Science of the Total Environment 553 (2016) 519–523

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Comparative analysis of water quality and toxicity assessment methods for urban highway runoff

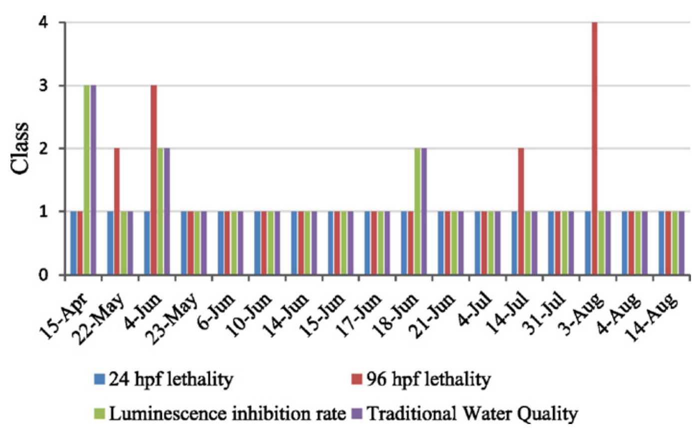
Rui-Hong Chen [a], Fei-Peng Li [b,*], Hai-Ping Zhang [a], Yue Jiang [c], Ling-Chen Mao [b], Ling-Ling Wu [a], Ling Chen [a]

[a] Key Laboratory of Yangtze River Water Environment, Ministry of Education, College of Environmental Science and Engineering, Tongji University, Shanghai 200092, China
[b] School of Environment and Architecture, University of Shanghai for Science and Technology, Shanghai 200093, China
[c] Shenyang Urban Planning Design and Research Institute, Shenyang 110004, China

HIGHLIGHTS

- Urban runoff biotoxicology was assessed by Nemerow index and biotoxicity tests.
- Nemerow index cannot reflect the mixture toxicity and main pollutants in runoff.
- Zebrafish embryo and luminescent bacteria are sensitive to contaminants in runoff.
- Three indexes of biotoxicity test were proposed for runoff biotoxicology assessment.

GRAPHICAL ABSTRACT



Water quality grade of runoff samples based on different assessment indexes, including the traditional water quality assessment method and biotoxicity tests, using zebrafish (*Danio rerio*) embryos and luminous bacteria (*Vibrio qinghaiensis. Q67*).

ARTICLE INFO

Article history:
Received 4 November 2015
Received in revised form 19 February 2016
Accepted 19 February 2016
Available online 28 February 2016

Editor: D. Barcelo

Keywords:
Highway runoff
Water quality
Toxicity
Assessment method

ABSTRACT

In this study, comparative analyses of highway runoff samples obtained from seventeen storm events have been conducted between the traditional water quality assessment method and biotoxicity tests, using zebrafish (*Danio rerio*) embryos and luminous bacteria (*Vibrio qinghaiensis. Q67*) to provide useful information for ecotoxicity assessment of urban highway runoff. The study results showed that the Nemerow pollution index based on US EPA recommended Criteria Maximum Concentrations (CMC) (as traditional water quality assessment method) had no significant correlation with luminous bacteria acute toxicity test results, while significant correlation has been observed with two indicators of 72 hpf (hours post fertilization) hour hatching rate and 96 hpf abnormality rate from the toxicity test with zebrafish embryos. It is therefore concluded that the level of mixture toxicity of highway runoff could not be adequately measured by the Nemerow assessment method. Moreover, the key pollutants identified from the water quality assessment and from the biotoxicity evaluation were not consistent. For biotoxic effect evaluation of highway runoff, three indexes were found to be sensitive, i.e. 24 hpf lethality and 96 hpf abnormality of zebrafish embryos, as well as the inhibition rate for luminous bacteria *Q67*. It is therefore recommended that these indexes could be incorporated into the traditional Nemerow method to provide a more reasonable evaluation of the highway runoff quality and ecotoxicity.

* Corresponding author.
E-mail address: leefp@126.com (F.-P. Li).

http://dx.doi.org/10.1016/j.scitotenv.2016.02.143
0048-9697/

1. Introduction

Urban highway runoff has been considered as one of the major sources of organic, heavy metal and nutrient pollution (Ngabe et al., 2000; Davis et al., 2001; Huang et al., 2004; Zhu et al., 2009) in particular in China with the increase of infrastructure construction during the rapid urbanization process in recent years. Storm runoff carrying various pollutants (such as PAHs, biocides, heavy metals and nutrients) accumulated on roads converges into the water body, significantly threatening nearby aquatic habitats (Marsalek et al., 1999; Gobel et al., 2007; Wei et al., 2010). Contaminants in urban runoff have several characteristics including wide temporal and spatial distribution of contamination sources, randomness and diversity of pollution pathways, as well as complication and variation in pollution composition (Li et al., 2008; Lee et al., 2011; Xie et al., 2012; Zhang et al., 2011; Petrucci et al., 2014). There are more than 600 potential contaminants in rainwater and runoff (Eriksson et al., 2007), often with remarkable spatial and temporal variation in both composition and concentration (Eriksson et al., 2005; Kayhanian et al., 2008; Chen and Zhou, 2009). It is neither cost-effective nor necessary to make a 'full-scan' of those contaminants in terms of concentration and ecological effects. With wide application of low impact development (LID) approaches to managing stormwater runoff in China and around the world, greater efforts will be made on the development of runoff evaluation methods concerning both the contaminants and the associated ecological risks.

Different urban land uses usually have different features of pollutant composition and concentration in stormwater runoff, and physicochemical tests often fail to indicate the toxicity level of highway runoff since they do not take into consideration the synergistic effects of these pollutants (Grant et al., 2003); whereas toxicity assessment has the advantage of providing the information of mixture toxicity, but is unable to trace the sources of contamination (Wu et al., 2014). The purpose of this study is to compare the information obtained from the Nemerow water quality assessment and biotoxicity tests of runoff samples collected from a highway in Shanghai, China in an attempt to develop a new assessment method for highway runoff by combining traditional physicochemical analysis and biotoxicity tests in the future.

2. Material and methods

2.1. Sampling and analysis

Highway runoff samples were collected during seventeen rainfall events from April to August 2011, with both grab and composite samples at the end of downpipes located in a downtown area of Shanghai using polyethylene or glass bottles with polypropylene lids. Three grab samples were collected every 15 min throughout the rainfall events of 15th April, 22nd May and 4th June, lasting for 60, 30 and 30 min, respectively. The other fourteen composite samples, of equal volume, were collected throughout the rainfall. In addition, three parallel samples were taken for all the rainfall events.

Samples contained in polyethylene bottles were used for the analysis of TSS, COD_{Cr}, TN, TP, TOC and eleven heavy metals. Specifically, TOC was analyzed with the Shimadzu TOC-VCPN with the solid sample module (SSM-5000A, Japan), with an overall standard deviation of measurements <3% (n = 3); whereas the concentration of eleven heavy metals (As, Se, Zn, Pb, Cd, Ni, Fe, Mn, Cr, Cu and Al) was determined with ICP-AES (Optima 2100 DV, Perin Elmer, USA) after HCl/HNO_3 acidification.

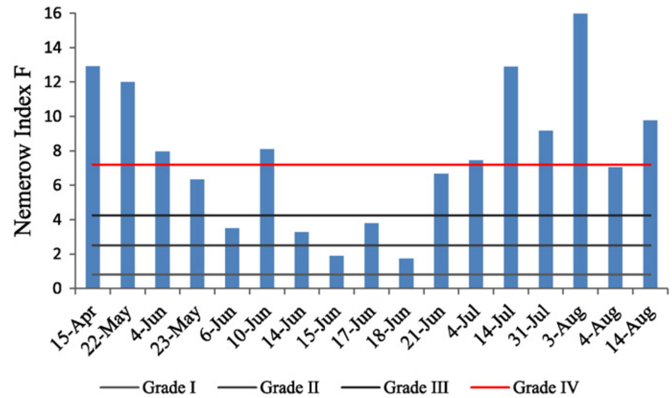


Fig. 1. Nemerow index F and water quality grade of runoff samples.

The rest of the samples preserved in glass bottles and kept in a dark place under 4 °C were used for the PAHs analysis and biotoxicity tests, with 0.45 μm mesh glass microfiber membrane filtration prior to toxicity testing using either zebrafish (*Danio rerio*) embryo or luminous bacteria (*Vibrio qinghaiensis. Q67*). Descriptions of the methods were provided in Zhang et al. (2014) and Jiang (2012) for PAHs determination and in Wu et al. (2014) for biotoxicity testing. All measurements were carried out within 36 h of sample collection except for zebrafish embryo toxicity tests which required a longer period of exposure.

2.2. Water quality assessment

The Nemerow pollution index assessment is one of the most popular methods used in water quality assessment (Gu et al., 2002), which has the advantages of easy processing, simple calculation and a clear physical concept. However, the traditional Nemerow assessment method has been criticized owing to its over-emphasis on the effect of the most essential pollution component for water quality, which actually might not be the largest threat to human health. Therefore an improved version of the Nemerow index was adopted in this study to take into consideration the weight of all the factors (Li et al., 2009).

As a direct reflection of the influence of highway runoff pollution on aquatic organisms, biotoxicity assessment could provide useful information for toxicity studies of runoff, especially the combined toxicity from the chemical components, as well as the influence of environmental factors on chemical toxicity. Therefore, biotoxicity assessment was adopted for the evaluation of the potential ecological risk of urban highway runoff.

3. Results and discussion

3.1. Runoff quality

There was a wide range of TSS, COD_{Cr} and TOC concentrations in highway runoff samples, which varied from 82 to 7610 mg L^{-1}, 5 to 535 mg L^{-1} and 8.64–164.2 mg L^{-1}, respectively. For TN and TP, the concentrations ranged from 2.62 to 9.99 mg L^{-1} and 0.35–2.28 mg L^{-1}, respectively. According to the National Standard of Surface Water Quality of China (GB3838-2002), the runoff was highly contaminated and categorized as Grade V or worse (the poorest grade) due to

Table 1
Weights Wi of pollution factor of urban highway runoff.

	COD_{Cr}	TN	TP	TOC	As	Se	Zn	Pb	Ni	Fe	Mn	Cr	Cu	Al	PAHs
Weights Wi	3.35×10^{-4}	9.44×10^{-3}	2.14×10^{-1}	3.35×10^{-4}	1.97×10^{-2}	3.60×10^{-2}	5.58×10^{-2}	1.03×10^{-1}	1.43×10^{-2}	6.70×10^{-3}	2.91×10^{-3}	1.14×10^{-2}	5.15×10^{-1}	8.93×10^{-3}	1.12×10^{-3}