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Research paper

A framework for evaluating the persistence of urban drainage risk management systems

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Abstract

Despite remarkable advances in urban flood management techniques, pluvial flood damages still occur throughout the world. This may be attributed to uncertainties in the rainfall events which may disrupt the normal performance of an urban drainage system and eventually lead to inundations and damages. Therefore, the conventional urban drainage management approach focusing on system security should be modified. As a new approach to urban drainage management, this paper defines the persistence of a system as the ability of a disturbed system to resist, buffer the effects of variable disturbances and return to accepted level of performance after disturbances and introduces a framework to evaluate the concept of risk management persistence for urban drainage systems based on joint consideration of resilience and resistance standpoints. Based on this perspective, some of the required indicators were selected from the literature and adapted to the present study in order to quantify urban drainage risk management (UDRM) systems persistence against disturbances. Evaluation of urban drainage measures would indicate the level of persistence achieved. As a case study, part of the urban drainage system of city of Tehran–Iran was analyzed using the proposed scheme. Four urban drainage measures including three best management practices (BMPs) and a conventional system were added to the current urban drainage system to assess the performance of various measures in improvement of the persistence of UDRM systems. Results indicate that the analysis of the systems persistence can efficiently enable urban planners to select measures with an insight into the behavior of the UDRM systems faced with disturbances.

Keywords: Persistence; Flood risk; Resilience; Resistance; Urban drainage

1. Introduction

Vegetation cover reduction and increased imperviousness due to urban development result in increase in peak and volume of stormwater runoff (Hong, 2008; Semadeni-Davies et al., 2008). Urban stormwaters have adverse impacts on the performance of urban infrastructures and the life of residents. These lead to extreme damages and disorder in the serviceability of urban infrastructures as well as transportation. The urban drainage management measures such as urban drainage channels, pipes or best management practices (BMPs) are mostly adopted to control the peak flow rate and the pollution load using various ways (Villarreal et al., 2004; Lee and Chung, 2007; Pokharel et al., 2009; Karamouz et al., 2011; Pyke et al., 2011; Jia et al., 2012; Park et al., 2012). Since these measures are designed for a given return period (return period of failure) (Karnib et al., 2002; Chen and Liu, 2013), they cannot absolutely resist the rainfalls greater than the design rainfall, and pluvial flood risk is inevitable. It is therefore essential to address the rainfall uncertainties and

Abbreviation: UDRM, urban drainage risk management; EAD, expected annual damage.

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the increased risk (Burrel et al., 2007; Mailhot and Duchesne, 2010) in order to gain insight into the performance of urban drainage measures and the post-inundation flood impacts. In doing so, the present study attempts to assess the capability of defining criteria using the concept of the systems persistence originated from ecology.

In recent years, more attention has been paid to consider the ability of urban drainage measures to reduce urban flood risks (Ashley et al., 2005; Arnbjerg-Nielsen and Fleischer, 2009; Peck et al., 2013). To this end, flood risk management is an approach which is repeatedly suggested by different flood related organizations (APFM, 2008). In this context, three steps should be followed: (a) risk assessment, (b) planning and implementing suitable measures and (c) reassessment of risk. Therefore, in order to understand the effects of the implemented measures on reducing flood risks, the risks should be initially accurately quantified. The expected annual damage (EAD) is often used as an indicator for risk assessment in terms of monetary value (Yazdandoost and Bozorgy, 2008; Maharjan et al., 2009; Merz et al., 2009; Meyer et al., 2009; Pingel and Watkins, 2010). The question arises, “can EAD be employed as a measure of the persistence of an urban drainage risk management (UDRM) system?” If not, how is the persistence of a system measured? The persistence of a system is associated with the behavior of that system under various disturbing situations (De Bruijn, 2005). However, in general, flood risks given as final EAD values do not represent the varying flood impacts on a system over a range of possible disturbances (Mens et al., 2011) and how the system recovers from these impacts. Therefore, the current risk assessment approach that relies on estimating only EAD as a risk indicator should be further enhanced by specific considerations so that the behavior of the system can be quantified when disturbances occur.

Holling (1973) stated the persistence of a system results from the resilience of the system. Whereas O'Neill (1976) declared that persistence of a system requires resistance to and recovery from disturbances. Hence, it may be deduced that resilience and resistance are two prime system characteristics which should be considered for persistence. The combination of resistance and resilience concepts to evaluate the persistence of a system are considered here. Resistance is typically perceived to define the safe margins for designing urban drainage measures. Specific rainfall intensities and storm events with different frequencies for which urban drainage measures should be designed from a resistant perspective have been suggested by various works (Brown et al., 2001; Ashley et al., 2007; USDCM, 2008). In the case of urban flood resilience, many studies attempt to qualitatively explore policy options and strategies to enhance urban flood resilience (Gupta, 2007; Zevenbergen et al., 2008; Wardekker et al., 2010; Djordjević et al., 2011; van Ree et al., 2011). However, from a practical perspective, it is important to adopt a framework to quantitatively evaluate the behavior of UDRM systems under various rainfall events based on consideration of both resistance and resilience.

De Bruijn (2004a) defined resilience for flood risk management systems. She described the new attitude in these systems by applying system approach (Blackmore and Plant, 2008). In another study, she proposed the indicators to quantify resilience for the lowland rivers (see De Bruijn (2004b)). Mens et al. (2011) proposed a framework to analyze system robustness for flood risk management based on the analysis of system response and recovery against disturbances and a set of indicators to quantify robustness.

The present study applies the framework proposed by Mens et al. (2011) however, termed as “persistence of system” here implying the same meaning as “robustness of system” and considering the concepts defined by De Bruijn (2004a,b) in the context of UDRM systems. This framework investigates the persistence of UDRM systems under extreme rainfalls using combination of resilience and resistance concepts in urban drainage planning and management strategies. In the context of this framework, some indicators are utilized to quantify presented concepts. Applying this framework to part of the municipal district of Tehran, capital of Iran as a case study, the indicators have been verified. Adopting a system approach in the process, involving comparison of measures, has provided a suitable platform for strategic management of UDRM systems.

2. Framework for evaluating the persistence of UDRM systems

2.1. Defining systems persistence based on resilience and resistance concepts

As mentioned earlier, the persistence of a system is highly dependent on both resilience and resistance. For this reason, clear identification of resilience and resistance is needed to define the systems persistence. There are two views to define resilience. The first view, termed “engineering resilience” (Folke, 2006), focuses on system's behavior near stable equilibrium and is indicative of a system's speed of return to an equilibrium following a disturbance (Pimm, 1984). Based on this assumption, resilience can be measured by resistance to disturbances and rate of return to equilibrium (O'Neill, 1976; Pimm, 1984; Tilman and Downing, 1994).

The second view, concentrates on a system's behavior near the boundary of a domain of attraction far from any equilibrium where instabilities can flip to another domain (Holling, 1973; Ludwig et al., 2002; Blackmore and Plant, 2008) and is a buffer capacity or ability to absorb perturbation (Adger, 2000). This is measured as magnitude of a disturbance which can be absorbed before system changes its structure by changing variables and processes that control system's behavior (Holling and Meffe, 1996).

In the context of flood management, De Bruijn (2004a) used both above definitions to define resilience. Inspired by her definition and abovementioned definitions, this work defines the persistence of a system as ability of a system exposed to disturbances to resist, absorb, and recover from disturbances to an accepted level of performance. De Bruijn (2004a) also argued taking a look at system's reaction can best give an insight into resilience and resistance definitions. Moreover, since resilience and resistance are utilized jointly to reach at a