Contributions to increase the availability of water supply in regions of water shortage: the case study of São Paulo, Brazil

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Abstract

Discussions over water availability increase, as society perceives the shortage of this good essential to human life. However, there is still a long way to go to ensure the efficient and equitable distribution of water. To increase the availability of water, often utilities consider catchment from new sources that constitutes supply-side water management. Currently, new sources of drinking water are scarce. An alternative is the planning based on the demand-side which is the rational management of water in its various uses through greater control measures and use of efficient equipment, water loss reduction, and public awareness. Here, we identify and prioritize relevant criteria to increase water availability via demand-side management in the state of São Paulo, Brazil. Based on interviews with experts in the field, the criteria for increasing water availability were defined and divided into groups that structure water demand and water supply management. The results highlight the priorities for water reuse and individualized micro-measurements.

Keywords: water supply, water resources management, multicriteria analysis, water loss reduction, water reuse systems.

1 Introduction

Discussions over water availability increase, as society perceives the shortage of this good essential to human life. Despite extensive research on water resource
management, there is still a long way to go to ensure efficiency and fair distribution of water. In this paper specifically, we address the problem of water scarcity in the Metropolitan Region of São Paulo (MRSP). For many years the concern centered on finding and securing enough water supply to fuel growth. The last half of the twentieth century experienced a paradigm shift, albeit gradually, towards using and managing available water resources more efficiently by emphasizing in water demand management [1–5].

In Brazil, the National Atlas of Water Supply is an important tool for research studies and assessments of the country’s water resources [6]. The Atlas predicts that in 2015, considering the current water availability and distribution systems, 55% of Brazilian municipalities may have a deficit in residential and industrial water supply, including major cities like São Paulo, Rio de Janeiro, Salvador, Belo Horizonte, Porto Alegre and the Federal District. According to the National Water Agency (ANA), Brazil’s regulatory water agency whose mission is to promote integrated water management through sustainable means, investments should be prioritized towards water springs and the collection and treatment of wastewater [7]. ANA estimates that investment of $22 billion USD would be required to expand and improve production of the water collection, treatment, and distribution systems by 2015, and a total of $70 billion USD by 2025, to prevent urban water shortage [6]. Nevertheless, in the context of these impending shortages, plans based solely on finding adequate water sources are not enough.

Utilities often prioritize building infrastructure for water resources management. The construction of reservoirs, treatment plants, water supply networks, and other facilities are in fact critical to the well being of the population. However, plans based on water demand tend to provide a rational allocation of the diverse uses of water resources. In this case study, providing the efficient use and conservation of water through controlled measures, higher efficiency equipment, reduction of water losses, and public awareness and education campaigns. To improve planning based on water demand management, it is necessary to prioritize the factors that most impact the availability of water and to consider specific components to the production and water supply system.

Here we show several strategies to increase the water availability in the state of São Paulo, Brazil, using multicriteria evaluation methods. We emphasize the need to improve water demand management by finding new strategies for using existing water resources more efficiently. In order to increase efficiency in water use, SABESP in partnership with the Agency Japan International Cooperation Agency – JICA, created in 2009, the Loss Reduction Program, and has become a reference in the reduction of water losses in Brazil. Japan is a world reference in the subject with only 3% loss, while in Sao Paulo current values are 25.6% [8].

1.1 The case of the state of São Paulo

The state of São Paulo has been historically at the heart of the Brazilian economy. With only 2.9% of the country’s area, it contributes 32.6% (i.e., $581 million USD at 2.30 exchange rate) of Gross Domestic Product – GDP [9]. São Paulo is also the most populous state in Brazil with 43.6 million residents, representing 22% of Brazil’s population, and a population density of 166.2 inhabitants/km² [9].
State of São Paulo has two very important regions: the Metropolitan Region of São Paulo (MRSP) and the Metropolitan Region of Campinas (MRC), which combined account for 20.9% of the national economy and 64.1% of the state economy [10, 11].

The state of São Paulo has limitations in accessing water. There is a large variation in annual precipitation throughout the state; for example, the northeastern coast average rainfall is around 3,000 mm/year, while the average in the western region is 1,300 mm/year. The MRSP’s aquifers have a rock formation that has to be fractured to access groundwater. In the remaining part of the state there are various aquifers of which three stand out, the aquifers of Bauru, Botucatu, and Guarani. This feature plus intense urbanization and industrialization observed in the region since the 1950s result in two main problems: the volume extracted from rivers, groundwater is scarcely replenished and the municipalities downstream of São Paulo face floods in the rainy season [12]. Moreover, existing water sources are at risk as degradation intensifies due to domestic and industrial wastewater discharge and the inadequate occupation of the territory without proper water treatment. This means contamination of rivers and streams with pollutants that are not being treated and, as a result, these bodies of water are reaching critical states with significant environmental consequences for the main drinking water sources. The confluence of these factors makes the per capita water availability in the MRSP only 200 m³/inh/year [12]; this is considered very low according to the United Nations Environment Programme (UNEP) (Table 1).

<table>
<thead>
<tr>
<th>UN/UNEP Classification</th>
<th>Values (m³/inh/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>&gt; 20.000</td>
</tr>
<tr>
<td>State of São Paulo</td>
<td>10.000–20.000</td>
</tr>
<tr>
<td>Piracicaba, Capivari, and Jundiaí River Basins (RB-PCJ)</td>
<td>5.000–10.000</td>
</tr>
<tr>
<td>MRSP – Alto-Tietê River Basin</td>
<td>2.000–5.000</td>
</tr>
<tr>
<td>MRSP – Alto-Tietê River Basin</td>
<td>1.000–2.000</td>
</tr>
<tr>
<td>MRSP – Alto-Tietê River Basin</td>
<td>&lt; 1.000</td>
</tr>
</tbody>
</table>

Source: UNEP (2002) [13].

In the 1960s, growing water needs, due to high population and industrial growth in the MRSP, initiated a long and contentious dispute over water allocation for residential and commercial uses with upstream basins. This dispute and economic growth led to the construction of the Cantareira System (Figure 1) in order to divert water from the Piracicaba, Capivari, and Jundiaí water basins (where the MRC is located) upstream to provide water for half of the population in the MRSP. The Cantareira System is a large infrastructure project made up of five major reservoirs connected in a network by tunnels, canals, and a pumping station that are jointly operated. It is formed by the rivers Jaguari and Jacareí,
Cachoeira, Atibainha, and Juqueri of which the first three are located in the headwaters of the Piracicaba river basin and the last in the Alto Tietê river basin.

The total production capacity of water Cantareira System is approximately 36 m³/s. This water is allocated for human uses between two regions – 31 m³/s for the MRSP and 5 m³/s for the PCJ basins – but historically low rainfall experienced in 2014 has compromised this allocation. Based on SABESP records, 73 mm of water were recorded in February 2014, while the historical average for this month is 202.6 mm [15]. Contrary to the National Atlas’ predictions, January and February of 2014 had one of the lowest average monthly rainfall recorded since 1930s [6]. The drought faced by the region in recent months has caused reservoir levels to recede dramatically to approximately 16% of its active volume capacity. This means that the allocation was decreased from 5 m³/s to 4 m³/s due to water rationing in some municipalities of the PCJ basins. The Piracicaba, Capivari, and Jundiaí (PCJ) water basin consortium estimates that the amount of water stored in the Cantareira system reservoirs could be totally consumed in about 80 days if low rainfalls persist and the current water withdrawals from the system are maintained [15]. According to the PCJ’s technical report, estimate rainfall of 17 mm average per day will be required for 60 days – or 1000 mm accumulated rain – in order to return to operate the Cantareira System reservoirs at 50% of its water storage capacity. Thus, it is crucial to research other options and to identify innovative ways to meet the region’s water demands, especially in the areas most affected by water shortages.
2 Literature review

Problems of water shortages are not unique to Brazil. Similar experiences of growing urban water needs have driven a “paradigm shift” in management based on an integrated water management approach [3]. Among other things, it calls for the integration and equal consideration of Water Supply Management (WSM) and Water Demand Management (WDM) strategies. This new water management paradigm has questioned if WSM alone is sustainable and can guarantee water for present and future generations. Water supply management policies rely heavily in large infrastructure projects that dredged, diverted, and channel water to provide for various human uses [4, 5]. Consequently, WSM is dependent on continually finding new water sources or transporting large water quantities from neighboring basins or more distant places. Such large water transfers are common in Brazil, as are the major transboundary conflicts that they entail. Although the country is endowed with larger quantities of water, for the most part, they are distributed away from the large population centers. Thus, the São Paulo case displays the growing need to obtain water in greater volume, from greater distances, causing tension between basins, and often generating political and environmental problems that affect the region [16].

While WSM aims to increase water sources, WDM aims to prolong the life of resources that are already available by using them more effectively. WDM involves technology, but it also demands manager’s know-how for implementing new strategies that conserve water. It includes strategies like economic incentives, education and awareness programs, rainwater harvesting, water reuse, reduction of water loss in the distribution systems, use of efficiency appliances, and educational measures. This type of management is more decentralized as it involves public, private, and civil society to engage in an effort to change behaviors towards rates and water uses. In Brazil, the main job of water utilities has been to provide clean potable water for human use. Nevertheless, several strategies exist to reduce water demand, as we identify bellow.

Water losses refer to the volumes of water not accounted for. In this case, we consider actual and apparent losses [17]. Actual losses are leaks in the networks, while apparent losses correspond to unaccounted volumes caused by illegal or non-registered users, malfunctioning or broken meters, and water meters fraud [18]. In 2010, utility companies in Brazil averaged a 37.57% share revenue loss due to water losses [19]. Revenue loss varied greatly by regions in the country: the average regional distribution was 51.55% in the north, 44.93% in the northeast, 32.59% in the midwest, 35.19% in the southeast, and 32.29% in the south [19]. In some states, the rate of water loss reach alarming levels as in the case of Alagoas with 65.87%, and Amapá with 74.6% revenue loss [19]. Estimating the financial loss caused in 2010, a mere 10% reduction of water loss in Brazil would translate to $560 million USD in water revenues; this is equivalent to 42% of the investment in water supply made by all utilities in the entire country in the same year [19].

The waters of lower quality, such as sewers, particularly from households, agricultural drainage waters and brackish waters shall, whenever possible, be considered as alternative sources for less specialized uses. Currently, the use of
appropriate technologies for developing these reusable sources is, along with improving water efficiency and control of demand, the basic strategy for solving the universal problem of lack of water [17]. According to Shubo [20], some countries have been prominent in research on water reuse such as the USA in Arizona which recycles 80% of their wastewater, and in Japan where approximately 80% of the water used in industry is treated and reused. Moreover, in Japan, water from showers is reused for toilets in condominiums, hotels, and hospitals. In Brazil, the industrial sector of São Paulo has increased investment in the treatment and subsequent reuse of their effluents [21]. Although current efforts by large producers of water reuse like Aquapolo [22], it doesn’t have the ability to attend large number of consumers. However, present scenarios of water scarcity in the region cannot ignore the reuse of water in a much larger scale.

The main way to increase efficiency is to improve end water uses, such as switching to equipment and technologies available that consume less water [23]. Furthermore, awareness campaigns are very important for large consumers and for society as a whole, and they may be regarded as a form of direct communication with the public [23].

Finally, rainwater-harvesting practices are an old and recognized tradition in many cultures. Over time, the collection of rainwater began to be replaced as new and modern supply systems were built [24]. However, more recently water shortages revived in various countries and sectors of society the tradition of rainwater harvesting. Countries like Germany, United Kingdom, Japan, Singapore, Hong Kong, China, Indonesia, Thailand, India, Australia and the United States have developed extensive research in the use of rainwater [25]. In Brazil, rainwater has mostly been used and stored through tanks in arid and semi-arid regions like the northeast. Despite water shortage in these regions of the country, rainwater harvesting is still not a considerable source of water.

2.1 Multicriteria expert elicitation methods

To achieve our goal, the Delphi method and AHP method were used. The Delphi technique is a structured and systematized sequential individual interviews seeking expert opinion, often through a series of questionnaires and feedback mechanisms [26]. It focuses on solving complex problems based on the opinion and/or judgment of a panel of expert [27]. The first questionnaire tends to focus on broader issues, while each subsequent questionnaire is based on answers to previous questionnaires. The number of interactions of this method can range between three and five [28], depending on the degree of agreement between experts’ responses and whether the amount of information obtained is sufficient to solve the problem.

Zuffo [27] also states that the Delphi technique is especially recommended when there is not sufficient or reliable data to extrapolate, or, even when there are expectations of structural changes in the determinant factors of future occurrence. Despite these advantages, Zuffo [29] explains that the relative importance of each criterion will be reduced insofar as values outside the range defined by the 1st and 3rd quartiles are discarded, and all the remaining assigned values approach a narrow range. In most applications the maximum and minimum values end up in
a small range of values between 7 and 9 (on a 1-10 scale). To avoid that, we complemented the analysis with the Analytic Hierarchy Process (AHP) method. The AHP consists of creating a hierarchy of criteria and alternatives of the proposed problem with the main objective of maintaining the highest level of hierarchy. The second level consists of criteria and the third level of alternatives; however, both levels should also be prioritized. This is done by a pairwise comparison of alternatives and by analyzing the influence caused by each alternative on each criterion. Consequently, one arrives at the influence that each alternative causes on the general objective of the problem [31–33]. In the AHP method, first the criteria are ranked from highest to lowest [31].

3 Methodology

On the first stage we choose four professional experts from the field of water resources with extensive knowledge in the water management sector. Upon selecting the respondents, individual meetings were scheduled with each of them in which questions were raised on various important criteria when considering the best options for increasing water availability. In this initial stage, experts are given an opportunity to include other criteria not identified by the interviewer, but which allowed for an organized manner to construct a cognitive map for each of the respondents and then grouping criteria.

In the second phase, we made use of Vue software for grouping the criteria that resulted in the following groups: structural, technological, economic, sociocultural, and environmental criteria. The Visual Understanding Environment (VUE) is a software for drawing up a mental map. For this, use is made of designs, words, pictures, designs, and other constructions.

In the third stage, the Delphi method was employed to aid decision-making. To obtain and prioritize the values of each criterion, 30 web questionnaires (webDELPHI method) were distributed with priority levels ranging from 0 to 10 for low to high priority, respectively. Of the total questionnaires sent 20 responses were received, or a 67% return rate, enabling the application of Delphi method. The answers were statistically analyzed after being organized into a database. Additionally, we applied Analytic Hierarchy Process (AHP) to the database, to separate the weights of prioritization between criteria and to compare the results of prioritization between the two methods, thus, generating consistent results.

4 Results and discussion

4.1 Data evaluation

Within WSM and WDM, it was necessary to define from the point of view of experts which criteria should have a greater emphasis. Even if managing in integrated manner (same weight is given to supply and demand), priorities within criteria need to be identified. It is interesting to note that when only given the option to choose between managing based on supply-side and demand-side (without detailing the appropriate actions in each of the groups), we obtained a
result of 56.4% for WDM and 43.6% for WSM (based on the Delphi method). Thus, there is a tendency among experts to prefer integrated water management. However, to evaluate the advantages of an alternative with respect to others, we must first know their actual costs. Otherwise, costs could prove prohibitively high to be applied. Such costly alternatives only take place with the support of government or private sector and are often forced by environmental pressures or resource scarcity with lack of other viable options to meet demand.

In the multicriteria method comparison, the degree of importance of WDM was perceived to be above WSD in both Delphi and AHP method. Based on the AHP results, WDM was considered twice as important as WSD measures (20.3% compared to 10.1% respectively). Thus, there is a consensus among expert opinions that WDM should be prioritize over measures to increase WSM. Based on our results, WDM proved a viable and important criterion to take into account. Additionally, by applying the AHP method to the data, we asked experts to rank the alternatives and opportunities of working with demand management options to ensure increased availability of water. Figure 2 presents the results.

<table>
<thead>
<tr>
<th>Action</th>
<th>Delphi</th>
<th>AHP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainwater use (11)</td>
<td>5.5%</td>
<td>2.9%</td>
</tr>
<tr>
<td>Increased water prices (10)</td>
<td>5.8%</td>
<td>3.0%</td>
</tr>
<tr>
<td>Hydraulic pumps and valves (9)</td>
<td>6.3%</td>
<td>3.5%</td>
</tr>
<tr>
<td>Water-Efficient Equipment (8)</td>
<td>6.4%</td>
<td>3.7%</td>
</tr>
<tr>
<td>Environmental importance (7)</td>
<td>7.7%</td>
<td>4.7%</td>
</tr>
<tr>
<td>Pressure control (6)</td>
<td>6.3%</td>
<td>5.0%</td>
</tr>
<tr>
<td>Optimization of Water (5)</td>
<td>6.7%</td>
<td>5.1%</td>
</tr>
<tr>
<td>Wasting Water (4)</td>
<td>7.4%</td>
<td>5.4%</td>
</tr>
<tr>
<td>Micro-measurement (3)</td>
<td>6.6%</td>
<td>5.5%</td>
</tr>
<tr>
<td>Water reuse (2)</td>
<td>7.0%</td>
<td>7.1%</td>
</tr>
<tr>
<td>Water losses (1)</td>
<td>7.8%</td>
<td>11.2%</td>
</tr>
</tbody>
</table>

Label: (1) Reduction of real and apparent water losses; (2) Water reuse; (3) Micro-measurement of Water; (4) Avoid Wasting Water; (5) Optimization of Water Networks; (6) Pressure Management System for drinking water supply; (7) Environmental importance in the water demand management; (8) Water-Efficient Equipment; (9) Improving the efficiency of hydraulic pumps and valves; (10) Increased water prices; (11) Rainwater use.

Figure 2: Importance of actions in the management of water demand.

Here we show the AHP prioritization results because this method refines the results obtained with the Delphi method and more clearly shows the distances among the criteria. Reducing real and apparent water losses scored 11.2% priority on interviewed expert opinion. In the analysis shown in Figure 2, one can conclude that reducing water loss is the most important action and the one that could
contribute the most in increasing the availability of water in the state of São Paulo. This result is confirmed by the need to decrease the 30% to 40% average water loss in the MRSP distribution system [18].

According to expert opinion, reuse of water (7.1%) is the secondary measure that will increase water availability for less vital uses and will decrease the use of high quality water for secondary purposes like flushing toilets, watering plants, or washing cars. Ranked third was sub-metering and individualized micro-measurement (5.5%). This characteristic can be directly related to the current situation of water scarcity due to lack of rains in the state of São Paulo. Individual micro-measurements encourage savings and reduce water wastage due to direct charges to the individual.

Measures that take into account water rationing are also directly related to reducing water waste and optimizing. The extent of water wastage reduction at 5.4% occupies fourth place in the priority list of experts. This result follows the general belief that through education and awareness campaigns and the eminent threat of water rationing, society as a whole learns to value water as a scarce resource and conserves water. On the issue of water distribution networks, a block of measures could be jointly organized for the optimization of hydraulic network (5.1%) and the reduction of network pressure (5.0%).

Environmental factors are criteria of fundamental importance, yet, they still rank low in the weights and considerations of experts. In the evaluation of this study, the importance of the environment represented 4.7%, ranking number seventh in priority. Nevertheless, environmental impacts are directly linked to the continual maintenance of flora, fauna, and river flows. Environmental factors include the protection of water springs and are directly related to water quality, supply, and overall availability.

Despite being recognized as an important measure in water conservation programs, the use of water-efficient equipment showed only 3.7% in terms of expert priority. This decision is directly linked to the fact that currently the equipment that consumes less water in the execution of these services is standardized for large use [33]. The same occurs with the criterion for improving the efficiency of hydraulic pumps and valves that ranked ninth with a weight of 3.5%. These two last criteria show the low index of modernization and technology replacement in the water utilities sector.

Finally, among the experts’ choice, the criteria of rainwater use obtained a weight of 2.9%, which is representative of the current weather condition. Record low rainfall since December 2013 proves that water management and planning that depend on weather conditions come at high risk. Furthermore, there are several structural problems like moving residence, new construction, modification, and storage unites, as well as, public health problems such as the protection of the local storage from insects and other vectors, that pose other challenges.
5 Conclusions

In the context of impending water scarcity, plans based solely on water supply management and the increase of new water sources are subject to supply problems. Thus, it is necessary to discuss other strategies to increase future water availability. For developing this study, the choice of the Delphi and AHP methods enable us to structure the study objectively and proved to enrich our understanding of the alternatives available for water planning and management. In this sense, three criteria were defined as essential: 1) the reduction of real and apparent losses at 11.2%; 2) water reuse was at 7.1% was second; and 3) sub-metered and individualized micro-measurement at 5.5%. It is worth noting the similarities between the weights given in the assessment criteria by the technical experts, despite their different areas of expertise, such as utility companies, universities, and basin committees. These results provide a starting point for a longer discussion on the main benefits and challenges to the implementation of various WDM strategies in the MRSP, which will be performed by the group in a future work, in a second and third round of data. Lastly, the results obtained in this study provide a basis for the application of other methods, such as the CP, CGT and fuzzy method.

Rapid urban changes and demographic growth pose unique challenges for water management. As this study demonstrates finding new strategies to address the water shortages based on this method has its limitations; it can be time consuming and the measures and criteria identified by managers vary with context. Nevertheless, water demand management needs to be integrated as a strategy to water supply management in order to effectively address water shortages in densely populated urban regions like the metropolitan region of São Paulo.

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