Trend analysis of stormwater hydrology and pollutants: A case study of Chassieu Catchment in France

Analyse des tendances d'hydrologie et polluants des eaux pluviales : Un cas d'etude dans le bassin de Chassieu en France.

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RÉSUMÉ

L'évolution dans le temps des caractéristiques hydrologiques et de qualité des rejets est essentielle pour mieux comprendre les processus prépondérants et aider à élaborer des stratégies de gestion des eaux pluviales afin de contrôler l'impact des rejets sur le milieu. Cette étude porte sur l'évaluation des tendances en matière d'hydrologie et de qualité d'eau à l'exutoire d'un bassin versant urbain français. Les concentrations en matières en suspension (MES) mesurées en continu sont utilisées pour caractériser la qualité. La méthode Mann-Kendall permet de détecter les tendances. L'incertitude des résultats est discutée sur la base de simulations de type Monte Carlo. Les résultats montrent qu'aucune tendance liée à la pluie n'est présente alors qu'une croissance est détectée pour le ruissellement recueilli à l'exutoire du bassin. L'augmentation du coefficient de ruissellement est probablement due à un accroissement de l'urbanisation. Les MES ne présentent pas d'évolution alors que les masses montrent une tendance à la hausse, l'augmentation des masses de polluants étant due à l'augmentation des volumes collectés. L'étude montre également que la principale source d'incertitude sur les résultats vient davantage des lacunes dans les séries que de l'incertitude sur les mesures. Mieux vaut donc réduire les données manquantes plutôt que de chercher à augmenter la qualité de la mesure des grandeurs observées pour la détection de tendances d'évolution.

ABSTRACT

The assessment of evolution in stormwater hydrology and quality is essential for better understanding the relevant processes and further aiding in developing stormwater management strategies to control the impact of stormwater on natural aquatic bodies. This study addresses hydrological and water quality trend assessment in a French urban catchment. The Mann-Kendall method is used for the detection of a trend in variables that representing characteristics of stormwater hydrology and quality. Uncertainty in the trend analysis results is discussed based on Monte Carlo simulations. The results show that a trend is absent in the driving force (precipitation) of the hydrological process, and an increasing trend is found in the urban runoff. The increasing trend in the runoff coefficient (i.e., the ratio of runoff to precipitation volume) is likely due to increasing imperviousness because of urbanization. The total suspended solid (TSS) is used to characterize stormwater quality. The event mean concentration of TSS does not present a trend, whereas the event load of TSS is likely to show an increasing tendency. The major uncertainty source in the trend detection results is missing events, rather than measurement uncertainty, which suggests that it is more important to reduce missing data in order to obtain reliable trend detection results in practice.

KEYWORDS

Total suspended solid, trend analysis, uncertainty, urban hydrology, urbanization

1 INTRODUCTION

Stormwater is one of the major causes for surface water quality impairments in many urban catchments. It is now extensively recognized that effects related to human activities, such as climate change and urbanization can result in significant alternation of stormwater hydrology and quality. The assessment of evolution in stormwater hydrology and quality is essential for better understanding relevant processes and further aiding in developing stormwater management strategies to control the impact of stormwater on natural water and environment.

While the traditional monitoring system via sampling campaigns only provides “fragged” or lumped information of hydrographs and pollutographs, continuous on-line measurements, which are able to capture the complete dynamics of hydrographs and pollutographs, are increasingly used in monitoring urban drainage systems (e.g., Barraud et al., 2002; Métadier and Bertrand-Krajewski, 2012). This study focuses on stormwater hydrology and quality assessment using 2-minute continuous measured data from 2004 to 2011 in the Chassieu catchment, France. The trends in a number of variables are analysed using an event based approach. Variables representing urban hydrology characteristics, including rainfall and runoff volumes and other characteristics, runoff coefficient and lag time are identified based on data analysis. The total suspended solid (TSS) concentration, which is calculated as a function of the turbidity with calibrated relations, is used to characterize stormwater quality. In addition, the impact of uncertainty due to different sources on trend analysis results is investigated.

2 DATA AND METHODS

2.1 Chassieu Catchments

The Chassieu catchment is used as the case study. It is located in the east of Lyon in France and covers an industrial area of 185 ha with the imperviousness coefficient approximately 0.72. The catchment is drained by a separate stormwater sewer system, which also receives dry weather flows from cooling of industrial processes (that can be assumed to be clean). The dry weather flows, which are usually less than 5L/s, are generally insignificant compared to wet weather flows.

In the Chassieu catchment, rainfall is measured by a tipping-bucket rain gauge installed within the catchment and the data is available with a six-minute time step. The catchment outflow rate and indirectly the TSS concentration in stormwater are monitored continuously at the outlet of the catchment. The catchment runoff flows are derived from measured water depth and velocity. The turbidity of stormwater is measured in an off-line monitoring flume in a shelter, and is converted to TSS concentration using a calibrated polynomial relation (see Métadier and Bertrand-Krajewski, 2011, 2012 for more details).

2.2 Man-Kendall Method for trend detection

The Mann-Kendall method, which is a rank-based nonparametric test extensively applied in climatic and hydrological studies, is used. The null hypothesis of this test H_0 states that the data is a sample of n independent and identically distributed random variables. The alternative hypothesis H_1 is that the distribution of x_k and x_j are not identical ($k, j <= n$ and $k \neq j$). The test statistic S is defined as:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}\left(x_j - x_k\right) \tag{1}$$

Under the null hypothesis, the statistic S is asymptotically normal. The P-value of the statistic S is calculated and compared with a predefined significance level (5% in this study) to determine the presence of a trend. The magnitude of a trend is assessed by the Sen’s slope β if a trend is confirmed:

$$\beta = Median\ \left(\left(x_j - x_i\right)/\left(j-i\right)\right)\ , \qquad i < j \tag{2}$$

2.3 Uncertainty in trend analysis

Two uncertainty sources, i.e., uncertainty in measurements and uncertainty due to data availability, are investigated for examining their influence on trend analysis results. The Monte Carlo simulation (MCS) method is used to study the sensitivity of different uncertainty sources. When uncertainty in measurements is investigated, the uncertainty of each value in an event-based data series is considered by randomly generating data samples in the corresponding two-minute time series based on normally distributed uncertainty in measurements. 10^4 MCS samples of data series are generated and the Mann-

Kendall test is implemented to each sample of the data series. The uncertainty in trend detection results is represented by a range of *P*-values obtained from the Mann-Kendall test for randomly generated event-based data series. When uncertainty due to data availability is considered, *m* events are randomly selected from the pool of all the available *n* events to constitute a data series ($m<n$), and a *P*-value from the Mann-Kendall trend detection test is obtained for each data series. 10^4 MCS samples of data series are generated and the range of *P*-values obtained for the samples of data series represents uncertainty in trend detection results due to available events. Data series of different lengths (with different values of *m*) are considered.

3 RESULTS AND DISCUSSION

3.1 Trend in stormwater hydrology

A total number of 716 rainfall events are identified from 2004 to 2011. Due to missing values, only 521 events with complete data of runoff flow time series are available. Table 1 shows the trend detection results of variables characterizing stormwater hydrology. All of the rainfall variables do not present a trend. In contrast, runoff presents a significant increasing trend. According to the Sen's slopes, the event runoff volume and mean runoff flow are estimated with increasing rates of approximately 137 m^3 and 12.3L/s per year, respectively. As a result of relatively stable rainfall and increasing runoff, the runoff coefficient has an increasing tendency, which is probably attributed to growing impervious areas caused by urbanization in the study period. The response time of the catchment to a rainfall event, which is measured by the lag time, does not show a significant trend.

Table 1. Summarized statistics and trend detection results for event rainfall and runoff data series

Variable category	Variable (unit)	*P-value* (%)	Trend presence	Slope (-/year)
Rainfall (716 events)	Depth (mm)	20.8	No	-
	Mean Intensity (mm/h)	35.2	No	-
	Duration (h)	70.8	No	-
Runoff (521 events)	Volume (m^3)	0.00	Yes	136.9
	Mean flow (L/s)	0.01	Yes	3.54
	Max flow in two minutes (L/s)	4.05	Yes	12.3
Rainfall-runoff (521 events)	Runoff coefficient (-)	0.00	Yes	0.018
	Lag time (min)	43.6%	No	-

Note: runoff coefficient is the ratio of the runoff volume to rainfall volume of one event. The lag time measures the response time of a catchment to a rainfall event, which is evaluated as the time difference between the mass centres of the hyetograph and hydrograph.

3.2 Trend in stormwater quality

Among the 521 events with complete runoff time series data, 162 events have complete TSS time series data and 403 events have TSS data for over 50% time steps. The event mean concentration (EMC) and event load (EL) of TSS are calculated respectively for the 162 events and 403 events. Trend detection results for both data sets are listed in Table 2. The EMC values of TSS do not present a trend for both series. No trend is detected in the shorter EL data series, in contrast to a confirmed trend in the longer data series. Therefore, the presence of a trend in EL data series needs to be carefully studied taking into account the uncertainty due to availability of event data.

Table 2 Trend detection results for event data series of runoff and TSS variables

Events	Variable (unit)	P-value (%)	Trend presence	Slope (-/year)
162 events with complete TSS data	Runoff volume (m^3)	2.3	yes	118
	EMC (mg/L)	85.3	No	-
	EL (kg)	9.6	No	-
403 events with 50% TSS data	Runoff volume (m^3)	0.01	yes	177.7
	EMC (mg/L)	89.2	no	-

	EL(kg)	0.6	yes	14.7

3.3 Uncertainty in trend detection

Continuous TSS measurements suffer to a great extent from missing data. Only 162 events are available with complete TSS data in a total number of 521 events with complete runoff data. Uncertainty in trend detection results for the EL of TSS due to measurement uncertainty is firstly investigated using the 162 events. A lack of trend is always found when taking measurement uncertainty into account. A median *P*-value of the trend detection tests is 9.5% and the 90% confidence interval covers the range of [8.4%, 10.5%].

The impact of uncertainty due to available events to trend detection for EL data series is then studied. The 521 events with complete runoff data represent a full sampling pool. The MCS method is performed assuming a random relation between the event runoff volume and EMC and a log-normal distribution of the EMC. For a fix number of events, events are selected randomly from the 521 events in chronological order. EMC values are randomly generated from the identified log-normal distribution. The EL value is calculated as the product of a runoff volume and an EMC value. Fig. 1 shows the *P*-values from the Mann-Kendall trend detection test. For a data series of 162 data, the median *P*-value of the trend detection tests is 6.7% and the 90% confidence interval is in the range of [0.1%, 70%]. The trend detection *P*-value for the 521-event data series is not a fixed number, but contains uncertainty with the 90% confidence interval [0.01%-1.5%], because of uncertainty due to the randomness of EMC from the log-normal distribution. Uncertainty in *P*-values due to event data availability increases dramatically with reduced number of events in a data series. The power of the Mann-Kendall test for detecting a trend is highly dependent on the number of available events in a data series. It is highly probable to reject the presence of a trend when applied to a short data series (for instance, the probability for the rejection of a trend in a data series of 100 events is 70%), in contrast to the presence of a trend in a data series of 521 events confirmed with a high probability of 99%. This implies that a lack of event data may lead to a false indication of trend presence.

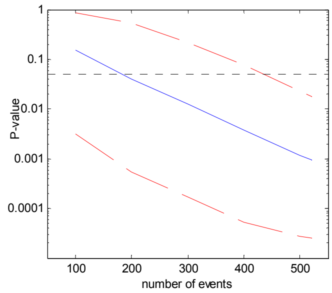

Figure 1. *P*-values for the Hypothesis H_0 of no trend in EL of TSS with different numbers of events

4 CONCLUSIONS

This study addresses hydrological and water quality trend analysis in urban catchments. Based on trend analysis of rainfall and runoff relevant variables as well as TSS in the Chassieu catchment, the following conclusions can be drawn: 1) A trend is absent in the driving force (precipitation) of the hydrological process, while an increasing trend is found in the urban runoff, likely due to increasing urbanization. 2) The EMC of TSS does not present a trend, whereas the EL is likely to show an increasing tendency. 3) The major uncertainty source in trend detection results is missing events rather than measurement uncertainty. The results are of importance for better understanding urban stormwater hydrology and quality, which may further benefit evaluating and controlling the impact of stormwater on natural water and environment.

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