Sustainable Cities and Society 20 (2016) 199–209

Contents lists available at ScienceDirect

Sustainable Cities and Society

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

The importance of integrated solutions to flooding and water quality problems in the tropical megacity of Jakarta

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ARTICLE INFO

Article history:
Received 20 March 2015
Received in revised form
17 September 2015
Accepted 18 September 2015
Available online 25 September 2015

Keywords:
Water quality
Urban flooding
Urban river corridors
Integrated solutions
Jakarta

ABSTRACT

Rapid urbanisation is transforming many urban rivers by affecting their hydraulic conditions and water quality. This process is particularly intense in some areas of the planet, where migratory phenomena and the associated urbanisation pace and conurbation are extreme. In these cases, the lack of water supply and sewerage infrastructures can lead to enormous pressure on urban river corridors, which often implies irreversible pollution of surface waters and shallow aquifers. In this article we address the problem of how integrated planning of urban river corridor management is essential to achieve sustainable solutions and how modern simulation tools can contribute to this effect. This is done by reporting about an exemplary case study, the Ciliwung River flowing through Jakarta, which is highly polluted and floods frequently large areas of the city. Indonesian authorities' highest priority is to reduce the flood problem but without a clear integrated rehabilitation strategy that accounts for water quality issues. Through field campaigns and model simulations we demonstrate how measures to solve the flood problem can further deplete water quality if the pollution load is not reduced. Results suggest that the current hydraulic river regime produces a benefit for the river health by increasing oxygen levels, natural degradation processes and dilution. A reduction in the average discharge by means of dam construction, as currently considered by the authorities, is likely to increase contamination levels of surface water and shallow aquifer, which is recharged by the river.

1. Introduction

In 2010, 80% of the world's population was exposed to high levels of threats to water security for human or ecosystems wellbeing (Vörösmarty et al., 2010). The struggle to protect water resources is a worldwide endeavour and has become remarkably acute in urban areas, in general, and in Asia, in particular, where urbanisation is at its fastest rate and is expected to lead to a population concentration in urban areas between 56% and 64% by 2050 (UN, 2014).

Groundwater is of utmost importance in some of the fast growing cities as it is frequently used as a direct source of drinking water, which compensates for the lack of robust public water supply systems. Failures or lack of urban infrastructures have been shown, however, to significantly contribute to groundwater deterioration and urban stormwater pollution (Zoppou, 2001) through sewage infiltration, leakage from landfills and direct connection of wastewater sewage systems to stormwater drains.

Widespread pollution in urban environments, frequently increasing during storms and flooding, have been linked to rises in viral infections, caused by either direct contact or ingestion of contaminated waters (e.g. Phanuwan et al., 2006).

This evidence speaks for an urgent need to develop a methodological framework that can address sustainable water management solutions in the context of urban rivers and provide an integrated assessment of surface and groundwater systems, of their interplay and, more in general, of how these are affected by urban planning and may have an impact on public health. Mark et al. (2015), for instance, shows an interesting case where advanced simulations of cholera spreading through urban flooding can give valuable information for health risk management in major Asian cities.

To discuss the contribution that joint monitoring and modelling of water quantity and quality can provide in assessing remediation or planning of urban river corridors, we use the case of the Ciliwung River flowing through Jakarta, the capital city of Indonesia.

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http://dx.doi.org/10.1016/j.scs.2015.09.009
2210-6707/

This is an extreme case, which combines river and groundwater pollution with other problems such as flooding, land subsidence, saline intrusion in the context of rapid and often uncontrolled urbanisation. The shallow groundwater system is highly polluted by typical urban contaminants, including nitrate (NO_3^-) (Kagabu, Shimada, Nakamura, Delinom, & Taniguchi, 2010), and the situation is unlikely to improve as both the public water supply and wastewater systems are limited in their extension and poorly maintained (Lanti, 2006), and excessive pumping has increased the interaction between the shallow groundwater and the deeper aquifer. This favours the downward transport of pollution, thus increasing the risk of mobilization of contaminants and deterioration of the deeper aquifer. Moreover, because the Ciliwung is generally losing water through infiltration to groundwater (i.e. losing stream) as it flows through Jakarta, fluctuations of its surface water quality are likely to affect riverine groundwater. For instance Irawan et al. (2014) investigated the interactions in the large Jakarta area between this river and the groundwater system and noted that groundwater chemistry is highly variable in space and complex at localized scales.

In addition to pollution related problems, many riverine communities along the Ciliwung in Central Jakarta are repeatedly flooded each year during the wet season. Events of bigger proportions are less frequent but recurrently inundate large areas of the city and cause significant damage. One of these events occurred in February 2007 is estimated to have flooded 60–70% of the city, caused more than sixty deaths and displaced 450,000 people (Gaillard, Texier, & Texier, 2008). Reducing flooding in Central Jakarta is thus a high priority for the Indonesian authorities, and mitigation measures, which already started in some of the most vulnerable areas such as Kampung Melayu, Bukit Duri and Kampung Pulo, include channelization of the river margins and dredging of the river bed.

Long term plans to reduce flooding include additionally the construction of a dam in Ciawi (e.g. Martdianto & Kadri, 2013) in the upper catchment region and a giant sea wall in the Jakarta Bay (e.g. Sagala, Lassa, Yasaditama, & Hudalah, 2013). The latter is expected to reduce the enhancement of tidal flood negative effects, which are aggravated by subsidence that increases backwater phenomena, by creating large lagoons that can buffer river outflows. Yet, the problem of pollution and of its interplay with the flood protection measures remains unfortunately largely unsolved, undocumented and unlikely to be addressed.

Through a few short field campaigns complemented with model simulations, we highlight in this study the importance of integrated solutions to the flood and water quality problems in Jakarta (and in other comparable cases) and show how this approach can contribute to explore pathways to sustainable planning of urban river management policies. For instance, high and turbulent flows typically reduce contamination levels through dilution and favours higher oxygen levels through enhanced reaeration, thus allowing faster natural aerobic degradation of contaminants. Changing the variable river flow regime by means of structural flood protection measure, such as river channelization and upstream retention basins, is likely to hinder the river's self depuration capacity if the pollution load is not reduced, with consequences on the groundwater system, as shown by our analysis.

2. Jakarta and the Jabodetabek region

2.1. Demography and infrastructures

Located in West Java, Jakarta is the capital and largest city of Indonesia. The surrounding urban area, officially referred to as the Jabodetabek area, includes the cities of Bogor, Depok, Tangerang, South Tangerang and Bekasi (Fig. 1).

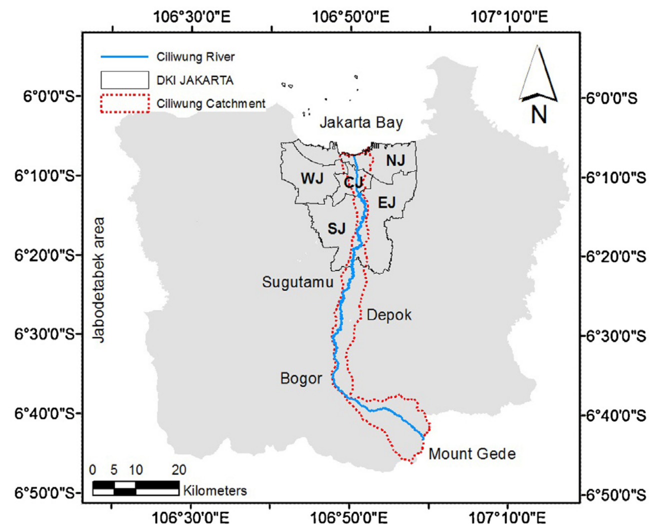

Fig. 1. Ciliwung River basin and location of the Jabodetabek area. Three major cities are located along the river: Bogor, Depok and Jakarta. The metropolitan area of Jakarta starts at Sugutamu and is divided into North (NJ), West (WJ), East (EJ), Central (CJ) and South (SJ) Jakarta. As a province, the official name of Jakarta is Daerah Khusus Ibukota Jakarta ("Special Capital City District of Jakarta"), which in Indonesian is abbreviated to DKI Jakarta.

Since 1960 the region has experienced an unprecedented shift from prime agricultural land to urban and industrial areas (Firman, 2000; Verburg, Veldkamp, & Bouma, 1999). The population rose in Jakarta from 2.7 million to 9 million between 1960 and 2007 (BPS, 2007), and the green space in the central area (CJ, Fig. 1), which was estimated in 1984 as 28.8% of the total area, was reduced to 6.2% by 2007 (Firman, 2009).

The city is undergoing efforts to expand the public water supply system to reach the whole population by 2022 (Lanti, 2006). However, since 1996 the service coverage has instead steadily decreased from 41% to 36% by 1998 and to 31% by 2008 (ADB, 2013). To compensate for the insufficient municipal water supply service, many communities became heavily dependent on pumping wells as a source of drinking water (e.g. Vollmer & Grêt-Regamey, 2013). In Jakarta alone, the estimated rate of groundwater abstraction increased fourteen times in the past 60 years (Kagabu, Shimada, Delinom, Nakamura, & Taniguchi, 2013).

The sewerage network is also very limited with only 3% of the population being serviced in 2002 (Sukarma & Pollard, 2002). As a consequence most households either discharge wastewater directly into the river or use poorly maintained and leaking septic tanks (IndII, 2014), the number of which has been estimated above 900,000 in 1994 (Morris, Lawrence, & Stuart, 1994).

2.2. Water resources, land use and pollution signatures

Jakarta is criss-crossed by thirteen rivers, the Ciliwung being the largest and at the same time one of the most polluted in Indonesia. With a length of approximately 130 km and a catchment area of 390 km^2, it originates at the semi-natural forest of Mount Gede and flows through the urbanised Jabodetabek region, emptying in the Jakarta Bay. This river represents an important water source for both the agricultural and domestic sectors (Phanuwan et al., 2006). A water treatment plant (WTP) treats river flows and supplies fresh water to parts of Bogor and Depok cities.

The water quality of the Ciliwung has been classified as very poor citepPalupi199517, with studies showing evidence of high levels of NO_3^- and biological oxygen demand (BOD) (Costa, Gurusamy,