Science of the Total Environment 479–480 (2014) 233–240

Contents lists available at ScienceDirect

Science of the Total Environment

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

A Bayesian regression approach to assess uncertainty in pollutant wash-off modelling

Prasanna Egodawatta [a], Khaled Haddad [b], Ataur Rahman [b], Ashantha Goonetilleke [a,*]

[a] *Science and Engineering Faculty, Queensland University of Technology, GPO Box 2434, Brisbane 4001, Australia*
[b] *School of Computing, Engineering and Mathematics, University of Western Sydney, Building XB, Locked Bag 1797, Penrith, NSW 2751, Australia*

HIGHLIGHTS

- Water quality data is inherently uncertain leading to significant model uncertainty.
- Quantifying uncertainty is very important in stormwater management decision making.
- Uncertainty assessed for pollutant wash-off modelling using WLSR and OLSR methods.
- Bayesian/Gibbs sampling regression framework proposed to assess model uncertainty.
- WLSR method can provide more realistic uncertainty estimates than the OLSR method.

ARTICLE INFO

Article history:
Received 8 October 2013
Received in revised form 27 January 2014
Accepted 2 February 2014
Available online 21 February 2014

Keywords:
Model uncertainty
Stormwater quality
Pollutant wash-off
Bayesian analysis
Monte Carlo simulation
Stormwater pollutant processes

ABSTRACT

Due to knowledge gaps in relation to urban stormwater quality processes, an in-depth understanding of model uncertainty can enhance decision making. Uncertainty in stormwater quality models can originate from a range of sources such as the complexity of urban rainfall–runoff-stormwater pollutant processes and the paucity of observed data. Unfortunately, studies relating to epistemic uncertainty, which arises from the simplification of reality are limited and often deemed mostly unquantifiable. This paper presents a statistical modelling framework for ascertaining epistemic uncertainty associated with pollutant wash-off under a regression modelling paradigm using Ordinary Least Squares Regression (OLSR) and Weighted Least Squares Regression (WLSR) methods with a Bayesian/Gibbs sampling statistical approach. The study results confirmed that WLSR assuming probability distributed data provides more realistic uncertainty estimates of the observed and predicted wash-off values compared to OLSR modelling. It was also noted that the Bayesian/Gibbs sampling approach is superior compared to the most commonly adopted classical statistical and deterministic approaches commonly used in water quality modelling. The study outcomes confirmed that the predication error associated with wash-off replication is relatively higher due to limited data availability. The uncertainty analysis also highlighted the variability of the wash-off modelling coefficient *k* as a function of complex physical processes, which is primarily influenced by surface characteristics and rainfall intensity.

1. Introduction

Stormwater quality modelling is based on the mathematical replication of fundamental stormwater pollutant processes, namely, pollutant build-up and wash-off. The mathematical replication of these processes involves simplification of reality dictated by the limitations of the knowledge base. This results in uncertainty in the overall modelling approach and consequently, the outcomes derived. Typically, the sources of uncertainty in relation to computer models can be categorised as structural, epistemic, parametric and experimental. The structural and epistemic uncertainties arise from the lack of knowledge of underlying physical processes and simplification of known scientific knowledge in modelling practices, respectively. These are mostly associated with conceptual model development and mathematical replication. Parametric uncertainties arise from the use of unknown or lumped parameters to represent reality while experimental uncertainty is associated with the use of measured data in modelling approaches including uncertainty associated with sampling procedure (Merz and Thieken, 2005; Oberkampf et al., 2002). Both, parametric and experimental uncertainties arise during simulations and the generation of numerical solutions (Dotto et al., 2014).

Knowledge of model uncertainty is an essential element in informed decision making (Bertrand-Krajewski et al., 2002). In particular, an understanding of uncertainty in stormwater quality modelling outcomes is important for effective stormwater treatment system design, receiving water impact assessment and for evaluating model reliability (Freni et al., 2009). A range of studies have focused on assessing uncertainty

---

* Corresponding author. Tel.: +61 731381539; fax: +61 731381170.
E-mail address: a.goonetilleke@qut.edu.au (A. Goonetilleke).

0048-9697/$ – see front matter © 2014 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.scitotenv.2014.02.012

in stormwater quality modelling approaches. For example, Bertrand-Krajewski (2007), Liu et al. (2012a,b) and Sohrabi et al. (2003) have focused on parametric and/or experimental uncertainties associated with stormwater quality modelling while Dotto et al. (2012), Freni et al. (2008) and Kanso et al. (2005) have focused on assessing the overall uncertainty of stormwater quality models. There have been limited studies undertaken on assessing the structural and epistemic uncertainties associated with the processes embedded in stormwater quality models, which are commonly deemed as being unquantifiable.

Providing essential insight into structural and epistemic uncertainties of stormwater quality models is important. In estimating these uncertainties, regression-based techniques are often adopted, e.g. Ordinary Least Squares Regression (OLSR) (e.g. Driver and Tasker, 1988; Zoppou, 2001; Rahman et al., 2002; Haddad et al., 2013), Weighted Least Squares Regression (WLSR) (Stedinger and Tasker, 1985; Haddad et al., 2010) and Generalised Least Squares Regression (GLSR) (Reis et al., 2005; Haddad and Rahman, 2012; Haddad et al., 2012; Micevski et al., 2014). In this context, this paper discusses a statistical modelling framework for determining structural and epistemic uncertainties associated with the replication of pollutant wash-off from urban roof surfaces using regression-based techniques. Previously, Haddad et al. (2013) investigated uncertainties associated with the replication of the pollutant build-up process using Bayesian OLSR and WLSR. The statistical framework adopted for the study discussed in this paper entailed a significant extension of the Haddad et al. (2013) study. The reasons being, the involvement of different and complex physical processes in pollutant wash-off compared to build-up and the range of parameters influencing the wash-off process and consequently, the resulting dataset created. This led to the use of an enhanced Bayesian methodology for the intended statistical framework development. Bayesian based frameworks were selected for this study due to its superiority in assessing the wash-off process with coefficients expressing behavioural parameters (Dotto et al., 2012; Freni and Mannina, 2010).

Investigations by Egodawatta et al. (2009) have confirmed that the pollutant wash-off process for road and roof surfaces, which are the primary impervious surfaces in an urban catchment are mathematically similar despite the differences in surface and pollutant load characteristics. They have noted that these differences can be accounted by utilising different sets of coefficients for the same exponential equation for roads and roofs. Therefore, the application of uncertainty analysis to roof surfaces is easily extendable to road surfaces. Furthermore, as noted by Egodawatta et al. (2012), in an urban catchment, the total roof area can be 2–3 times greater than the total road area with the clear potential to contribute relatively high pollutant loads compared to road surfaces.

2. Materials and methods

This research study used roof wash-off data collected at a number of study sites located in South East Queensland, Australia. Wash-off samples were collected from model roofs used as test plots (3 m^2). This approach eliminated the possible heterogeneity in pollutant distribution and the practical difficulties in collecting pollutant wash-off samples from actual roof surfaces. The model roofs were mounted on a scissor lift arrangement as shown in Fig. 1. The roofs were raised to the typical roofing height to enable pollutant accumulation under a typical urban-setting and then lowered to ground level for wash-off sample collection using a rainfall simulator as discussed below. Two roofing products, corrugated steel and concrete tiles were used for cladding since these products are the most widely used roofing materials in the study region. The roofing angle used was 20°. The model roofs were placed in an area which is mostly residential with a few major roads in the vicinity. Further details on the wash-off sampling, including the solid loads initially available on roofs, fraction wash-off for different rainfall durations and particle size distribution in the wash-off are available in Egodawatta et al. (2009).

2.1. Rainfall simulation

Simulated rainfall was used for the pollutant wash-off investigation on the model roof surfaces. This approach was adopted to eliminate the dependency on naturally occurring rainfall events due to their inherent variability and provided better control over influential variables such as rainfall intensity and duration. A specially designed rainfall simulator was used to simulate the rainfall events. The simulator was designed to replicate natural rainfall events as closely as possible based on two key rainfall characteristics, namely, drop size distribution and kinetic energy of rain drops (Hudson, 1963; Rosewell, 1986). Details on the design and operation of the rainfall simulator can be found in Herngren et al. (2005).

2.2. Sample collection

Sample collection was undertaken in two phases. Firstly, half of each roof surface was used to collect build-up samples by washing the

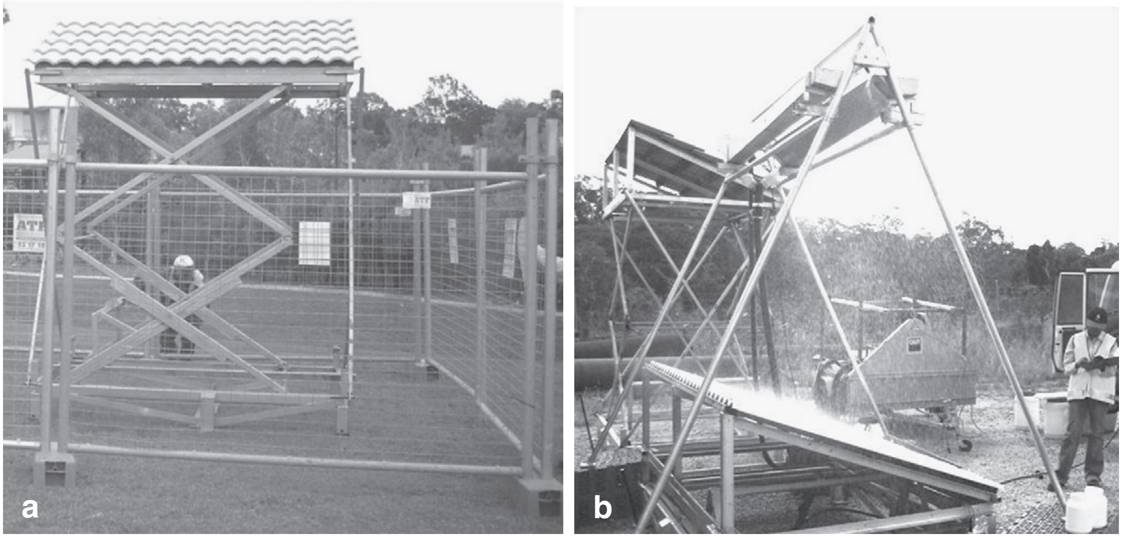

Fig. 1. Model roof surfaces: (a) model roofs with the scissor lift arrangement; (b) pollutant wash-off investigation using the rainfall simulator.