



Research article

A framework to support decision making in the selection of sustainable drainage system design alternatives



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ABSTRACT

This paper presents a new framework for decision making in sustainable drainage system (SuDS) scheme design. It integrates resilience, hydraulic performance, pollution control, rainwater usage, energy analysis, greenhouse gas (GHG) emissions and costs, and has 12 indicators. The multi-criteria analysis methods of entropy weight and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) were selected to support SuDS scheme selection. The effectiveness of the framework is demonstrated with a SuDS case in China. Indicators used include flood volume, flood duration, a hydraulic performance indicator, cost and resilience. Resilience is an important design consideration, and it supports scheme selection in the case study. The proposed framework will help a decision maker to choose an appropriate design scheme for implementation without subjectivity.

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1. Introduction

Storm drainage systems are traditionally designed to meet the standards of design storm and design flooding return periods (Butler and Davies, 2011). Now, due to urbanization and climate change, such designed systems are increasingly threatened (Mugume and Butler, 2016) and urban flooding has occurred in many cities around the world. As such, sustainable drainage systems (SuDS), low impact development (LID), water sensitive urban design (WSUD) and spongy cities are receiving more and more attention (Fletcher et al., 2015; Jia et al., 2013; Qin et al., 2013).

Construction of SuDS utilizes a series of SuDS components (such as green roof, bioretention, pervious pavement, swale, etc., also called LID techniques, LID practices or LID controls) (Chui et al., 2016; Joyce et al., 2017; Qin et al., 2013). Because of the variety of options available, many scheme designs are possible. At present, there are a number of literature on comparison and selection of SuDS alternatives, but the indicators used are not the same (Jia et al., 2013; Liu et al., 2016; Zhang et al., 2013). Zhang et al.

(2013) selected SuDS solutions based on the total SuDS components costs and the total watershed runoff volume constrained by pre-development peak flow rates. Jia et al. (2013) proposed a set of SuDS components selection indices, which consist of 12 first-level indices (site conditions, soil characteristics, groundwater characteristics, topography, catchment properties, space requirement, runoff quantity control, runoff quality control, additional benefits, capital cost, operation and maintenance, and system reliability). Liu et al. (2016) developed a decision support tool to optimally select best management practices and LID practices to obtain maximum environmental benefits (minimum runoff and pollutant loads) with minimum costs. However, these frameworks to optimally select SuDS schemes have not considered system resilience.

Resilience is defined as “the degree to which the system minimizes level of service failure magnitude and duration over its design life when subject to exceptional conditions” (Butler et al., 2014). For system design, it is necessary to consider resilience to extreme conditions (Butler et al., 2014; Sweetapple et al., 2016). Mugume et al. (2015) and Mugume and Butler (2016) investigated structural and functional resilience in urban drainage systems using a global analysis approach and concluded that “the developed approach can be applied to inform decision-making processes for example during prioritization of investments in capital or asset management interventions that are required to build resilience in UDSs

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[urban drainage systems]". Sweetapple et al. (2016) proposed a framework for reliable, robust, and resilient system design and demonstrated it with application to wastewater-treatment plant control under design conditions and extreme conditions. Joyce et al. (2017) developed a multi-scale modeling system for resilience assessment of green-grey drainage infrastructures in a coastal watershed.

Design of urban storm drainage systems is beginning to address resilience and sustainability (Butler et al., 2014). However, no frameworks for decision making and scheme selection in the SuDS design stage include resilience analysis and greenhouse gas (GHG) emissions. This can be considered an important limitation. This paper presents a new framework to support decision making in SuDS design, based on resilience, hydraulic performance, pollution control, rainwater usage, energy analysis, greenhouse gas (GHG) emissions and costs aspects, including 12 indicators, in order to provide an understanding of how resilience and other indicators for SuDS contribute to scheme selection. To demonstrate the framework, a case study in China is presented.

2. Framework for SuDS scheme selection

Proposing a framework for selection of SuDS schemes is challenging due to many factors. For example, inclusion of an exhaustive list of indicators is hard to achieve because the selection of indicators is affected by stakeholders involved, their preference and specific conditions of case studies (Jia et al., 2013; Liu et al., 2016; Zhang et al., 2013) and the consequent complexity. In this study, seven categories of indicator which are considered important for

SuDS were selected based on a review of SuDS-related literature. The framework is illustrated in Fig. 1, and integrates resilience, hydraulic performance, pollution control, rainwater usage, energy analysis, greenhouse gas (GHG) emissions and costs.

It has 12 indicators (Table 1) and utilizes multi-criteria decision analysis (MCDA). The entropy weight and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) (Yoon and Hwang, 1995) were selected to support SuDS scheme selection. Details for each indicator and the rationale for their selection are described in the following sections.

2.1. Resilience analysis

It is important that urban drainage systems are resilient (Mugume et al., 2015); therefore, a resilience index is included in the framework. The resilience to each degree of pipe failure, R_0 , is computed using eq. (1) (Mugume et al., 2015), based on performance under the extreme rainfall conditions defined in section 3.3 and considering the effects of failure in up to 100% of pipes in the system. This provides indicators of resilience to a 100-year return period rainfall event and different degrees of pipe failure.

$$R_0 = 1 - \frac{F}{V_{ti}} \times \frac{D}{t_n} \quad (1)$$

where R_0 ranges from 0 to 1; with 0 indicating the lowest level of resilience and 1 the highest level resilience to the considered extreme rainfall scenarios (Mugume et al., 2015). F is the total flood volume (sum of flood volume at all nodes); V_{ti} is the total inflow

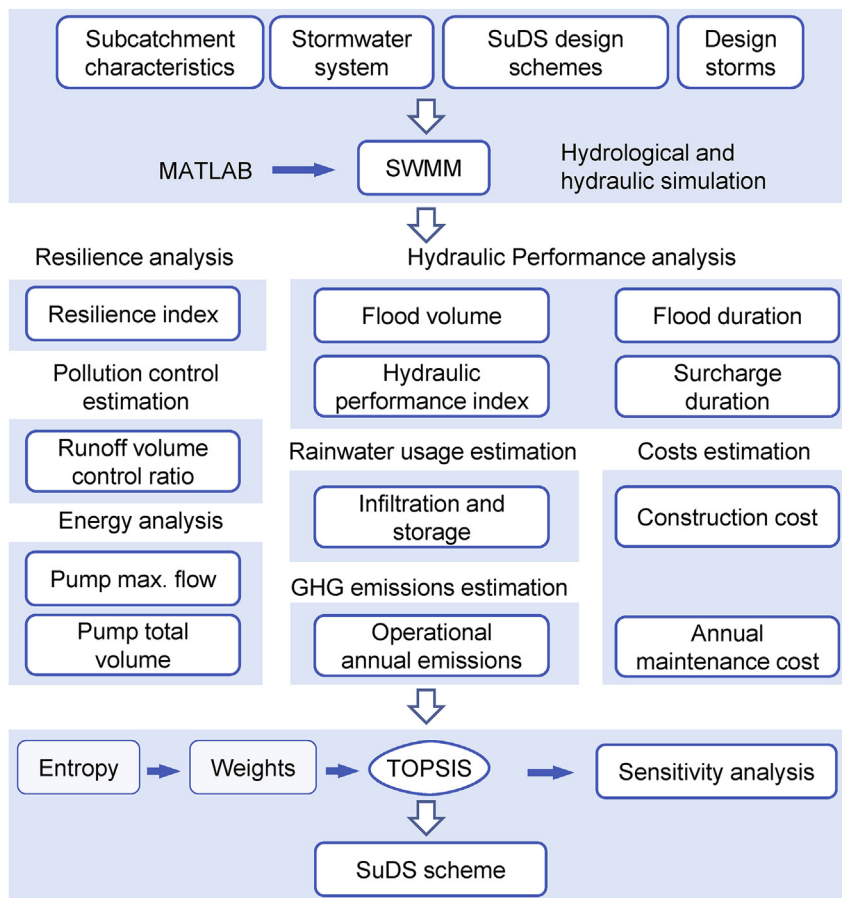


Fig. 1. Framework for SuDS scheme selection.

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