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Estimating the potential water reuse based on fuzzy reasoning

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ABSTRACT

Studies worldwide suggest that the risk of water shortage in regions affected by climate change is growing. Decision support tools can help governments to identify future water supply problems in order to plan mitigation measures. Treated wastewater is considered a suitable alternative water resource and it is used for non-potable applications in many dry regions around the world. This work describes a decision support system (DSS) that was developed to identify current water reuse potential and the variables that determine the reclamation level. The DSS uses fuzzy inference system (FIS) as a tool and multi-criteria decision making is the conceptual approach behind the DSS. It was observed that water reuse level seems to be related to environmental factors such as drought, water exploitation index, water use, population density and the wastewater treatment rate, among others. A dataset was built to analyze these features through water reuse potential with a FIS that considered 155 regions and 183 cities. Despite some inexact fit between the classification and simulation data for agricultural and urban water reuse potential it was found that the FIS was suitable to identify the water reuse trend. Information on the water reuse potential is important because it issues a warning about future water supply needs based on climate change scenarios, which helps to support decision making with a view to tackling water shortage.

1. Introduction

Planned water reuse projects are identified around the world, however, there are circumstances where alternative water resources are only sought after emergency situations. Water shortage causes a substantial damage considering the losses of crops and livestock in many countries, and poses a risk to human health when is not enough for drink and cleaning or when contaminated water sources are used. Identification and discussion of the factors that drive risks on water supply security is important for decision making systems development and useful to manage water resources efficiently.

Global warming, water consumption and population growing trends suggest a worsening in water shortages (World Water Assessment Programme, 2009). The trends towards persistent drought increase constitute a warning about safety and security of water supply. Results of simulations based on global climate models (GCMs) show that there will be significant increases in consecutive dry days (IPCC, 2012). The trend towards reduced precipitation and/or increased evapotranspiration, higher than medium confidence level, is that droughts will intensify in the 21st century. It applies to southern Europe and the Mediterranean region, central Europe, Central North America, Central America, northeastern Brazil, and southern Africa (Dai, 2011).

Besides climate change, population growth in megacities also increases water access vulnerability in densely populated regions such as Beijing (China), Tokyo (Japan) and Delhi (India). Water shortage in these regions will become more frequent because of higher water consumption and water stress intensification (Bates et al., 2008). The water consumption may decrease when water price increases (Fig. 1), however, higher water tariffs are a limitation to water access in some regions. A prolonged drought is one of the factors that may increase the price of water. For instance, San Diego (USA) and Barcelona (Spain) have already imported water from regional wholesale suppliers and by boat transport during droughts, which means higher payments for raw water (Walton, 2011).

The scenarios presented for water availability have shown the need of future alternative sources of supply necessities. In regions

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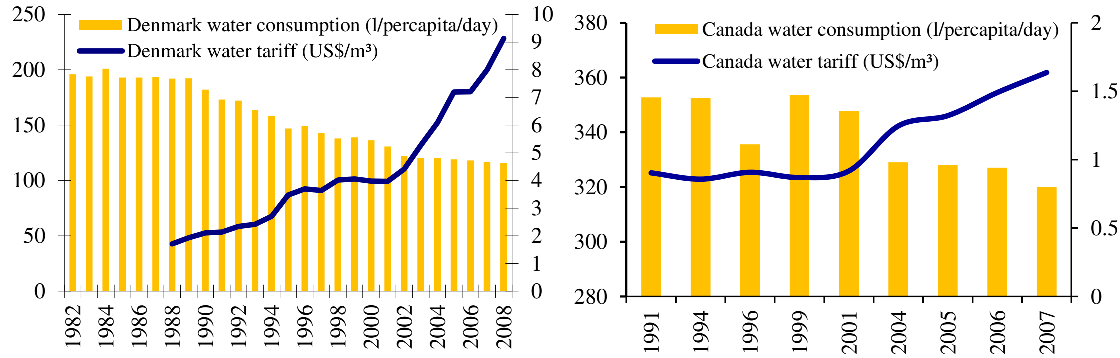

Fig. 1. Trends in water consumption and tariff: Denmark (DANVA, 2011) and Canada (AECOM and NRC, 2009).

with high scarcity the treated wastewater may be an important resource. Irrigation is the main activity related to treated wastewater use since it consumes most water (AQUASTAT/FAO, 2012). Urban water reclamation for golf course irrigation, toilet flushing and street cleansing is also considered, although water reuse for artificial aquifer recharge, industrial cooling and irrigation in restricted areas are better accepted.

Researchers worldwide are developing water management systems in order to solve many water supply problems. The AQUAREC Project has developed integrated concepts for reusing upgraded wastewater in European countries. The decision support software for water treatment for reuse with Network Distribution WTRNet developed within the AQUAREC Project provides an integrated framework for the treatment and distribution aspects of the optimization of water reuse and the selection of end-users (Joksimovic et al., 2008). Other authors (e.g. Zarghami et al., 2007; Tkach and Simonovic, 1997; Hyde et al., 2005) propose multi-criteria decision making (MCDM) tools to solve various water management problems in light of the flexibility needed to deal with environmental data. The evaluation of future alternative of water resources necessities depends on the adaptive management tools development. The environmental model, which aims to identify those necessities, must take into account some aspects related to water stress.

Realizing the importance of tools that support water management decisions, we present in this paper the rationale and results of a fuzzy inference system (FIS) that estimate the potential for regional reuse using factors (i.e. drought, water exploitation, water uses, wastewater treatment rate among others) considered relevant to the perceived need for reuse. The main objective of this manuscript is to present the agricultural and urban water reuse potential model and results considering a dataset for 155 regions and 185 cities. It also aims to support decision makers, providing insights to tackle water shortage and to promote discussions about factors that incentive water reuse.

2. Methodology

The identification of the main types of recycled water use was the first step in this research work. Taking into account the largest water reclamation users (Europe, Israel, California, Japan and Australia) more than a half of recycled water is used for agricultural purpose. Urban use is the second most used type of recycled water in these regions, immediately followed by ground water recharge (Table 1).

Due to agricultural and urban water reuse tendency, factors that stimulate these two types of reuse were considered when developing the system. In this work the urban water reuse was considered for watering (gardens, parks, landscapes, etc.), washing (streets, vehicles, public monuments, etc.), firefighting and toilet flushing in metropolitan public areas. The crops irrigation was considered for agricultural water reuse. Other urban reclamation options were not considered because it was observed that governments' stimulation is usually responsible for a large scale water reuse. In addition, some industrial, residential and commercial water reuse is related to private incentives that are driven by economic concerns rather than water conservation reasons.

In the second phase, the main factors that encourage agricultural and urban water reuse were identified. These factors were considered as features in the proposed system. The features used to analyse agricultural water reuse potential were the drought, the water exploitation index (WEI) and the ratio between agricultural water use and urban water supply use. For urban water reuse potential, the features were WEI, drought, demographic density and wastewater treatment rate. 155 regions were selected from around the world to analyze the features that drive the agricultural water reuse in order to design the water reuse potential model. For urban water reuse 185 cities were surveyed. The regions and cities were chosen taking into account its water reclamation relevance and available data. Other regions firstly selected due to its water reuse relevance were left out of this work due to difficulties in finding

Table 1
Water reuse by type.

Regions	Water reuse (Mm^3/a)						
	Total	Agricultural	Ground water recharge	Industrial	Ecologic use	Urban use	Domiciliary
Europe and Israel	963	674	164	39	48	39	0
California-EUA	434	213	61	22	56	82	0
Japan	206	16	0	16	66	78	29
Australia	166	50	0	66	5	40	5
Total (Mm^3/a)	1769	953	224	143	175	239	34
Percentage (%)		54	13	8	10	14	2

Source: Adapted from: Report on integrated water reuse concepts (Wintgens and Hochstrat, 2006).