Journal of Hydrology 533 (2016) 200–212

Contents lists available at ScienceDirect

Journal of Hydrology

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

Developing a stochastic conflict resolution model for urban runoff quality management: Application of info-gap and bargaining theories

Seyed Hamed Ghodsi [a], Reza Kerachian [b,*], Siamak Malakpour Estalaki [a], Mohammad Reza Nikoo [c], Zahra Zahmatkesh [a]

[a] School of Civil Engineering, College of Engineering, University of Tehran, Tehran, Iran
[b] School of Civil Engineering and Center of Excellence for Engineering and Management of Civil Infrastructures, College of Engineering, University of Tehran, Tehran, Iran
[c] School of Civil Engineering, Department of Civil and Environmental Engineering, Shiraz University, Shiraz, Iran

ARTICLE INFO

Article history:
Received 10 July 2015
Received in revised form 7 November 2015
Accepted 29 November 2015
Available online 8 December 2015
This manuscript was handled by Geoff Syme, Editor-in-Chief

Keywords:
Urban runoff
Low Impact Development (LID)
SWMM
Uncertainty analysis
Info-gap theory
Bargaining theory

SUMMARY

In this paper, two deterministic and stochastic multilateral, multi-issue, non-cooperative bargaining methodologies are proposed for urban runoff quality management. In the proposed methodologies, a calibrated Storm Water Management Model (SWMM) is used to simulate stormwater runoff quantity and quality for different urban stormwater runoff management scenarios, which have been defined considering several Low Impact Development (LID) techniques. In the deterministic methodology, the best management scenario, representing location and area of LID controls, is identified using the bargaining model. In the stochastic methodology, uncertainties of some key parameters of SWMM are analyzed using the info-gap theory. For each water quality management scenario, robustness and opportuneness criteria are determined based on utility functions of different stakeholders. Then, to find the best solution, the bargaining model is performed considering a combination of robustness and opportuneness criteria for each scenario based on utility function of each stakeholder. The results of applying the proposed methodology in the Velenjak urban watershed located in the northeastern part of Tehran, the capital city of Iran, illustrate its practical utility for conflict resolution in urban water quantity and quality management. It is shown that the solution obtained using the deterministic model cannot outperform the result of the stochastic model considering the robustness and opportuneness criteria. Therefore, it can be concluded that the stochastic model, which incorporates the main uncertainties, could provide more reliable results.

1. Introduction

Population growth, changing land use patterns and climate variability and change are affecting the quantity and quality of surface runoff in urban areas. Considering increased water demand along with water shortage, surface runoff can be managed to be used for recreational and outdoor water uses sometimes after partial purification (Jia et al., 2014). Therefore, runoff quality and quantity control and management in urban areas are of great importance. Best management practices (BMPs) and Low Impact Development (LID) measures are tools which can be effectively utilized for this purpose. LID techniques such as green roofs, rain gardens, bio-retention cells, detention/retention ponds, porous pavements and rainwater harvesting are cost effective alternatives that can be used for land planning and engineering design to manage runoff quality and quantity in urban areas. LIDs are usually designed to be economically and environmentally efficient in reducing pollutants concentration in urban runoff and/or changing that runoff hydrograph.

In the past decades, many studies have been done to investigate the efficiency of LIDs for urban water quantity and quality management (e.g. Montalto et al., 2007; van Roon, 2007; Gilroy and McCuen, 2009; Pyke et al., 2011; Qin et al., 2013; Joksimovic and Alam, 2014; Sin et al., 2014; Zahmatkesh et al., 2014; Jia et al., 2015; Liu et al., 2015).

In recent years, the tendency for using optimization models to determine the optimal characteristics of LIDs has been increased. Location and area of different types of LIDs in an urban area should be optimized for controlling quantity and quality of urban runoff. Jia et al. (2012), Lee et al. (2012) and Yazdi and Neyshabouri (2014) are examples of who have worked on optimal design of LIDs in urban and suburban areas. To identify ideal LID design and location in urban catchments, characterizing the tradeoff curves

* Corresponding author.
E-mail addresses: hamed.ghodsi@ut.ac.ir (S.H. Ghodsi), kerachian@ut.ac.ir (R. Kerachian), malakpour@ut.ac.ir (S.M. Estalaki), nikoo@shirazu.ac.ir (M.R. Nikoo), zhr_zahmatkesh@yahoo.com (Z. Zahmatkesh).

http://dx.doi.org/10.1016/j.jhydrol.2015.11.045
0022-1694/

between LID performance indicators and costs is crucial to defensible urban stormwater management decision-making (Giacomoni, 2015). Therefore, multi-objective optimization or multi-attribute decision making techniques have been employed in several studies to determine optimal LID implementation strategies for urban stormwater runoff quality and quantity control. Jia et al. (2013), for example, developed a multi-criteria index ranking system for selecting LIDs for urban storm water management. Chiang et al. (2014) compared the selection and placement of LIDs in Lincoln Lake CEAP[1] watershed, using multi-objective optimization and targeting methods. Objective functions in their optimization model were minimizing LID placement areas and pollutant losses.

Using partially treated urban runoff, as a new source of water, often causes conflict of interests among stakeholders, who would like to improve only their own utilities. Game theory can be used to describe interactions among different players, who give preference to their own utilities. Outputs of the game theory, which are based on each player's utility function, usually differ from outcomes of optimization techniques (Madani, 2010). Madani (2010) reviewed application of game theory to water resources management problems and demonstrated the dynamic structure of water resource problems and the importance of considering the game's evolution path. As a branch of game theory, bargaining theory can be applied where conflicts exist over how to share a resource of a finite size among different stakeholders. In the bargaining problems, it should be determined that which strategies and consequently agreements have to be taken to be accepted by all stakeholders. Applications of bargaining theory in urban water resources management have been very limited. Bazargan-Lari et al. (2009) developed a surface and groundwater allocation model for urban and suburban areas using the Young bargaining theory. Kerachian et al. (2010) proposed a fuzzy bargaining model based on Rubinstein Theory to resolve conflicts among different water users in an urban region in Tehran, Iran. Rafipour-Langeroudi et al. (2014) utilized the Nash and Young bargaining theories for conflict resolution among different stakeholders, which are involved in surface and groundwater quantity and quality management in urban areas. In decision making for urban runoff quantity and quality management, incorporating uncertainties is important especially when some input data and parameters such as urban watershed characteristics are scarce or incomplete. In such cases, application of probabilistic models would be difficult because of insufficient information. Modeling under uncertainty, which seeks to identify robust rather than optimal decisions, can be an appropriate choice for urban water quantity and quality management. A robust policy acts satisfactorily over a broad range of possible future scenarios. Lempert and Collins (2007), for example, used a simulation model to compare optimal and robust decision making under uncertainty. They revealed that robust strategies are preferable to optimum ones especially when the uncertainty is considerable. In addition to robust decision making, Information-gap (info-gap) theory also provides a structured approach to planning under uncertainty (Lempert et al., 2003). Both approaches have been applied to a variety of water management problems (e.g., Groves and Lempert, 2007; Lempert and Groves, 2010). Info-gap theory efficiently portrays system performance with robustness and opportuneness variation plots summarizing system performance for different plans under the most desire and favorable sets of future conditions (Matrosov et al., 2013). Info-gap is a basic approach for decision making, especially when limited data are available with high level of uncertainty (Hipel and Ben-Haim, 1999). Lempert et al. (2003) defined deep uncertainty as the condition in which analysts do not know the probability distributions or fuzzy membership functions to represent uncertainty about main parameters in the models and/or how to value the desirability of outcomes of different scenarios.

[1] Conservation Effects Assessment Project (CEAP).

Uncertainty as the size of the gap between what is known and what could be known could be quantified by info-gap models. Being weaker characterizations of uncertainty than probability models, info-gap models are usually more readily verified when limited information is available (Ben-Haim, 1999). These models are tools that compare candidate strategies performance under a wide range of plausible futures (robustness) and their potential for rewards (opportuneness) under favorable future scenarios (Hall et al., 2012). Ben-Haim (1999) formulated structural design codes based on info-gap models of uncertainty rather than probabilistic and possibilistic concepts. Hipel and Ben-Haim (1999) utilized a number of problems in watershed management to explain how info-gap can be employed in practice. Matrosov et al. (2013) applied robust decision making and info-gap theory to the problem of London's water supply system expansion in the Thames basin, UK. Kasprzyk et al. (2013) introduced multi-objective robust decision making frameworks, and applied it to a case study in the Lower Rio Grande Valley in Texas, USA. Results showed that including robustness, as a decision making criterion, can dramatically change the formulation of environmental management problems and the negotiated selection of candidate alternatives to implement.

The main purpose of this study is to provide a general stochastic conflict resolution framework for controlling runoff quality and quantity in an urban watershed, considering the main existing uncertainties in rainfall–runoff modeling process. We propose a computational model which simulates the process of negotiation among stakeholders involved in an urban stormwater management problem using SWMM simulation model, bargaining models and info-gap theory.

In the following, the proposed methodology is presented and explained in detail. Then, the case study is described and finally the results and conclusion are presented and discussed.

2. Methodologies

In the following sections, details of the proposed deterministic and stochastic methodologies are presented:

2.1. Deterministic approach

In the deterministic methodology, all models' parameters are assumed to be known with certainty. As presented in Fig. 1, this approach includes six main steps.

2.1.1. Data collection

Different data sets related to rainfall time series, topographic and hydrologic characteristics of the watershed in the study area, pollution loads, characteristics of stakeholders and their preferences as well as Low Impact Development (LID) practices are collected and used. The collected data is used for calibrating the urban runoff quantity and quality model (i.e. SWMM) and developing optimization and bargaining models.

2.1.2. Design rainfall

Intensity and duration of rainfall play a vital role in urban runoff quality and quantity management and consequently designing LIDs in urban areas. Rainfalls with return periods of 2, 10, 25, 50 and 100 years have been used for designing different flood control facilities. The design rainfalls can be determined by frequency