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A multi-stakeholder framework for urban runoff quality management: Application of social choice and bargaining techniques

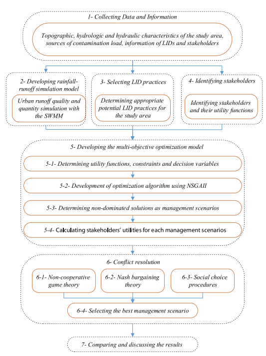
Seyed Hamed Ghodsi [a], Reza Kerachian [b,*], Zahra Zahmatkesh [a]

[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

HIGHLIGHTS

- Urban runoff quality is managed using bargaining and social choice theories.
- The SWMM is used to simulate stormwater runoff quality and quantity.
- The methodologies are applied to the Velenjak urban watershed, Tehran, Iran.
- Utility functions are based on minimizing LIDs' costs, runoff volume and pollution.

GRAPHICAL ABSTRACT



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ABSTRACT

In this paper, an integrated framework is proposed for urban runoff management. To control and improve runoff quality and quantity, Low Impact Development (LID) practices are utilized. In order to determine the LIDs' areas and locations, the Non-dominated Sorting Genetic Algorithm-II (NSGA-II), which considers three objective functions of minimizing runoff volume, runoff pollution and implementation cost of LIDs, is utilized. In this framework, the Storm Water Management Model (SWMM) is used for stream flow simulation. The non-dominated solutions provided by the NSGA-II are considered as management scenarios. To select the most preferred scenario, interactions among the main stakeholders in the study area with conflicting utilities are incorporated by utilizing bargaining models including a non-cooperative game, Nash model and social choice procedures of Borda count and approval voting. Moreover, a new social choice procedure, named pairwise voting method, is proposed and applied. Based on each conflict resolution approach, a scenario is identified as the ideal solution providing the LIDs' areas, locations and implementation cost. The proposed framework is applied for urban water quality and quantity management in the northern part of Tehran metropolitan city, Iran. Results show that the proposed pairwise voting method tends to select a scenario with a higher percentage of reduction in TSS (Total Suspended Solid) load and runoff volume, in comparison with the Borda count and approval voting methods. Besides, the Nash method presents a management scenario with the highest cost for LIDs' implementation and the maximum values for percentage of runoff volume reduction and TSS removal. The results also signify that selection of an appropriate management scenario by stakeholders in the study area depends on the available

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

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financial resources and the relative importance of runoff quality improvement in comparison with reducing the runoff volume.

1. Introduction

Population growth, increasing rate of development and climate variability are driving forces threatening the quality and quantity of water resources in urban areas. Shifting scale to rainfall–runoff process in urban watersheds; when runoff volume is more than the drainage system capacity, it can be managed and used for recreational and outdoor water uses. Low Impact Development (LID) measures are economically and environmentally efficient tools for runoff quality and quantity management and control in urban watersheds (Zahmatkesh et al., 2014).

Speaking of urban runoff, selection of appropriate management scenarios depends on more than one objective, such as increasing runoff quality and quantity while decreasing the implementation costs of the LIDs. Therefore, to find the most preferred scenario for urban runoff management, multi-objective optimization tools are preferably used. The NSGA-II (Deb et al., 2002), for instance, has been proved to be an effective and efficient multi-objective search technique in various urban management applications. In the current paper, the NSGA-II algorithm is used for optimizing areas and locations of different LID measures. Details of this algorithm and its applications in water resources management can be found in Nazemi et al. (2006), Muschalla (2008), Nikoo et al. (2014), and Rafipour-Langeroudi et al. (2014).

Usually, in decision-making problems in urban watersheds, more than two stakeholders with different interests are involved. The non-dominated solutions obtained from the optimization problem, are considered as management scenarios of the main stakeholders in the bargaining model. Conflict is known as the disagreement among stakeholders that differ in attitudes, beliefs, values or needs (Karamouz et al., 2006). When conflict exists among stakeholders, the preferred action is to reach an agreement mostly through bargaining. Bargaining can be performed using cooperative and non-cooperative game theoretic approaches. Game theory is defined as the study of the interactions among different decision makers with conflicting objectives. It provides systematic pattern to plan strategies for providing resolutions of conflicting situations. To deal with conflicts among different stakeholders, Nash cooperative bargaining theory is also an alternative modeling approach. This theory is one of the most effective methods in bargaining problems which incorporates the utility functions of the decision makers and the stakeholders, and their relative authorities (Nash, 1950). Bargaining methods and game theory can be used to find the stable solution for the decision making problems (Madani et al., 2014). Modeling bargaining processes have been performed by different researchers such as: Dinar et al. (1992) for regional cooperation in the use of irrigation water; Shahidehpour et al. (2001) to consider the problem of optimizing hydropower generation; Kerachian and Karamouz (2006, 2007) for water quality management in river–reservoir systems; Kerachian et al. (2010) for surface and groundwater quality management in urban areas; Skardi et al. (2013) for best management practice (BMP) cost allocation among landowners in a watershed; Rafipour-Langeroudi et al. (2014) for conjunctive use of surface and groundwater resources; Safari et al. (2014) to resolve conflicts among different water users and water suppliers while considering environmental requirements and the system's constraints and Parsapour-Moghaddam et al. (2015) to determine evolutionary stable equilibrium strategies for conjunctive surface and groundwater allocation to stakeholders with conflicting benefits.

Similar to the game theory and Nash bargaining model, social choice theory is concerned with relationships between individuals' preferences (Fishburn, 1973). Social choice procedures are also applicable to reach some level of cooperation in multi-criteria decision making problems. Social choice procedures can produce outputs which fall between non-cooperative game theory/bargaining approaches and multi-criteria decision making approaches (Madani et al., 2014). The basic objective of social choice is to combine individual preferences into a collective choice. When individual utility functions are combined, the aggregation could be interpreted as a social welfare function (Martin et al., 1996). Examples to use social choice theory in hydro-environmental management problems are as follows. d'Angelo et al. (1998) applied social choice procedures to solve a water resources management problem in Northern Arizona. They used social choice procedures of plurality voting, pairwise voting and dictatorship. These procedures can be applied when several alternatives are simultaneously ranked by different decision makers, with conflicting utilities. Srdjevic (2007) investigated different contexts in modeling decentralized decision problems in water management. He used analytic hierarchy process and social choice methods to support group decision making. Madani et al. (2014) applied several commonly used voting methods to solve a multi-stakeholder water management problem. Comprehensive examples of social choice procedures can be found in Taylor (1995), McNutt (1996), d'Angelo et al. (1998), Kelly (2013), Laukkanen et al. (2002), Mahjouri and Bijani-Manzar (2013) and Mahjouri and Abbasi (2015).

This paper discusses the importance of incorporating conflicting utilities of stakeholders in integrated runoff quality and quantity management. The proposed framework is used for a real world case study, Velenjak urban watershed in Tehran, Iran, which is simulated utilizing the SWMM (Storm Water Management Model) rainfall–runoff model.

Surface runoff in Tehran is an important source for watering landscapes and garden plants as well as irrigation of agricultural lands. High population, industrial activities and climatic attributes negatively impact the runoff quality. Different agencies are involved in the decision making process for controlling runoff quality and quantity, each suggesting different and sometimes diverse management scenarios. Therefore, studies are required to be conducted in order to provide an integrated scheme for runoff quality and quantity management. Application of the proposed methodology helps incorporate the main factors affecting successful modeling of runoff quality and quantity in urban areas.

2. Methodology

A framework is proposed for improving runoff quality and quantity considering existing conflict of interests among different stakeholders. In this framework, a set of simulation, optimization and bargaining models are incorporated. The SWMM rainfall–runoff model is used for runoff simulation. Main stakeholders are identified and the corresponding utility functions are formulated. An optimization algorithm is developed using the NSGA-II and linked with the SWMM to find the Pareto optimal solutions. Location and area for different types of LIDs are the decision variables in the optimization model.

To select the most preferred solution (management scenario), different social choice and *n*-person bargaining models are utilized. Flowchart of the proposed methodology is presented in Fig. 1. Details of different steps of the proposed methodology and applied tools and models are presented in the following.

2.1. Data collection

In order to develop the methodology and apply it for a real world case study, different data sets are used. These data include observed