

Water loss performance indicators in peripheral areas of a metropolitan region in Amazonia

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SUMMARY

This paper aims to quantify and compare the losses of two isolated water supply systems with similar characteristics (Canarinho e Benjamin Sodré), located in the Metropolitan Region of Belém, state of Pará, Amazonia-Brazil. The methods included diagnosis of the systems, technical documental and commercial surveys from the water supply utility company, *in loco* flow measurements (portable ultrasonic flow meter and pitometer type equipment with transducer and data logger), statistical treatment of data and determination of Distribution Network Loss Index (DTI), Gross Linear Loss Index (GLLI), Loss per Connection Index (LLI), Hydrometric Index (HI), Average Per Capita Consumption (AACC) and Non-revenue water (NRW). High IPD were obtained: 81.98% and 70.04% for the SC and SBS, respectively. These values can be related to those obtained for the LLI (3.2 and 7.2 times higher, respectively, in relation to the national average) and the DTI. The high water loss rates are a characteristic of the northern region of Brazil and are reflected in the data obtained from the studied systems. Losses of this magnitude can make systems economically unsustainable due to frauds, lack of maintenance and a poor quality or degradation of infrastructure, thus contributing to a decrease in the quality of service.

KEYWORDS: Losses. Index. Amazonia. Non-revenue water. Water meter.

INTRODUCTION

Water supply in urban zones has become one of the main challenges of the present days, since many of them do not satisfactorily serve users due to the high demand for water use, the quality of the water offered, the difficulty in finding new sources of water, and the resources required to expand existing systems. Hence, the most rational option is to improve the operational management of the water supply system (WSS) with a careful observation of all the factors that can negatively impact the units of the WWS, so it can be managed more efficiently (NAZIF *et al.*, 2010; PIETRUCHA-URBANIK & STUDZIŃSKI, 2019) specifically the distribution networks, since, water pipes are prone to leakage and affect the amount of water supplied (HU *et al.*, 2021).

There are many factors that impact water loss, including the geographical conditions of the country, the physical characteristics of the WSS, and population density (VAN DEN BERG *et al.*, 2015). The services of fresh water supply in the world do not satisfactorily meet the high demand for water usage. In the world, approximately 48 billion cubic meters of water are produced every year without any charge for the consumer, an amount equal to the consumption of a whole year in North America (SCHOUTEN & HALIM, 2010). It is estimated that the annual cost of water losses, also called non-revenue water (NRW), is around US\$ 14.6 billion dollars worldwide, with US\$ 5.8 billion dollars lost in developing countries (KINGDOM *et al.*, 2006).

NRW includes physical losses (also called as real losses) which are normally leakages in the several units of the system, apparent losses (non-authorized uses, measurement errors, errors in issuing bills) and the non-billed authorized consumption for things such as firefighting and water tank trucks, among others (JALALKAMALI & EFTEKHARI, 2012; MUTIKANGA *et al.*, 2013; SARDINHA *et al.*, 2015). The apparent losses are a large part of NRW, mainly in developing countries, where distortions in consumption data can affect the management decisions and technical studies (MUTIKANGA *et al.*, 2011).

This control of water losses has several benefits such as reduction of production costs, increase of revenues and expansion of the system capacity, while avoiding water safety hazards (HU *et al.*, 2021). The volume of water lost in a year is an important indicator for the efficiency of a WWS. High water losses and constant improvements are indicators of an ineffective

planning and construction of the system, as well as improper operation and maintenance (OZTRK *et al.*, 2007).

Therefore, accurate measures of water loss are an initial step to avoid the problem and raise the revenue generated by the water utility company (TROJAN & MORAIS, 2012). For example, in Jamshedpur, India, besides technical actions, fieldworks were performed to identify non-authorized connections and legalize them. Approximately 1,600 disconnections were performed as well as the regularization of each one of those consumers. As a result, NRW was reduced from 36% in 2005 to 9.9% in 2009 (MADHAVAN & SAHAI, 2012). The city of Cartagena, Colombia, was able to reduced 32.42 % with the implementation of technical and commercial strategies and, as result problems were solved such as: imperceptible leak detection, water quality, service provision level through the implementation of pressure levels, and reduced NRW rate (ÂNGULO *et al.*, 2017).

According to Kingdom *et al.* (2006), NRW is around 15% in developed countries, 30% in Eurasia (CIS), and 35% in developing countries such as those in Latin America. Cities in Asia, for example, present an NRW around 30%, being able to reach higher values. More specifically, in Malaysia, the average of NRW was 38% in 2012, in Manila, Philippines, it was over 60%, in Cartagena, Colombia it was 31,58% (ÂNGULO *et al.*, 2017), and in Colombo, Sri Lanka and Kuala Lumpur, Malaysia, it was approximately 35%. However, in general, when the water losses get to the level of 20%, in most cases, it is already considered satisfactory, as it is the case of East Manila, with 11% in 2011 and Bangkok, Thailand, with 25% in 2012 (SEE & MA, 2018). In some cities such as Konyaalti (Turkey), Phnom Penh (Cambodia), Jamshedpur (India) and Singapore, after measurements to identify and control water losses by improving maintenance, repairs and expansion of WSS these levels reached values below 20% (ADB, 2010; KARADIREK, 2012). In 2014, the Ministry of Forestry and Water Affairs of Turkey has issued new regulations to reduce water losses to 25% (MUHAMMETOĞLU *et al.*, 2018). Mutikanga *et al.* (2011) have systematized several methods and tools to the management of losses that have been developed in the world for WSS, highlighting, however, that their full-scale use has been quite limited, which could considerably decrease loss rates in these countries.

Thus, besides the NRW, others indicators are used for improving the management of WSS including The Gross Linear Losses Index (GLLI), Connection Losses Index (CLI), Average Per Capita Consumption (APCC), and the Distribution Network Losses Index (DNLI). According to the National Sanitation Information System - SNIS (BRAZIL, 2021) the average losses in WSS in Brazil, considering only the distribution, are around 40.1%, varying between regions. The North region presents the highest percentual of losses in the country, with 51.2%, Northeast with 46.3%, South with 36.7%, Southeast with 38.1%, and Midwest with 34.2%. The Amazon Region is located mostly in North region with the losses distributed in the states: Acre (62.1%), Amapá (74.6.2%), Amazonas (59.3%), Mato Grosso (43.2%), Pará (36.9%), Rondônia (59.6%), Roraima (60.5%), Tocantins (33.9%), and a portion of the State of Maranhão (59.1%) (BRASIL, 2021). The highest magnitude of water loss in Brazil is in the state of Amapá, but more work is needed to quantify the magnitude of water loss in the North region of Brazil (MUTIKANGA *et al.*, 2011).

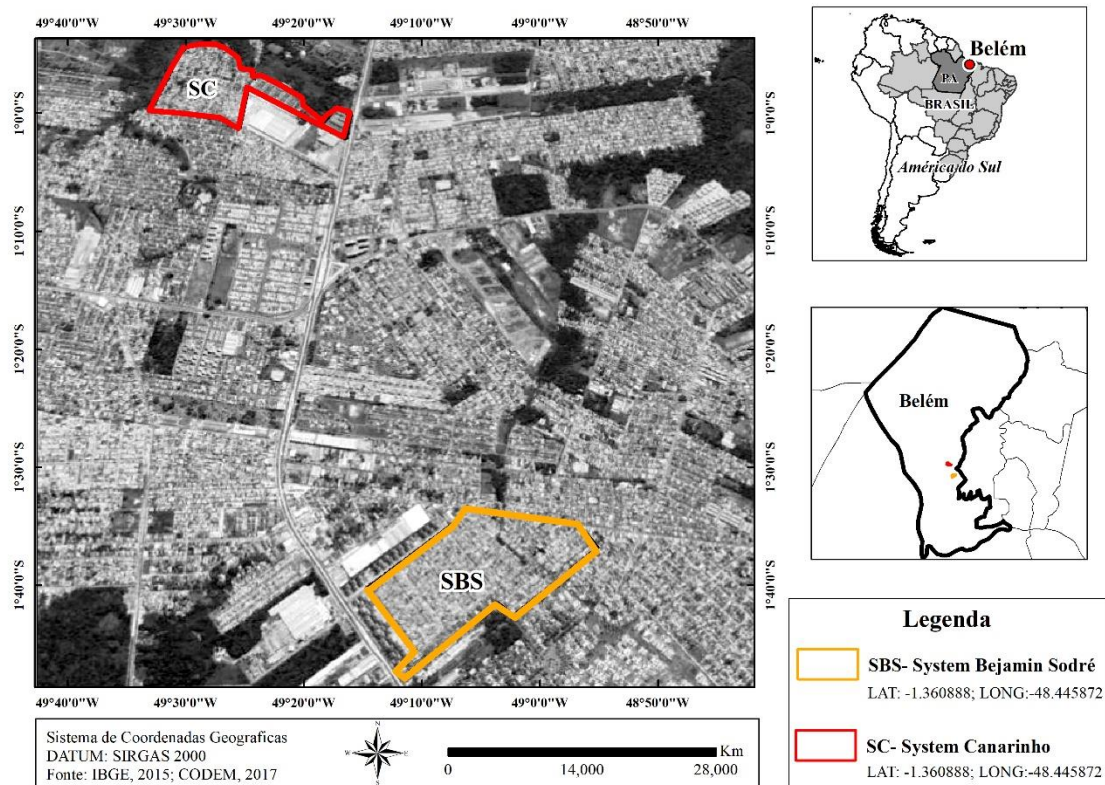
In this context, this paper aims to compare the water losses of two isolated WSS with similar characteristics, located in the Metropolitan Region of Belém, State of Pará, Brazil, with

the objective of identifying project parameters and loss rates, aiming to contribute to the management and planning of WSS in the Amazon.

METHODOLOGY

This study was conducted in two SAAs with similar characteristics, both located in the Metropolitan Region of Belém (RMB)-PA, Benjamin Sodr  System (SBS) and Canarinho System (SC). The geographic location of the studied area is presented in Figure 1.

Figure 1: Location of SBS and SC in the Metropolitan Region of Bel m- Par -Brazil.



The SBS is a water supply sector managed by the local utility, completely isolated, composed of a 220 meter deep well, a pumping system with a flow rate of 54.90 m³/h, which transfers water to a water treatment plant (WTP) for iron removal. The treated water is taken to two reservoirs (semi-buried and elevated, 156 m³) and directed to a distribution network with 5,778 meters, 730 connections, 631 of which are active, serving a population of 3,650 inhabitants. The SC is similar to the SBS with a 170 meter deep well, a pumping system with a flow of 117.5 m³/h, power of 40 CV, semi-buried reservoir of 120 m³ and an elevated reservoir of 274 m³. The distribution network is 11,371 meters long, with 730 connections, 639 of which are active and serving a population of 5,855 inhabitants.

The methods included diagnosis of the systems, technical documental (physical data of the systems) and commercial surveys from the water supply utility (number of connections,

estimated volume, micro-measured volume, and revenue volume), *in loco* flow measurements, statistical treatment of data and determination of WSS performance indicators.

Flow measurements were taken at: the raw water collection pipe (P1), at the WTP outlet (P2) and at the elevated reservoir outlet (P3). In SBS, the measurements were performed for 10 months and in the SC for 12 months. In P1, the measurements were performed with pitometer type equipment with transducer and data logger. In P2, at SBS, a triangular spillway was used while at SC a portable ultrasonic transit-time flow meter was used. Finally, in P3, in both systems the measurements were performed with a portable ultrasonic transit-time flowmeter.

The data obtained from the measurements were treated with descriptive statistics to determine their water flows and average volume at the different units of SBS and SC, for the calculation of NRW, DNLI, GLLI, CLI, HI and APCC, according to the formulation proposed by SNIS (BRAZIL, 2021), except for NRW that considered the concept used by Mutikanga *et al.* (2011).

RESULTS AND DISCUSSIONS

The values obtained in the flow measurements and the data surveys are summarized in Table 1 and Table 2. It is verified through the analysis of the revenue volume that the consumption patterns are similar for the inhabitants of both areas, despite of the fact that the metered connections of SC are lower than the SBS one (Table 1). Another point to be highlighted is that the volume distributed in the SC is 70% higher than the one in SBS (Table 2), the low number of active micro metered connections and the large number of unauthorized connections found in the SC, observed during field visits.

Table 1: Commercial data of SC and SBS.

System	Unmetered Connections		Metered Connections		Total of Active Connections	Total revenue (m ³ /month)
	Active Connections	Volume (m ³ /month)	Active Connections	Volume (m ³ /month)		
SC	552	9,275.00	87	2,079.00	639	11,354.00
SBS	175	4,290.00	456	7,198.50	631	11,488.50

Table 2: Metered data of SC and SBS.

System	Well (m ³ /month)	WTP output (m ³ /month)	Reservatory Output (m ³ /month)	Service volume (m ³ /month)
SC	74,025.00	66,540.00	66,009.90	540.00
SBS	39,528.00	39,442.29	39,094.20	225.00

Data from Table 1 and 2 were further used to determine water losses in the several units that compose the SC and SBS (Figure 2). It is highlighted that the largest percentage differences found refer to losses in the WTPs and in the distribution networks. The largest loss in the WTP in SC is due to the raw water flow (117.5 m³/h) which is superior to the treatment capacity of the WTP (100 m³/h) and leads to leakage overflows, a fact that does not occur in SBS. The same problem did not occur in SBS. The high percentages of losses in the distribution networks may be related to non-authorized connections, leakages in the network, under-measurements, what is much more serious in SC due to the largest number of non-authorized consumption and lower hydrometric index.

Figure 2: General flowchart of the daily volume of water in the SBS and SC.

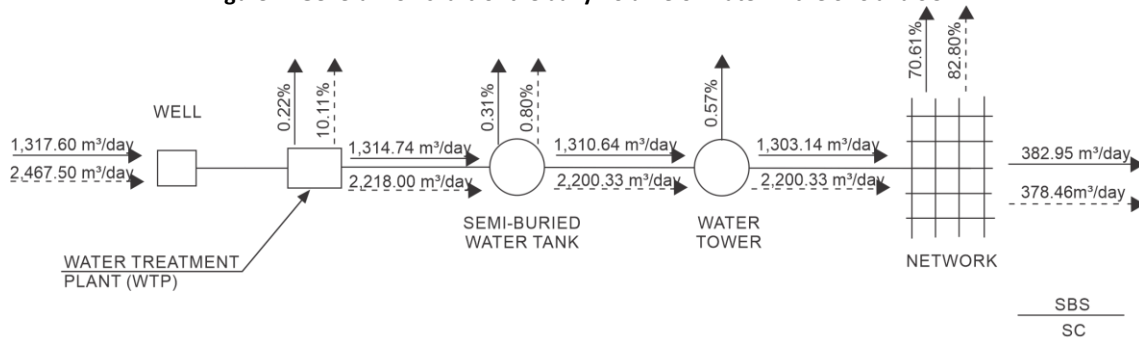


Table 3 presents the DNLI, HI, NRW, CLI, GLLI and APCC of the studied systems as well as their regional and national averages, according to the most recent data from the SNIS (BRAZIL, 2021). It is notorious that there is a huge difference between the DNLI obtained in the systems studied that of the city of Belém, 71% higher in SBS and 100% in SC, where both systems are located. Such difference may represent anomalies in the analyzed sample field in order to obtain the index for the municipality, or the fragility of the data, once they are declared by the water utility to the SNIS, and the water utility company, in many cases, does not have proper instrumentation to obtain accurate information. The same trend was detected to GLLI and CLI.

Table 3: Performance Indexes from WSS.

	DNLI (%)	RLI (L/m.day)	CLI (L/connection.day)	WMI (%)	APCC (L/inhab.day)	NRW (%)
SBS	70.04%	157.96	1,446.00	72.27%	104.92	70.93%
SC	81.98%	159.00	2,820.00	13.61%	64.64	84.66%
Belém/PA*	40.99%	41.65	396.98	47.83%	117.60	-
Regional Average.*	51.20%	-	595.90	61.90%	140.00	-
National Average*	40.10%	-	343.40	91.30%	152.10	-

Fonte: *BRAZIL, 2021

The low HI determined in SC (13.61%) favors the occurrence of unauthorized consumptions in the system, once these are necessary for greater control and quantification of water use. The low APCC recorded (64.64L/Inhab.d) and the high CLI (2,820.00L/connections.d) are a result of the low number of meters implanted in the SC (Table 2) and calculated based on the consumed volume registered by the water utility company, including metered and unmetered connections, that is, an estimated volume. Hence, it is noticeable that the majority (84.66%) of the water volume available to the distribution network is lost as a unauthorized consumption.

This assertion can be ratified in SBS, besides the high value of 70.93%, the NRW presented is 16,2% lower than SC. This can be explained based in the 72.27% HI what leads to a more accurate measure of per capita (APCC) and a lower distribution loss index (DNLI). What is noticed in the case of isolated systems in the city of Belém is that, regardless of water meters, there is a huge number of physical losses and fraud of system, what also justifies the higher values for DNLI in relation to the other regions in Brazil.

The APCC of SC and SBS presented lower values than the municipal, regional and national average, which may be related to the high NRW values. All variables analyzed in the SBS and SC systems presented values for NRW (70.93% and 84.66%, respectively) higher than those found in the international literature for developing countries (30%) and for other regions in Brazil. According to the literature review, only Manila presented a similar value with more than 60% (ÂNGULO *et al.*, 2017).

In general, the elevated indexes of losses show a countersense, since the Amazon is the region where there is the largest availability of fresh water in the world, there are also the largest indexes of water losses. It is clear that the region suffers from a deficient management of the WSS and scarcity of investments in water loss prevention. It is important that the authorities focus on the rational and qualitative use of water in the North region of Brazil, both in planning and in the operation/maintenance of the systems, with actions such as modernization of the infrastructure, automation of the systems, technical training of the teams, preparation of operational manuals, environmental education, among others.

CONCLUSIONS

The mean DNLI obtained was 76% for the systems studied, higher than the mean value reported by the SNIS for the city of Belém, North region and Brazil as a whole, but for NRW, the SBS and SC did not show significant alteration (14.5%), which may be related to the unauthorized consumption verified in these systems, mainly in the SC.

The low HI has a significant impact on APCC and NRW, a fact that is also observed with high CLI values for SBS and SC (3.2 and 7.2 times higher, respectively, compared to the national average), and can be explained by unauthorized consumption and maintenance problems.

High water loss rates are a characteristic of the northern region of Brazil and are reflected in the data obtained in the systems studied, mainly in peripheral and specific areas such as SBS and SC, where the rates are higher than the regional and national average. Losses of this magnitude make systems economically unsustainable and result in poor quality of water services and infrastructure degradation.

In summary, careful analysis of the socioeconomic conditions of the region is necessary during the implementation of a WSS. Besides this, actions should be taken to reduce this problem, such as proportional investments per region, training of employees, adequate maintenance of the systems and application of innovative strategies to reduce water losses.

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