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Evaluation of pollution prevention options in the municipal water cycle

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ABSTRACT

The impact on water resources caused by municipal wastewater discharges has become a critical and ever-growing environmental and public health problem. In order to be able to efficiently address this problem, it is important to adopt an integrated approach that includes a decrease in and control of contamination at its source. These principles have been successfully applied in the industrial sector and now these concepts are also being applied to integrated water resources management. In this context the conceptual model of the Three Steps Strategic Approach (3-SSA) was developed, consisting of: 1) minimization and prevention, 2) treatment for reuse and 3) stimulated natural self-purification. This paper is focused on the first step. The assessment includes a case study in the expansion area of the city of Cali, Colombia (410,380 new inhabitants). The evaluation of alternatives is done using two different system boundaries: (1) reduction in water supply costs for households, savings associated with the drinking water infrastructure and the avoided costs in the infrastructure of additional sewerage and wastewater treatment facilities; and (2) only taking into account the reduction in water supply costs for households and the savings associated with the drinking water infrastructure. The alternatives of minimization and prevention were hierarchized using an analytic hierarchy process and grey relational analysis. A cost-benefit analysis was carried out to compare the highest ranked alternatives with the conventional approach, which considers a 'business as usual scenario' of high water use, end-of-pipe wastewater treatment plant and the conventional water supply system with drinking water quality for all uses. The best minimization and prevention alternatives for Cali's expansion zone were found to be those which consider dual flush toilets and the possibility of using rainwater harvesting for laundry purposes. However, the minimization and prevention alternatives considered are only viable if these are implemented in more than 20% of household units.

1. Introduction

To achieve sustainable urban water management, the conventional approach of high water volumes and high quality for all use functions needs to be revisited. Traditionally, pollution control consists primarily of centralized and end-of-pipe solutions. Due to the high costs of this approach, it is estimated that worldwide only about 15% of all people are connected to a wastewater treatment facility that is built to provide a primary or secondary level of treatment (Bos et al., 2004). The number of people connected to modern wastewater treatment facilities that include nutrient removal comprises only an estimated 2% of the world's population. It is clear that the vast majority of the indicated coverage for wastewater treatment is found in developed regions (UNEP/GPA and UNESCO-IHE, 2004). As a result, the overwhelming majority of municipal sewage is discharged untreated into rivers, lakes and coastal waters, leading to severe water quality deterioration. In fact, achieving Target 10 of the Millennium Development Goals for drinking water will lead to a further increase in sewage production, and therefore could trigger a further worsening of the already critical water quality crisis globally. A change in urban water management is necessary in order to improve the system's sustainability, and must integrate economic, social and environmental issues with practices such as integrated management of storm water, water conservation, reuse of wastewater, rational energy management, recovery of nutrients and source separation (Daigger, 2009).

Cleaner Production (CP) can be defined as the approach in which processes and activities are carried out in such a manner

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that the environmental impact thereof is as low as possible. As a result, the approach is now shifting from "waste management" to "pollution prevention and waste minimization" (Siebel and Gijzen, 2002; Veenstra et al., 1997). CP production concepts have been successfully applied in the industrial sector, and could also help transform the urban water sector. It has been proposed that these concepts could be applied to water resources integrated management, searching for new alternatives to the limited achievements provided by end-of-pipe solutions. In this context the conceptual model of the Three Steps Strategic Approach (3-SSA) was developed, consisting of: 1) minimization and prevention, 2) treatment for reuse and 3) stimulated natural self-purification (Siebel and Gijzen, 2003; Naphi and Gijzen, 2005; Gijzen, 2006). The minimization and prevention concept refers to the reduction of residues, emissions and discharges of any production process through measures that make it possible to decrease, to economically and technically feasible levels, the amount of contaminants generated which require treatment or final disposal (Cardona, 2007; Siebel and Gijzen, 2002). The minimization proposals can be classified in three main actions (Cardona, 2007; Nhapi and Gijzen, 2005): a) reduction at source, which includes a change in consumption habits and application of low consumption devices; b) in situ recycling techniques, and c) rainwater harvesting. The first action proposes a shift to low consumption devices, such as water-saving toilets, showers and aired faucets that generate a decrease in the consumption of water, allowing for the possibility of supplying more users, without the need for new water sources and treatment capacity. The second and third actions, in situ recycling techniques, recognize new alternative water sources, such as rainwater harvesting and grey water. Lastly, the use of treated grey water is feasible for toilet flushing, the washing machine, plant watering, and the washing of floors and outdoor areas (Liu et al., 2010; Mejia et al., 2004; Sierra, 2006; Gijzen, 2006), golf courses, agriculture and groundwater recharge (Ottoson and Stenström, 2003).

This study focuses on Step 1: minimization and prevention (by applying cleaner production principles) and applies this to the case study in the city of Cali, Colombia (the expansion area). The evaluation of alternatives is done using two different system boundaries: (1) a reduction in water supply costs for households, the avoided costs in the additional drinking water infrastructure and the additional sewerage and wastewater treatment facilities; and (2) only taking into account a reduction in water supply costs for households and the savings associated with the drinking water infrastructure. The alternatives of minimization and prevention were hierarchized using an analytic hierarchy process (AHP) and grey relational analysis (GRA). A cost-benefit analysis was carried out to compare the highest ranked alternatives with the conventional approach, which considers a 'business as usual scenario' of high water use, end-of-pipe wastewater treatment plant and the conventional water supply system with drinking water quality for all uses.

In the holistic, integrated wastewater approach it is essential to know the impacts of particular decisions and selected strategies. An integration of technical, environmental, social, cultural, economic, policy and regulatory aspects allows for a transition from the traditional approach to one of closed and efficient processes (Zein, 2006). This approach has had gaps and has usually been focused on the wastewater treatment plant (WWTP) investment (end-of-pipe solutions), mainly in developed countries. Also most of the strategies (models, guides, algorithms, among others) to support the technology selection process have been mainly oriented towards treatment systems. Most of these tools do not consider strategic approaches such as the Three Steps Strategic Approach (3-SSA). The common selection criteria for most authors can be classified into the following factors: treatment objectives, technological aspects, costs, operation and maintenance, wastewater characteristics, demographical and socio-cultural factors, site characteristics, climate factors, environmental impact, capacity and willingness to pay, and construction aspects (Galvis et al., 2006). Before selecting and investing in wastewater technology it is preferable to investigate whether pollution can be minimized or prevented (Veenstra et al., 1997). Some selection models that incorporate multi-criteria analysis are: PROSAB, SANEX, WAWTTAR and PROSEL. More recent models, such as the Urban Water Optioneering Tool UWOT, facilitate the selection of combinations of water-saving strategies and technologies and support the delivery of integrated, sustainable water management for new developments (Makropoulos et al., 2008).

Water management is typically a multi-objective problem which makes multicriteria decision analysis (MCDA) a well-suited decision support tool (Hajkowicz and Collins, 2007). There is no single MCDA method that can claim to be a superior method for all decisions (Mutikanga et al., 2011). Whilst selection of the MCDA technique is important, more emphasis is needed for the initial structuring of the decision problem, which involves choosing criteria and decision options (Hajkowicz and Higgins, 2008). The wastewater treatment alternative selection is a MCDA, where uncertainty, complexity and hierarchy need to be considered. Zeng et al. (2007) propose a multi-criteria analysis methodology including: Analytic Hierarchy Process (AHP) and Grey Relational Analysis (GRA). AHP is useful for handling multiple criteria and objectives in the decision-making process. The GRA is a measurement method in grey system theory that analyzes uncertain relations between one main factor and all the other factors in a given system (Liu et al., 2005; Tosun and Pihtili, 2010). The hierarchy GRA combines the traditional GRA with the idea of the hierarchy of the AHP. It enables a more effective evaluation than just the mono level-based evaluation. The different levels of importance of the criteria are reflected through weighting factors to avoid subjectivity and randomness. In addition, the quantified evaluating scale, namely the integrated grey relational grade, makes the wastewater treatment alternative selection more comparable and comprehensive. Grey system theory was developed by Deng (1982) and has been successfully applied in engineering prediction and control, social and economic system management, and environmental system decision making in recent years.

The study therefore aims to identify and validate ways to maximize the benefits of the strategy (3-SSA) in the municipal water cycle and to provide the tools and approach for the selection of viable and effective alternatives under Step 1. The research presents the potential usage of AHP + GRA in the hierarchies of water-saving alternatives in households, leading to domestic wastewater pollution minimization and prevention. This selection methodology includes a cost-benefit analysis (CBA) among the highest-rated alternatives (AHP + GRA results) and a comparison with the conventional approach, which considers a 'business as usual scenario' of high water use, end-of-pipe wastewater treatment plant and the conventional water supply system with drinking water quality for all uses.

The Three-Step Approach as compared to more conventional approaches may lead to a more cost-effective policy choice, assuming similar health gains (Bos et al., 2004). According to WHO (2004), investing in sanitation and water supply projects provides economic benefits due to the fact that for each US$ invested, there is an economic benefit ranging between US$ 3 and US$ 34, depending on the region. These economic benefits include impacts on: population health, environment, agriculture, industry, economy, tourism, etc. (OPS, 2008). This study uses the incremental cost-benefit analysis and it does not consider the common costs and benefits to compare the approaches. It also did not consider benefits of minimization and prevention in relation to the other