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Managing hydrological infrastructure assets for improved flood control in coastal mega-cities of developing nations

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ABSTRACT

Every year, coastal mega-cities situated in developing nations suffer severe losses associated with flood hazards. In response to this problem, these cities often rely on engineering interventions or structural measures, which typically necessitate an informed management of hydrological infrastructure assets such as waterways or drainage channels, detention reservoirs, high-protection levees, seawalls, dikes, dams, pumping stations and floodgates. Unfortunately, flood management outcomes, based on the use of these hydrological infrastructure assets, are undermined by lack of data and resources to support decision makers. The aim of this study is to provide strategic action plans to address this problem. First, the study reviews literature on flood-related issues and interventions in several coastal mega-cities situated in developing nations. Then, outputs of the review are synthesized into threats, opportunities, weaknesses and strengths common to these cities in relation to infrastructure-based approach to flood management. Using this information, situational analysis is carried out and appropriate strategies are recommended to help support informed management of hydrological infrastructure assets as means of improving flood control in coastal mega-cities situated in developing nations.

1. Introduction

Flooding is a major problem in coastal urban areas (Takagi et al., 2016). This problem is expected to worsen due to climate change through increased frequency and intensity of extreme weather events and sea-level rise (Lau et al., 2010; Waters et al., 2003). Coastal mega-cities in developing nations (hereafter abbreviated as “CMDN”) are highly vulnerable to severe flood hazards due to their physical geography, population explosion, rapid urbanisation, and inadequate or poorly managed flood control infrastructure (Dewan, 2013; Gasper et al., 2011; Li, 2003). When compared to developed nations, it is observed that the average number of victims from natural hazards, including flooding, is 150 times greater and economic losses are around 20 times higher in developing countries (Wenzel et al., 2007). This situation calls for improved response to flood hazards in developing nations.

In responding to the problem of flooding, coastal cities in developing nations often adopt structural and non-structural measures to flood mitigation (Caljouw et al., 2005). Structural measures or engineering interventions rely on efficient management of hydrological infrastructure assets, including waterways or drainage channels, detention reservoirs, high-protection levees, seawalls, dikes, dams, and other hydraulic components such as pumping stations and floodgates (Arthurton, 1998; Chan et al., 2012; Okoye and Ojeh, 2015; Wilby and Keenan, 2012). The challenge of efficiently managing these often aging and deteriorating infrastructure assets in order to improve flood control outcomes is enormous, particularly under the prevailing conditions in developing nations, which typically include inadequate funding, skills shortage and the lack of actionable data to support decision making (Brecht et al.,

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2012; Sarzynski, 2015). Inefficient decisions related to the maintenance and real-time operations of flood control infrastructure often result in sub-optimal outcomes that further exacerbate flood hazards, potentially causing significant loss of life and property damage worth billions of dollars (Brinkman and Hartman, 2008; Few, 2003; Ward et al., 2011). Managing authorities in CMDN are therefore faced with the need to carefully assess the challenges and opportunities unique to their environment and consequently design suitable strategies to improve the management of their hydrological infrastructure assets.

The management of hydrological infrastructure assets is a concept that applies infrastructure asset management to hydrological systems. "Asset management", in the context of infrastructure systems, is a concept that is difficult to define and one that means different things to different people (Lemer, 2000). Adopting a widely accepted definition proposed by the Federal Highway Administration (FHWA), infrastructure asset management can be defined as a systematic process of maintaining, upgrading, and operating infrastructure cost-effectively (U.S. Department of Transportation, 1999). Infrastructure asset management requires optimised decision making that is justified by evidence (Pantelias, 2005). This approach to infrastructure management decision making often requires a significant amount of actionable data, often lacking in developing countries (Halfawy, 2008). Hence, an important aspect of infrastructure asset management that is quite relevant to developing countries entails the development of capabilities, methodologies and computerised tools to help generate the quantitative data required to support managers at different levels in the decision making process (Pantelias, 2005).

At an infrastructure network level, decision-making focuses on network-wide optimisation of maintenance, construction and operation of infrastructure assets, which are often widely distributed within a large geographical area as determined by the physical extent of the entire network under consideration (Pantelias, 2005). Network level decision-making involves system-wide planning and an evidence-based structured approach to identifying key assets, vulnerable components and areas of priority within a specific infrastructure network, so that limited resources can be judiciously channelled to the maintenance, rehabilitation, extension, and operational efficiency of the given network (Haas et al., 1994). The absence of actionable data to drive this city-scale network-level thinking and decision making can further increase the complexity and sophistication of infrastructure management processes, creating the risk of imprecise decisions that often lead to infrastructure failure and economic loss (Halfawy, 2008).

In the context of CMDN, the lack of accurate and reliable data about the geographical location, physical attributes and current conditions of assets in the hydrological network can lead to infrastructure failure associated with imprecise flood control decisions (Nasir and Muhammad, 2011). A recent study focusing on flooding in – Jakarta (Indonesia) reports that flooding is often associated with preventable failures of the flood control infrastructure and a lack of actionable data that limits the efforts of decision makers and managing authorities (Sedlar, 2016). Henceforth, to minimise flood hazards in CMDN, there is a need to design new strategies of sourcing actionable data or reliable information to support network level decision making and management of hydrological infrastructure assets.

This study aims to address this problem by gathering, categorising and analysing relevant situational information about the threats, opportunities, weaknesses and strengths (TOWS) that are common to several case studies, in relation to improving infrastructure-based approach to flood management in CMDN. Relevant situational information used for the study are gathered through a literature review process. Following the review, a comprehensive description of coastal mega-cities of developing nations (CMDN) is presented. A situational analysis is then carried out using the TOWS strategy tool and information retrieved from literature. Based on the outcome of the situational analysis, the study further contributes by recommending appropriate strategies to help support an informed management of hydrological infrastructure assets as a means of improving flood control in CMDN. The methodology adopted is further described in the following section.

2. Methodology

2.1. Overview

Several CMDN suffer from flooding and the experiences have been well documented in the literature. A structured synthesising of these studies can generate a rich and reliable information resource that can potentially aid in understanding commonalities in terms of causal factors, aggravating conditions, mitigation strategies, constraints, and institutional response to the problem of flooding in CMDN. This review first focused on retrieving relevant information about flood-related issues and interventions from each CMDN. Then, this information was organised into threats, opportunities, weaknesses and strengths, as required for TOWS analysis (Ravanavar and Charantimath, 2012). Using this information, TOWS analysis was subsequently carried out and a set of strategic action plans recommended.

2.2. Literature review process

TOWS analysis has never been carried out in order to establish strategies of improving infrastructure-based approach to flood management in CMDN. To perform such analysis, it was necessary to first carry out a systematic review of literature in order to synthesise the required information. A literature search was performed and articles identified by using a combination of relevant keywords as shown in Fig. 2. Academic databases such as Web of Science and Scopus were initially used to search for articles, but very scanty records were returned. This is mainly because academic databases such as Web of Science and Scopus do not search beyond titles and abstracts and there are only a few studies reporting on CMDN within their titles and abstracts. However, the Google Scholar search engine was found to be particularly useful for finding articles that have discussed CMDN within the body of the text. Consequently, a total of 14,700 articles were initially retrieved after removal of duplicates. Depending on the focus of the study, these