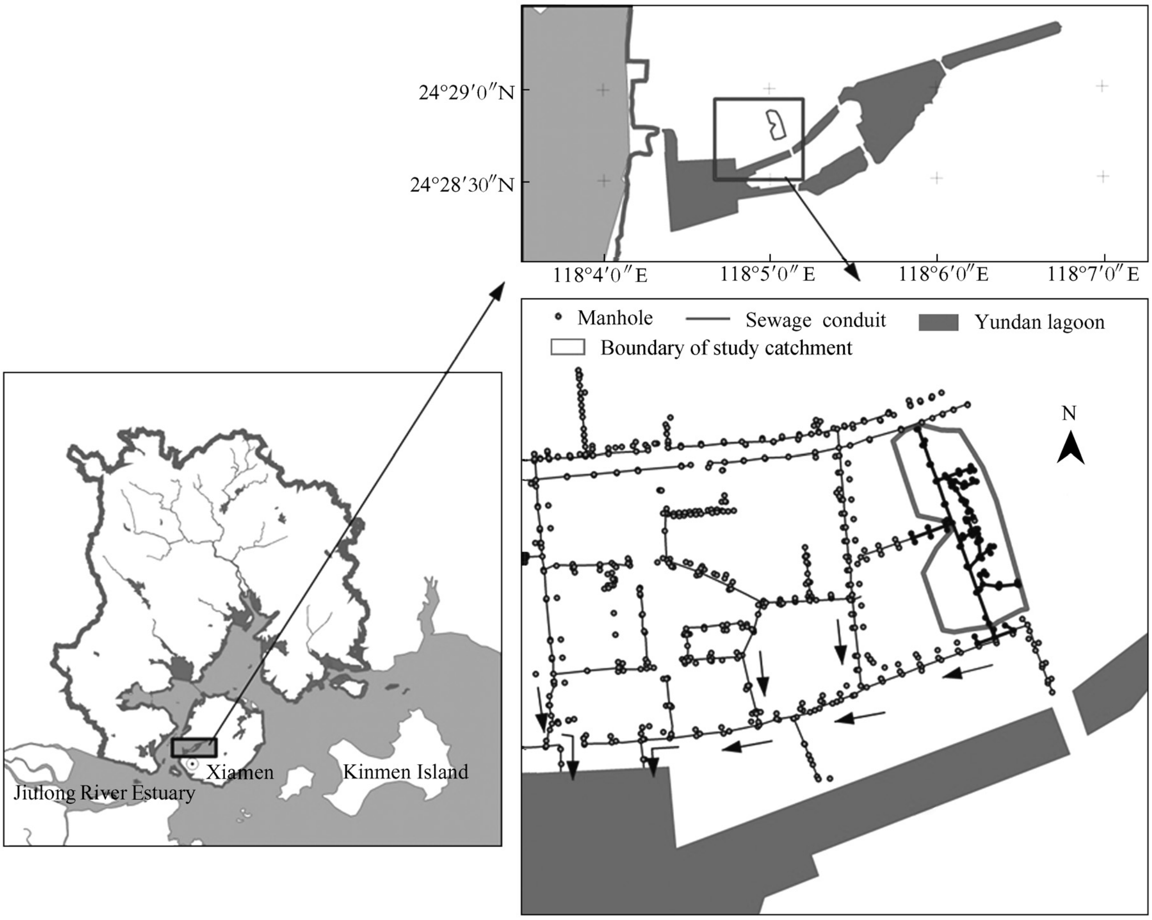

Fig. 1 Location of the study catchment.

Table 1 General description of five rainfall events monitored in the study catchment

Date	Time	Duration (min)	Rainfall depth (mm)	Total runoff volume (m^3)	Average rainfall intensity (mm/min)	Antecedent dry weather period (day)	No. of samples
2008-11-08	08:42–13:00	258	1.42	7.99	0.0055	10	6
2009-03-05	16:28–18:38	130	1.41	26.97	0.011	13	6
2009-03-13	18:55–20:45	110	12	85.89	0.109	3	12
2009-03-27	19:22–20:47	85	2.46	9.43	0.029	4	12
2009-04-13	10:37–11:42	65	4	42.34	0.062	2	12

to April, 2009. A general description of the five rainfall events monitored is given in Table 1.

The samples were collected and analyzed according to the standard methods developed by the State Environmental Protection Administration of China (2002). Water quality parameters included TSS and COD.

1.3 Methods designed for estimating uncertainties due to discrete sample collection and flow measurement

The uncertainty in measured stormwater runoff data is often broken into four categories: flow measurement, sample collection, sample storage and laboratory analysis (Harmel et al., 2006b). The four sources of uncertainties were considered as follows:

Flow measurement uncertainty: Flow measurement with the auto-flowmeter and the manual-volumetric method were compared.

Sample collection uncertainty: Two different positions in the manhole were chosen to collect samples for estimating sampling uncertainty, namely, at the higher entrance (position I) and at the lower outlet (position II) (Fig. 2).

Storage uncertainty: Storage involved three different time steps (2, 4 and 6 hr) under refrigeration in the laboratory after sample collection. Storage uncertainty was evaluated by comparing the pollutant concentration at different storage times.

Laboratory analysis: The analytical uncertainty was obtained by analyzing a given sample several times.

1.4 Methods for quantifying uncertainties in monitored stormwater runoff data

1.4.1 Uncertainties due to sample collection, storage and laboratory analysis

Relative uncertainties of discrete sample concentration from one specific sampling procedure can be calculated using Eq. (1):

$$\frac{\overline{\Delta X}}{\overline{X}} = \frac{\sum\limits_{i=1}^{n} \frac{|X_i - \overline{X}|}{\overline{X}}}{n} \times 100 \quad (1)$$

where, X_i is the measured value for the sampling procedure i; ΔX is the deviation error of X_i; and $\overline{X}$ and $\overline{\Delta X}$ are the mean values of X_i and ΔX.

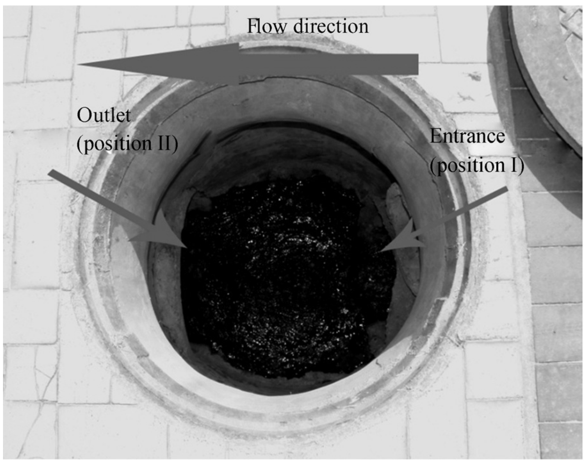

Fig. 2 Sampling positions.

The overall uncertainties of the discrete pollutants' concentration measurements from various sampling procedures can be calculated using Eq. (2):

$$u(C) = \sqrt{\sum_{i=1}^{n} u(C_i)^2} \quad (2)$$

where, $u(C_i)$ is the concentration measurement uncertainty which comes from different steps of the given sampling procedure; and $u(C)$ is the total uncertainty of pollutant concentration measurement.

1.4.2 Method for quantifying uncertainty of flow measurement

Equation (1) was adopted to quantify the uncertainty of flow measurement by comparing the manual-volumetric and the auto-flowmeter methods.

1.4.3 Law of propagation of uncertainties (LPU)

After quantifying the uncertainties of discrete sample uncertainty in terms of flow measurement, sample collection, storage and laboratory analysis, error propagation was further taken into account based on the LPU equation, given in first-order Taylor (Eq. (3)):

$$y + \Delta y = f(x_1 + \Delta x, x_2 + \Delta x, ..., \mathrm{x}_i + \Delta x_i) \quad (3)$$

where, y is the dependent variable; Δy is the variable quantity of the dependent variable; x_i is the independent variable, and Δx is the variable quantity of the independent variable.

Taking the differential coefficient with the Taylor formula and deleting the high step item, we can define the uncertainty Eq. (4) as follows (McCathy et al., 2008):

$$\begin{aligned} u(y) = &\sum_{i=1}^{n} u(x_i)(\tfrac{\delta f}{\delta x_i}) + \\ &2\sum_{i=1}^{n-1}\sum_{j=i+1}^{n} R(x_i, x_j)u(x_i)u(x_j) \times \tfrac{\delta f}{\delta x_i} \times \tfrac{\delta f}{\delta x_j} \end{aligned} \quad (4)$$

where, $u(y)$ is the uncertainty; x_i is the real value of uncertainty sources; $u(x_i)$ is the uncertainty of x_i; f is the function of x_i to y; and $R(x_i, x_j)$is the coefficient of correlation between x_i and x_j, which can be calculated as in Eq. (5) (Li, 2003):

$$R(x_i, x_j) = \frac{\sum (x_i - \frac{\sum_{i=1}^{n-1} x_i}{n-1})(x_j - \frac{\sum_{j=2}^{n} x_j}{n-1})}{\sqrt{\sum (x_i - \frac{\sum_{i=1}^{n-1} x_i}{n-1})^2 \sum (x_j - \frac{\sum_{j=2}^{n} x_j}{n-1})^2}} \quad (5)$$

1.4.4 Uncertainties for event flow volume, event pollutant loads, and pollutant EMCs

The total flow volume (V) and total pollutant loads (L) for a given rainfall event were calculated as in Eq. (6) and Eq. (7), respectively:

$$V = \sum_{i=1}^{n} Q_i \Delta t_i \quad (6)$$

$$L = \sum_{i=1}^{n} C_i Q_i \quad (7)$$

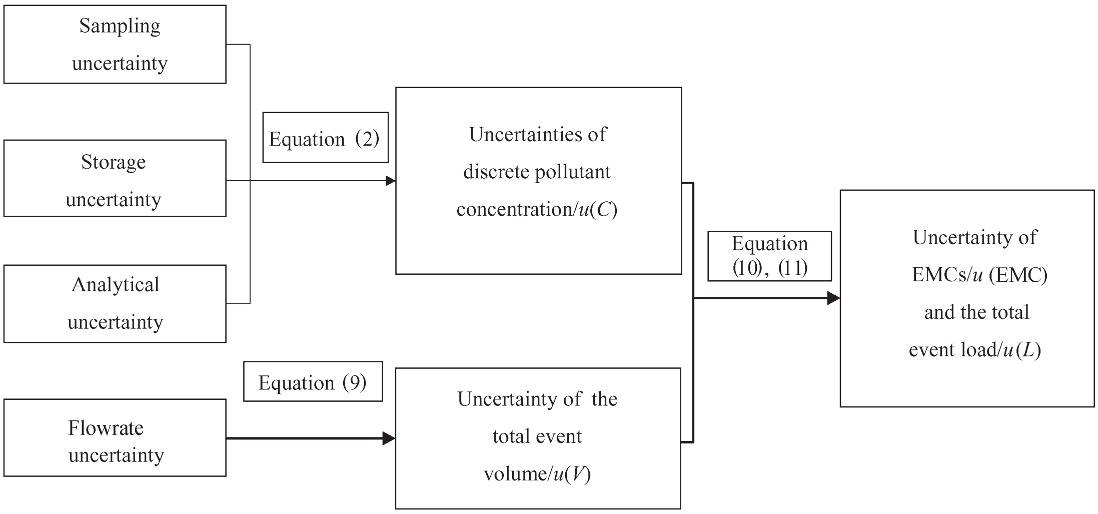

Fig. 3 Flow chart of this study.

where, C_i, Q_i are the pollution concentration and flowrate at the ith interval; and Δt_i is the duration at the ith interval. EMC can be calculated as in Eq. (8):

$$\mathrm{EMC} = \frac{L}{V} \tag{8}$$

Based on the LPU function, the uncertainty of V and L are calculated as in Eq. (9) and (10) (McCarthy et al., 2008):

$$u(V)^2 = \sum_{k=1}^{m} u(Q_k^2)\Delta t_i^2 + 2\sum_{k=1}^{m-1}\sum_{j=k+1}^{m} \Delta t_i^2 R(Q_k, Q_j)u(Q_k)u(Q_j) \tag{9}$$

$$u(L)^2 = \sum_{i=1}^{n} u(C_i)^2(V_i)^2 + \sum_{k=1}^{m} u(Q_k)^2(C_k)^2 + 2\sum_{k=1}^{m-1}\sum_{j=k+1}^{m} R(Q_k, Q_j)u(Q_k)u(Q_j) \tag{10}$$

where, $u(V)$, $u(L)$ are the uncertainty of V and L; $u(Q)$ is the uncertainty of the flow measurement; and $u(C)$ is the uncertainty of discrete pollutant concentration.

Finally, the uncertainty of the EMC can be calculated in Eq. (11):

$$u(\mathrm{EMC}) = \sum_{i=1}^{n} \frac{u(L_i)}{V} + \sum_{i=1}^{n} L\frac{u(V_i)}{V^2} \tag{11}$$

The flow chart of this study is shown in Fig. 3.

2 Results and discussion

2.1 Uncertainties of discrete sample and flow measurement

The uncertainty of flow measurement, uncertainties of discrete COD concentration due to sample collection, storage, and laboratory analysis, and uncertainty of TSS concentration due to sample collection are presented in Table 2.

As shown in Table 2, flow measurement uncertainty varied greatly between rainfall events, with a value between 5.38% and 29.80%. For sampling, TSS concentration showed a greater uncertainty in sample collection than that of COD concentration, as McCarthy et al. (2008) suggested. For uncertainties of COD concentration, the order of uncertainties was storage > sample collection > laboratory analysis based on the average values in this study.

2.1.1 Flow measurement uncertainty

Flow measurement uncertainty is presented in Fig. 4 by comparing the two results obtained using the manual-volumetric method and the auto-flowmeter. The results showed that the flow data obtained using the manual-volumetric method was always smaller than those of the auto-flowmeter, especially during the period of near peak flow. This was due in part to the fact that the flow volume could not be fully measured using the manual-volumetric

Table 2 Uncertainties of flowrate, TSS and COD in monitored stormwater runoff data

Uncertainties	Flow measurement (%)	Sample collection (%)		Storage for COD (%)	Lab. analysis for COD (%)
		COD	TSS		
2008-11-08	5.38	6.23	–	15.99	3.64
2009-03-05	8.23	12.43	–	31.03	19.00
2009-03-13	29.80	12.39	33.23	17.32	11.22
2009-03-27	7.30	9.60	21.61	10.13	6.94
2009-04-13	13.38	29.31	40.06	22.92	20.59
Mean	12.82	13.99	31.63	19.48	12.28
Max.	29.80	29.31	40.06	31.03	20.59
Min.	5.38	6.23	21.61	10.13	3.64

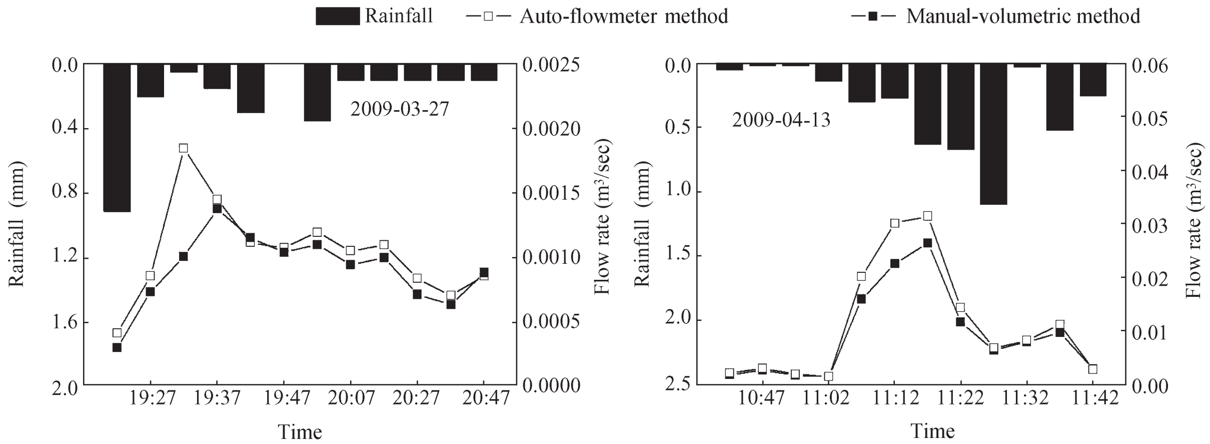

Fig. 4 Flow measurement uncertainty.

method when the intensity of rainfall and runoff became too strong.

Flow measurement uncertainty was related to stormwater runoff discharge characteristics. In our study, the relative uncertainty between the manual-volumetric and the auto-flowmeter was between 5.38% and 29.80%, and the average value was 12.82%, as shown in Table 2. That was smaller than the result (20%) by Ahyerre et al. (1998), and slightly different from the result by Harmel et al. (2006a). Additionally, Bertrand-Krajewski and Bardin (2002) found that the flow measurement uncertainty is about 9%–13%. McCarthy et al. (2008) used an HACH SIGMA 950 to measure the flowrate and find the uncertainty is between 5% and 2000%. They believe that the phenomenon is due to the flow being too small to be measured accurately. Our study also had the same observation that uncertainty of flow measurement varied greatly between rainfall events, as shown in Table 2. It should be mentioned that hydraulic control structures are often used for flow measurement in small watersheds. The uncertainty of flow measurement can be overcome by stage measurement (Harmel et al., 2009).

2.1.2 Sample collection uncertainty

The pollutant concentration in stormwater runoff should be different between position I and position II (Fig. 2). It can be surmised that when sampling at the bottom of a manhole, sediment in the stormwater will be disturbed and collected with the sample. In fact, it was observed that the COD concentration of the samples collected in position I and position II were different during the two selected rainfall events which occurred on March 27, 2009 and April 13, 2009 (Fig. 5). It should be noted that the peak concentration of COD collected in position II lagged behind that in position I for the April event, which to some extent indicated that sample collection will influence the identification of urban stormwater runoff discharge characteristics.

Although the sample collection uncertainty of TSS was greater than that of COD (Table 2), the overall trend of the sample collection uncertainty of TSS was similar to COD. Namely, for the April event, TSS concentration in position II was mostly larger than that in position I (Fig 6). However, the peak concentration of TSS collected in position II preceded that in position I for the March event.

The sample collection uncertainty for TSS was 21.61%–40.06% and the average value was about 31.63% (Table 2). Compared to some findings regarding the uncertainty of TSS (15%–20%) (Martin et al., 1992; Ahyerre et al., 1998; Bertrand-Krajewski and Bardin, 2002), our study result was much higher. As for different pollutant concentrations, the sample collection uncertainty of COD was smaller than

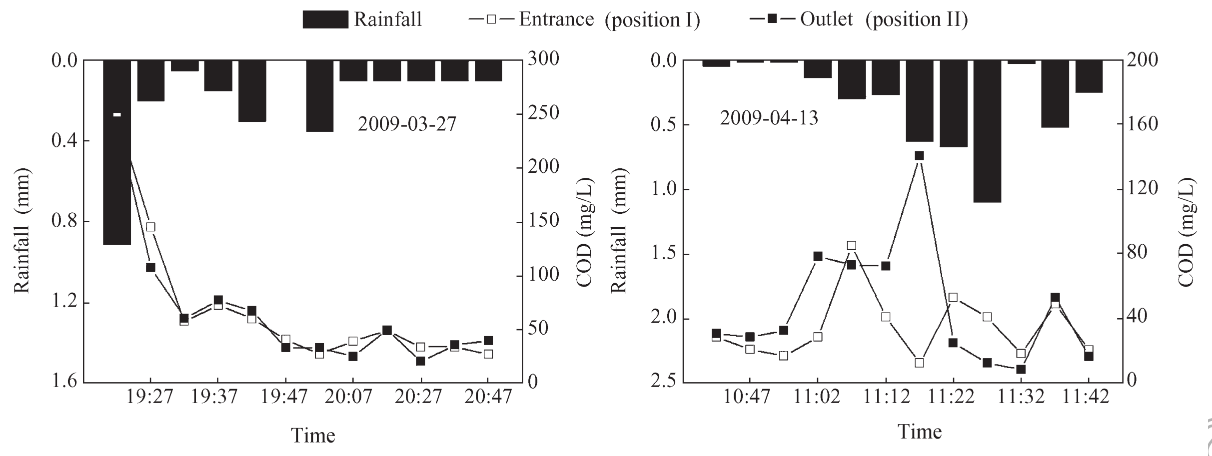

Fig. 5 Sample collection uncertainty of COD.

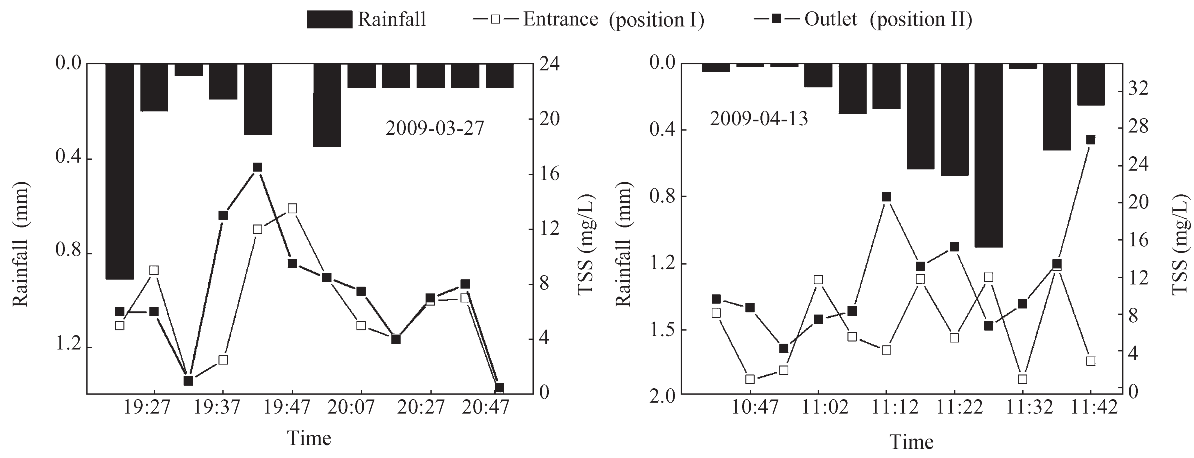

Fig. 6 Sample collection uncertainty of TSS.

that of TSS, but larger than that of most dissolved nitrogen pollutants noted by Harmel et al. (2006b) and *Escherich coli* noted by McCarthy et al. (2008).

2.1.3 Storage uncertainty

The physical and chemical properties of pollutants should be the main factors influencing storage uncertainty. In this study, different storage time, namely 2, 4 and 6 hr after sample collection, were designed to detect the storage uncertainty of COD from urban stormwater runoff. The results for three typical rainfall events are given in Fig. 7.

As shown in Fig. 7, the concentration of COD decreased with the extension of storage time, the relative uncertainty was between 10.13% and 31.03%, and the average value was 19.48%, as shown in Table 2. The storage uncertainty of COD in our study was larger than the storage uncertainty of TSS (10% in Bertrand-Krajewski and Bardin, 2002) and total nitrogen (TN) (1%–9% in Harmel et al., 2006a), but smaller than *E. coli* (25%) in McCarthy et al. (2008), nitrate nitrogen (NO_3^--N) (50%) and total phosphorus (TP) (67%) as provided by Kothlash and Chessman (1998). In conclusion, the storage uncertainty of COD fell between TSS and dissolved matter or *E. coli* due to their different physical and chemical properties.

2.1.4 Laboratory analysis uncertainty

The laboratory analysis uncertainty was related to several factors including experimental operational error,

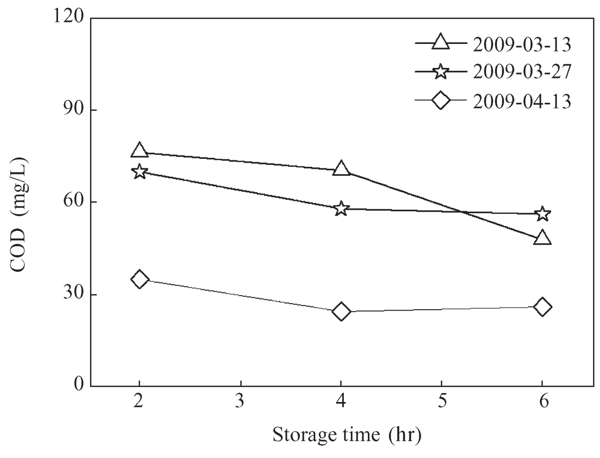

Fig. 7 Storage uncertainty of COD.

experimental pharmacy configuration and the experimental methods (State Environmental Protection Administration of China, 2002; Harmel et al., 2006b). In our study, the laboratory analysis uncertainty of COD varied from 3.64% to 20.59%, with an average of 12.28% (Table 2). It was larger than that of TSS (Gordon et al., 2000; Bertrand-Krajewski and Bardin, 2002), but smaller than that of TN and *E. coli* (McCarthy et al., 2008).

2.2 Quantifying error propagation by LPU in monitored stormwater runoff data

Based on the LPU, uncertainties in terms of stormwater event volumes, COD EMCs, and COD event loads were further estimated.

As shown in Table 3, the uncertainty of event flow volume varied from 1.63% to 15.43%, with an average of 7.03%. This was smaller than the result 10%–38% provided by McCarthy et al. (2008), which was measured with an HACH SIGMA 950. It was also smaller than the range 2%–20% given by Harmel et al. (2006a), measured using the velocity-area method.

Pollution load is one of the major parameters for characterizing rainfall runoff pollution. Uncertainty of event pollutant loads relates to the error propagated from both event flowrate measurement and discrete pollutants concentration from urban stormwater runoff. Uncertainty of COD event loads ranged from 4.86% to 37.09%, with an average of 18.47% (Table 3). Harmel et al. (2006a) show that the uncertainty of event loads for NO_3^--N, NH_3-N, TN, TP, TDP and TSS varies from 3% to 421%. It should be noted that uncertainty of NO_3^--N event loads

Table 3 Error propagation in monitored stormwater runoff data

Relative uncertainties	Event flow volume (%)	COD event loads (%)	COD EMCs (%)
2008–11–08	1.63	13.72	10.34
2009–03–05	6.72	28.25	9.25
2009–03–13	15.43	8.43	2.96
2009–03–27	1.91	4.86	15.12
2009–04–13	9.44	37.09	13.64
Mean	7.03	18.47	10.26
Max.	15.43	37.09	15.12
Min.	1.63	4.86	2.96

reaches 421%. Obviously, our results were much smaller, although the uncertainty of COD event loads was the largest compared to event flow volume and COD EMCs in this study.

Uncertainty of EMCs related to the error propagation from both event flow volume and pollutant mass discharges from urban stormwater runoff. The results in our study ranged from 2.96% to 15.21%, which were lower than the *E. coli* with 14%–25% obtained by McCarthy et al. (2008).

3 Conclusions

Integrating discrete sample analysis and error propagation analysis, this study quantified the uncertainties in monitored stormwater runoff data in an urban lawn catchment, located in Xiamen, Southeast China. The results show that the uncertainties of sampling procedure can not be neglected in urban stormwater monitoring. The uncertainties resulted from sample collection, storage and laboratory analysis for COD concentration in stormwater runoff were 13.99%, 19.48% and 12.28%, respectively. Meanwhile, the flow measurement uncertainty was 12.82%, and the sample collection uncertainty of TSS from stormwater runoff was 31.63%. The uncertainties in terms of event flow volume, COD EMC and COD event loads were quantified as 7.03%, 10.26% and 18.47%, respectively.

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References

Ahyerre M, Chebbo G, Tassin B, Gaume E, 1998. Storm water quality modelling, an ambitious objective? *Water Science & Technology*, 37: 205–213.

Behrens B, Riddle J H, Gillespie J, 2004. Tips to improve wet weather monitoring. American Public Works Association (APWA) Reporter. http://www.apwa.net/ Publications/Reporter/ReporterOnline/index.asp?DISPLAY= ISSUE&ISSUE_DATE= 092004&ARTICLE_NUMBER= 889 (27 November 2009)

Bertrand-Krajewski J L, 2007. Stormwater pollutant loads modelling: epistemological aspects and case studies on the influence of field data sets on calibration and verification. *Water Science & Technology*, 55(4): 1–17.

Bertrand-Krajewski J L, Bardin J P, 2002. Evaluation of uncertainties in urban hydrology: application to volumes and pollutant loads in a storage and settling tank. *Water Science & Technology*, 45: 437–444.

Deletic A B, Maksimovic C T, 1998. Evaluation of water quality factors in storm runoff from paved areas. *Journal of Environmental Engineering*, 124(9): 869–879.

Freni G, Mannina G, Viviani G, 2009. Uncertainty assessment of an integrated urban drainage model. *Journal of Hydrology*, 373(3-4): 392–404.

Gordon J D, Nland C A, Gagliardi S T, 2000. Laboratory performance in the sediment laboratory quality-assurance project, 1996–1998. USGS Water Resources Investigation Report 99-4184. Washington DC.

Haydon S, Deletic A, 2009. Model output uncertainty of a coupled pathogen indicator-hydrologic catchment model due to input data uncertainty. *Environmental Modelling & Software*, 24: 322–328

Haggard B E, Soerens T S, Green W R, Richard R P, 2003. Using regression methods to estimate stream phosphorus loads at the Illinois River, Arkansas. *Applied Engineering in Agriculture*, 19(2): 187–194.

Harmel R D, King K W, Slade R M, 2003. Automated storm water sampling on small watersheds. *Applied Engineering in Agriculture*, 19(6): 667–674.

Harmel R D, Cooper R J, Slade R M, Haney R L, Arnold J G, 2006a. Cumulative uncertainty in measured stream flow and water quality data for small watersheds. *American Society of Agricultural and Biological Engineers*, 49(3): 689–701.

Harmel R D, King K W, Haggard B E, Wren D G, Sheridan J M, 2006b. Practical guidance for discharge and water quality data collection on small watersheds. *American Society of Agricultural and Biological Engineers*, 49(4): 937–948.

Harmel R D, Smith D R, King K W, Slade R M, 2009. Estimating storm discharge and water quality data uncertainty: A software tool for monitoring and modeling applications. *Environmental Modelling & Software*, 24: 832–842.

Leecaster M K, Schiff K, Tiefenthaler L T, 2002. Assessment of efficient sampling designs for urban stormwater monitoring. *Water Research*, 36: 1556–1564.

Li J, 2003. Error Theory and Measure Uncertainty Assessment. China Measurement Publishing Company, Beijing 105, 223.

Kothlash A R, Chessman B C, 1998. Effects of water sample preservation and storage on nitrogen and phosphorous determinations: Implications for the use of automated sampling equipment. *Water Research*, 32: 3731–3737.

Martin G R, Smoot J L, White K D, 1992. A comparison of surface-grab and crosssectionally integrated streamwater-quality sampling methods. *Water Environment*, 64(7): 866–876.

McCarthy D T, Deletic A, Mitchell V G, Fletcher T D, Diaper C, 2008. Uncertainties in stormwater *E. coli* levels. *Water Research*, 42: 1812–1824.

United States Environmental Protection Agency, 1983. Results of the nationwide urban runoff program. Vol. I-final report, Washington D C.

US EPA (United States Environmental Protection Agency), 2007. National Water Quality Inventory: Report to Congress (2002). US EPA, Rep 841-R-07-001, Washington, DC.

XMEPB (Xiamen Environmental Protection Bureau), 2009. Xiamen Environmental Quality Bulletin in 2008. http://www.xmepb.gov.cn/sj/ContentView.aspx?CmsList= 102&CmsID=14.

Yin C Q, 2006. Urban diffuse pollution – A new challenge to the rapid urbanization in China. *Acta Scientiae Circumstantiae*, 26(7): 1053–1056.

State Environmental Protection Administration of China, 2002. Methods of Monitoring and analyzing for Water and Wastewater. China Environmental Science Press, Beijing. 105, 223.