Water loss indicators used in public water supply services in Brazil: Literature research and review

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ABSTRACT: The amount of water loss, expressed through indicators is an important element in assessing the efficiency of water supply services. The International Water Association (IWA), in the late 90's, laid the normative basis of the performance indicators for water supply services. The standard of IWA indicators was successful, being adopted by many countries. In Brazil there is still no consolidated national standard of loss indicators and therefore a lot of indicators are used by managers of the water supply sector. Through systematic review of the technical and scientific literature, this project aims to investigate the various types of loss indicators adopted in Brazil, highlighting the variations in terminology, units and formulas. In the literature 164 case studies of various regions of the country were evaluated. The results show that there is not a standard for loss indicators in Brazil, since different nomenclatures and formulas are used to express the same display in different documents. Finally, it emphasizes the need for national standardization of language and concepts for a clearer definition of loss indicators, in order to allow a coherent assessment of the effectiveness of the managing bodies of water supply systems as to combat losses.

Keywords *Water losses. Indicators. Water Supply.*

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1. INTRODUCTION

Water loss indicators are valuable tools for the systematic evaluation of the efficiency of water supply systems (Abes 2013) because a system with high loss rate may require frequent interruptions in supply, compromising the quality of services (Almandoz et al. 2005).

You can find in the literature several loss indicators in different formats (Miranda 2002). And the lack of uniformity in the procedures for determining such indicators, coupled with the lack of rigor in handling information, denigrates the credibility of the use of this tool, generally effective, because it hinders the comparison of the water loss performance management among different water supply systems (Lambert et al. 2014).

As a result, the International Water Association (IWA), in the late 90's, laid the normative basis of the performance indicators for water supply services. The standard of IWA indicators was successful, being adopted by several countries (Kanakoudis et al. 2011).

However, in Brazil there is still no consolidated national standard of loss indicators and therefore a lot of indicators are used by water supply sector, making it difficult benchmark performance in combating losses between different water supply companies (Miranda 2002). In this context, this article aims to investigate the various types of water loss indicators adopted in Brazil, observing variations in terminology, units and formulas.

1.1 Concept of water losses

According to the International Water Association (IWA), water losses are the difference between the given volume of water delivered to the supply system and the authorized consumed water volume (Alegre et al. 2006). The concept of water losses, however, goes further.

In the environmental area, water losses are a waste of water resources. In the context of water bodies severely stressed in the face of growing demand with current consumption patterns, losses are a huge risk to the balance of local ecosystems (Kanakoudis et al. 2011).

In the economic aspect, considering that the cost of treated water is actually made up of several items such as spending on chemicals and energy for water treatment, water losses represent huge operating costs (Giustolisi et al. 2013). Thus, the high rate of water losses is a decrease in revenues from sanitation companies and thus decreases their ability to invest in improvements of services and expansion of existing water production systems (Abes 2013).

It follows in many cases the need to increase the water tariff rates, which will increase the social dimension of water losses, when one reflects on the fundamental right of access to drinking water.

In addition, high rates of water losses may indirectly pose risks to public health, as a network with physical failure, low pressure or intermittent supply may be exposed to the intrusion of pathogens and chemical contaminants that affect water quality (Almandoz et al. 2005).

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1.2 Types of water losses

Water losses are divided into two types: apparent losses and real losses.

Real losses are physical losses of the water supply system, including leaks in the distribution network (both in system pipes as valves and pumps discharge) and extravasations in the reservoirs (Tabesh et al. 2009).

As for the apparent losses account for the changes in volume of water due to inaccuracies in the measurements or estimates of the volume of water produced and consumed, the unauthorized use, to errors in handling flow data and volume of water and the failures in the commercial register (Alegre et al. 2006). In summary, apparent losses (commercial losses) are produced by human error of measurement and management (Tabesh et al. 2009).

2. METHODS

The method selected for the literature research was systematic review of the literature, which differs from traditional literature research (narrative review), to be a more focused research, by applying systematic research methods for critical analysis and synthesis of information selected. In order to implement the method, the procedures recommended by Sampaio & Mancini (2007) were followed, which are outlined in the following flowchart:

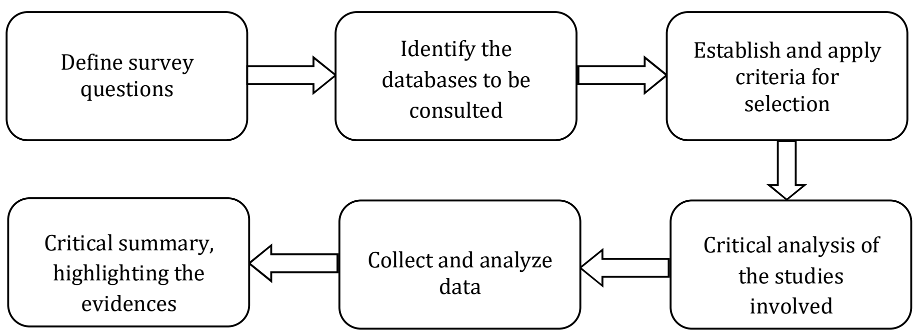

Figure 1. Systematic review of the literature. Source: Adapted from Sampaio & Mancini 2007.

2.1 Definition of survey questions

The research questions were formulated according to the project objectives. Thus, the systematic review of the literature was developed to answer the following questions:

- What are the types of water loss indicators commonly adopted in Brazil?
- What are the terminologies commonly used for these indicators?
- What are the most used units for these indicators?

2.2 Identification of databases

As a source of secondary data was selected technical and scientific work in three categories: theses and dissertations; papers presented in technical and scientific events and published articles in scientific journals.

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- Theses and dissertations

It was adopted as database the Brazilian Digital Library of Theses and Dissertations (BDTD) of the Brazilian Institute for Information in Science and Technology (IBICT). The BDTD brings together in one online research portal, theses and dissertations presented in Brazil and abroad by Brazilians. Currently, the database BDTD has a partnership with 74 educational institutions, including the University of São Paulo (USP), the State University of Campinas (Unicamp) and the Federal University of Rio de Janeiro (UFRJ).

- Papers presented in technical and scientific events

For this category, it was considered the technical and scientific relevance of the event (congress, symposium, conference, etc.) for the environment, particularly in the sub-area sanitation, and online availability of articles. Table 1 shows the technical and scientific events selected for analysis in the study.

Table 1. Technical and scientific events selected

Event	Organizer
Brazilian Congress of Sanitary and Environmental Engineering	Brazilian Association of Sanitary and Environmental Engineering (ABES)
Exhibition of Municipal Experiences in Sanitation	National Association of Municipal Sanitation Services (ASSEMAE)
National Congress of Sanitation and Environment	Association of Engineers of Sabesp (AESabesp)

Source: Own authorship.

- Published articles in scientific journals

Given the same selection approach adopted in the previous category, the literature review concentrated on the four journals shown in Table 2.

Table 2. Journals selected

Periodical	Site
Journal of Environmental and Sanitary Engineering	http://abes-dn.org.br/d2_Publicacoes_eng.html
Journal of Water Resources	http://www.abrh.org.br/
Journal of Technology and Environment	http://periodicos.unesc.net/index.php/tecnoambiente
Journal of DAE	http://revistadae.com.br/site/artigos-aprovados/

Source: Own authorship.

It should be emphasized that the review was not limited to these journals. Articles that were considered relevant for the purpose of research and met the established criteria were selected for the study.

2.3 Definition and application of the selection criteria

The following selection criteria were defined:

- Research type: case studies;
- Local: research conducted in Brazil;
- Year of publication: inclusion of works published between the years 2009-2015;
- Subject: contain in the title, abstract or keywords the terms: "water loss", "performance indicators" and "water supply services".

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After the selection of the articles, theses and dissertations that met the requirements for inclusion in the study, it was searched within the set of publications which ones effectively answered the survey questions. Readings and summaries played a central role in this phase. For each document a reading record containing summary was created, and some transcriptions of excerpts that could be used later. All publications were filed in folders, at the same time the collection continued. The criterion for such organization was the source of the document.

2.4 Collection and analysis of data

After the selection of information sources, the collection and recording of the surveyed data were held in an orderly way. The works have been exported to an Excel spreadsheet and organized by categories (articles, theses and dissertations), year of publication and study areas. Then a thorough job by reading and data collection was undertaken. Information was collected on the types of loss indicators presented in the studies, the units and terminologies used and the methods employed. Data were aggregated and analyzed critically, synthesizing relevant evidence to answer the research questions.

3. RESULTS AND DISCUSSION

After extensive systematic review of the literature, considering the selection criteria defined in the methodology, 239 publications were collected. However, of these only 164 were selected for the study, since the other studies did not have sufficient data for the purpose of the research.

3.1 Characteristics of the sample

Regarding the type of publication, the category "papers presented in technical and scientific events" was the most significant, with more than 80% of publications, followed by the category "theses and dissertations" with 14%. Regarding the representativeness of the sample for each region, considering the selection criteria of this research, there were a greater number of case studies on the topic loss in the southeast, about 60.4%, followed by the northeast (16.5%) and the southern region (13.4%). With reference to the year of publication, there are a greater number of studies from 2009, about 26.2%, followed by 2015 (18.9%) and 2011 (16.5%). The year which had lower representation in the survey was 2010, with only 3% of the total sample.

3.2 Water loss indicators

Water loss indicators were grouped into four types: total losses, revenue losses, real losses and apparent losses. Figure 2 shows the frequency of the four types of water loss indicators found in the sample study.

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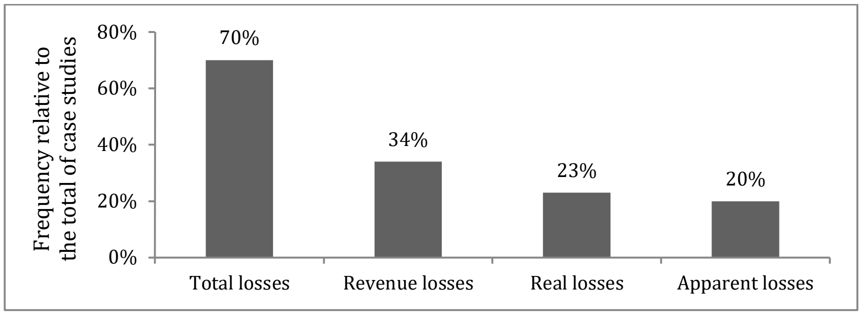

Figure 2. Types of loss indicators. Source: Own authorship.

In Figure 2, it is noted that 70% of the sample case studies presented indicators of "total losses" that consider the total volume lost (real and apparent losses). It is the most widely used indicator because of the ease of understanding and calculation that does not require a lot of data, only some information that is generally available (e.g. Available and consumed volume). However, it should be noted that the IWA recommends distinguishing, whenever possible, the real water losses from apparent water losses. This breakdown allows the calculation of a set of more specific performance indicators that guide decision-making on priority actions to combat water losses.

Figure 2 also shows that only 23% of the case studies presented real loss indicators (physical loss) which represent the volume of water lost due to the occurrence of leaks in pipes and overflowing in reservoirs. And 20% of the case studies presented indicators for apparent loss (not physical loss) which represent the volume of water consumed but not recorded by the sanitation company due to measurement errors, fraud, illegal connections and failures in the commercial register. It was observed that the real and apparent losses are generally evaluated indirectly through other operating information, such as listed in Table 3.

Table 3. Additional indicators assessing water losses

Real losses	Apparent losses
Leaks on mains length;	Customer reading efficiency;
Leaks on service connections;	Unmetered water;
Total identified visible leaks;	Total theft notifications;
Total identified invisible leaks;	Total illegal use notifications;
Active leakage control interventions;	System flow meters calibration;
Location + repair time on main;	Total meter replacement;
Location + repair time on service connections;	Average age meters;
Mains or connections replacement;	Variation consumption *X* replacing meters;
Variation of the night minimum flow.	Variation consumption *X* removes of theft and illegal use.

Source: Own authorship.

Another indicator widely used is the "revenue losses" that differs from the previous indicator by considering the formula the billed water volume instead of consumed water

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volume[1]. According to the IWA, this indicator should be used only for a preliminary financial assessment of the problem and should not be used as an operating indicator.

It was not identified in the sample a case study which presented "non-revenue water by cost," which is a more complete financial indicator for assessing the financial impact of losses in revenues and costs of production and distribution of treated water, as recommended by IWA.

Of the 164 study cases, only 11 studies calculated the ILI (Infrastructure leakage index) that relates the actual real losses and an estimate of the minimum real losses that could be technically achieved for the system operating pressure, average service connection length and service connection density (Alegre et al. 2006). This indicator allows the comparison of the efficiency of different systems and different operators.

Only three studies showed loss indicators in production and only a study of the sample suggested a loss rate in adduction of the raw water and in production of the treated water. Table 4 shows examples of these indicators proposed by Beloni & Paper (2015).

Table 4. Water loss indicators in adduction and production.

Code	Indicator	Formula	Unit
IPRP	Real loss index in production	$\frac{(VCAP - VPRO) * 100}{VCAP}$	%
IPRA	Real loss index in adduction	$\frac{(VCAP - VADD) * 100}{VCAP}$	%
IPTR	Real loss index in treatment	$\frac{(VADD - VPRO) * 100}{VCAP}$	%

Parameters: VCAP - Volume captured; VPRO - Volume Produced; VADD - Volume adducted
Source: Beloni & Paper 2015.

3.3 Units

Figure 3 shows the most used water loss indicators units.

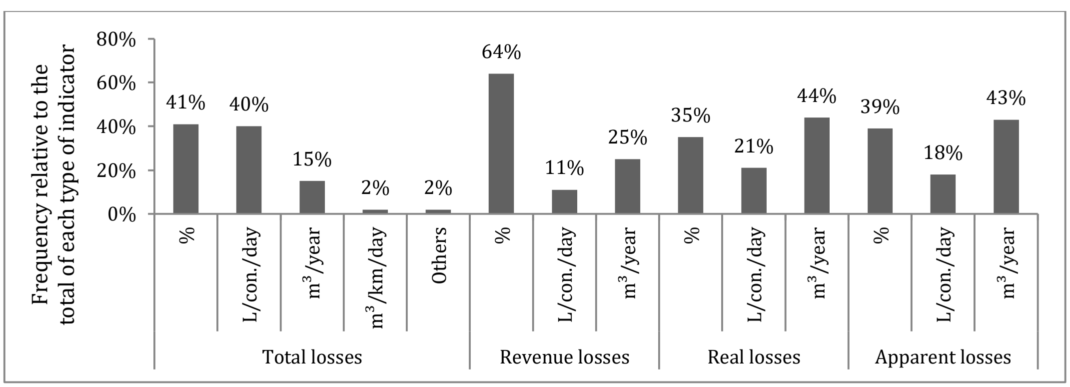

Figure 3. Water loss indicators units. Source: Own authorship.

In Figure 3, it is observed that more than 40% of total loss indicators are expressed as a percentage. These indicators relate the volume of water lost to the total volume produced

[1] It should be highlighted that the billed volume differs from the consumed volume, as the companies of water supply services adopt minimum or average consumption parameters, which can be higher than the volume actually consumed. Generally, the value of the invoiced amount is greater than or equal to the consumed volume (Brazil 2016).

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or available to the system or subsystem analysis. The great disadvantage of these indicators is the difficulty to compare the water loss performance management throughout time, as they are heavily influenced by the variation of consumption and should not be used as operational indicator for loss management.

On the other hand, there is still a tendency shown in Figure 3 to express the total losses in the unit in liters per connection per day, about 40%. The use of loss indicators associated with a scaling factor, such as network size and number of connections or savings, is more suitable for the management of water losses, because the variation of these parameters over time is generally less, unlike the variable volume of water produced or consumed. Consequently, loss indicators in units "liter per connection per day", "liter per economy per day" or "cubic meter per kilometers per day" are more stable to variation due to random factors.

Revenue loss indicators of the sample study are usually expressed in percentage, about 65%. Regarding the real loss and apparent loss indicators, these are usually expressed in percentage or m^3 / year.

3.4 Terminology

Table 5 shows the various terminologies used for different types of loss indicators. It is observed that there is a large list of loss indicators used by providers of water services. Although these indicators present different terminologies or acronyms, many agree in their formulations and units.

Table 5. Water loss indicators terminologies.

Type of indicator	Unit	Terminology
Total losses	%	Loss index in distribution; Loss index in percentage; Loss index by volume; Non-account water index; Annualized loss index.
	L/con./day	Loss index per connection; Gross loss index per connection.
	m^3/km/day	Loss index per extension; Gross loss index per extension; Gross linear loss index.
Revenue losses	%	Non-revenue water Revenue loss index Unbilled water index Loss index in percentage; Water not converted into revenue.
Real losses	% ou m^3/ year	Real loss index; Physical loss index.
Apparent losses	% ou m^3/year	Apparent loss index; Non-physical loss index. Commercial loss index.
Real losses in infrastructure	-	Infrastructure leakage index; Leakage rate in infrastructure; Infrastructural index.

Source: Own authorship.

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However, the following case was also observed: indicators with the same nomenclature but with different formulations, especially in the delimitation of the water balance components. For example, there is difference between "Infrastructure leakage index" (ILI) in Negrisolli (2009) and in Melato Zahed & Filho (2011). The first reference ILI relates the volume of total losses (real and apparent losses) to the volume of total inevitable losses (the minimum level of total losses expected for the system). In the second reference, ILI reports the real losses to the inevitable minimum real losses, as it is recommended by IWA.

Another example is the differences in the formulation of "revenue loss index." In the formula of the indicator, some references exclude the service water volume (authorized unbilled consumption) of the offered volume following the methodology of the National Sanitation Information System (SNIS), which is currently the largest database of the Brazilian sanitation sector (Brazil, 2016). In other references, the formula of the indicator includes service water volume to the total of non-revenue water volume, as recommended by the IWA (Alegre et al. 2006) and Miranda (2002).

It is also observed that the "loss index in percentage" terminology used to represent both the total loss (non-accounted water index) and also the loss of revenue (non-revenue water index).

It should be emphasized the difference in meaning between the terms index and indicator, which are often mistakenly used interchangeably. Indicators come from a synthesis of primary data and indexes of aggregate indicators (Brazil 2011). In this article, it was chosen to use the original term of reference even to highlight the differences in terminologies adopted in the references.

4. CONCLUSIONS

The results of this research show that there is still not a consolidated set of standardized loss indicators in Brazil. The main divergence between the indicators is the delimitation of the volume control, which does not always consider the imported, exported or service water volume.

This study provides evidence that indicators expressed by percentage continue to be widely used by water supply companies, even those not being recommended by IWA for technical loss management.

It should be emphasized that there is no perfect indicator, because the set of indicators should be analyzed and decided which best portray the situation of losses. And there should be standardization in the indicators calculation methodology across all process agents (water supply companies and regulatory agencies) for a clearer definition of the loss indicators, in order to allow a coherent assessment of the effectiveness of the water supply companies as to combat losses.

Finally, this study does not intend to exhaust the theme of the research, but draw attention to the need for further studies for an appropriate proposal of standardization of the water loss indicators to Brazilian needs.

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