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AN EVALUATION OF WATER LOSS INDICATORS IN A PERIOD OF WATER SCARCITY IN THE CITY OF VITÓRIA IN THE STATE OF ESPÍRITO SANTO

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Abstract: This article aims to evaluate the performance of water distribution services in the City of Vitória - ES, through loss indicators. The methodology applied was through the collection of basic information in the SNIS (National Sanitation Information System) and INMET (National Meteorological Institute) databases for the period of water scarcity in the State of Espírito Santo between 2012-2018. The results presented, through Figures, were discussed based on bibliographic references. It was concluded that the control of the volume distributed and consumed as a management strategy to reduce water loss is not enough, as it deals with supply and demand information. The concept of water loss has to supply this and imply the need for efficient actions by the service provider through the key factors. As a suggestion, it is relevant to apply the PRAI and IVI operational indices to determine the real performance of a distribution system.
Keywords*:* Water; loss; indicators; PRAI; IVI.

INTRODUCTION

The Diagnosis of Water and Sewage Services, conducted by the National Sanitation Department of the Ministry of Regional Development based on data from the National Sanitation Information System - SNIS, presents information and indicators of water distribution in Brazilian cities, since 1995. The most current published indicators are from two years prior to the Year of publication, in this case, they refer to the history of 2018.

The City of Vitória system obtained, in 2018, the level of 32.2% in the indicator of loss in distribution. Loss indicators are important for evaluating prStates services and can result in increased water supply and savings in natural, operational, electricity and financial resources (BRASIL, 2019).

This article aims to evaluate the service performance of the water distribution system of the City of Vitória - ES, through information on volume distributed, consumed, number of active connections, temperature, total precipitation, revenue, investment, product expense. chemical, electricity consumption and expenses compared to the water loss indicators published by the SNIS, referring to the history from 2012 to 2018.

WATER DISTRIBUTION SYSTEM IN THE CITY OF VITÓRIA

The capital of ES, the city of Vitória, is supplied through three Water Treatment Stations (ETA), which are located in the cities of Cariacica, Serra and Vila Velha. ETA Carapina, located in City da Serra, collects water from the Santa Maria da Vitória River and distributes an average daily flow of 400 L/s, while ETA Cobi and ETA Vale Esperança, located in City de Cariacica and Vila Velha, collect water of the Jucu River and distribute an average daily flow between 400 and 600 L/s to the City of Vitória, respectively (Figure 1).

The reduction and control of water loss in the Vitória distribution system is based on the Technical Documents released by the National Program to Combat Water Waste (PNCDA, 2015) that cover the topics presented in figure 2:

In addition to these technical topics guided by the PNCDA, the service provider operating in Vitória carries out other control and loss reduction activities:

- Critical analysis of the volume of water distributed (macro measurement);
- Critical analysis of the volume of water consumed (micro-measurement);
- Combating visible leaks;
- Level control of distribution tanks to prevent overflows.
- Search for non-visible leaks
- Operational control of lifts and pressure regulating devices.

The service provider also works with improvements in the water distribution system in the City, such as the execution and expansion of the distribution network and household connections, to meet the goals defined in the Municipal Plan for Basic Sanitation (2015), the Municipal, State and Federal.

MEASURING SYSTEMS - MACROMEASUREMENT AND MICROMEASUREMENT

The volume of water distributed in Vitória is measured using macro flow meters at the outlet of the WTPs and transmitted daily through telemetry equipment to the service provider's data system, which allows managing and analyzing the behavior of water distribution in real time.

The systems for measuring the volume of water distributed in the system - macro-measurement and the volume used by consumers - micro-measurement are the basic information for calculating the loss indicators and are essential tools for management. The adequate knowledge of this information allows exploring the best ways of operating the supply systems (BRASIL, 2019).

Measuring the water consumption in each Link makes it possible to share the costs of maintenance and implementation of improvements, in the same way that it also contributes to the preservation of the environment, as it indicates possible leaks or high consumption of water in the consumer's residence. Associated with flow measurement at the outlets of the system's treatment stations, it helps to identify distribution losses and provides fundamental information for the control and operation of the distributed volume of water (BRASIL, 2019).

Advanced measurement and data transfer technologies allow to evaluate the behavior of water distribution, analyze high resolution data and point out unusual patterns caused by water leakage (FERRANTE et al., 2007). The importance of controlling flow data at this level must not be underestimated, because this information on excessive water consumption indicates inefficiency in use and makes it possible to investigate leaks in the infrastructure.

WATER LOSS INDICATORS

Water loss is defined by the difference between the volume of water distributed and what is effectively accounted for as consumption by the population (ALEGRE et al., 2006). Loss indicators in the water distribution system are indications of leaks, irregular connections and measurement failures (BRASIL, 2019).

Loss indicators are calculated and published by the SNIS (Table 1), which is the Brazilian sanitation SECTOR database and is similar to the IWA (International Water Association) loss concepts and standards:

> "The SNIS calculates loss indicators in water distribution systems according to three different units: in percentage – distribution loss index (IN049); in liters per Link per day – loss rate per Link (IN051); and in cubic meters per kilometer of network per day – gross linear loss index (IN050). [...] It is important to highlight that the three indicators calculated by the SNIS do not differ the value of the real and apparent loss, that is, it cannot be affirmed that the published values are characterized as waste of water, necessarily. This limitation is mainly due to the collection of information by some service providers that do not have more accurate techniques in the assessment of leaks in the network, under-measurement in water meters, fraud, among others" (BRASIL, 2019).

The loss indicators that could overcome the technical operational limitations of the IN049, IN050 and IN051 would be those recommended by the IWA (Table 2), known

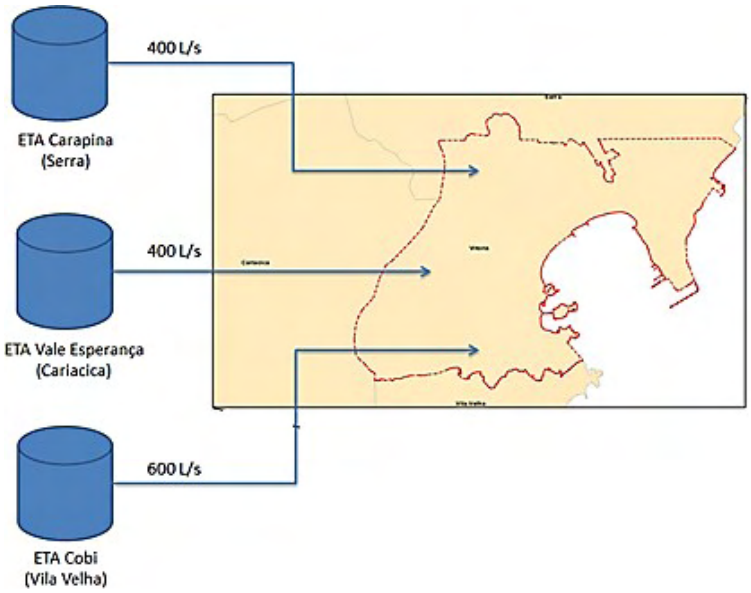

Figure 1 - Scheme of the flow distributed by WTP to the supply of Vitória Source: Data produced by the author (2022)

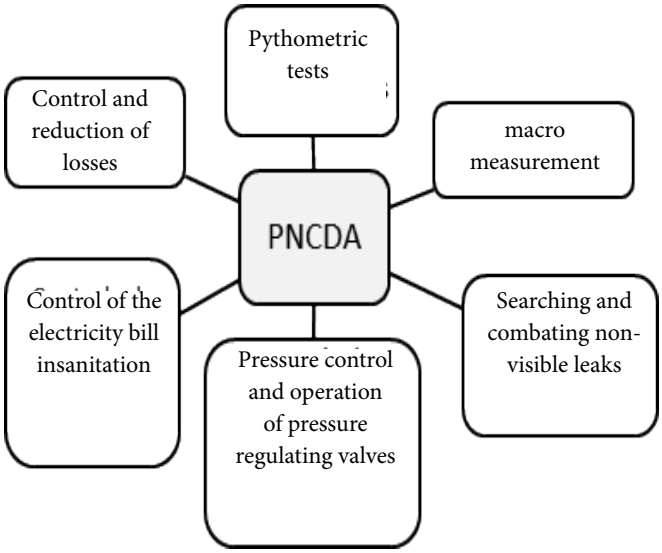

Figure 2 – Themes in water loss management of the national program to combat water waste (PNCDA)

Source: Data produced by the author (2022)

as PRAI (Inevitable Actual Annual Loss Index) and IVI (Infrastructure Leakage Index), because they use in the calculation the average operating pressure, network length and average branch length. These indicators help to characterize the share of the real loss, due to leakage, but are not calculated by the SNIS.

The PRAI index is a true loss estimate for any system that has good infrastructure, intensive active leak control, and all detectable leaks repaired quickly and effectively. Indicates the unavoidable and inherent lost volume of the distribution system on a daily basis.

The IVI calculation does not imply that the pressure in the system is minimal, and it is generally possible to reduce the leakage volume by better active pressure management. The real loss management approach through the IVI discriminates against utilities that operate under high pressures and favors those that carry out rigorous pressure management measures, according to the World Bank and IWA classification (MCKENZIE and SEAGO, 2005; Journal AWWA, 2005).

The World Bank and IWA classify distribution systems by Technical Performance Category for non-developed countries, according to the pressure range, IVI and IPL (LAMBERT, 2014; RADIVOJEVIC, MILICEVIC, PETROVIC, 2007).

The IWA recommends the use of the IN051, traditionally known as the "technical indicator for loss", measured in liters per Link-day, as it has operational applicability, compared to the Distribution Loss Index - IN049, which is measured in percentage, despite the ease of understanding and distortions that make it difficult to compare different supply systems or SECTORS (LAMBERT et al., 2014).

Tardelli (2015) states that there is no "zero loss" in water distribution systems, no matter how much care is taken and efforts made, there will always be a remaining loss value in the system ("unavoidable loss"), measured by the IVI. Another point is that, if actions to combat loss are not carried out regularly, these will gradually increase in the system (concept of "natural growth of loss").

METHODOLOGY

This article was limited to evaluating the behavior of the volume distributed and consumed and the water loss indicators IN051 and IN049, made available by the SNIS of the Vitória supply system, between 2012-2018. This period covered the water shortage in the Southeast region and affected the Jucu and Santa Maria de Vitória springs that supply the City.

The work was developed according to the steps described below:

1. First step: obtain from the service provider the monthly history of the average volumes distributed and consumed.
2. Second stage: obtain access to the meteorological database of the National Meteorological Institute (INMET) the monthly history of the average temperature and total precipitation in Vitória, in order to correlate with the demand variables of the average volumes of water and the loss indicators.
3. Third step: obtain the annual historical series of information (volume distributed, volume consumed, volume of service water and number of active connections) and loss indicators consolidated by the service provider and published by the SNIS.
4. Fourth step: obtain the annual historical series of information on revenue, investment, chemical product expenses and electricity consumption and expenses, in order to compare

Item	IN049 – Distribution loss index (IPD)		
01	Calculation Form $\frac{AG006 + AG018 - AG010 - AG024}{AG006 + AG018 - AG024} \times 100$	information involved AG006 – Volume of waterdistributed AG010 - Volume of waterconsumed AG018 - Volume of importedtreated water AG024 - Service water volume	Unit %
Item	IN050 – Gross linear loss index		
02	Calculation Form $\frac{AG006 + AG018 - AG010 - AG024}{AG005 *} \times \frac{1.000}{365}$	information involved AG005 – Extension of waternetwork AG006 - Volume of waterdistributed AG010 - Volume of waterconsumed AG018 - Volume of importedtreated water AG024 - Service water volume	Unit m³/day/km
Item	**IN051 – Link loss rate (IPL)**		
03	Calculation Form $\frac{AG006 + AG018 - AG010 - AG024}{AG002 *} \times \frac{1.000.000}{365}$	Informações envolvidas AG002 – Number of active water connections AG006 - Volume of waterdistributed AG010 - Volume of waterconsumed AG018 - Volume of importedtreated water AG024 - Service water volume	Unit L/day/link

Comments: AG005* - the arithmetic mean of the values of the reference Year and the Year preceding it is used.

Comments: AG002* - the arithmetic mean of the values of the reference Year and the Year preceding it is used.

Table 1 - Loss indicators calculated by the SNIS

Source: Adapted from SNIS, 2019.

Item	PRAI – Inevitable annualized real loss index		
01	Calculation Form $\left(18\frac{C_8}{C_{24}} + 0,8 + 0,025C_{25}\right)\frac{D_{34}}{10}$	information involved C8 - Network extension (km). C24 - Number of activeconnections C25 - Average length of branches(m) D34 - Operating pressure (KPa)	Unit L/day
Item	**IVI– Infrastructure leakage index**		
02	Calculation Form $\frac{IPL\ (IN051)}{\left(18\frac{C_8}{C_{24}} + 0,8 + 0,025C_{25}\right)\frac{D_{34}}{10}}$	information involved IN051 – Link loss rate C8 - Extension of the network(Km). C24 - Number of activeconnections C25 - Average length of branches(m) D34 - Average operating pressure(KPa)	DimensionlessUnit

Table 2 - Loss indicators recommended by the IWA

Source: Adapted from SNIS, 2019

with the operational loss indicators published by the SNIS.

5. With the data from the above steps, it was possible to discuss the primordial aspect as an answer to the question – the indicators of water loss: do they allow, in fact, to evaluate the performance of the water distribution services?

RESULTS AND ANALYSIS

The distributed volume of treated water in the City of Vitória was impacted by two phases of service performance management (Figure 3).

Phase 1 was a program applied by the service provider through the Loss Problem Analysis and Solution Methodology (MASPP) and the creation of a Distribution Control Center (CCD).

Phase 2 was characterized by water scarcity, historical moments of inclement weather and low supply of water for use, which forced the service provider to reduce the volume of treated water distributed in the City of Vitória between February 2015 and September 2017 by three defined moments:

- Moment 1: On February 4, 2015, the State Government, through Decree No. 3779- R/2015, decreed water scarcity in the State and provided guidelines for reducing household consumption and rational use of water by large consumers.

- Moment 2: Between August and November 2016, the State Government issued Resolutions, through the Water Regulatory Agency (AGERH), with guidelines and actions to reduce the use of water resources. In order to comply with these resolutions, the service provider implemented a rotation system in the supply of water in the neighborhoods of the Metropolitan Region, which are supplied by the two main springs, Jucu and Santa Maria. The Metropolitan region was grouped into seven distinct regions and each day of the week a region had its water supply suspended for a period of 24 hours, always starting at 12:00 (noon), with a guarantee of normalization within 24 hours. hours after the interruption period. The City of Vitória was divided into 4 SECTORs with alternating supply between the days of the week. (Table 3).

- Moment 3: The months between June 2017 and September 2017 were an atypical period in terms of the climatic season, being a cold and rainy period, providing a reduction in water consumption and consequently a reduction in the volume distributed.

Figure 3 not only clearly represents the change in the level of the volume distributed and volume consumed, but also the difference between these volumes, with little variation, through the range between the curves of the graph it can be observed that the curve of the distributed volume is only the reflection of the demand of the volume consumed and that the fight against the loss did not go beyond the monitoring of the flow demanded by the distribution system.

Seasonality influences the water supply and demand curve in the distribution system. When comparing the average temperature curve with the curve of the average volume distributed (AG006) and consumed (AG010), it is observed that the tracings of the curves are similar (Figure 5).

In other words: in a hot month, consumption tends to increase; in a cold month consumption tends to decrease; therefore, in a hot month the system operation increases the water distribution, while in a cold month it reduces it. But this is not a determinant and control parameter for reducing the loss rate, when low temperature occurs, there is also a high loss rate. Figure 6 demonstrates this

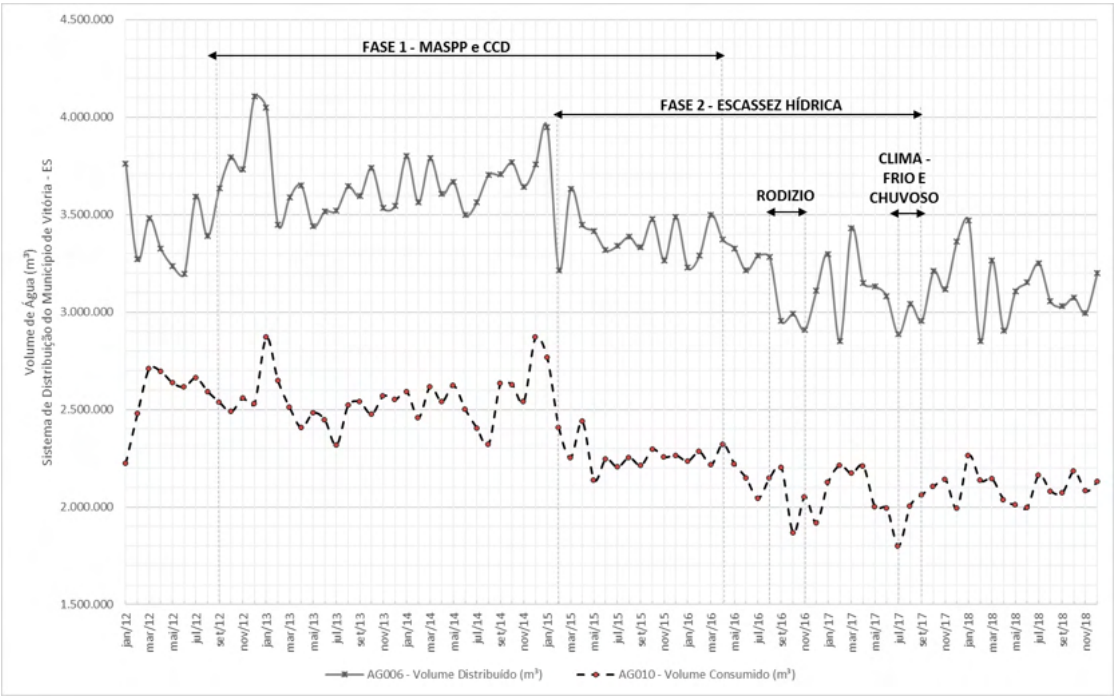

Figure 3 - History of the average monthly volume distributed (AG006) and average monthly volume consumed (AG010) in Vitória 2012-2018.

Source: Data produced by the author (2022)

SUPPLY SECTOR	**Sun-Mon**	**Mon-Tue**	**Tue-Wed**	**Wed-Thur**	**Thu/Fri**	**Fri-Sat**	**Sat-Sunday**
SECTOR A							Every sector undersupplied
SECTOR B	Every sector undersupplied						
SECTOR C	High part ofthe sectorwithout supplies				Low part of the sectorwithout supplies		
SECTOR D	Low part ofthe sectorwithout supplies		High part of the sectorunder-supplied				

Table 3 – Rotation of supply of sectors of City of Vitória.

Source: Data produced by the author (2022)

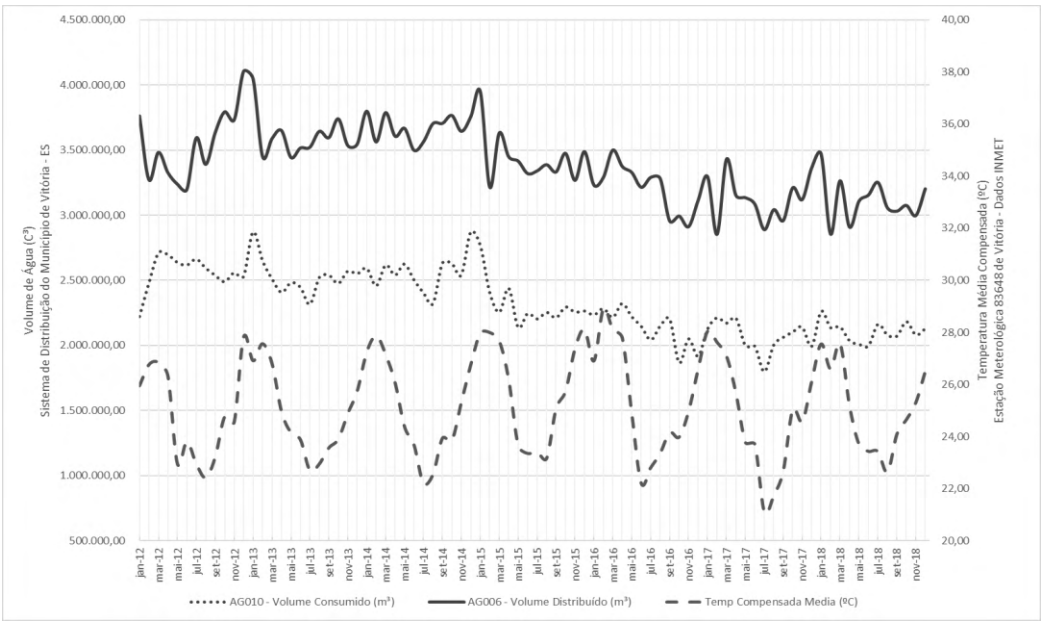

Figure 5 – Average monthly temperature curve, volume distributed and volume consumed.

Source: Data produced by the author (2022)

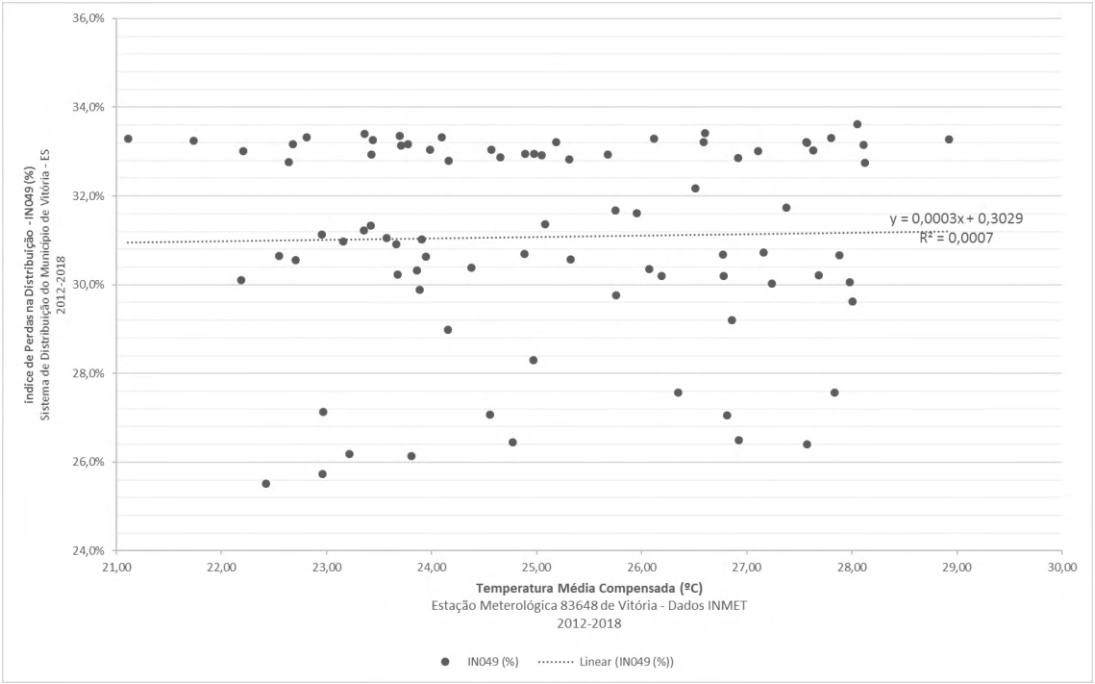

Figure 6 – Dispersion between distribution loss index and average temperature.

Source: Data produced by the author (2022)

statement by scattering the loss index data in the distribution (IN049) with the temperature data.

Expressing the loss as a percentage between distributed and consumed volume, unified and presented by the IN049 indicator curve - FIGURE 7, offers an illusory perspective of the true performance of the service, which may vary seasonally and from one year to the next, and is not under the control of the concessionaire, because it does not take into account any specific key factor of the system, but the supply and demand relationship.

For example, when the supply was low and consumption was low, the IN049 increased, it is observed in the period of water scarcity and rotation, however, in the period of high supply and high consumption this indicator was lower, it is observed in the period before the water scarcity. The variation of this indicator basically implies the mathematical formula of the relationship, that is, for this indicator to reduce the volume distributed, it must tend to decrease, while the volume consumed tends to increase, in considerable and ideal proportions.

For the IWA, the most adequate evaluation of the operational efficiency of a system is the one that considers the network extension, the number of active connections, the average time of water distribution and the average operational pressure. Because they enable a more accurate technical and operational diagnosis of the problem.

The IN051 indicator curve – Figure 8 differs from the IN049 indicator curve as it relates in its calculation the number of active connections in the distribution system, in addition to the supply and consumption variables, and for this reason it is characterized as a technical indicator.

The period when this indicator was at its lowest level was when there were fewer active connections in the system, the volumes distributed and consumed were higher and the weather conditions were wetter. On the other hand, in the period with higher levels, the system had more active connections, smaller volumes distributed and consumed, and dry weather conditions (Table 4).

When analyzing the annual history of the volume distributed/produced (AG006) and the volume consumed (AG010) concomitantly with the history of the loss rates IN049 and IN051, it is observed that the smaller the difference between these volumes, the lower the loss rates (Figure 9). Therefore, to obtain an effective reduction of this index, it would have to guarantee a low and effective volume distributed with a high and conscious volume of water consumed.

In contrast, in the period in which the rotation and strategic control of flow management by the service provider were applied, there was also a positive incentive for the conscious use of water, which reduced the volume consumed (AG010) and consequently the reduction in the volume of water distributed. (AG006), expected a reduction in these indicators, but the difference between these volumes was in the range between 12,600-12,800m³ which resulted in a level of 33% in the IPD indicator and 598 L/lig.day in the IPL indicator.

The role of indicators IN049, IN050 and IN051 is to support the assessment of water loss in distribution systems. The IN051 (l/lig. day) is more correlated with the performance of the service provider and, therefore, is closer to measuring an efficiency regime. On the other hand, it is understood that IN049 has the advantage of better communication for the lay public (BRASIL, 2019). The IN050 is correlated with the renewal of the distribution network infrastructure (asset) by the service provider and makes it possible to assess the level of investment.

The IN050 index proves that the expansion

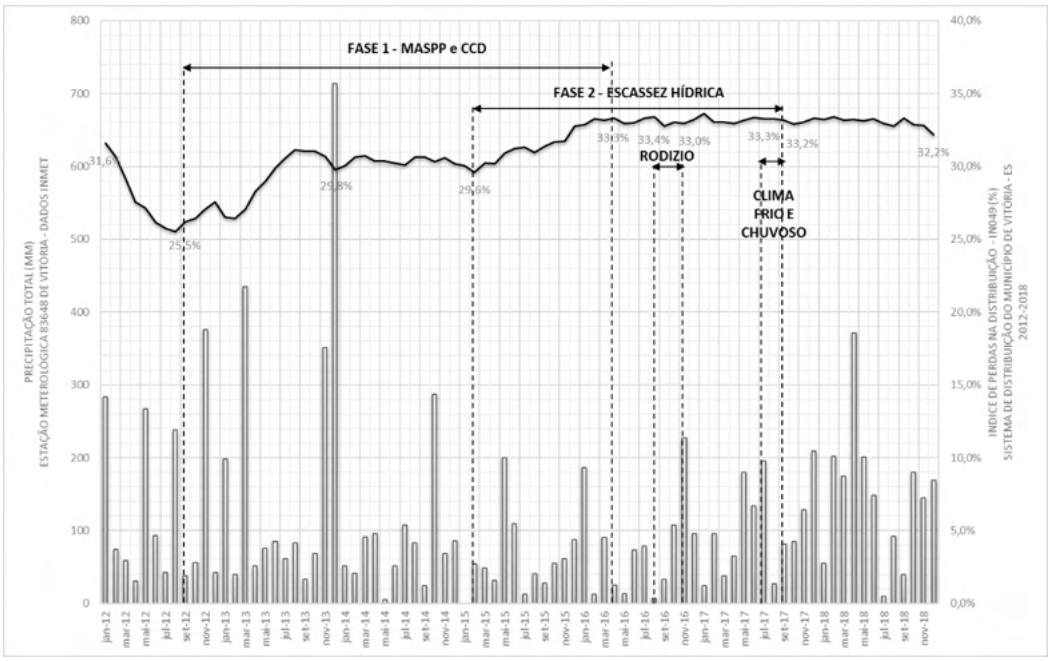

Figure 7 – Curve of the distribution loss indicator (IN049) related to total precipitation in the City of Vitória - ES.

Source: Data produced by the author (2022)

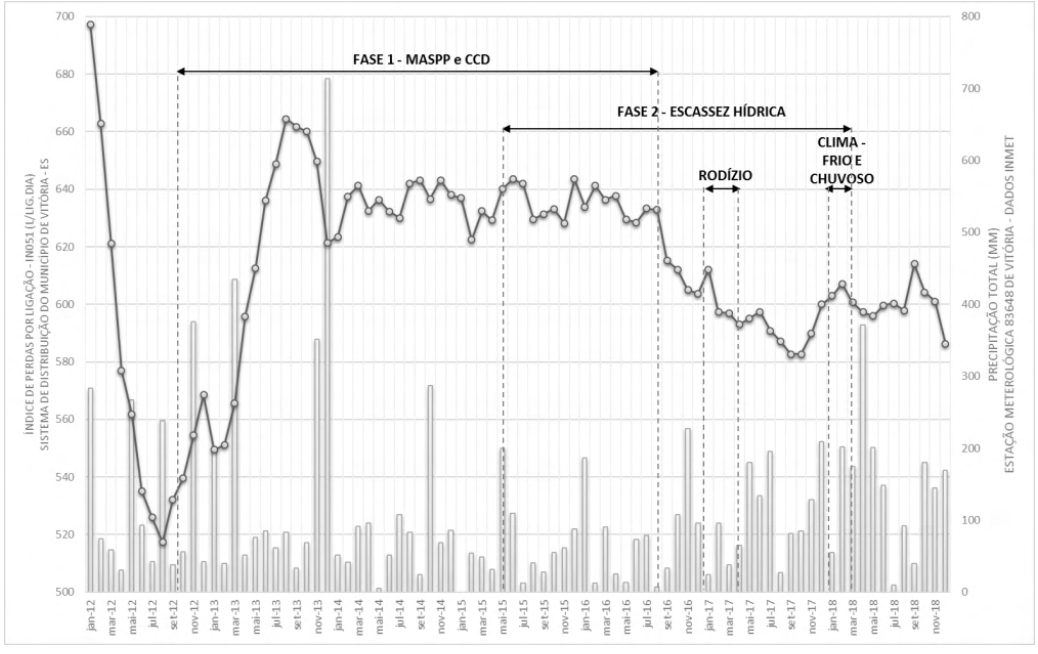

Figure 8 – Link loss indicator curve (IN051) related to total precipitation in the City of Vitória - ES.

Source: Data produced by the author (2022)

City	State	Year of reference	AG002 - Number of active water connections	AG005 - Extension of the water network	AG006 – Volume of waterdistributed/ produced	AG010 - Volume ofwater consumed	AG024 - service volume
			Link	Km	1.000 m^3/Year	1.000 m^3/Year	1.000 m^3/Year
		2012	56.182	561,19	42.533,7	30.722,9	119,7
Vitória	**ES**	2013	56.897	572,94	43.284,8	30.332,3	100,4
		2014	57.293	827,89	44.072,8	30.723,6	59,6
		2015	57.663	842,57	41.272,6	27.732,2	34,8
		2016	57.683	850,89	38.476,3	25.655,4	64,4
		2017	55.725	855,86	37.522,1	24.818,3	314,6
		2018	56.111	858,53	37.364,03	25.295,47	66,99

Table 4 - Operational information about water loss from the City of Vitória distribution system 2012- 2018.

Source: Brazil - SNIS, (2019)

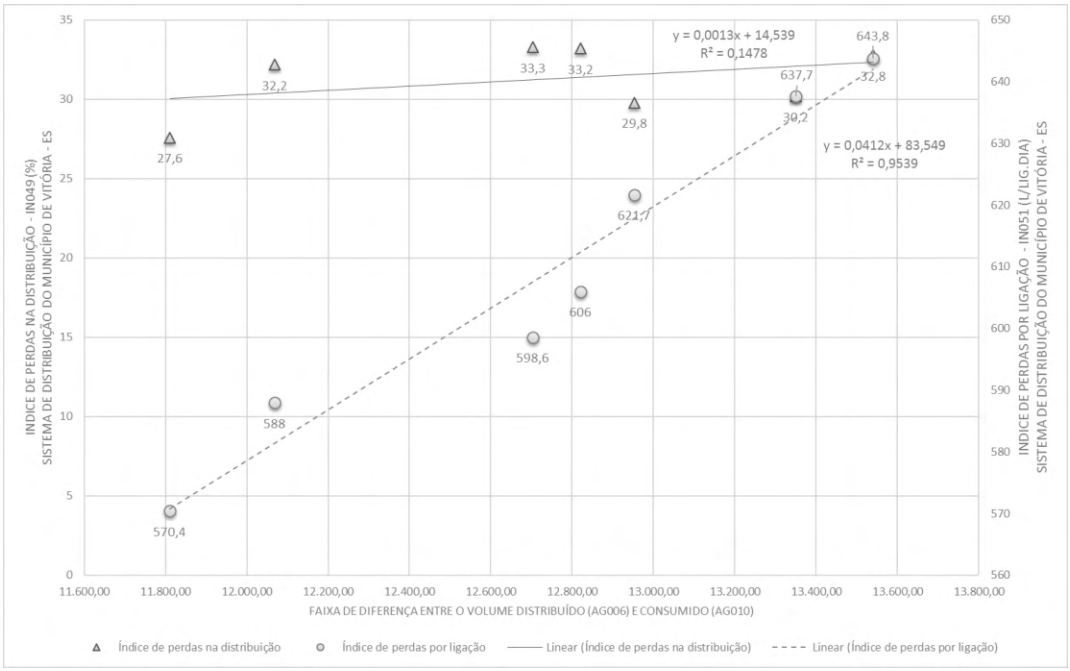

Figure 9 - Dispersion of loss rates related to the difference between the volume distributed and consumed in the distribution system of the City of Vitória - ES.

Source: Data produced by the author (2022)

of the infrastructure (AG005), even with the subtle investment in recent years, coupled with the reduction of volumes AG006 and AG010 allowed the reduction of loss. The IN051 index measured two types of crisis that the service provider went through: water crisis (2015-2016) and financial crisis (2014-2017); in which the first impacted the reduction of AG006 and AG010 volumes and the second contributed to the reduction in the number of active connections, in addition to the volume distributed. This index shows that the service provider was efficient during these crises. However, on the other hand, the IN50 and IN051 indicators admit an assessment that is less appropriate for the operation and maintenance of assets, and more appropriate for the consumption ratio.

So far, the volume of service water (AG024) and the volume of imported water (AG018) were disregarded in the analyzes because it refers to a small and null value, compared to the other volumes, respectively.

The loss indicators are also correlated with information on operating expenses and revenues in the water distribution system, for example, the annual historical series of these indicators and information described in Table 5 and Table 6.

When there was investment (FN023), in 2014-2015, there was an increase in loss indicators, due to interference in the distribution system during the execution of works and improvements, which sometimes may have caused rupture failures and consequently leaks, in addition to of the repressed demand as a result of the paralysis of the system.

It can be said that when there was a reduction in the volume distributed, for consistency, there is a reduction in energy consumption (AG028), since the characteristic of the water distribution system in Vitória is predominantly composed of pumps, which also explains the reduction in energy consumption. expenditure on chemical products (FN011) in the water treatment process for distribution.

However, the financial performance (IN012), considering only the water service, did not obtain gains, despite the fact that the expenses on inputs have been reduced, because the study period, 2012 to 2018, was also a period of economic recession in the State. of the Holy Spirit.

CONCLUSION

The evaluation allowed to conclude that the loss indicators did not reach lower levels only with the control of the distributed and consumed volume of treated water as a management strategy and it was proved that there is no direct relationship between seasonality and loss indicators. So much so that the loss indicators pointed to an increasing trend for the future, if the actions to combat loss are not implemented through the key factors: pressure and flow. The expansion of consumers, regularization of clandestine and defaulting connections; investments in preserved infrastructure, diligent operation linked to the detection of leaks in the treated water distribution system in the municipality of Vitória, are also continuous, strategic and effective actions for better performance.

Sanitation information is necessary because it enables the assessment of loss indicators and makes it possible to guide the definition of management strategies to combat the problem. In order to achieve the low loss rate, it is essential for the service provider to disseminate the complexity of the problem and the integrative character among the teams, because the information that composes the calculations comes from different processes of the provider.

It is valid to suggest to the Ministry of Regional Development the extinction of

City	State	Year	AG028 - Total consumption of electricity in water systems	FN013 - Electricity expenses	FN011 - Expenditure on chemicals	FN002 - Direct operating income from water	IN012 - Financial performance indicator in water services	FN023 - Investment made in water supply by the service provider
			(1.000 kWh/Year)	(R$/Year)	(R$/Year)	(R$/Year)	%	(R$/Year)
Vitória	ES	2012	6.931,62	8.345.491,00	1.395.689,00	94.195.196,03	124	6.511.914,67
		2013	7.105,06	7.713.006,49	1.273.783,77	102.357.394,77	122	5.272.304,81
		2014	7.650,89	9.065.970,23	1.177.863,39	109.493.753,05	114	12.256.817,81
		2015	6.773,58	14.714.191,91	1.136.904,31	107.361.558,89	106	8.118.242,41
		2016	6.792,38	13.417.645,80	1.878.303,63	114.336.935,73	110	4.224.022,96
		2017	6.592,28	14.060.130,63	2.193.151,13	119.754.953,35	112	6.373.239,61
		2018	6.568,50	16.349.372,40	2.272.705,67	126.550.337,96	106	5.643.162,56

Table 5 - Information on operating expenses and revenues in the distribution system of the municipality of Vitória 2012-2018.

Source: Brazil, SNIS (2019)

City	State	ReferenceYear	IN049_AE – Distribution lossindex	IN050 - Gross linear lossindex	IN051_AE – Loss rate percall
			Percentage	m^3/day/km	L/day/link
Vitória	ES	2012	27,6	57,62	570,4
		2013	29,8	62,09	621,7
		2014	30,2	51,98	637,7
		2015	32,8	44,30	643,8
		2016	33,2	41,28	606,0
		2017	33,3	39,77	598,6
		2018	32,2	38,36	588,0

Table 6 - Loss rates in the distribution system of the municipality of Vitória 2012-2018

Source: Brazil, SNIS (2019)

the loss in distribution indicator (IN049), measured in percentage, as it does not represent the real performance of a distribution system. The application of the PRAI and IVI indicators have recommendations, operational efficiency ranges and, above all, they use key factors such as pressure and flow, which allow diagnosing the efficiency of the operation of the water distribution system and identifying the problem of water loss, proper.

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