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The impact of various land uses on the microbial and physicochemical quality of surface water bodies in developing countries: Prioritisation of water resources management areas

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ABSTRACT

To protect water resources, the WHO recommends assessing land use influence on water quality, taking into consideration residential development and waste disposal amongst others. Thus, we investigated the impact of unconstructed plots, an informal settlement, an urban residential area, and an industrial area on the microbiological and physicochemical quality of two main tributaries within the Klein Jukskei catchment, Johannesburg, South Africa, to identify areas where immediate resource management strategies were needed. Water samples collected from the tributaries' sources and upstream and downstream from each land use type (Winter and Spring) were analysed for *E. coli* (indicator organism), using the Colilert® 18 system. Physicochemical parameters (Temperature, pH, dissolved oxygen, electrical conductivity, turbidity and total dissolved solids) were measured using multiparameter instruments. The tributaries' sources had the lowest *E. coli* counts (Sandspruit – 0.74; North Ridingspruit – 1.18 $\log_{10}$ MPN/100 mL) during the study. After flowing through the various land uses, mean *E. coli* counts reached 5.98 (Sandspruit) and 4.85 $\log_{10}$ MPN/100 mL (North Ridingspruit). *E. coli* values and all physicochemical parameters (but for pH) downstream from most of the land uses did not meet the South African drinking water quality guidelines. The informal settlement had the most negative impact on the microbial and physicochemical quality of the water within the tributaries. Thus, providing informal settlements with appropriate sanitation facilities is likely to prevent pollution of the water bodies. Protection of the sources should also be implemented while industrial wastes need to be monitored for conformity with water quality guidelines before discharge.

1. Introduction

The detrimental effects of water pollution on environmental and human health have been reported for many decades through numerous studies conducted in many different parts of the world. Despite this abundance of knowledge, the world's water resources continue to face extreme challenges regarding their quantity and quality, mostly due to a fast growing global population (Lee and Schwab, 2005; Okello et al., 2015). The quality of these water resources is usually influenced by the different types of land uses around the water catchments (Ding et al., 2015; Yang et al., 2016). Different land uses have been found to exert varying degrees of pressure on aquatic environments in different parts of the world. In a study conducted along the Florida coastline, USA, the authors found out that surface runoff from urban areas, and cattle ranches had the highest number of faecal indicator bacteria than that from other sources (Liang et al., 2013). In their study, the authors looked at the quality of runoff over different land use types following rainfall events. Similarly, Ding et al. (2015) concluded that urban land use was the primary source of pollutants in a subtropical river basin in China. This conclusion was based on computer simulations through remote sensing, geographic information systems, and statistical techniques. In Malawi, urban areas and sewage treatment works (point-sources) and agricultural areas, industrial activities mining and residential areas (non-point sources) were reported to negatively affect

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the waters of the Likangala catchment, with the quality (physical, chemical and microbial) degrading even more during rainfalls (Pullanikkatil et al., 2015). Several other studies around the world have reported similar impact on the chemical as well as on the microbial quality of water catchments (Ding et al., 2015; Mei et al., 2014; Schreiber et al., 2015; Singh, 2014; Sliva and Williams, 2001; Sun et al., 2016; Tong and Chen, 2002; Walsh and Wepener, 2009; Wilbers et al., 2014; Yang et al., 2013, 2016). However, most of these studies have focused on surface runoff over the land uses and have not looked at how the water from these catchments deteriorates as it leaves the source and flows through the different land uses. As such, investigating the quality of water from its source and after it has passed through a given land use, one can conclude that the pollution observed downstream is as a result of that particular land use, especially in the absence of any impact of runoff from rainfall events.

Africa as a whole has been reported to be arid despite its high annual rainfall, due to the higher temperatures experienced by the continent (Pimentel et al., 2013). In addition to the water shortages due to increased demand for food production (intensive irrigational agriculture), there is also an ever-increasing deterioration of water quality as a result of the waste discharged by these same processing industries into the water bodies (Pimentel et al., 2013). This constant pressure accompanied by a lack of proper environmental management of these resources ultimately results in a reduction in water availability for human needs as well as loss of biodiversity (Durand, 2012; Johnson and Paull, 2011). In South Africa, major surface water resources are facing even more severe reductions due to a significant drop in the total amount of rainfall and number of rain days which the country has experienced over the years (MacKellar et al., 2014). The available water resources are also being highly polluted by the country's growing population, rapid industrialisation and unregulated industrial and municipal wastewater discharge from failing sewage treatment infrastructures (Bezuidenhout et al., 2013; Mema, 2010; Nkwonta and Ochieng, 2009; Teklehaimanot et al., 2015). Some of the pollutants that enter into surface water sources could be chemicals such as antibiotics (Zheng et al., 2011) or microorganisms (Hampson et al., 2010). These organisms which include bacteria, viruses, and parasites (Abraham, 2011) have been shown to constitute the greatest threat to human health associated with water quality as a result of the many waterborne diseases they cause (Schreiber et al., 2015; UNEP GEMS/Water Programme, 2008).

Adverse impacts of improper water resource management plans are mostly felt in highly populated low-income settlements (Neswiswi, 2014). As a central role in the management of drinking water sources, the WHO recommends the protection of such sources as the first line barrier (World Health Organization, 2011). Many countries have also set country-specific guidelines for managing their water resources. In South Africa for example, to address the growing concern of pollution of the country's water resources, guidelines have been set at the national level for the management of the different water classes (DWAF, 1996a,b,c,d,e). Like in many developing countries, however, at the municipal level the ecological health of rivers and streams is usually not well documented. The lack of such information could be a significant impediment to the setting up of sound management strategies for the protection of water resources in these countries. To setup such management plans therefore, it is important to understand how different land uses affect the quality of these water resources, especially in most developing countries with insufficient or total lack of access to clean pipe-borne water. Highly polluted waters represent a public health threat to users of such water as well as may increase the cost of treating the water for supply to communities. Therefore, the current study aimed at investigating the impact of different land uses on the microbiological and physicochemical quality of surface water, using two main tributaries within the Klein Jukskei catchment in the city of Johannesburg, South Africa, as a case study.

2. Material and methods

2.1. Study site

This study was carried out on two large tributaries that form part of the Klein-Jukskei River, between the month of July 2016 and September 2016. The Klein Jukskei River (a.k.a. Little Jukskei River) rises in Roodepoort (Florida Hills) at a height of 169 m above mean sea level. From Roodepoort, it flows into Randburg in the Gauteng Province of South Africa. At its upper reach, the river flows through informal settlements, residential and industrial areas, while in the northwestern and northern part it flows mainly through agricultural holdings where it is used for irrigation. The two tributaries included in the present study were selected based on the various land uses around them. From its source, the first tributary (Sandspruit) flows through Zandspruit (informal settlement) and Cosmo Cities (urban residential area) before joining the main Klein Jukskei River. The second tributary (North Ridingspruit) on the other hand, flows through small unconstructed plots and then through Kya Sand (industrial area) before entering the main river. The industries in this area usually discharge poorly treated or untreated effluents into the tributaries, thereby affecting their qualities (Fig. 1). The Klein-Jukskei River forms part of the river network that flows into the Hartbeespoort Dam (Dudula, 2007).

2.2. Sample collection

Sampling was done in July (winter) and September (spring) 2016. Eight sampling sites were selected as indicated in Fig. 2.

Sites one to six were all located on the two selected tributaries while sites seven and eight were on the main Klein Jukskei River, upstream and downstream from the points where the tributaries entered the river. A total of 192 triplicate samples were collected during the entire study.

Fig. 1. Change in physical quality of the water within the tributaries due to industrial discharge.