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Benefits of an integrated water and nutrient reuse system for urban areas in semi-arid developing countries

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ABSTRACT

Urban areas of developing countries face the challenge to implement adequate water and sanitation infrastructures while using natural and financial resources sustainably. The objective of this study was to identify benefits and challenges of different nutrient and water reuse systems. For this, we evaluated and compared four systems; (1a) the local conventional water and sanitation system, (2a) a novel water and nutrient reuse system connecting sanitation, advanced wastewater treatment and nutrient-rich water reuse for the irrigation of human food crops, (1b) the local conventional water and sanitation system adapted for water reuse and (2b) the novel water and nutrient reuse system adapted to be low-tech. Our case study, a town in Namibia, exemplifies the typical problems of urban areas in developing countries. We compared the four systems using ecological, economic, societal, institutional, political, and technical criteria, via multi-decision criteria analysis with the Analytic Hierarchy Process (AHP). Our results indicate that the novel water and nutrient reuse system (2a) scores highest with environmental and societal criteria when weighting all evaluation criteria equally. Its challenges lay especially in the economic criteria. Nonetheless, for our case study, an urban area in a developing country, the novel water and nutrient reuse system (2a) is a viable sanitation, wastewater and irrigation infrastructure for using fewer resources, being economically feasible, institutionally and politically practical and technically sound. However, the preference for a particular water and sanitation infrastructure also depends on which criteria the decision-maker is willing to assign the highest weight to. The presented methodology helps decision-makers and engineers with complex decision–making by evaluating numerous criteria in order to have proper information on the benefits and challenges of water and sanitation systems.

1. Introduction

2.4 billion people in developing countries (756 million in cities alone) lack adequate sanitation and wastewater treatment (WHO, 2016). Also, adequate infrastructures for the provision of sufficient water and fertilizers for urban agriculture are major issues in semi-arid developing countries. In the past decades there has been a paradigm shift in regarding wastewater no longer as a waste, but as a local resource for water and nutrients (Guest et al., 2009). Thus, the conventional sanitation and wastewater treatment infrastructure also needs to be adapted in order to form resource recovery systems for water and nutrients (Guest et al., 2009; Adewumi et al., 2010; McCarty et al., 2011). Among the numerous emerging water reuse concepts, the challenge is to select the system that is best suited to the specific local context. This is important for policy-makers, engineers and the general public in order to have the proper information about the benefits and challenges of different options for water and nutrient recovery systems.

To find the best suited system, decision-support systems are helpful tools especially designed to support complex multi-criteria decision making (Power, 2002). Evaluating and comparing alternative options of resource recovery systems using sustainability criteria and indictors is a common method (ASCE, 1998; Morrison et al., 2001; Balkema et al., 2002; Palme et al., 2005; Cinelli et al., 2014). While multi-criteria decision analysis such as the AHP method have been previously used to evaluate wastewater management technologies (e.g. Molinos-Senante et al., 2014, 2015; Aydiner et al., 2015), to the knowledge of the authors, this approach has not yet been applied to resource recovery systems in a developing country setting. In addition, to be as context specific as possible, a wide range of criteria needs to be integrated into the evaluation.

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However, integrating a wide range of sustainability criteria (ecological, economic, societal, institutional, political and technical) into the evaluation of resource recovery systems has not been widely employed so far (Garcia and Pargament, 2015; Molinos-Senante et al., 2014; Balkema et al., 2002).

In spite of its potential, so far, the collection and treatment of municipal wastewater and its direct reuse in urban agriculture is not widely practiced in developing countries due to a lack of appropriate water infrastructure. Instead, highly polluted waters from surface waterbodies are reused for the irrigation of urban agriculture, predominantly unplanned and unintentionally (Drechsel et al., 2010; Scheierling et al., 2010). For wastewater treatment in developing countries, in the past decades wastewater stabilization ponds have become an increasingly popular option, because of their easy operation and maintenance, low cost and energy requirement, high pollutant removal efficiency, robustness and high potential for water and nutrient reuse. Their challenges include their high sludge accumulation and that they become overloaded if badly managed, spilling over during heavy rain storms and floods constituting a health risk. In addition, they may release odors, have high land requirements, may also be breeding grounds for mosquitos and therefore pose a serious health problem, energy which cannot be recovered as methane is emitted into the atmosphere and the treated water may be of poor quality (Verbyla et al., 2016; Libhaber and Orozco-Jaramillo, 2012; von Sperling and de Lemos Chernicharo, 2005; Mara, 2003). Therefore, the question is, whether wastewater stabilization ponds could be a viable option for resource recovery systems for reusing water and nutrients for the irrigation of urban agriculture.

The objective of this study was to identify benefits and challenges of different water and nutrient reuse systems. For this, we evaluated a novel water and nutrient reuse system and compared it to the conventional system with ponds in the area and to two adapted systems proposed by this study. A novel resource recovery system has been implemented in 2013 in semi-arid north-central Namibia in the northern part of the town of Outapi by the CuveWaters research project (CuveWaters, 2013). This novel water and nutrient reuse system directly connects water supply, improved sanitation, advanced wastewater treatment and the reuse of nutrient-rich water for the irrigation of urban agriculture. This water and nutrient reuse system can be considered as novel, as the direct and intended reuse of treated nutrient-rich water for human crop production has not been implemented before on a) such a small-scale (1400 inhabitants, 3 ha crop area) and b) in an urban area of a developing country. The water reuse potential and the amount of nutrients and salts contained is not the focus of this study and has been presented in Woltersdorf et al. (2015, 2016).

2. Study area

Four settlements in the town of Outapi in central-northern Namibia served as our case study. Outapi exemplifies the typical problems of urban areas in semi-arid developing countries: inadequate water supply for hygiene and agriculture, low access to sanitation facilities, inadequate wastewater treatment, nutrient poor soils, population growth, further urbanization (see Deffner et al., 2012), and a mix of low-density informal settlements (with shacks) and low-density formal settlements (with brick houses). According to the former CEO of Outapi, Outapi's population is currently doubling in number roughly every 3 years; Outapi having about 13,200 inhabitants (in 2014) and the four settlements having about 1400 inhabitants (September 2015). Central-northern Namibia is a semi-arid and water scarce region. Mean precipitation is 464 mm/y occurring from November to April. In the absence of perennial water resources, water is supplied by an open canal and pipelines originating from the Angolan-Namibian border river Kunene (Heyns, 1995). Currently, the town council plans extensive new agricultural areas for food crops in the surroundings of the city, using tap water for irrigation and mineral fertilizer. The region has a high demand for agricultural products to increase food security and import substitution (Government of Namibia, 2006).

In the southern part of the town, a conventional water and sanitation system, typical for the area, is in place (see option 1a, section 3.2.1); a conventional gravitational sewer system transports the wastewater from connected formalized buildings outside of the city to a series of large wastewater stabilization ponds. The water is evaporated and not used anymore. In 2015, visiting these ponds, they were found to be technically non-functional, they were barely managed without any responsibilities assigned within the Outapi Town Council, their sludge accumulating without being removed and their wastewater spilling over during the frequent floods in the area constituting a health risk for the local population.

In four settlements in the northern part of the town, there was no conventional water and sanitation system in place before the implementation of the novel nutrient and water reuse system. The four settlements (Fig. 1) were estimated to have about 1400 inhabitants (September 2015) and included informal settlements with shacks and an open market ("Onhimbu", "Okaikongwe", "Tobias Hainyeko" settlements, 1200 inhabitants) and a formalized settlement with brick houses ("Shack Dwellers" settlement, 200 inhabitants). Before the implementation of the novel system (see option 2a, section 3.2.3), the previous water and sanitation infrastructure in the four settlements comprised the water pipeline scheme with communal water taps, some private taps and some public-pit latrines (Kramm and Deffner, in prep.). However, the minority of the inhabitants had access to latrines (37% in Shack Dwellers, 44% in Tobias Hainyeko, 4% in Okaikongwe, 90% in Onhimbu) and most practiced open defecation (Kramm and Deffner, in prep.). Then, in April 2013, the novel water and nutrient reuse system started its operation as a pilot plant, in the frame of the CuveWaters project. The CuveWaters project monitored the operation of the pilot plant from April 2013 until September 2015.

3. Methodology

The methodology consists of four steps: (1) establishing the goal, scope and boundaries of the evaluation, (2) designing the options to be evaluated, (3) setting up the evaluation team, (4) selecting an appropriate method for multi-criteria decision making, (5) assessing the sensitivity of results due to a varying of the weight of the evaluation criteria and (6) identifying benefits and challenges of the novel system.

3.1. *Goal, scope, spatial and temporal boundary of the evaluation*

The objective of this evaluation was to identify benefits and challenges of different water and nutrient reuse systems. The scope of the evaluation includes the five pillars of sustainability, adding to the "triple bottom line" including economic, ecological and social criteria (WCED, 1987), also technical, institutional and political criteria, due to the complexity associated with a resource recovery system. All four systems were compared based on the same spatial boundary with the four settlements in the city of Outapi having an estimated 1400 inhabitants (Fig. 1). Therefore, all options were assumed to be in the position where the novel system (option 2a) is currently implemented in northern Outapi. This includes the position of the households, wastewater treatment and the agriculture site (Fig. 1). All four systems were also compared based on the same temporal boundary with the situation in September 2015.