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A multi-objective approach with soft constraints for water supply and wastewater coverage improvements ☆

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ABSTRACT

In Brazil, due to public health, social and economic cohesion problems, access to water and wastewater services is certainly one of the main concerns of the different stakeholders in the Brazilian water sector. But as the focus is mainly on the expansion and building of new infrastructures, other features such as the robustness and resiliency of the systems are being forgotten. This reason, among others, highlights the importance of sustainable development and financing for the Brazilian water sector. In order to assess that goal, a multi-objective optimization model was built with the aim of formulating strategies to reach a predefined coverage minimizing time and costs incurred, under specific hard and soft constraints, assembled to deal with key sustainability concepts (*e.g.*, affordability and coverage targets features) as they should not be left apart. For that purpose, an achievement scalarizing function was adopted with three distinct scaling coefficient vectors for a given reference point. To solve this combinatorial optimization problem, we used a mixed integer-linear programming optimizer that resorts to branch-and-bound methods. The work developed, paves the way toward the creation of a decision-aiding tool, without disregarding the number of steps that need to be taken to achieve the proposed objectives.

1. Introduction

Water is a key prerequisite for human and economic development, as well as for ecosystems maintenance. However, poor governance and inadequate investment leave large populations without access to the water services they need and the failure to manage this situation has seriously jeopardized service delivery. Above all, those concerns greatly undermine some developing and transition economies (OECD, 2009).

Brazil is one of such countries. Therefore, due to public health along with social and economic reasons, among others, access to Water supply and Wastewater Services (WWS) is certainly the main concern of stakeholders in the Brazilian water sector. From water utilities, to customers, regulators or politicians, no one denies that this is a top priority in this country. Those services mostly cover drinking water supply and wastewater collection and treatment. Despite the substantial investments done in the past years, the access to improved *water supply*, and mainly, the access to improved *wastewater collection and treatment* is still unquestionably low (IBGE, 2011).

Huge investments are also required to improve the quality of service, or the robustness and resiliency of the systems. Lack of continuity, high water losses, untreated and inappropriate drinking water supplied, inefficient and inadequate wastewater treatment are also other troublesome issues which have a tendency to worsen in the future as the focus is centered on the expansion and building of new infrastructure (Marques, 2013a).

The most surprising issue is that in Brazil the lack of financial resources is not the bottleneck, like in most countries around the world, despite its great regional heterogeneity. In Oliveira, Scazufca, and Marcato (2011), the authors highlight that the difficulty to carry out water and wastewater projects, and the infrastructure systems' management, are related to a set of factors. The institutional confusion and the enormous bureaucracy are some of the most important. To deal with this situation, the Federal Government delegated to the Ministry of Cities the development of a national plan, the PLANSAB (Plano Nacional de Saneamento Básico, translated to English as National Plan for Water, Wastewater, Drainage and Urban Waste Sectors), to create an investment forecast by producing guidelines to support sustainable and continuous long run policies (SNSA, 2013a).

☆ Case study: Water supply and wastewater services in Brazil.

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The PLANSAB refers to the need of investing R$ 304 thousands of millions (Brazilian real), of which R$ 122 thousands of millions relate to water supply and R$ 182 thousands of millions to wastewater collection and treatment in order to achieve a desired universalization in 2030 (99 percent in water supply and 92 percent in wastewater), being the date later postponed to 2033. However, the past investment trends suggest otherwise, raising doubts about the values and deadlines presented. Indeed, if the current *status quo* remains, this target will not be fulfilled and the cost of universalization will be much higher. Note that the PLANSAB also predicts further relevant investments in drainage and solid waste service, although those services go beyond the scope of this analysis.

From the improvement of access to WWS perspective, the problem relies on the assumptions made, what data is considered as a viable input (*e.g.,* the principles that account for improved WWS, the technological options to be adopted). In the related literature, as far as investments needed in low-income countries (Hutton, 2013; Mugisha & Borisova, 2010; OECD, 2011; UNDP, 2006; WHO, 2012) are concerned, many situations adopted (*e.g.,* network solutions vs individual) do not always make sense for Brazil, particularly in the South, Southeastern and Center-Western regions. Note that some individual solutions might be inadequate, since some of them are very rudimentary. That is the reason why these individual solutions should always be under the responsibility (for maintenance purposes) of designated providers. The policy for the water sector (*e.g.,* PLANSAB) does not take into account those principles and, politically speaking, the hypothesis of different solutions for the Brazilians is not well accepted or welcomed. Due to the above mentioned uncertainties, the current paper analyzes the desired service's expansion, resorting to an Operations Research approach, from the Ministry of Cities point of view, as the supervisor of the water sector sustainable development. In order to achieve that goal, a multi-objective optimization (MOO) model was built, so as to formulate strategies to reach a predefined coverage minimizing time and costs incurred, under specific hard and soft constraints, assembled to deal with important sustainability concepts (*e.g.,* affordability), those types of constraints (*i.e.*, the use of soft and hard constraints) are broadly documented in literature surveys (van den Bergh, Beliën, de Bruecker, Demeulemeester, & de Boeck, 2013; Greenberg, 1995).

In this *a posteriori* approach, the computerized Decision Support System (DSS) aims at finding, or approximating the set of efficient solutions, to deliver a range of desirable options for the Decision Maker (DM) to consider. The use of a reference point method is particularly adequate to deal with this kind of situations by using an achievement scalarizing function to make a projection of the reference point onto the Pareto frontier. Thus, three distinct scaling coefficient vectors for a given reference point were used to build a set of options able to guide the decision making process in this Multiple Criteria Decision Analysis (MCDA).

This method of projecting a given reference point (also labeled as reservation or aspiration points) that represents the objective, criteria or outcome values desired by the DM, onto the set of efficient solutions, has been widely developed; see, for example, Wierzbicki, Makowski, and Wessels (2000). The vast application of this methodology range from its use in discrete multicriteria problems where no function is optimized (Cabello, Ruiz, Pérez-Gladish, & Méndez-Rodríguez, 2014), to MOO reference point based approaches applied in the design of interactive systems for adaptive traffic control (Dujardin, Vanderpooten, & Boillot, 2015), or in determining regional public budget assignments among hospitals (Ruiz, Luque, Miguel, & del Mar Muñoz, 2008). From a different perspective recent cases apply the mentioned methodology with metaheuristic algorithms, see Figueira, Liefooghe, Talbi, and Wierzbicki (2010) for an application on a bi-objective flow-shop scheduling problem using multiple reference points implemented in a parallel evolutionary algorithmic framework. Furthermore, the model was compiled using the IBM ILOG Cplex Optimization Studio v12.6© program, hereafter Cplex. This document is organized as follows. Section 2 briefly describes the Brazilian context, analyzing prior investment trends in the Brazilian water sector so as to devise a scope of action for the posterior sections. Section 3 briefly highlights particular MOO concepts, and Section 4 displays the MOO model built and the results achieved. Finally, Section 5 provides concluding remarks and draws relevant perspectives.

2. The Brazilian context

In this section, the Brazilian context will be briefly described by stating the current situation and analyzing the investments trend. Thus, the WWS framework and some of its problems will be first discussed. Then, by comparing the investments undertaken with coverage improvements achieved, the scope of action of the model will be outlined.

2.1. Water supply and wastewater services: the status quo

In order to understand the Brazilian *status quo*, it is necessary to mention that although there is a complete and diversified set of information available, it is sparsely aggregated and the questionnaire methods used have a significant room for improvements (Marques, 2013b, chap. 8) . As for the input needed, they had to be found in different databases belonging to distinct Ministries, namely:

1. IBGE – the national statistics, including demographic *census* from 2000 and 2010, a national search of water and wastewater (PNSB) from 2000 and 2008, a national household search (PNAD) from 2001 to 2011;
2. SNIS – general information on water and wastewater from 2010, from the Ministry of Cities;
3. Sisagua – water quality for human consumption from 2010 to 2012, from the Ministry of Health, and;
4. Sedec – Department of National Defence, from 2007 to 2009, from the Ministry of National Integration.

Another important aspect is related to what is considered as an improved service, which is highlighted in Table 1 for the WWS. However, this classification is quite demanding, meaning that summarizing improved water supply services to in-house piped connections without interruptions and within quality parametric values, along wastewater collection network services, linked to further treatment facilities, and septic tanks, is quite a *golden plate standard* for a country as heterogeneous as Brazil. Still, the principles of improved water supply or improved wastewater services adopted in low-income countries may not always make sense for Brazil, at least for some areas, particularly in the South, Southeastern and Center-Western regions. But for most of the other regions they are an inherent reality (SNSA, 2013b).

The policy for the water sector (*e.g.,* PLANSAB) does not take into account those principles and, politically speaking, the hypothesis of different solutions for the Brazilians, as referred to, is not welcomed. Indeed, the expansion desired covers mainly network services. The only exception refers to a sparse use of those septic tanks already mentioned. Nonetheless, other individual solutions are widely accepted and should be welcomed (and considered in coverage statistics) as long as the responsibility for their operation and maintenance belongs to designated providers (UNDP, 2011).

The urban water sector in Brazil is completely detached from the rural counterpart. The protagonists, including the providers and ministries involved, and even the working rules, are different. The coverage levels presented in Table 2 encompass both urban and rural population. However, they will be lower in the rural areas which nowadays correspond to only a 15.6 percent (29,829 of 190,775, in thousands of inhabitants) of the Brazilian population (IBGE, 2012). Some of those rural areas are indeed in a dire situation with poor wastewater services coverage levels, lower than 25 percent.